International Conference
Nuclear Energy for New Europe 2002
Kranjska Gora, Slovenia, September 9-12, 2002
www.drustvo-js.si/gora2002

WWER-440 CONTROL ASSEMBLY LOCAL POWER PEAKING INVESTIGATION ON LR-0 REACTOR

Jan Mikus
Nuclear Research Institute Rez plc
250 68 Rez 130, Czech Republic
mik@ujv.cz

ABSTRACT

This paper presents information concerning the local power peaking problem induced by the WWER-440 control assembly and the investigation possibilities on the light water, zero power reactor LR-0 at the Nuclear Research Institute (NRI) Rez plc. A brief description is given about the disposable control assembly model, experimental arrangement and conditions on the LR-0 reactor with regard to the earlier performed investigations as well as to the relevant measurements to be realized in the near future.

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 has been performed on the LR-0 reactor for this purpose and the first of them is described in the report [2] (LR-0 reactor hall - bird view is presented in Figure 1, the main parts of the CA model - in Figure 2). Further measurements with CA model have been realized on LR-0 reactor with boron acid concentration 4.8 g/l in the frame of a contract concluded between NRI Rez and Hungarian NPP Paks [3]. In Figure 3 (a) the loading of the CA model into LR-0 core is presented as well as (b) - the bird view into LR-0 vessel and finally (c) - the core in detail with CA model in its centre.

It is to be noted that 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 at zero boron acid concentration. 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].

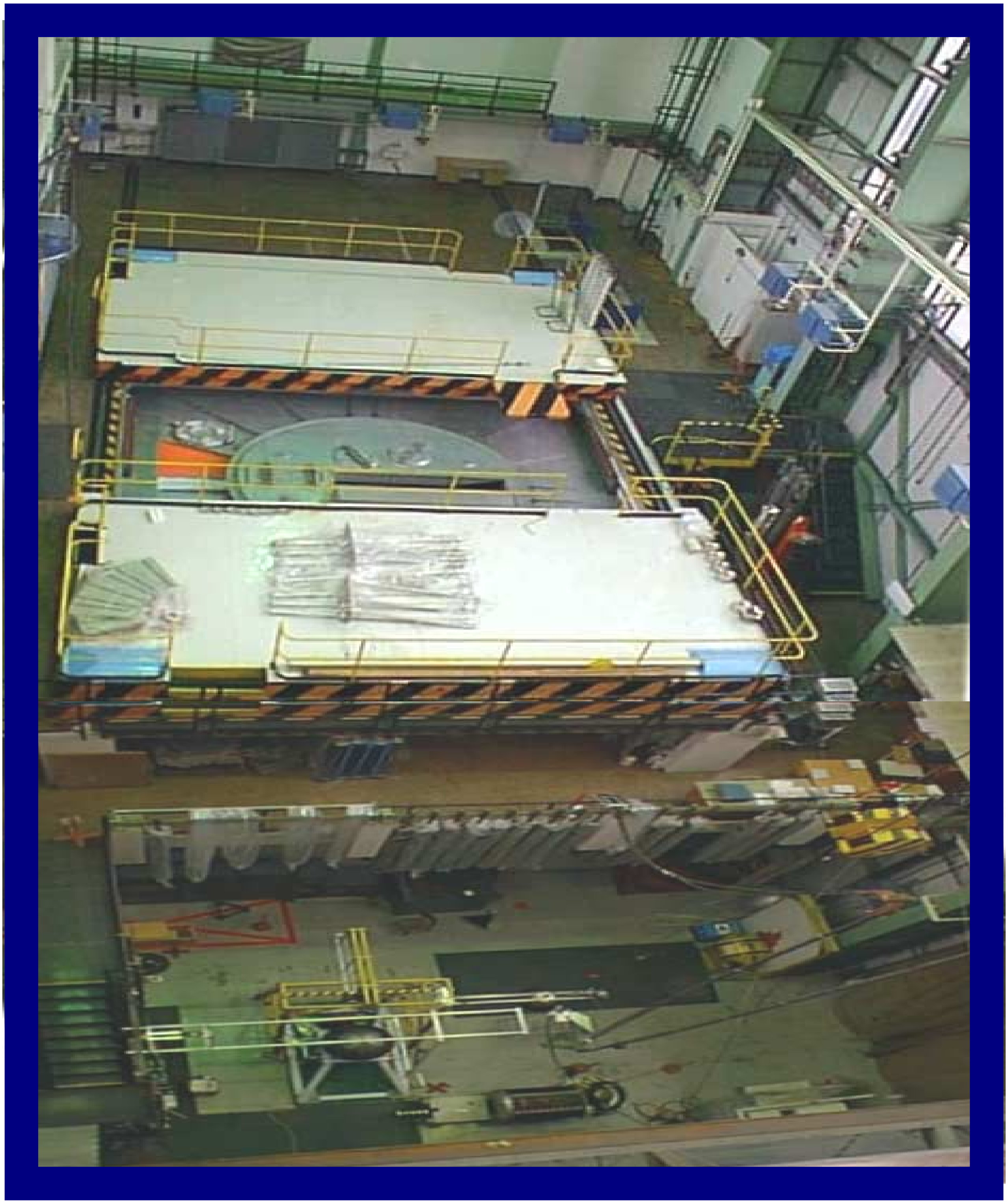


Figure 1: LR-0 Reactor Hall - Bird View

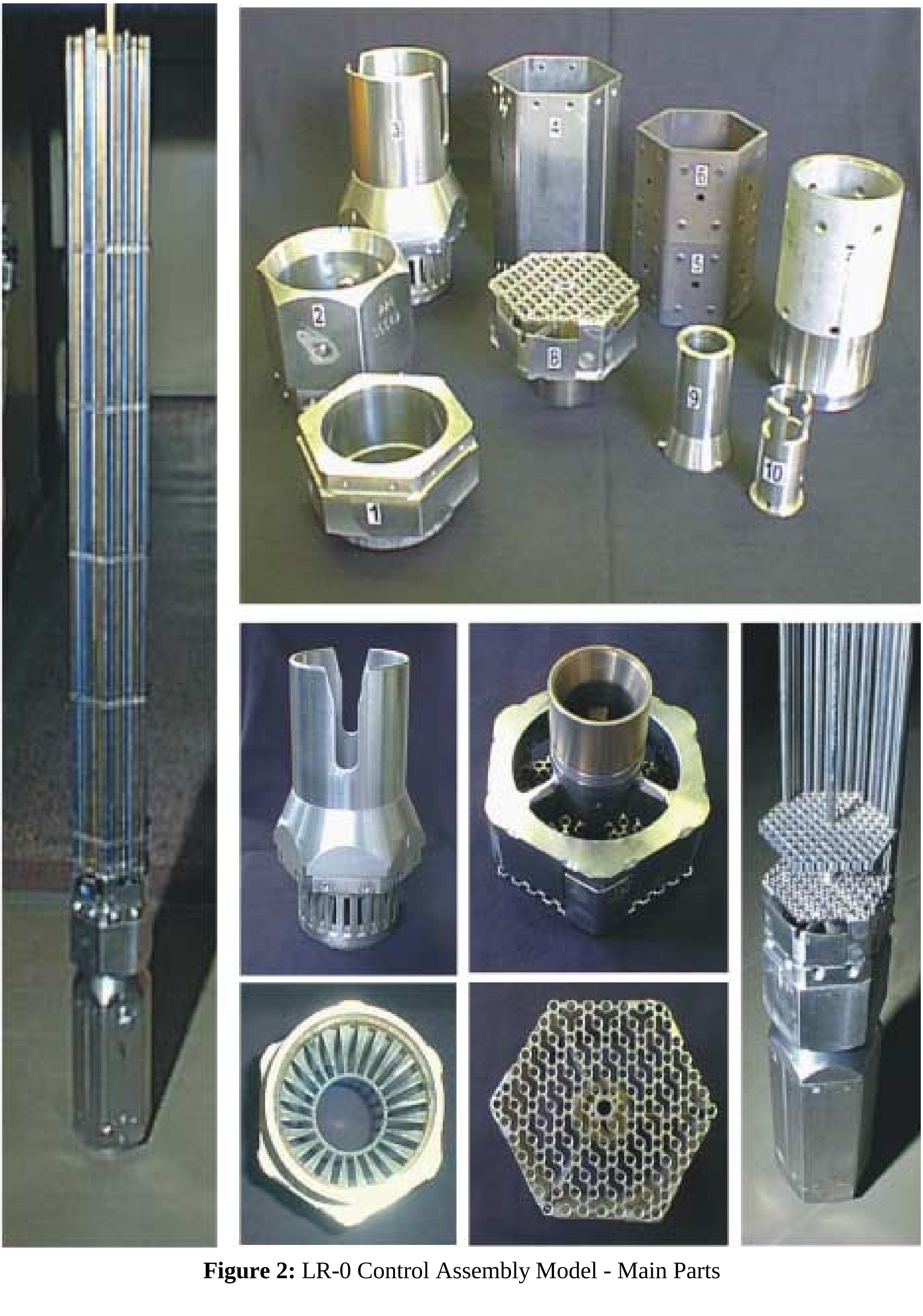
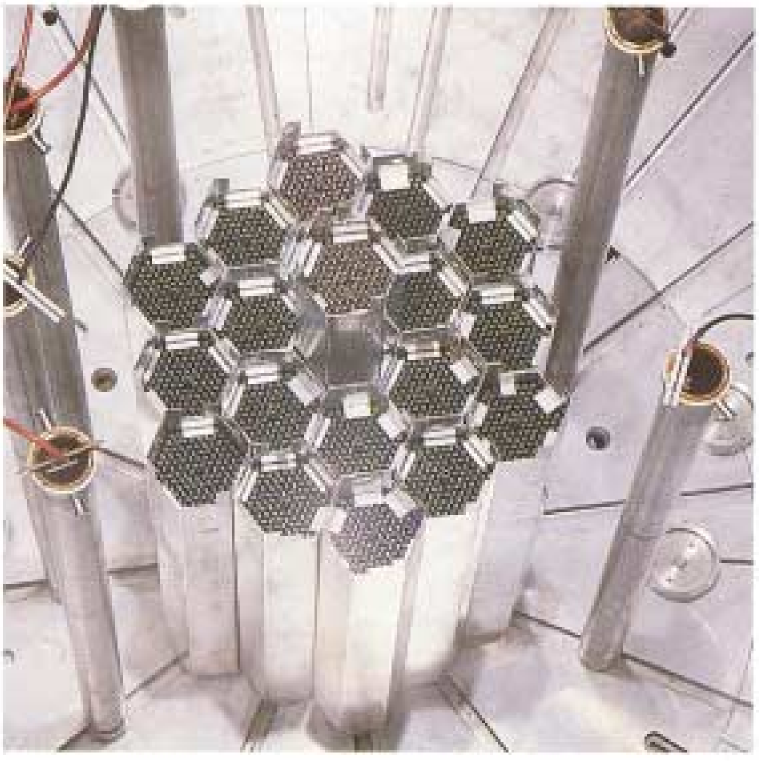


Figure 2: LR-0 Control Assembly Model - Main Parts

(a)

(b)



(c)

Figure 3 : A VVER-440 Type Core in LR-0 Reactor with Control Assembly (CA) Model:
(a) - CA Model Loading into LR-0 Core, (b) - Bird View into LR-0 Vessel,
(c) - LR-0 Core in Detail with CA Model in its Centre

On the other hand, some NPPs are operated with CA at their uppermost position practically during the whole cycle, e.g. 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 Russian Federation), another ones will be innovated in the near future (e.g. NPP Dukovany), other ones - later on, whereas some of NPPs are operated with inserted CA, other ones not. Relevant calculation using BIPR7-A, PERMAK-A and PERMAK-3D codes and 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 at the Institute of Nuclear Reactors, RRC "Kurchatov Institute", Moscow [5].

We can conclude, there are two situations concerning the WWER-440 type cores with CA 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 - with this concentration being high - practically at the start of fuel cycle. At the condition on the LR-0 reactor (room temperature, atmospheric pressure) this concentration can be about 6.5 g/l boron acid in moderator. Of course, the investigation of both situations mentioned above should also include both two variants - without and with hafnium 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. 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 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 will be 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. In all FA the standard type stainless steel spacing grids defining the hexagonal lattice of the fuel pins will be used at positions with vertical (axial) coordinates having step of 240 mm.

The vertical (axial) coordinates of the core arrangement will be:

- -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
- 209.5 mm - top of absorber segments
- 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 mm - achieved critical height

To start the preparation of an experiment with zero boron acid concentration in moderator, some needed calculations have been performed to determine a core having suitable properties. On the ground of these calculations [6], following core has been determined: it consists 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 Figure 4).

The achieved critical height of this core will be about 880 mm, enough to have possibility to investigate power peak in the vicinity of 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

The measurements of the axial fission density distribution will be performed at all 6 FA adjacent to CA, at each of them in following (equivalent) positions:

- In the middle position of the peripheral, to the CA adjacent row of fuel pins
- In the middle position of the 5^{th} row from the CA

These positions are the same as those investigated in connection with power peaking phenomenon in the paper [1] mentioned above. Further, the same axial measurements will be performed at 3 FA adjacent to CA with the step of 120°, for each of them at 2 their corner positions adjacent to CA. It means, each final axial distribution will be determined as a weighted mean of the 6 independent distributions, to obtain experimental data of high quality (reliability, accuracy).

Measurements will be based on gamma scanning technique of the irradiated fuel pins detecting their gamma radiation in the energy range (1) of 600 to 900 keV as well as (2) of La peak - 1596.5 keV. The measurements will be done (1) with variable step of 1, 2.5 or 5 cm: at heights 5, step 5 to 20, step 2.5 to 40, step 1 to 60, step 2.5 to 90 cm (i.e. at 46 positions) and (2) with a step of 1 cm: at heights 1, 2, …, 90 cm (i.e. at 90 positions).

Results obtained by both methods will be compared one another. Similar measurements will be prepared for investigation of the second situation - i.e. for a core with high boron acid concentration in moderator.

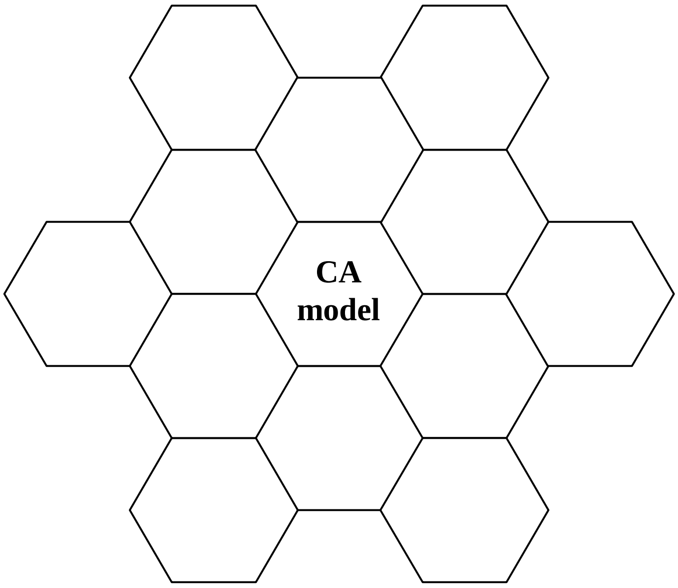


Figure 4: LR-0 Core to Be Investigated with the Control Assembly (CA) Model in its Centre

5 EXPERIMENTAL RESULTS UTILISATION

Parallel to the start of measurements the corresponding calculations can be initiated. More exactly, calculations need the critical height value determined by the first critical experiment. Further, the schemes of both measurements and calculations will be the same to have possibility of the results comparison. Therefore, both measurements and calculations will be carried out at the same positions and the obtained results will have the same normalization. On the ground of such comparison some correction of codes can be done including their validation.

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 proposed activity concerning the power peaking problem investigation has been presented above. Next program could utilize the validated codes 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 than the first part, because it is limited practically by the NPPs needs only.

More information about experiment to be realized can be found in the paper [7]. Other information concerning the power peaking phenomenon were papers presented in IAEA Technical Meeting on WWER-440 Local Power Peaking Induced by Control Rods (to be published).

7 REFERENCES

[1] A. Grishakov, V. Lushin, I. Vasilchenko, Yu. Ananiev, V. Kurskov, Yu. Kukushkin, “The Ways of Advancing the Design of Fuel Assemblies and Fuel Cycles of VVER-440 Reactor” (Russia, OKB Gidropress), Third International Seminar on WWER Fuel Performance, Modelling and Experimental Support, Pamporevo, Bulgaria, 4 - 8 October 1999, Paper 2.1.

[2] J. Bardos, J. Broulik, O. Hrazdil, F. Hudec, F. Kryl, J. Mikus, V. Rypar, “Experimental Determination of the Control Cassette Influence on Power Distribution in the Core of VVER-440 Type” (in Czech). Report UJV-7218 R,T. Nuclear Research Institute, Rez, 1985, 41 pp.

[3] J. Mikus, F. Hudec, “WWER-440 Control Assembly Influence Measurement”, Contract between Nuclear Research Institute Rez plc and NPP Paks No. PA-4-0704-3-HJ, Final report on experiment at the LR-0 reactor, Nuclear Research Institute Rez plc, Czech Republic, 1994, 45 pp.

[4] Riitta Kyrki-Rajamaki, “E-mail communication”, 2 September 1999.

[5] I. Aborina, P. Bolobov, Yu. Krainov, “Calculation and Experimental Studies of Power Distribution in the Vicinity of the Normal and Modernized CR of the WWER-440 Reactor”, Proceedings of the tenth Symposium of AER, Moscow, Russia, 18 - 22 October 2000, 30 pp.

[6] J. Kyncl, “Private communication”

[7] J. Mikus, “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.