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ASSESSMENT OF THE LINEAR POWER LEVEL IN FUEL RODS IRRADIATED IN THE CALLISTO LOOP IN THE HIGH FLUX MATERIALS TESTING REACTOR BR2

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ABSTRACT

The pressurized light-water-cooled testing facility CALLISTO was designed to test the behaviour of advanced fuel rods (UO_2 or MOX, possibly with burnable poisons) under conditions representative of actual LWRs up to high burn-up rates. The accurate determination of the fission powers in each of the nine rods, and hence of the burn-up values, is carried out according to a rather elaborate procedure.

1. Introduction

CALLISTO is a water-cooled test facility, in operation at BR2 since 1992, which consists of three rigs, irradiated simultaneously in three channels of the reactor, e.g. channels K49, D180 and K311 (Fig. 1). Per rig, nine (possibly pre-irradiated) MOX or UO_2 fuel rods (some of which could contain burnable poisons) are irradiated up to very high burn-up values in conditions similar to those encountered in PWRs.

The purpose of the irradiations is to provide fuel-material physics experts with well-characterized high-burn-up fuel rods e.g. for power transients or safety tests, in appropriate rigs [1]. The accurate determination of the fission powers in each of the nine rods (of one rig), and hence of the burn-up values, is carried out following a rather elaborate procedure, which will be explained in the next sections, after a brief description of the CALLISTO facility. The paper will end with the presentation of some typical results.

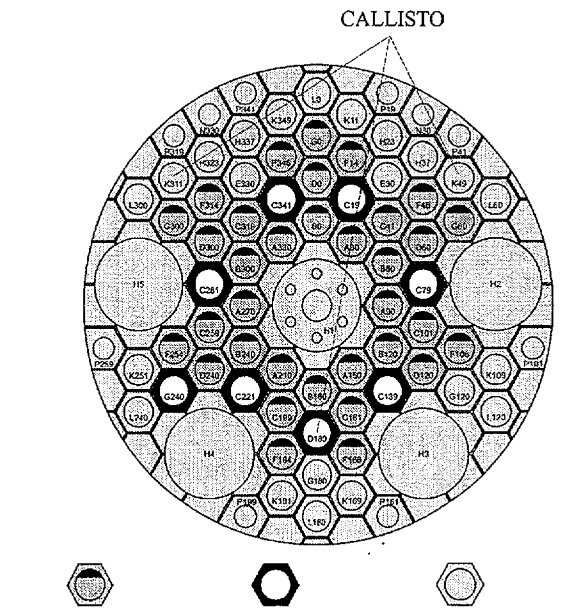

Fig. 1 Horizontal cross-section at reactor mid-plane of a typical BR2 loading, with three channels containing CALLISTO rigs.

2. Brief description of the CALLISTO irradiation facility

The CALLISTO irradiation facility is shown schematically in Fig. 2. As can be seen, a helium gas gap separates the water-cooled nine-fuel-rod bundle enclosed in the in-pile section (IPS) inner pressure tube from the outer part of the rig. For the application of the thermal balance method described in section 3, this helium gas gap constitutes the outer boundary of the system.

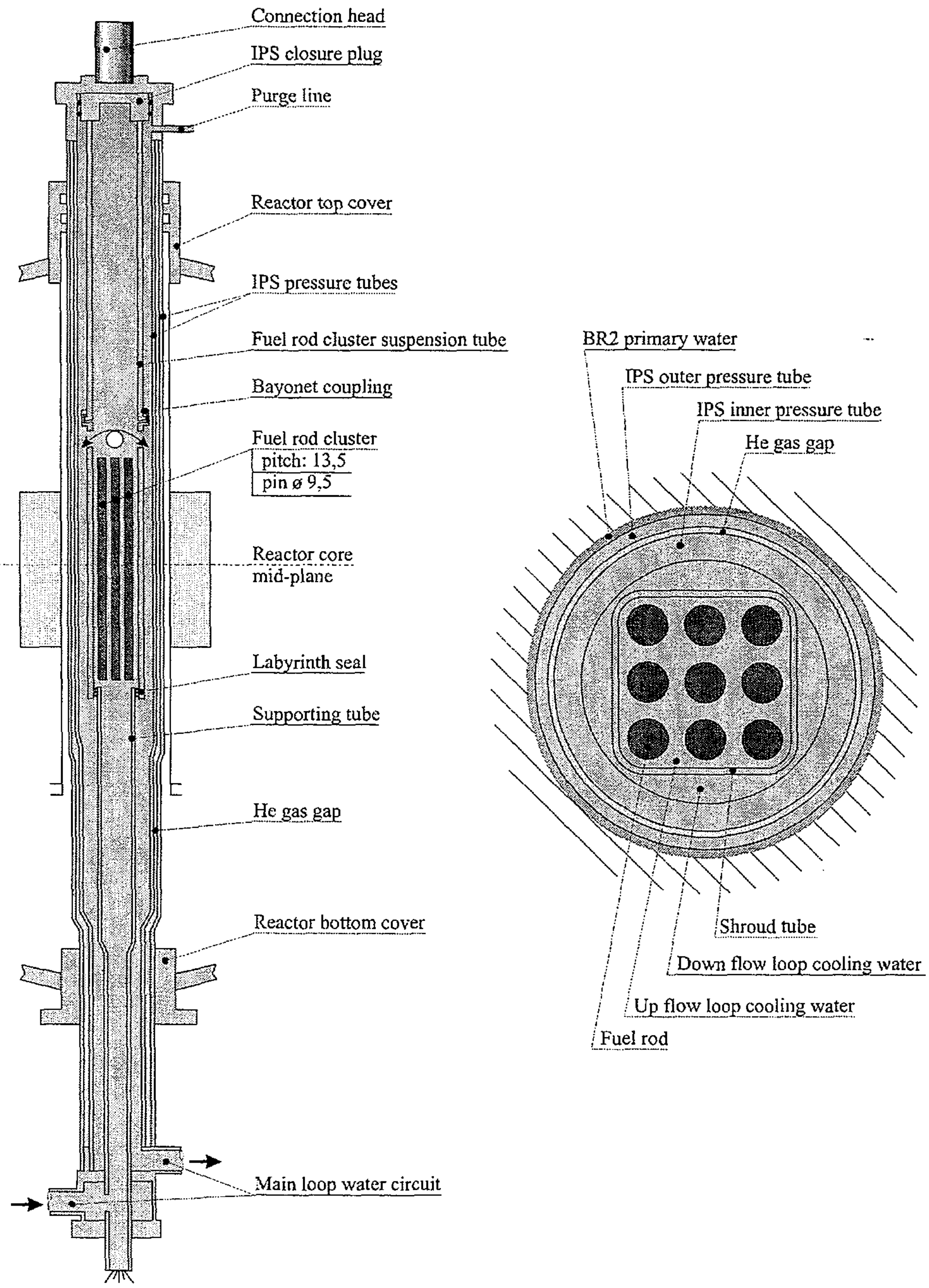

Fig. 2 Horizontal and vertical cross-sections of the CALLISTO irradiation facility

3. Methodology applied for the accurate determination of the linear powers in each of the nine fuel rods of a CALLISTO rig

The determination procedure of the rod-by-rod linear powers (and hence of the burn-up values) in a CALLISTO rig is schematized in the flow chart shown in Fig. 3. For each BR2 operation cycle, the total power in the rig (fission power in the fuel rods plus gamma heating rate in the fuel rods and in the structural materials around the bundle) is derived from a thermal balance, applied to the inner components of the device (i.e. to the volume limited by the helium gap in the IPS). The gamma heating rates in the fuel rod bundle and in the structural materials of the device are determined separately, starting from measurements performed during calibration campaigns with a dummy stainless steel rod loading in the IPS. To these measured gamma heating rate values, corrections are applied in order to match the conditions of the actual BR2 operation cycle with those of the calibration campaigns. The correction factors are obtained with the aid of indications provided by a monitor placed during each BR2 operation cycle in a (neutron and gamma) equivalent reactor channel in the vicinity of the CALLISTO loop.

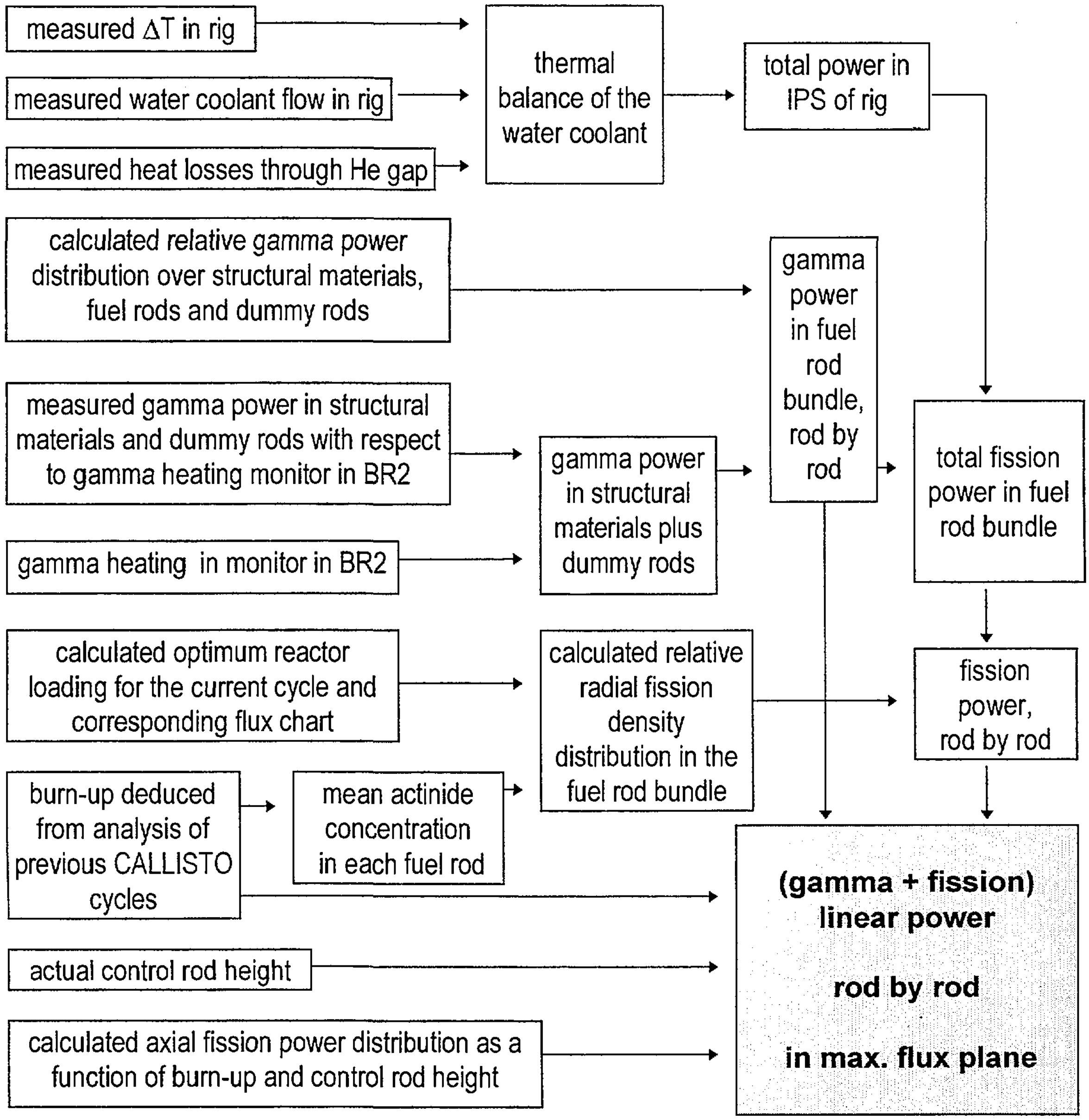

Fig. 3 Flow chart of the procedure for the accurate determination of the linear powers in the nine fuel rods of a CALLISTO rig

The radial distributions of the fission powers and of the gamma heating rates over the nine fuel rods are calculated for each cycle. These distributions are combined with the absolute average fission power and gamma heating values derived from the thermal balance in order to obtain rod-by-rod power distributions (fission and gamma). In addition, axial profiles are introduced, taking into account the axial position of the BR2 control rods. Moreover, all these deductions account for the burn-up of each of the nine fuel rods.

The final result indicated in Fig. 3, viz. the "(gamma + fission) linear power rod by rod in the max. flux plane", should be, as close as possible, in agreement with the specifications given by the experimenters. In fact, while increasing the total power of the BR2 reactor at the start-up of the cycle, this power is adapted in such a way as to meet these specifications.

4. Measurements carried out on the fuel rods

Between the various BR2 cycles, the fuel rod bundles are regularly unloaded from the reactor and gamma-spectrometry measurements are then carried out on the fuel rods (measurement of the activity of the long-lived fission product ^{137}Cs for the burn-up determination, and of the activity of the short-lived fission products ^{140}La, ^{131}I and ^{95}Zr for the linear power determination). At the end of the irradiation, i.e. when the rods have reached the burn-up desired, destructive measurements on selected samples can be performed (Nd method). More details concerning these non-destructive and destructive methods are given elsewhere [2]. Comparisons of the measured (with various techniques) and calculated results will be presented in section 6.

5. Neutron and gamma calculations

The "calculated relative radial fission density distribution in the fuel rod bundle" indicated in Fig. 3 is at present (i.e. since 1997) obtained by performing two-dimensional (X,Y) transport-theory calculations with the DORT S_N code [3] and the SCK•CEN 40-group library [4]. The BR2 half-core configuration, modelled as shown in Fig. 4 (except for CALLISTO), is used for these DORT calculations (the configuration is rotated over 60° with respect to Fig. 1). The core loading adopted for the BR2 operation and considered in DORT is determined by the BR2 reactor analysis team, based on calculations with the SCK•CEN code TRPT3 [5], leading to the "calculated optimum reactor loading for the current cycle and corresponding flux chart" (see Fig. 3). For the gamma calculations, the same code DORT is used, with an adequate gamma source derived from neutron calculations performed for the same configuration.

Till 1997, the calculated relative radial fission density distribution in the fuel rod bundle was provided by Belgonucléaire with a calculation scheme based mainly on the WIMS code system: see e.g. [6,7].

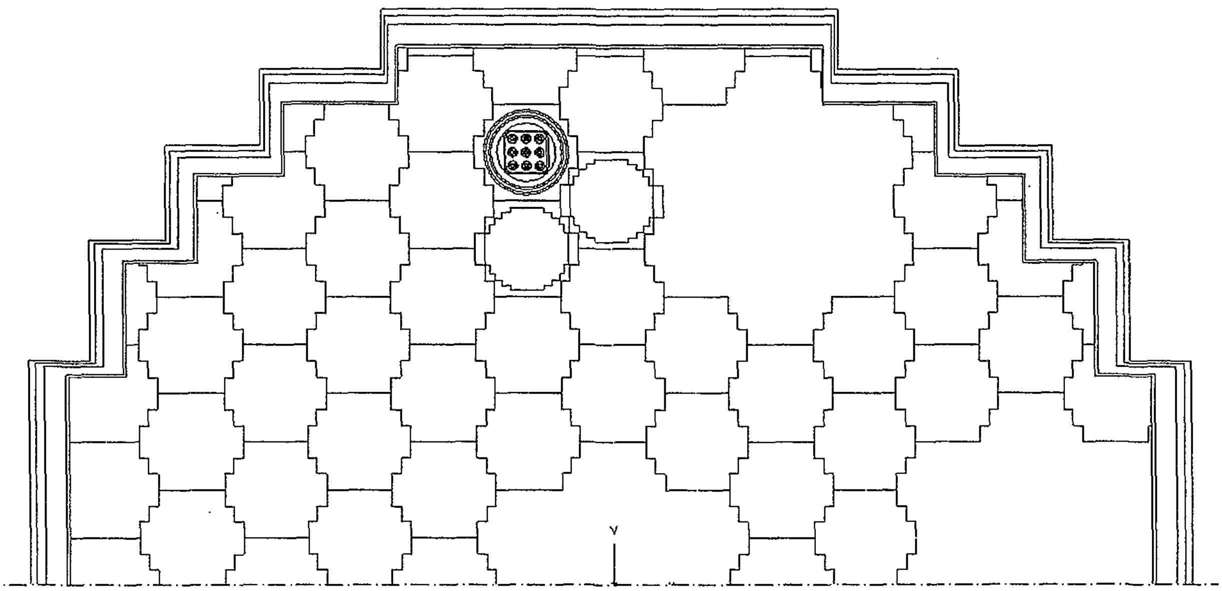

Fig. 4 (X,Y)-geometry model of BR2 for the DORT calculations with CALLISTO in channel K49

6. Selected results and discussion

The measured and calculated radial distributions of the fission density throughout the nine fuel rods in the CALLISTO rig (in channel K49) for BR2 cycle 1997/2 are collected in Fig. 5. The distributions are normalized to a bundle-averaged value of 1.00. The three fuel rods with lower enrichment (A, B, C) are situated nearest to the centre of the reactor. One observes that the measured and the calculated distributions differ maximum by 5 %.

I **1.05** 1.01 *(6.9%)*	H **0.88** 0.86 *(6.9%)*	G **1.03** 1.06 *(6.9%)*
F **1.14** 1.15 (6.9%)	E **0.93** 0.95 *(6.9%)*	D **1.12** 1.18 (6.9%)
C **1.00** 0.96 *(3.9%)*	B **0.89** 0.87 *(3.9%)*	A **0.97** 0.97 *(3.9%)*

Fig. 5 Radial distribution of the fission density across a fuel rod bundle irradiated in CALLISTO: measured (**bold**) and calculated (regular) results. The initial enrichments are indicated in *italics*. First line: rod position in the rig (A through I)

In Fig. 6, the peak burn-up values in the various fuel rods irradiated in CALLISTO are indicated, as determined by the three experimental methods considered in the present paper: the radiochemistry method, the gamma-spectrometry method and the thermal balance method. One observes that the results differ maximum by about 16%.

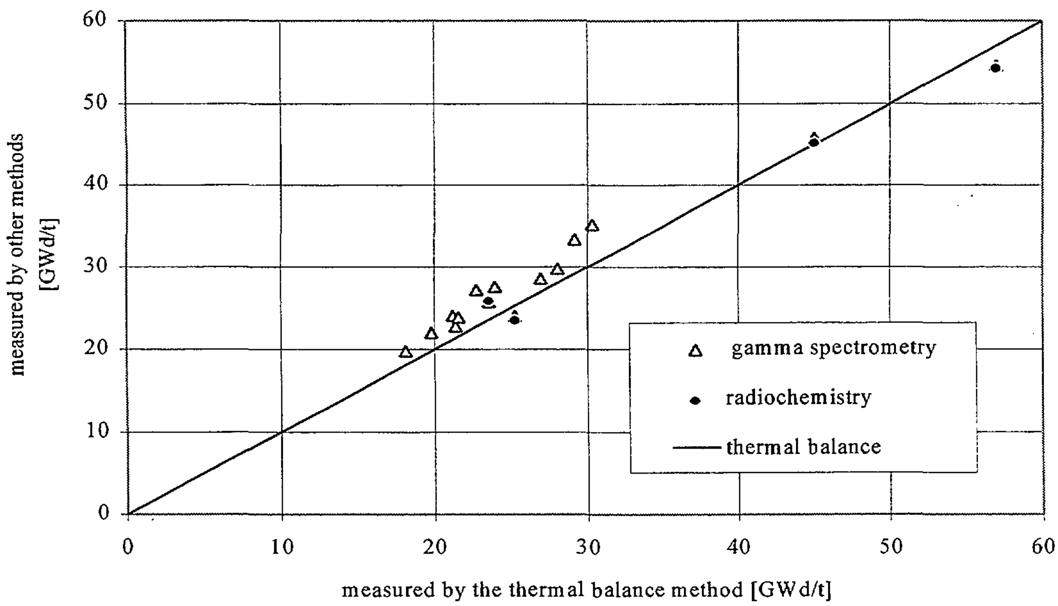

Fig. 6 Peak burn-up determination of the fuel rods in CALLISTO: comparison of the results obtained by various methods

7. Conclusions

The on-line monitoring and control of fuel rod irradiation conditions inside the CALLISTO facility in the Mol BR2 materials testing reactor relies on a good control of the fuel rod power. The safety and efficient operation of the loop requires:

- an optimal fuel rod distribution inside the loop;
- the adaptation of the BR2 loading;
- the determination of the maximum allowable linear power;
- the adjustement of the BR2 power to the maximun rod power;
- the on-line check that the power of each of the rods lies inside the specified margins.

To comply with these requirements, SCK•CEN, in collaboration with Belgonucléaire, has designed an *at hoc* methodology that combines thermal balance measurements and neutron-gamma transport calculations, both supported by calibrations, in order to accurately determine on-line the linear power of the fuel rods inside the loop. Independent techniques such as gamma-spectrometry and radiochemistry have validated the procedure: the maximum observed deviation does not exceed 16%.

Since the linear power of each specific rod is accurately known in real time, CALLISTO may be considered as a high-performance tool for investigating the behaviour of advanced fuel up to high burn-up values under representative PWR operation conditions.

8. Acknowledgements

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