POWER PEAK IN VICINITY OF VVER-440 CONTROL ASSEMBLY

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ABSTRACT

This paper presents information concerning the WWER-440 local power peaking problem induced by a control assembly (CA) and corresponding investigation possibilities on the light-water zero-power reactor LR-0 at the Nuclear Research Institute Rez plc. Brief description of the disposable CA model, experimental arrangement and conditions on the LR-0 reactor, preparation of the relevant measurements in the WWER-440 type cores with CA model, as well as some preliminary results of the fission density distribution obtained in a core without boron and with fuel assemblies having profiled enrichment are mentioned too.

1. INTRODUCTION

It is well known that WWER-440 control assembly (CA) has a significant influence on the space power (fission rate) distribution and can cause power peaks in adjacent fuel assemblies. This is a consequence of a deficiency in design of the butt joint (intermediate part) of the absorbing adapter (part) to the CA fuel part [1], that is, presence of water cavity, the beginning of which is the upper level of steel inserts in fuel assembly (FA) and the end - in FA cap; presence of the given cavity results in flash-up of thermal neutrons in periphery fuel pins (rods) of the adjacent operating assemblies.

Because of complicated geometry and material composition of the CA, the detailed calculations of power distribution are complicated too. Therefore it is useful to compare obtained results versus experimental data, i.e. to validate computation codes by measurements performed on experimental reactors in corresponding WWER-440 type cores, containing an appropriate CA model, because the detailed data of this type cannot be obtained in the NPPs. This way the desirable information can be obtained with sufficient accuracy to validate the existing codes needed for such calculations.

A set of critical experiments with CA model has been performed in the Nuclear Research Institute Rez plc (NRI) on the LR-0 reactor for this purpose, first of them are described in [2] (main parts of the LR-0 CA model are presented in Fig. 1). Further measurements of this type were realized on LR-0 reactor (at 4.8 g/l boron acid concentration in moderator) for the Hungarian NPP Paks [3]; the loading of the CA model into LR-0 core is presented in Fig. 2 (a) and the core in detail with CA model in its centre - in Fig. 2 (b).

It is to be noted the problems concerning CA can depend upon operation conditions, e.g., at the end of boron life the magnitude of power peaks in adjacent operating assemblies to

CA are dependent on position of group No 6 in the course of boron life, as described in [1]. In such cases a problem concerning *"the permissible linear heat rate of fuel rod"* at zero boron acid concentration in moderator can arise. Therefore it can be recommended to perform corresponding investigations on a research reactor also at zero boron acid concentration.

It is to be noted, to suppress neutron flash-up the plates of metallic hafnium are arranged on the inner surface of the jacketed tube in the region of butt joint of the innovated CA; the performed physical calculations showed that in case of arrangement of hafnium plates the neutron flash-up is prevented completely [1].

On the other hand, some NPPs are operated with CA at their uppermost position practically during the whole cycle, e.g. Finnish NPP Loviisa. There can be stated existence of a problem concerning *"an increased PCI-related fuel failure rate in assemblies next to regulating CA"*, probably caused by CA movements during the first power increase alone, i.e. at high boron acid concentration in moderator [4]. Therefore it can be recommended to perform measurements also at high boron acid concentration in moderator.

According to our information, some of NPPs are equipped with above mentioned *"hafnium innovation"* of CA (e.g., in the Russian Federation), another ones will be innovated in the near future (e.g., the Czech NPP Dukovany), other ones - later on, whereas some of NPPs are operated with inserted CA, other ones not. It is to be mentioned, the relevant calculation using BIPR7-A, PERMAK-A and PERMAK-3D codes as well as experimental studies of power distribution in the vicinity of the normal and modernized (with hafnium plates) CA have been carried out in the cores having 5.15 g/l boron acid concentration in moderator at the Institute of Nuclear Reactors, RRC "Kurchatov Institute", Moscow [5].

We can conclude, they are two situations that ought to be investigated: the first one corresponding to the end of fuel cycle, i.e. with zero boron acid concentration in moderator, and the second one - at the start of fuel cycle, i.e. with this concentration being practically highest (at the conditions on the LR-0 reactor - room temperature, atmospheric pressure - this concentration can be about 6.5 g/l). Of course, the investigation of both situations mentioned above should also include both two variants - without and with hafnium plates in CA, if possible.

2. AIM OF MEASUREMENTS

The aim of these measurements is to prepare a basis of experimental data that can be compared versus calculation ones to enable computer codes validation.

3. EXPERIMENTAL ARRANGEMENT AND CONDITIONS

It is to be noted that CA model on the LR-0 reactor is an *"authentic"* model, but in comparison with the original CA, the sequence of its height arrangement (the fuel, intermediate - butt joint and absorbing parts) is reverse. It consists of three parts. The lower one contains 2 absorbing segments from the original WWER-440 CA: hexagonal rings with outer diameter of 136 mm, thickness - 6 mm and height - 102 mm made of borated steel (2.0 wt.%) are placed in a stainless steel hexagonal tube (thickness 2 mm). Inside of these 2 hexagonal rings a stainless steel tube (outer diameter - 114.5 mm, thickness - 5 mm) is situated which has the following perforations: 6 apertures (60° symmetry) arranged in the rows with 100 mm distance between them. The upper part of the CA model is a 2.4 % enriched FA, placed in a hexagonal tube (thickness 1.5 mm) made of zirconium alloyed with niobium (2.5 wt.%). Between those two parts there is an intermediate one (butt joint) that contains original parts of the WWER-440 CA, too.

A shortened WWER-440 type fuel pins were used having a 1250 mm active fuel (uranium pellets) length with lower end 38 mm from the fuel pin end, excepting the 2.4% enriched pins of the CA model with their active length (uranium pellets) being 1073.6 mm and containing Zr tubes at their lower part (diameter 7.6/6.0 mm, length 56.7 mm, lower end 38 mm from the fuel pin end), continuing with stainless steel cylinder (diameter of 7.5 mm, length - 119.7 mm) and finally continuing with active fuel pin part (uranium pellets). The hexagonal tubes of all FA (excepting the 2.4 enriched one of CA model mentioned above) are made of aluminium (thickness 2 mm). In all FA the standard type stainless steel spacing grids defining the hexagonal lattice of the fuel pins in CA model (SG-CA) and in 12 FA of the core (SG-Co) were used at positions with vertical (axial) coordinates having step of 240 mm.

The vertical (axial) coordinates of the core arrangement:

- -38.0 mm - lower end of the fuel pins of 12 FA
- 0.0 mm - lower end of the active fuel part (uranium pellets) of 12 FA
- 5.5 mm - bottom of absorber segments at CA model
- 209.5 mm - top of absorber segments at CA model
- 465.0 mm - bottom of fuel pins at CA model
- 503.0 mm - bottom of Zr tubes at fuel pins of CA model
- 559.7 mm - top of Zr tubes and bottom of stainless steel cylinders at fuel pins of CA model
- 679.4 mm - top of stainless steel cylinders and bottom of fuel active part (uranium pellets) of CA model
- 880.24 - 880.29 mm - range of critical heights (see below).

To start the preparation of an experiment with zero boron acid concentration in moderator, some needed calculations were performed to determine a core having suitable properties. On the ground of these calculations [6], following core has been determined: it consist of the CA model placed in the core centre, around it - a ring of 6 fuel assemblies with fuel pins having 3.6% enrichment except their periphery rows where three pins in the corners have enrichment of 3.0 % and finally next 6 periphery fuel assemblies of the same composition around those ones mentioned above. Schematic arrangement of the fuel assemblies in the LR-0 core is presented in Fig. 3 (above) and arrangement of the fuel pins in fuel assemblies in LR-0 core with CA in its centre - in Fig. 4.

The critical heights of this core was in the range of 88.24 to 88.29 cm, enough to have possibility to investigate power peak in the vicinity of the CA intermediate part (see below). Such core represents a compromise between some NPPs conditions/needs (e.g. profiled enrichment of the fuel assemblies), LR-0 reactor possibilities (disposable fuel pins/assemblies) and suitable conditions for calculations (e.g. 60° symmetry).

4. MEASUREMENTS REALISATION AND SOME PRELIMINARY RESULTS

The measurements of the axial fission density distribution have been performed at all 6 FA adjacent to CA, at each of them in positions equivalent to the positions No 119 and No 17 of the FA No 2 in Fig. 3 (these two positions are the same as 119 and 17 ones in [1] mentioned above, respectively). Further, the same axial measurements have been performed at three fuel assemblies No 2, 4 and 6 (Fig. 3), at each of them at their 2 (equivalent) corner positions that are equivalent to the positions No 116 and 122 of the FA No 2. It means each final axial distribution was determined as a weighted mean of the 6 independent distributions, to obtain experimental data of high quality (reliability and accuracy).

Measurements was based on gamma scanning technique of the irradiated fuel pins detecting their gamma radiation in the energy range of La peak - 1596.5 keV. For this purpose a Na(Tl) scintillator crystal of 4 cm diameter was used with a stepping motor system, CAMAC modules controlled by PC with corresponding software and rectangular collimator 20x10 mm. The fuel pins were rotated around their own axis during gamma scanning. The measurements have been performed with a step of 1 cm.

Some preliminary results of the measured power (fission rate) distributions in positions No 119, No.116 (122) and No 17 are presented in Fig. 5; corresponding mean values of the relative errors of these power (fission rate) distribution values are 1.10%, 1.68% and 0.78% respectively. The power peak was observed at the height of about 52 cm from the lower end of uranium in the core. Further Fig. 6 presents the distributions of the ratio (peaking factor) of the power (fission rate) distributions of the "periphery" fuel pins No 119 and No 116 (122) to that from the central part of the same assembly in position No 17.

5. EXPERIMENTAL RESULTS UTILISATION

Problems concerning the CA were discussed in the frame of the Technical Meeting on "WWER-440 Local Power Peaking Induced by Control Rods" organized by the International Atomic Energy Agency in co-operation with Nuclear Research Institute Rez plc, held in Rez, 11 - 13 March 2002. Altogether 33 participants have represented the WWER-440 NPPs as well as the co-operating Research Institutes and other relevant Organisations from Armenia, Bulgaria, Hungary, Finland, IAEA, Russian Federation, Slovakia, Switzerland, Ukraine and the host country - Czech Republic. Based on the presentations and discussions, the following consensus was summarized:

- The power peaking phenomenon is safety related and the criteria affected are maximum linear heat generation rate, as well as pellet cladding interaction through high power ramps for fuel surrounding the control rods. Both criteria become significant in the future if plants move to high burn-up, load following operation or power up rating. Proper experimental verification is however needed since safety margins monitoring relies on adequate codes / methods for pre-calculation. No direct monitoring is possible.
- The information presented in meeting is qualitatively consistent, though there are some small quantitative differences, which can be explained with varying experimental conditions. The design modification including a Hafnium plate will reduce the power peaking effect significantly, of the order of 60%.
- New measurements at low boron concentration are desirable as suggested during the meeting for future LR-0 experiments at Nuclear Research Institute Rez.

- An extension of the Rez database is considered necessary, in particular for experiments with boric acid to compare the results against the Russian data.

6. CONCLUSIONS

We can conclude, the first part of the experimental activity concerning the power peaking problem investigation has been presented above. Next program could consist of the validated codes utilization to obtain more reliable computation results of the power density distributions in WWER-440 cores, re-loading schemes etc. This activity can continue for a longer time as the first part one, because it is limited practically by the NPPs needs only.

More information about measurements to be realized can be found in the paper [7] and other information concerning the power peaking phenomenon - in the papers presented in Technical Meeting mentioned above (to be published by the IAEA).

7. REFERENCES

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[7] Mikus J., *"Local Power Peaking Issue for WWER-440 and Relevant Measurements on LR-0 Reactor"*, IAEA - Technical Meeting on WWER-440 Local Power Peaking Induced by Control Rods, Rez, Czech Republic, 11 - 13 March 2002, 8 pp.

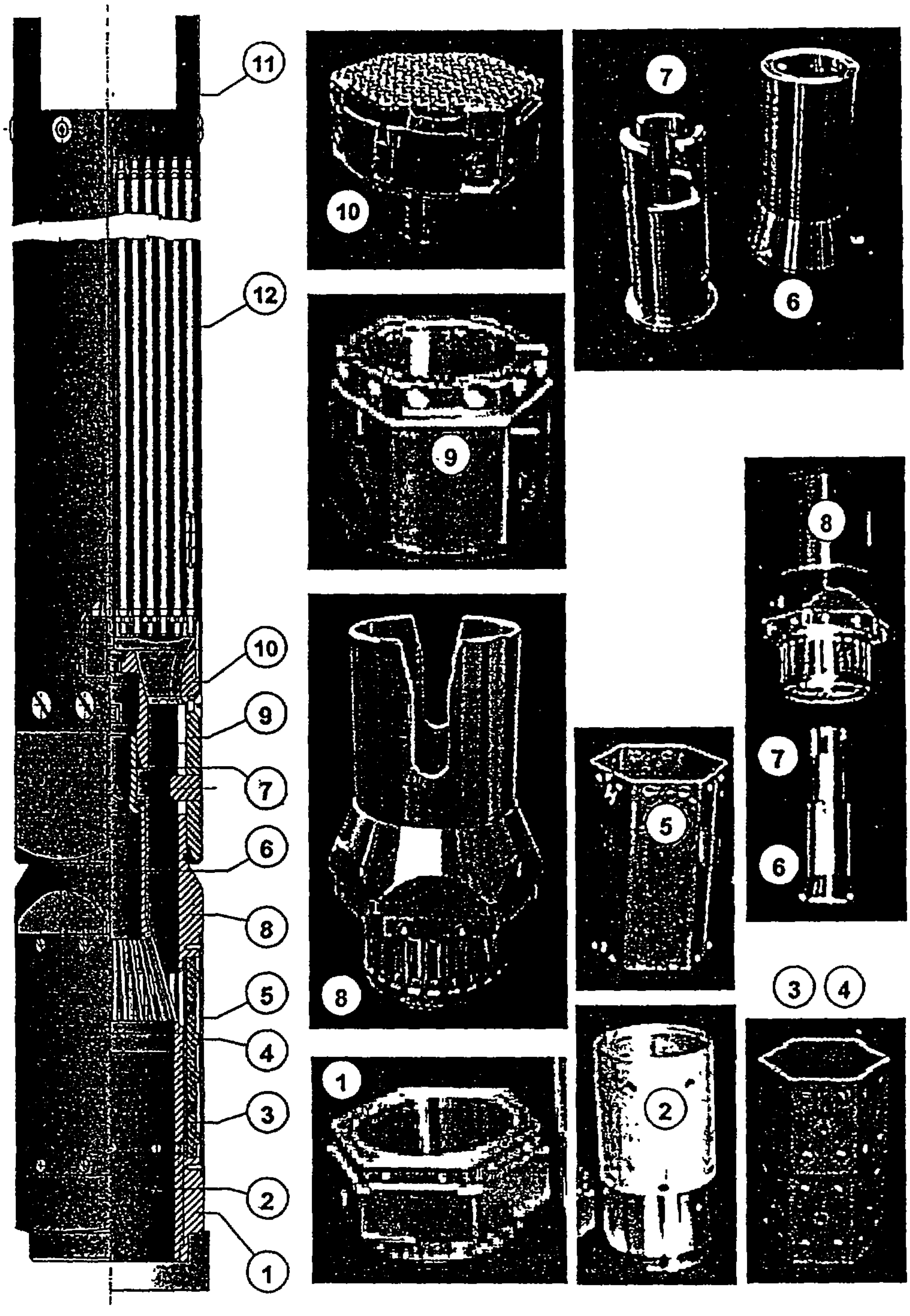

Fig. 1. LR-0 Control Assembly - Design and Real Parts

(a)

(b)

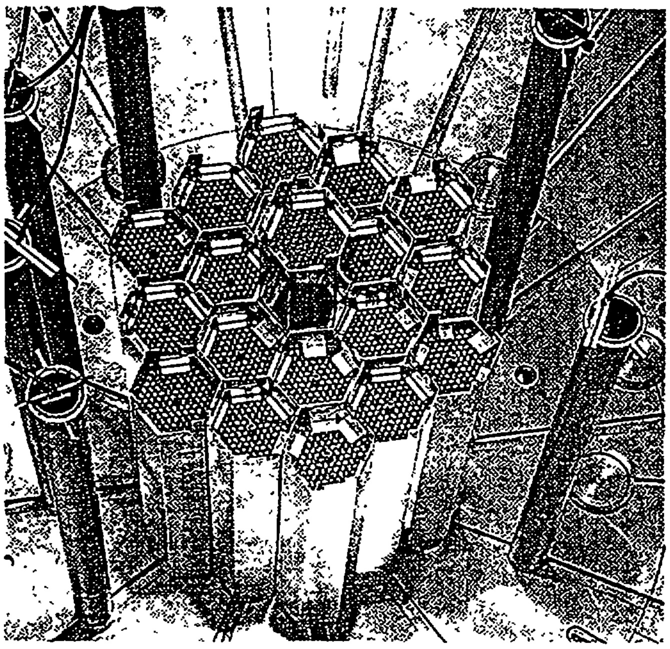

Fig. 2. A VVER-440 Type Core with LR-0 Control Assembly (CA):
(a) - CA Loading into LR-0 Core, (b) - in Detail

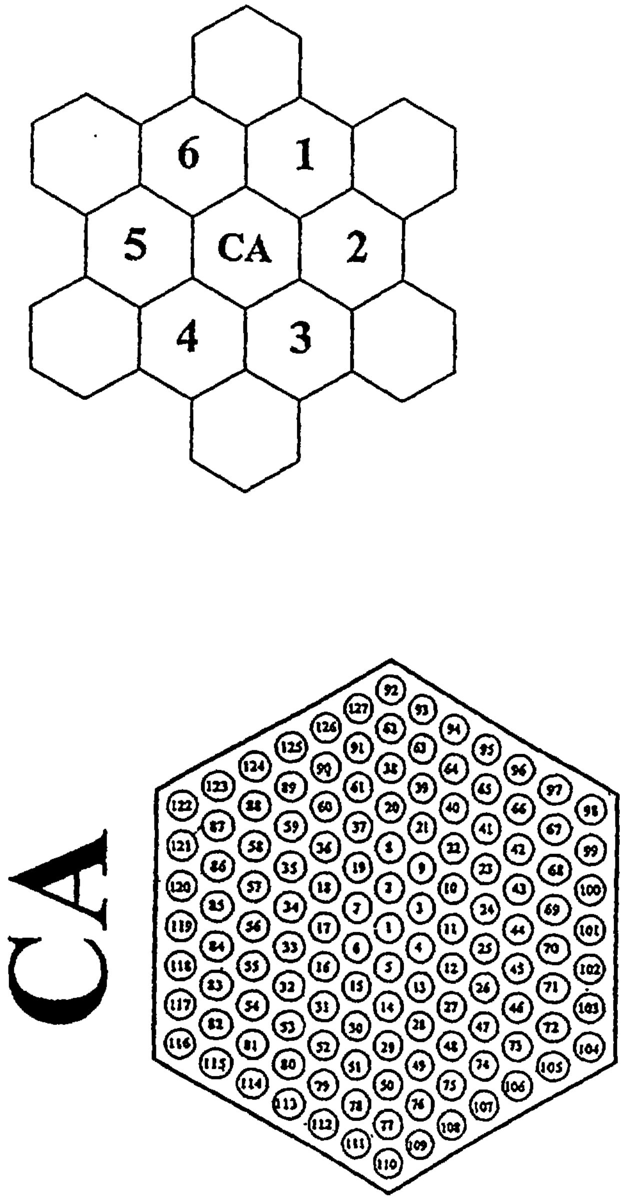

Fig. 3. Schematic Arrangement of the Investigated Core on the LR-0 Reactor (above) and Numbering of the Fuel Pins in the Fuel Assembly No 2 (below)

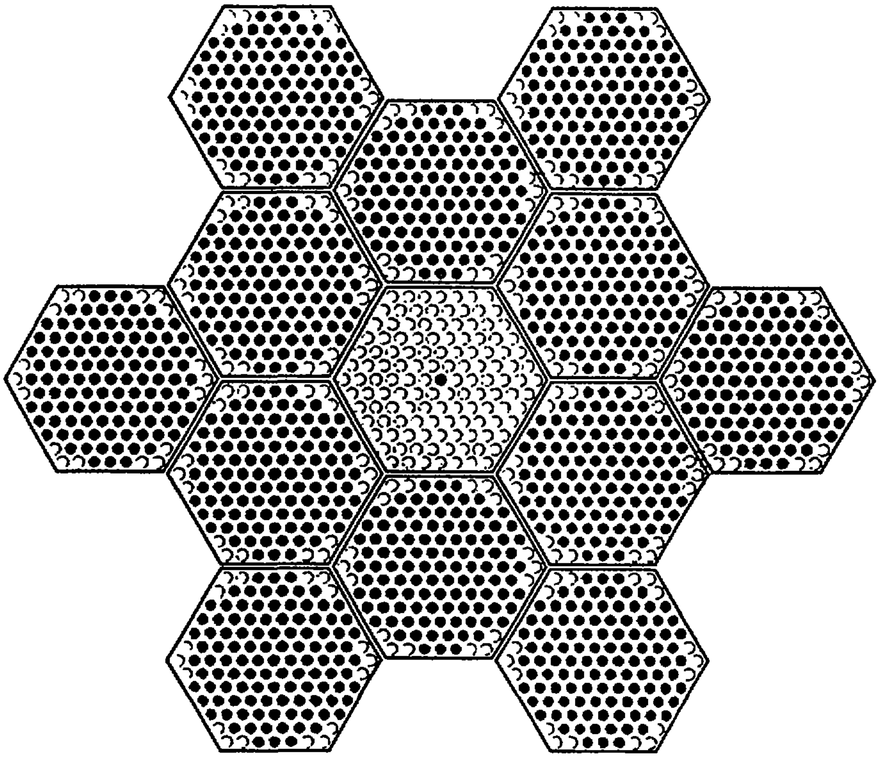

Fig. 4. Schematic Arrangement of the Fuel Pins in Fuel Assemblies in LR-0 Core with CA in its Centre

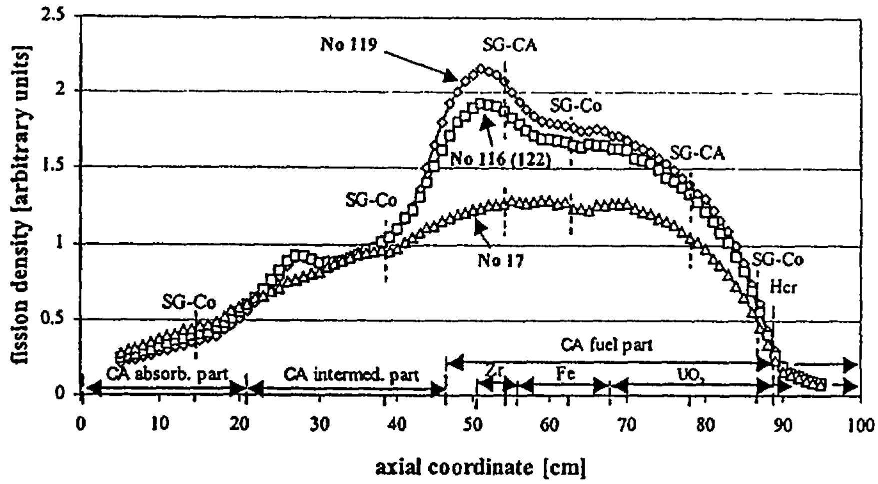

Fig. 5. Axial Power (Fission Density) Distribution in Positions No 119, No 116 (122) and No 17

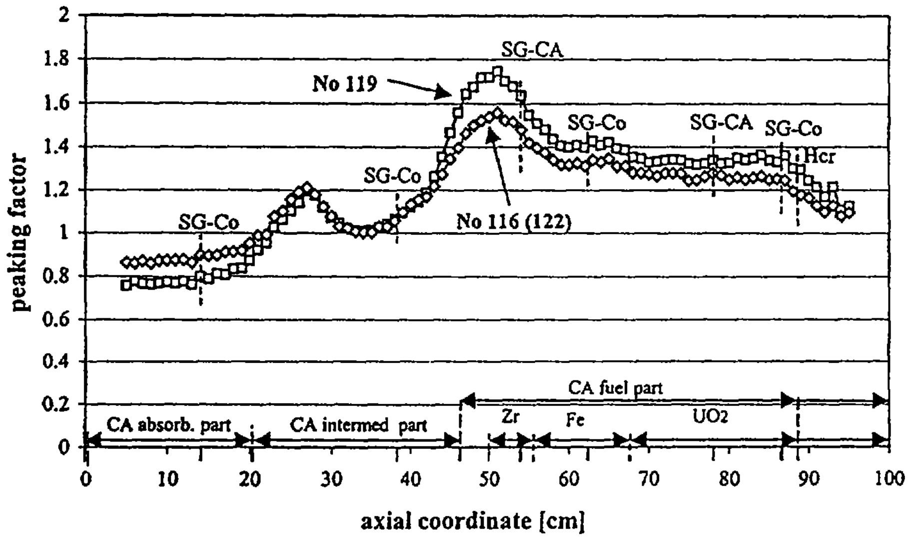

Fig. 6. Peaking Factors of the Power (Fission Rate) Distribution in Positions No 119 and No 116 (122) Regarding to Position No 17