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Fuel Pin Bowing and Related Investigation of the Gadolinium Fuel Pin Influence on Power Release Inside of Neighbouring Fuel Pins in a WWER-440 Type Core

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ABSTRACT

As known both the WWER-440 and WWER-1000 reactors are systematically modernized to enhance their safety and economical parameters of operation. For this purpose new fuel assemblies (FAs) were designed with improved technical parameters, e.g., containing fuel pins (FPs) in which Gd_2O_3 burnable absorber is integrated into fuel. Presence of such FPs in reactor core results in a strong depression of thermal neutrons in their positions and corresponding high gradients in neighbouring FPs. Consequently, similar situation in neighbouring FPs can be expected as for both the power release and temperature gradients.

The purpose of this work consists in investigation of the gadolinium FP influence on space power distribution, especially from viewpoint of the values and gradient occurrence inside of the neighbouring FPs that could result in static loads with some consequences, e.g., a contribution to FP / FA bowing. Since detailed power distributions cannot be obtained in the NPPs, needed information is provided by means of experiments on research reactors. As for the power release measurement inside of FPs, some special (e.g. track) detectors placed between fuel pellets are usually used. Since such works are relatively complicated and time consuming, an evaluation method based on mathematical modelling and numerical approximation was proposed by means of that, and using measured (integral) power release in selected FPs, needed power release values inside of investigated FPs, can be estimated. For this purpose, experimental results from light water, zero-power research reactor LR-0 obtained by measurements in a WWER-440 type core with 19 FAs at zero boron concentration and containing some FPs with gadolinium (Gd FPs) were utilized.

Application of the proposed evaluation method is demonstrated on investigated FPs neighbouring a Gd FP by means of the:

- Relative azimuthal power distribution estimation inside of investigated FPs on their fuel pellet surface in horizontal plane and
- Relative gradient estimation of the power distribution inside of investigated FPs in two opposite positions on their pellet surface that are situated to- and outwards Gd FP

Similar information can be useful from the viewpoint of the FP / FA bowing root causes investigation.

1 INTRODUCTION

The LR-0 reactor in the Nuclear Research Institute Rez plc is an experimental facility for the determination of the neutron - physical characteristics of the WWER and PWR type lattices and shielding with UO_2 or MOX fuel. The exploitation of this reactor is determined by the maximum power of 5 kW and maximum thermal flux of 10^{13} $n.m^2s^{-1}$, atmospheric pressure and room temperature (or heating up to 70°C). The fuel consists of the shortened WWER-1000 and WWER-440 type FAs containing the FPs with UO_2 pellets (O.D. 7.53 mm, internal central hole 1.4 mm) having a Zr+1%Nb cladding (O.D. 9.15×0.72 mm) with the active length of 1250 mm and enrichment of 1.6 - 4.4 wt.% in U^{235}. The FAs can be arranged in a reactor vessel of aluminium (diameter 3.5 m, height 6.5 m); the criticality is controlled by moderator level (boron acid with concentration up to 12 g/l) and control clusters (B_4C pellets).

The most important applications on LR-0 reactor concern the nuclear safety and economy of the WWER type NPPs operation. In the frame of their modernization, a set of experiments has been performed on the LR-0 reactor with new type FAs with various burnable absorbers arranged in appropriate configurations and cores of the both WWER-440 and WWER-1000 types including a number of experiments with FAs containing Gd FPs (e.g. [1]- [3]). It is well known that presence of such FPs in reactor core results in a strong depression of thermal neutrons in these FPs and corresponding high gradients in neighbouring ones. As a consequence, similar situation in neighbouring FPs can also be expected as for the power release and gradients of the temperature.

It is also well known (e.g. [4], [5]), that neutron flux non-uniformity, gradients of the temperature and neutron current can represent root causes of the FP / FA growth and bowing leading to local limitation of coolant flow, reduction of heat transfer, magnifying cladding corrosion and pellet / cladding interaction (PCI). Therefore detailed information about power distribution inside of FPs neighbouring a Gd FP can be useful for above phenomenon investigation, especially power release values on their fuel pellet surface, in particular in two opposite positions situated to- and outwards the Gd FP, where the maximum difference in power release can be expected. Since such data cannot be obtained in the NPPs, some experiments on research reactors are provided. Unfortunately corresponding measurements inside of FPs realized by means of special (e.g. track) detectors placed between fuel pellets are relatively complicated and time consuming. On the other hand results of usual (integral pin by pin) power distribution measurements can also be utilized. For this purpose an evaluation method based on mathematical modelling and numerical approximation [6] was proposed by means of that, and using above (integral) power release in selected FPs, some information about power release on fuel pellet surface of the investigated FP can be obtained.

As regards possible fuel failure occurrence, design criteria are defined to prevent cladding damage due to static and cyclic loads [7]. As for the fuel performance reliability and fuel failure rates and root causes concerning WWER fuel, it was stated [8]:
An overview on WWER fuel failure root causes identified during 1992 - 2002 shows, that:

- Most frequent cause is damage by debris
- Different from Western PWR fuel experience, fuel-rod-to-spacer-fretting doe not play a significant role
- On the other hand there is a very high number of defected fuel where no failure cause is known

In case of the PWR fuel the EPRI evaluation of 2004 on US PWR fuel failure rates shows:

- After a continuous decrease from 1980 to 2001 there is some increase observed in 2002 and 2003
- The major contributor to fuel failure rates in PWRs remains grid-to-rod fretting

- There is also an increase of fuel failures with unknown root causes that primarily affects optimized fuel designs with a thinner rod diameter.

The above information is in accordance with results concerning examination of 5 WWER-440 and 7 WWER-1000 FAs presented in [9]: causes of failure are debris fretting (54%), local overheating (15%), grid-rod fretting (8%) and "the cause is not determined" (23%).

2 AIM OF WORK

The aim of this work is providing some information concerning the Gd FPs influence on neutron flux non-uniformity in their vicinity by means of the relative azimuthal power distribution estimation on pellet surface of the neighbouring FPs including corresponding relative gradient estimation in two opposite positions on pellet surface situated to- and outwards Gd FP.

3 EXPERIMENTAL ARRANGEMENT AND CONDITIONS

The materials published in [2] were used for this work preparation. Experiment was realized on reactor LR-0 in a WWER-440 type core with 19 FAs at zero boron concentration, atmospheric pressure and room temperature (Fig. 1).

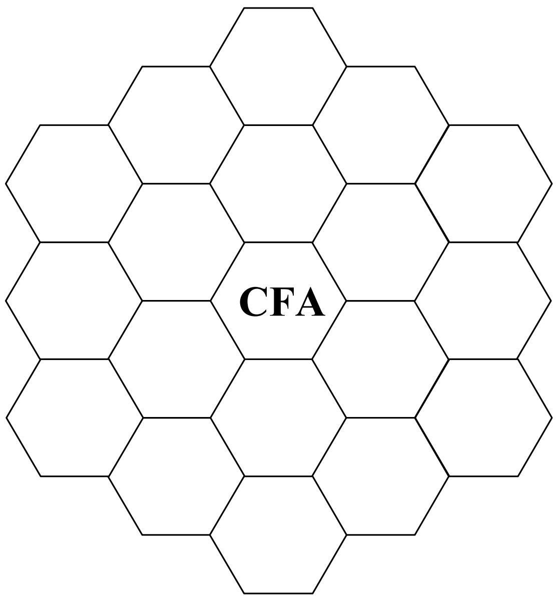

Figure 1: Schematic arrangement of the LR-0 reactor core containing 19 WWER-440 type FAs where in the central FA (CFA) the Gd FP influence investigation was performed

Power distribution values measured in selected FPs in central FA (CFA) were used in the frame of proposed evaluation method (Fig. 1). The CFA contains 120 FPs having enrichment of 3.6 wt.% in ^{235}U and 6 ones with 3.6 wt.% in ^{235}U and containing 2% Gd_2O_3 (pellets with O.D. 7.50 mm, internal central hole 1.5 mm), arranged with FP pitch of 12.2 mm (Fig. 2).

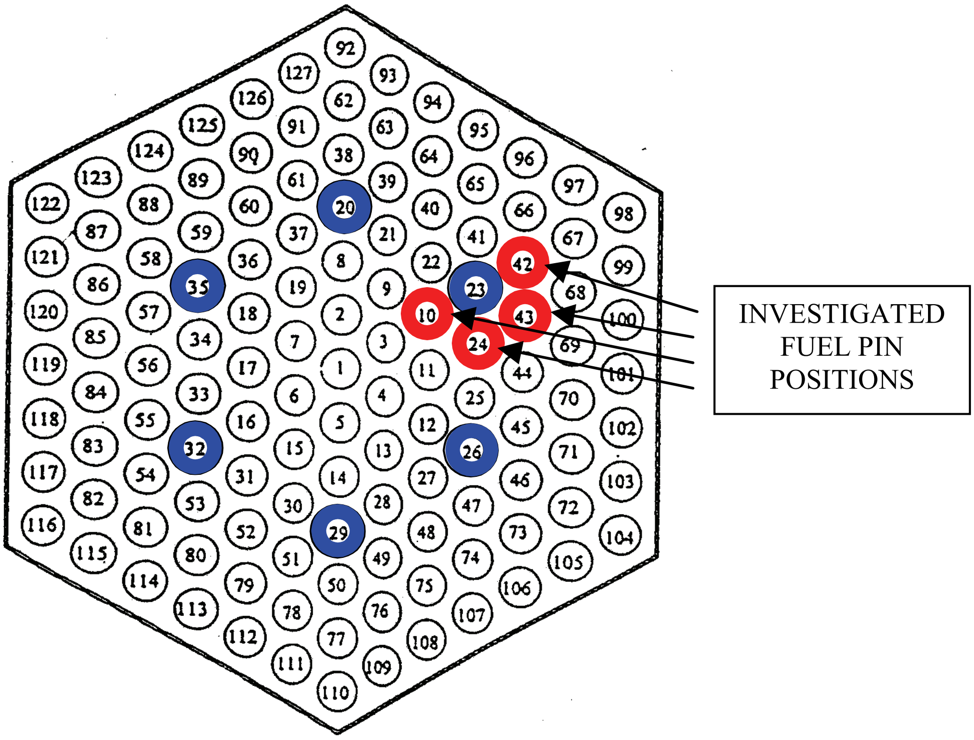

Figure 2: Positions numbering of the central tube (No 1) and FPs (No 2 - 127) in the CFA (Fig. 1). Denotation of the Gd FPs positions No 20, 23, 26, 29, 32 and 35 and investigated FPs No 10, 24, 42 and 43 neighbouring Gd FP in position No 23

More information concerning experimental arrangement and conditions are published in [2]. In this connection it should be mentioned, the experiment was realized in 1988 and therefore some technical parameters and the arrangement are different as used at present time. For example as can be seen in Fig. 2 the Gd FPs are situated in 6 equivalent corner positions of the fourth FP row and these positions differ of those ones used in present FAs that are in the corners of the second FP row (No 62, 67, 71, 77, 82 and 87). Further the above Gd FPs having enrichment of 3.6% ^{235}U / 2% Gd_2O_3 contents also differ of Gd FPs used in NPPs at present time, e.g., in the Czech NPP Dukovany the Gd FPs have enrichment of 4.0% ^{235}U / 3.35% Gd_2O_3 contents [10].

4 RESULTS OF THE ESTIMATION

The Gd FPs in the CFA (Fig. 2) are situated in six symmetric (equivalent) positions and therefore it is sufficient to perform the investigation only for FPs neighbouring one of them, e.g., in position No 23. But out of these (six) neighbouring FPs, two of them, in positions No 22 and 41, have the symmetric opposite ones in position No 24 and 43, respectively. Hence it was sufficient performing the above investigations only for FPs in four positions No 10, 24, 42 and 43 (Fig. 2) to have needed information for all FPs neighbouring six Gd FPs in the CFA.

Using proposed evaluation method mentioned above and power distribution measured in selected FPs in the CFA the following information concerning four investigated FPs were obtained (Fig. 3):

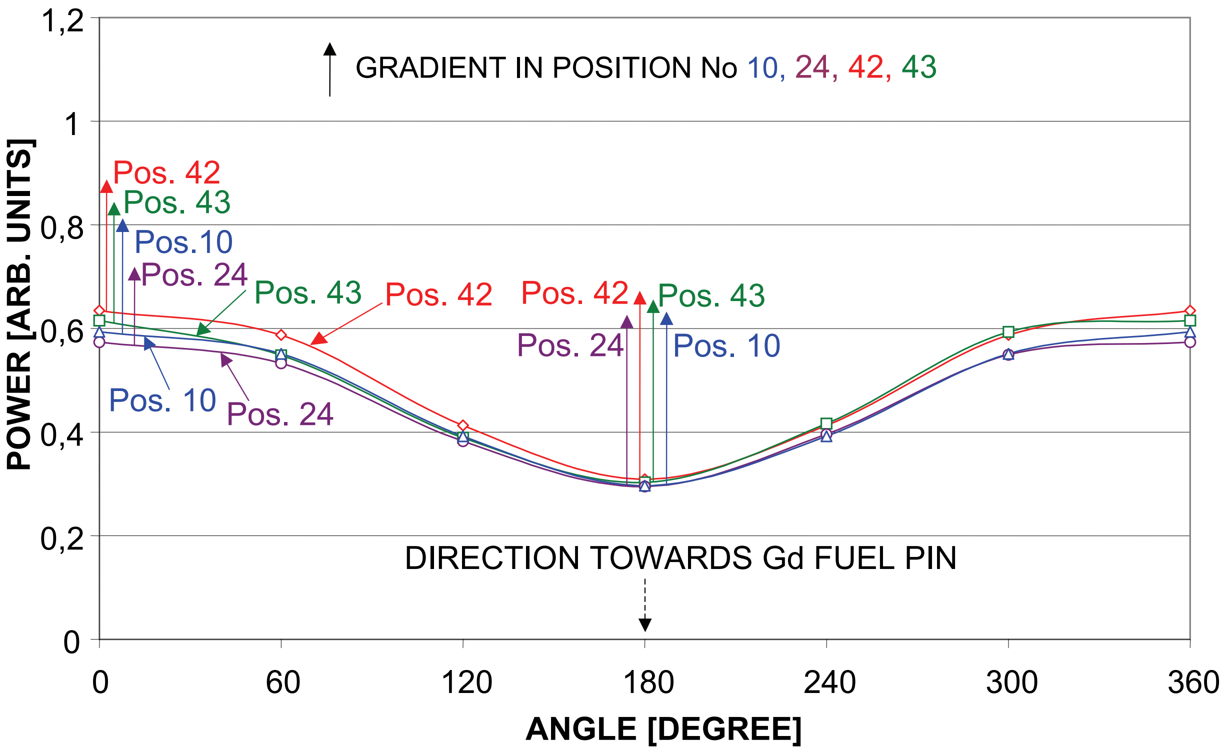

Figure 3: Relative azimuthal power distribution on pellet surface of four investigated FPs in positions No 10, 24, 42, and 43 neighbouring the Gd FP in position No 23 (joining lines serve only as eye guides). Relative gradients of the power distribution in two opposite fuel pellet surface positions out- and towards Gd FP in corresponding azimuthal coordinates (angles) of 0° and 180° respectively (for better visual illustration the above gradient presentations are a little shifted from 0° and 180° values)

- Relative azimuthal power distribution estimation presented by means of 6 values on fuel pellet surface positions - the first of them outwards Gd FP and next 5 ones with the step of 60°
- Corresponding relative gradient estimation of the power distribution in two opposite positions on pellet surface that are situated to- and outwards Gd FP.

The obtained results demonstrate:

- Influence of the Gd FP on power release inside of neighbouring FPs on their fuel pellet surface positions, in particular the maximum difference and corresponding distribution gradient to- and outwards Gd FP
- A possibility obtaining some useful information for both the temperature gradients and resulting loads estimation in vicinity of the Gd FPs to consider the contribution of these loads to root causes of the FP / FA bowing.

5 DISCUSSION

Of course the obtained results have a limited information relevance only, because they were determined on the basis of experiment realized on reactor LR-0 in 1988 at special conditions as mentioned above. Therefore they can differ from the results determined by means of the data from real NPP cores because of their dependence, e.g., on enrichment and dimensions of the (Gd) FPs, Gd_2O_3 contents, FP pitch and Gd FPs positions in FA, boron concentration, temperature, etc.

6 CONCLUSIONS

Using measured (integral) power release in selected FPs in a WWER-440 type core of the light water, zero-power reactor LR-0, a proposed evaluation method based on mathematical modelling and numerical approximation was applied for estimation of the:

- Relative azimuthal power distribution on pellet surface of the FPs neighbouring a Gd FP in horizontal plane and
- Relative gradient estimation of the power distribution in two opposite positions on pellet surface (of neighbouring FPs) that are situated to- and outwards Gd FP.

The results demonstrate a possibility obtaining some useful information for both the temperature gradients and resulting loads estimation in vicinity of the Gd FPs to consider the contribution of these loads to root causes of the FP / FA bowing.

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