IRRADIATION OF NOVEL MTR FUEL PLATES IN BR2

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ABSTRACT

Since the end of 1999, novel MTR fuel plates with very high density meat are being irradiated in BR2. The purpose of the irradiation is to investigate the behaviour of these fuel plates under very severe reactor operation conditions. The novel fuel plates are inserted in two standard six-tube BR2 fuel elements in the locations normally occupied by the standard outer fuel plates. The irradiation in BR2 was prepared by carrying out detailed neutron Monte Carlo calculations of the whole BR2 core containing the two experimental fuel elements for various positions in the reactor and for various azimuthal orientations of the fuel elements. Comparing the thus determined fission density levels and azimuthal profiles in the new MTR fuel plates irradiated in the various channels allowed the experimenters to choose the most appropriate BR2 channel and the most appropriate fuel element orientation.

1. Introduction

At the end of 1999, a series of irradiations of a novel type of materials testing reactor (MTR) fuel plates started in BR2, the Belgian high flux materials testing reactor (Fig. 1). The purpose of the irradiation is to investigate the behaviour of the new MTR fuel plates under the severe reactor operation conditions indicated in section 2. The new MTR fuel plates have a very high density meat zone and are clad with aluminium, in a way similar to the standard BR2 fuel element plates. The uranium enrichment is 35%. Two types of experimental fuel plates were irradiated, with densities of 5.8 g U_{tot}/cm^3 and of 4.8 g U_{tot}/cm^3.

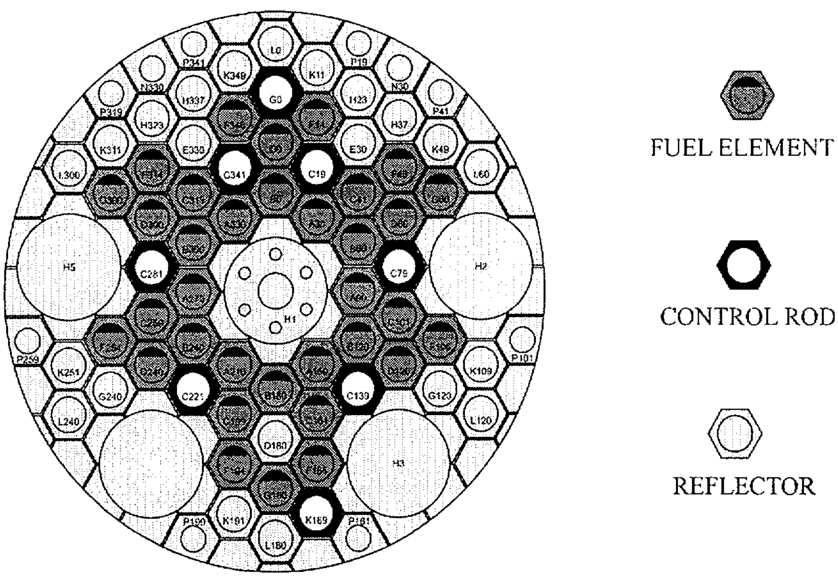

Fig. 1. Horizontal cross-section of the BR2 reactor at the reactor midplane, with a typical loading

Standard BR2 fuel elements (Fig. 2) consist of six concentric aluminium-clad fuel tubes maintained in place by three aluminium side plates positioned at 120° from each other, and hence present an azimuthal discontinuity of the meat zone. The azimuthal orientation of the elements in BR2 is therefore of great importance when investigating the hot spot in the fuel plates, as a maximum of the fission density occurs near the side plates, due to a reflector effect. The centre of the fuel element provides a free space with a diameter of 25.4 mm : it allows for experiments to be irradiated under very high neutron fluxes or for measurement devices.

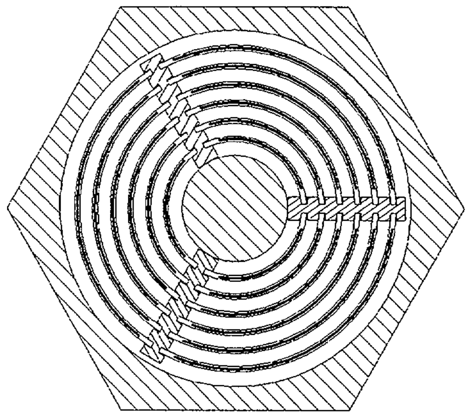

Fig. 2. Cross-section of a standard BR2 fuel element

Typical BR2 neutron fluxes are (in the reactor hot spot plane) :
- thermal conventional neutron flux : $v_0 \int_0^{0.5\,eV} n(E)\,dE$:
  2 to 4 10^{14} n / cm^{2}s in the reactor core
  2 to 9 10^{14} n / cm^{2}s in the reflector and core flux trap (H1);
- fast neutron flux : $\int_{0.1}^{\infty}{}_{MeV}\ n(E)\,dE$:
  4 to 7 10^{14} n / cm^{2}s in the reactor core.

The present nominal heat flux at the hot spot is 470 W/cm^2, the maximum value authorized for nominal cooling conditions (probable onset of nucleate boiling is 600 W/cm^2). The nominal BR2 full power depends on the core configuration; at the present time it ranges from 50 to 70 MW, maintaining a nominal power of 26.5 MW in the central ring (A and B channels).

The two types of new MTR fuel plates to be tested are inserted in two standard six-tube BR2 fuel elements, in the locations normally occupied by the standard outer fuel plates.

The irradiation in BR2 was prepared by carrying out detailed neutron calculations of the whole BR2 core comprising the two experimental BR2 fuel elements with the new MTR fuel plates, in order to determine the fission density profile in these new MTR fuel plates for various positions in the reactor and for various azimuthal orientations of the fuel elements. According to the results of these calculations, the most appropriate BR2 irradiation channel and azimuthal orientation of the fuel plates was chosen for the start of the irradiation and will be adapted as the irradiation campaign proceeds.

Next to the neutron calculations, thermohydraulic calculations are being carried out to determine the hot spot temperature, the heat evacuation, etc.

2. Imposed irradiation conditions

The azimuthal power rate distribution over the new fuel plates to be tested should be as flat as possible. The maximum heat flux level should not exceed 520 W/cm² fuel plate, but should be close to this value, in order to obtain a cladding temperature of the order of 160°C and a central fuel temperature of the order of 230°C, not taking into account the corrosion layer. Indeed, the experimental programme consists in studying the behaviour of such fuel dispersion with low thermal conductivity.

3. Neutron calculations

The calculations were carried out, in three dimensions, using the Monte Carlo code MCNP [1].

The general calculation scheme was as follows:

i. Calculations were first carried out for an idealized BR2 core configuration containing fresh fuel, no experiments nor inserted control rods. Several potential irradiation channels were investigated :
  - as to the fission density level obtained in the fuel plates tested under normal irradiation conditions
  - as to the azimuthal fission density profile all around the 360° of the fuel plates.

   To this end, the experimental fuel elements, containing the new MTR plates in the outer tube position, were introduced into possible irradiation channels. The purpose of these calculations was to find the most adequate channel and to optimize the azimuthal orientation of the radial side plates.

ii. Next, for the channels and fuel element azimuthal orientations that appeared to be the most interesting ones according to i., more detailed calculations were made, taking into account the actual average burn-up of the fuel elements in a BR2 core loading with partly inserted control rods.

iii. Finally, a still more realistic MCNP calculation was carried out taking in addition account of the presence (i.e. the perturbation) of the other BR2 experiments and of the radioisotope production rigs. The complex complete BR2 configuration, containing, next to the two experimental elements (with new MTR outer plates) to be examined (here in channels C41 and C319), the other BR2 fuel elements, each with its average burn-up, the partly inserted control rods, the BR2 experiments and the main radioisotope production rigs, is represented in Fig. 3.

In the calculations ii. and iii., the burn–up was assumed to be equal to the axially and azimuthally averaged value, i.e. no axial nor azimuthal differential distribution of the burn-up was considered.

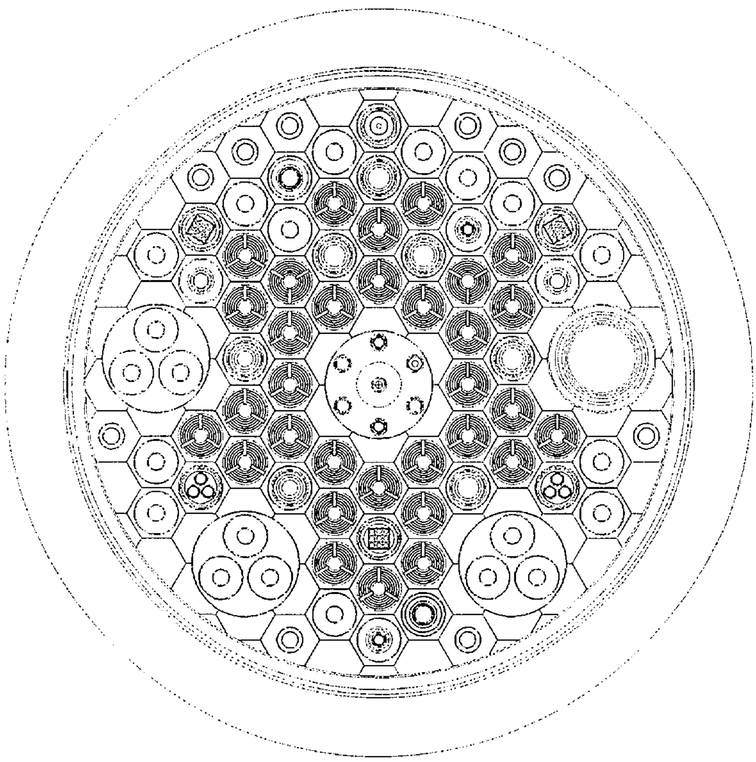

Fig. 3. Representation of the BR2 reactor with experimental loading (horizontal cross-section at the reactor mid-plane) in the MCNP calculational lay-out

4. Neutron calculations performed in parallel

In parallel with one of the calculations described in 3.i, a deterministic 2-D calculation in (R,Θ) geometry was performed, with the DORT3.5 neutron transport S_N code DORT3.5 [2], viz for one experimental fuel element irradiated in channel F14. The calculation model was centred in the experimental fuel element examined. The comparison between the DORT3.5 and the MCNP results is discussed in [3] : the azimuthal profiles calculated with both codes are practically identical.

Several validation calculations of MCNP were carried out, in which configurations studied experimentally in the past (1) in BR02, and (2) in BR2 low power trials , were calculated with MCNP. The comparisons with dosimetry work appear to be satisfactory [4].

5. Results

The neutronic calculations, carried out according to the sequence indicated in section 3 and started by considering the irradiation channels F as potential locations for the experimental fuel elements containing the new MTR fuel plates, finally led to the choice of channels C41 and C319 (for the meat densities 5.8 g U_{tot} /cm^3 and 4.8 g U_{tot} /cm^3, respectively) as the most adequate ones to perform the irradiations. The optimum orientation of the two experimental fuel elements is such that both for channel C41 and for channel 319 one of the radial side plates is oriented towards 60° (in the clockwise sense) with respect to the "north "of the reactor (see Fig. 3). All the other BR2 fuel elements were assumed to have one of their side plates oriented towards 0°.

The azimuthal distribution of the heat flux in the outer fuel plates of the experimental elements irradiated in channels C41 and C319 is shown in Fig. 4. The heat flux values (indicated in W/cm^2 fuel plate) are those calculated for the maximum flux plane of BR2, operating at 57 MW total power.

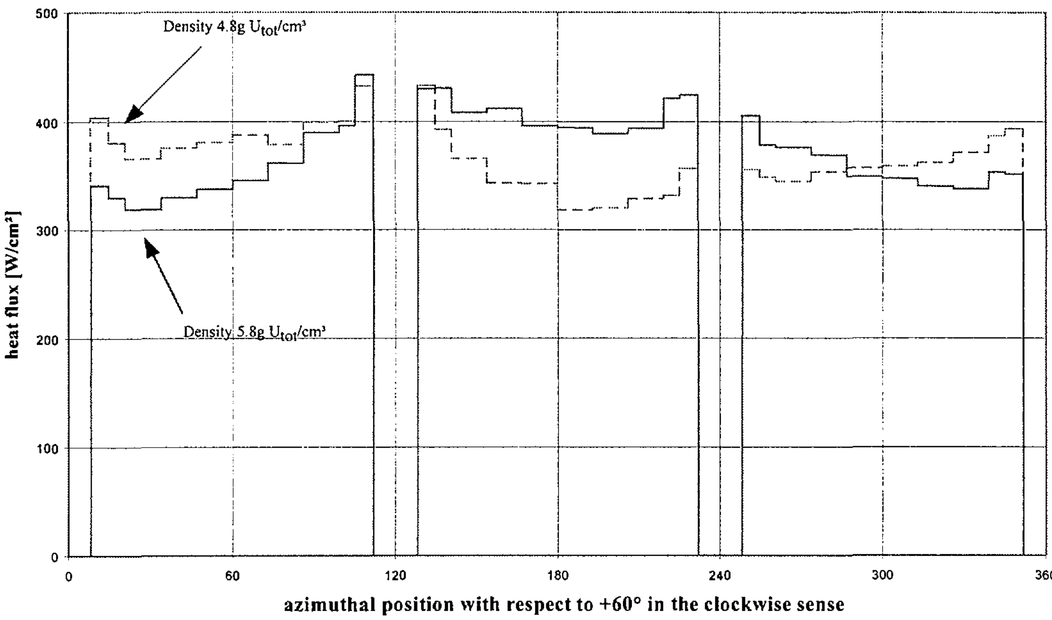

Fig. 4 Azimuthal distribution of the heat flux in the new MTR fuel plates with meat densities 5.8 g U_{tot}/cm^3 (irradiated in channel C41) and 4.8 g U_{tot}/cm^3 (irradiated in channel C319)

One observes that the azimuthal distributions are relatively flat in the highest rated MTR fuel plates of the two experimental fuel elements, which are oriented (as to the centreline of the plates) towards 240° (for channel C41) and 120° (for channel C319) with repect to the reactor north direction (see Fig. 3), corresponding to 180° and 60°, respectively, in Fig. 4. The calculated absolute heat flux levels, averaged azimuthally over 120° in the highest rated MTR fuel plates, amount to about 390 W/cm^2 (for the meat density 4.8 g U_{tot}/cm^3, in channel C319) and to about 410 W/cm^2 (for the meat density 5.8 g U_{tot} /cm^3, in channel C41). In both experimental fuel elements the calculated absolute heat fluxes in the new MTR fuel plates attain locally values equal to about 450 W/cm^2 ("hot spot value") near the radial side plate situated at 180° with respect to the reactor north direction (see Fig. 3), corresponding to 120° in Fig. 4. This hot spot value is about 13% lower than the maximum authorized value of 520 W/cm^2 (see section 2). Therefore BR2 has operated at 110% nominal power.

6. Comparison between calculated and measured axial fission rate profiles

During the irradiation, a Werz' calorimeter[1] was introduced into the central irradiation space (see Fig. 2) of one of the two experimental fuel elements, viz the one occupying channel C319. This calorimeter permits to measure practically on-line the U-235 fission rate [5]. The calorimeter was shifted upwards and downwards over the entire height (76.2 cm) of the active part of the tested new MTR fuel plates, which corresponds to the active height of a standard BR2 fuel element. The measurements were in good agreement with the calculated U-235 fission rate profile, obtained with the aid of MCNP : Fig. 5 (only the relative axial distributions were compared; the measured and calculated absolute fission rate levels will be compared in the near future).

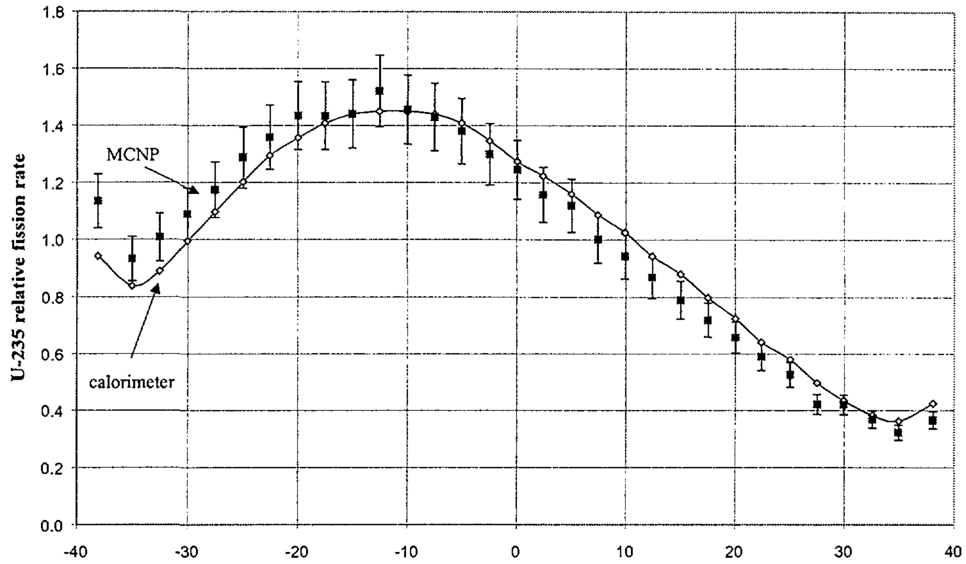

Fig. 5 Measured and calculated U-235 fission rate profiles in the axis of channel C319 (MCNP with 2-sigma error bars)

7. Conclusion

Using Monte Carlo MCNP calculations, the preparation (optimization as to location and orientation), from the neutronic point of view, of the irradiation of novel MTR fuel plates in BR2 was carried out in a satisfactory way notwithstanding the complexity of the reactor loading and its geometry.

8. References

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[1] In a Werz' calorimeter, the difference of fission and gamma heating in two miniature U-235 and Bi pellets is measured with differential thermocouples.