DETERMINATION OF THERMAL REACTIVITY COEFFICIENTS FOR THE FIRST FUEL LOADING OF MO34

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Received 26 April 2012; accepted 27April 2012.

Introduction

In general a reactor is initially started up from a cold condition by withdrawing control rods until the reactor is slightly subcritical, thus producing an exponentially increasing neutron population on a very long period. As the neutron population increases, the fission heating and thus the reactor temperature increase. This increase in temperature produces a decrease in reactivity (almost all reactors are designed to have a negative temperature coefficient) that would case the neutron population to decrease and the reactor to shut down.[1] The article introduces determination of thermal reactivity coefficients, especially summarized (isotermal) and moderator (density) reactivity coefficients between 200°C and 260°C with 2°C step, - in compliance with the assignment – for the first fuel loading into the RC of NP Mochovce units using 2nd generation fuel during the start-up using calculation code MCNP5 1.60.

Material and Methods

Transport method Monte Carlo and calculation code MCNP5 1.60 [2, 3 and 4] have enabled precise three dimensional designing of reactor core components and respective in-core construction parts. In the MCNP5 1.60 has been created a detailed VVER-440/V213 reactor model enabling significant level of flexibility in defining fuel load for the reactor core and reactor operation conditions. The calculation model for the reactor was created based on the available technical documentation from SE, a.s. Company and was optimized after subsequent testing, validation and verificaiton for effective calculation of critical conditions and thermal reactivity coefficients based on the equipment requirements. The reactor core model was created so that it enables to define any cartogram of a detailed model fuel assemblies (FA) and safety control rods for automatic protection, regulation and compesation (SCR). Geometric model of a working fuel assembly (PK-2) is consisting of the bunch of fuel pins, base and cladding tube. Fuel pins are in bundles located in a triangular grid with step 12.3 mm (FA-2). They are mutually interconnected through spacer grids in a "honey-comb pattern", secured to the central tube and bottom bearing grid in the base of the fuel assembly. In the structure of the fuel assembly is located upper spacer grid with wide rim and intermediate spacer grids (11 pc) and bottom load-bearing grid welded to the base.

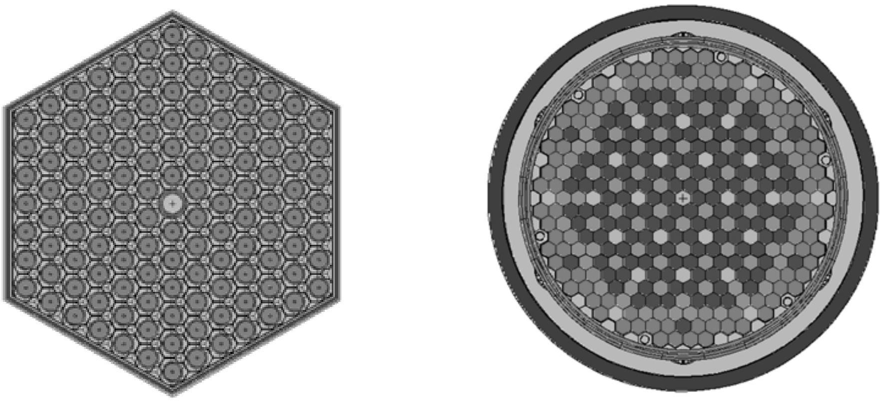

Fig.2.1: *Horizontal section through the fuel assembly through the spacer grid and horizontal section through the reactor core based on cartogram of the fuel assemblies in the unit 3 EMO.*

The calculation of the value of the summarized (isothermal) a_{PO} and moderator (density) a_M thermal reactivity coefficients by means of the calculation code MCNP5 1.60 can be executed using two approaches: the realistic or the combined conservative one, which differ from each other in the preparation of input parameters and in the evaluation of the resulting uncertainty of calculation results. The realistic approach assumes the use of the realistic model, the entering of real parameters and consideration of real conditions. The result of calculations must be carried out with the assessment of the uncertainty, which is the result of the sensitivity analysis of uncertainty components affecting the simulated process. The mean isothermal reactivity coefficient a_{PO} (all equation mentioned below are relevant for determination density a_M thermal reactivity coefficients) of the first fuel loading of SE a.s. MO34 units for the defined states through the H_3BO_3 critical concentration and positions of the 6th group of the SCR within the range of temperatures of 200 to 260°C with a step of 2°C is determined by calculation by means of the code MCNP5 1.60 according to the relation:

$$a_{PO_i} = \frac{\Delta\rho_i}{T_i - T_{i-1}} = \frac{k_{eff_i}^{MCNP} - k_{eff_{i-1}}^{MCNP}}{2\left(k_{eff_i}^{MCNP} + \Delta_{bias}\right)} \qquad (2.1)$$

Where $\Delta\rho_i$ - is the effect of reactivity caused by the change of temperature of the RC materials within the range of $T_i - T_{i-1}$, the size of temperature change in the whole examined interval is 2°C. $k_{eff_i}^{MCNP}$ and $k_{eff_{i-1}}^{MCNP}$ are the values of the effective multiplication coefficient determined by calculation by means of MCNP5 1.60 for the temperature T_i or T_{i-1} and Δ_{bias} is the systematic bias (error) of k_{eff} calculation by means of MCNP5 1.60. The uncertainty of determination of the isothermal reactivity coefficient σ_{PO_i} is as follows

$$\sigma_{PO_i} = \sqrt{\left(\frac{\partial a_{PO_i}}{\partial k_{eff_i}^{MCNP}}\right)^2 \sigma_i^2 + \left(\frac{\partial a_{PO_i}}{\partial k_{eff_{i-1}}^{MCNP}}\right)^2 \sigma_{i-1}^2 + \left(\frac{\partial a_{PO_i}}{\partial \Delta_{bias}}\right)^2 \sigma_{bias}^2} \qquad (2.2)$$

$$\sigma_{PO_i} = \sqrt{\left(\frac{\Delta_{bias} + k_{eff_{i-1}}^{MCNP}}{2\left(k_{eff_i}^{MCNP} + \Delta_{bias}\right)^2}\right)^2 \sigma_i^2 + \left(-\frac{1}{2\left(k_{eff_i}^{MCNP} + \Delta_{bias}\right)}\right)^2 \sigma_{i-1}^2 + \left(-\frac{k_{eff_i}^{MCNP} - k_{eff_{i-1}}^{MCNP}}{2\left(k_{eff_i}^{MCNP} + \Delta_{bias}\right)^2}\right)^2 \sigma_{bias}^2} \qquad (2.3)$$

where σ_i and σ_{i-1} are the uncertainties of determination of the effective multiplication coefficient determined by calculation by means of MCNP5 1.60 for the temperature T_i or T_{i-1} σ_{bias} is a combined uncertainty of determination of Δ_{bias}. The calculations of the summarised or also isothermal thermal reactivity coefficient were carried out without considering the power feedback.

Results

For the calculation of k_{eff} entering the expression for the thermal reactivity coefficent we used the calculation code MCNP5 1.60 with the libraries ENDF/B VII [5] and the values of bias Δ_{bias} determined from the valdiation calculations for the known critical concentration of H_3BO_3 $c_{Bkrit}^{\exp}$ of SE a.s. EMO Unit 2 during FS tests on 2 December 1999 at 2^{30} a.m.[6]. Similarly we determined the uncertainty $\sigma_{\exp}$ for the above state of critical reactor.

Summarised (Isothermal) Thermal Reactivity Coefficient a_{PO}

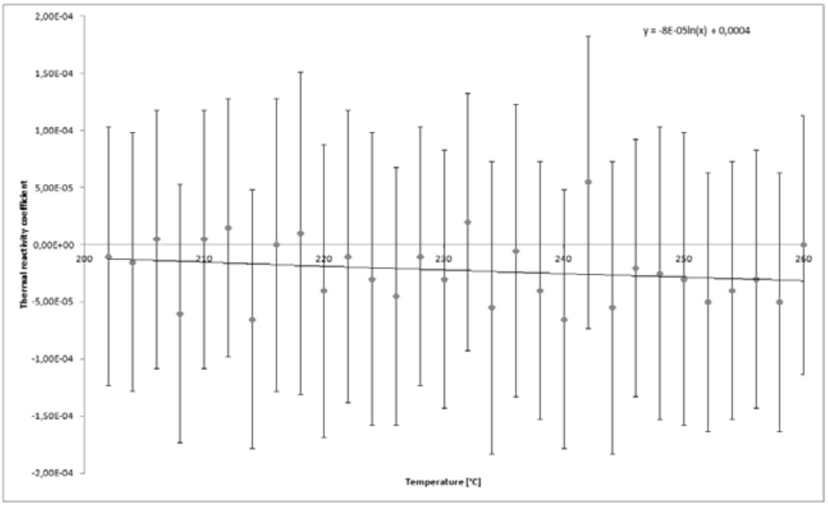

Fig. 3.1 Dependence between the mean value of the summarised thermal reactivity coefficient for 2nd generation fuel and the RC temperature of 200°C to 260°C.

Moderator Thermal Reactivity Coefficient a_M

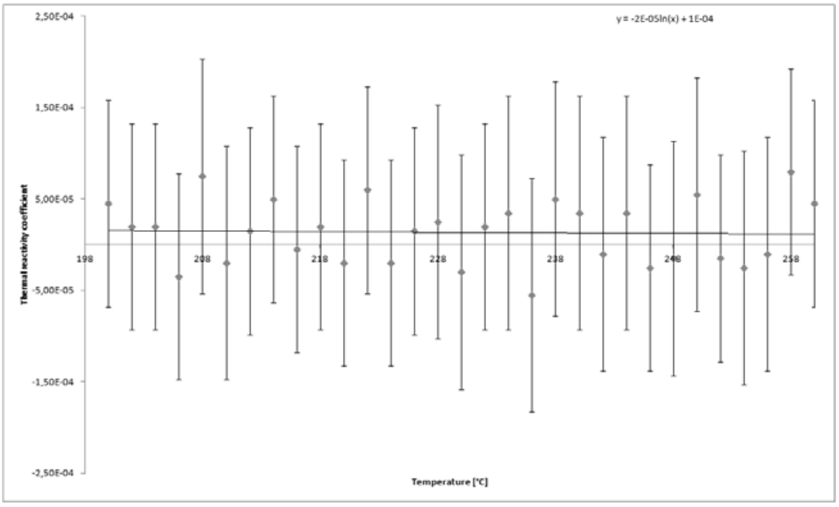

Fig. 3.2 Dependence between the mean value of the moderator thermal reactivity coefficient for 2^{nd} generation fuel and the moderator temperature of 200°C to 260°C.

Discussion

The analysis of the summarised thermal reactivity coefficient $a_{PO}(T)$ in the interval of temperatures from 200 to 260°C for the 2nd generation fuel has proved that the summarised thermal reactivity coefficient $a_{PO}(T)$ has the trend line, shown in Fig.3.1, in negative area and with the growing temperature $a_{PO}(T)$ it gets a higher absolute value, corresponding to theoretical assumptions. The moderator thermal reactivity coefficient, as we can see in Fig.3.2, has the trend line in positive area, but it is still close to zero and with the growing temperature the value of a_M decrease, since it is in line with expectations. Based on computed data represented by Fig.3.1 and Fig.3.2 we can claim that 2nd generation fuel satisfies safety requirements for start up core.

Acknowledgement

Authors acknowledge support would like to thank VEGA 0366/2012. This work was financially supported by SE, a.s.

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