MCNP CALCULATION OF THE CRITICAL H_3BO_3 CONCENTRATIONS FOR THE FIRST FUEL LOADING INTO THE REACTOR CORE OF NPP MO-3-4 UNITS

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1. Introduction

The purpose of the analysis was the determination of critical H_3BO_3 concentrations for the first fuel loading into the reactor core of MO34 units using 2nd generation fuel during the first start-up of new unit using calculation code MCNP 1.60 [1]. H_3BO_3 concentrations were computed for the given temperature of the primary circuit and position of the 6th safety control rod group. Because of the very first start-up of these units, detailed analyses of active-core parameters are required by National Regulatory Authority and needed for safe operation of nuclear facility**.**

2. Material and Methods

Transport method Monte Carlo and calculation code MCNP5 1.60 [1] 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. The calculation model was optimized after subsequent testing, validation and verificaiton for effective calculation of critical conditions and thermal reactivity coefficients based on the equipment requirements. The created whole-zone VVER-440/V213 model consists of reactor core and in-core construction components of the reactor. Detailed models of those fuel assemblies (FA) and safety control rods, for automatic protection, regulation and compensation (SCR), which will be used in the scheduled first fuel loading in the unit 3 EMO and those which were used in the first fuel loading of the unit 2 EMO were prepared. Geometric model of a working fuel assembly (PK-1 and PK-2) is consisting of the bunch of fuel pins, base and cladding. Fuel pins are in bundles located in a triangular grid with appropriate step. 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.

The model of the reactor internals was elaborated only for the part from the bottom edge of the bearing grid in reactor core basket to the bottom edge of the protecting tube system. In this segment were considered all important construction elements of the reactor internals see Fig.1.

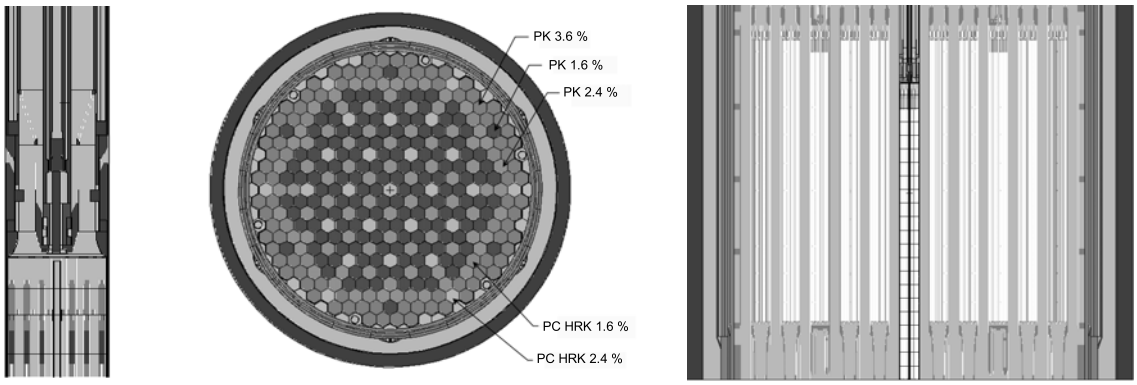

Fig.1: *Vertical section through the SCR in the connection of the fuel and absorption part, horizontal section through the reactor core based on cartogram of the fuel assemblies in the unit 3 EMO and vertical section through the reactor core model and.*

The model of the reactor shaft consists of vertical cylindrical vessel which has on the external surface (reactor core level) six pairs of channels to insert irradiation chains with samples of reactor pressure vessel materials. The irradiation channels are covered with a coating. The model did not consider filling them in with irradiation chains. Libraries of microscopic effective cross sections and probability tables entering the calculation code MCNP5 1.60 were prepared by NJOY99.364 code system. [4] Code system NJOY is a modular calculation system where each module is intended for solving a specific assignment. Verified library of microscopic effective cross sections ENDF/B-VII distributed by OECD NEA Data Bank consisting of 381 materials was used as an input for NJOY99.364 calculation.[5] The whole process of preparing libraries of microscopic cross sections was verified by using benchmarking tasks based on the International Handbook of Evaluated Criticality Safety Benchmark Experiments.[6] To process the microscopic effective cross sections by NJOY99.364 were used modules *Moder, Reconr, Broadr, Unresr, Leapr, Therm, Heatr, Purr, Gaspr, Viewr* and *Acer*. Principal simplified process of creating libraries of effective cross sections is demonstrated in the Fig.2.

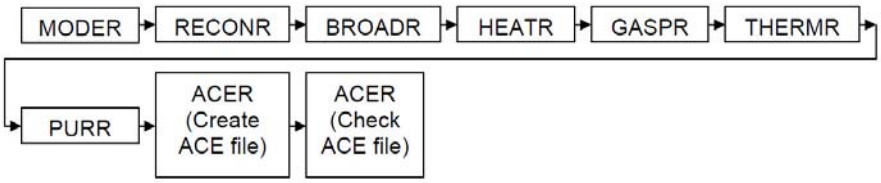

Fig. 2: *Main simplified process of creating libraries of effective cross sections using NJOY99.364 code system.*

Code MCNP5 1.60 used to calculate the critical H_3BO_3 concentration does not have the direct output of this value. The value, at which k_{eff}^{MCNP} is equal to one with the defined accuracy is considered the critical value of H_3BO_3. The result can be obtained in at least two ways: the simulation of the critical experiment or using the iteration method. Taking into account the time necessary for the determination of the critical H_3BO_3 concentration, we decided to use the iteration method in the analyses, which shortens the determination by more than one half because it is not necessary to analyse the gradual results of calculations. This method will allow finishing the calculation automatically after the achievement of the specified result's accuracy. The iteration numerical procedure using the bisection method and the Newton's iteration method was selected for the task of the determination of c_{Bkrit} H_3BO_3

critical concentration. A control script in the scripting language *csh* was prepared to control the calculation.

For the validation of calculations of H_3BO_3 critical concentration, the first well stabilised critical state of SE, a. s. EMO Unit 2 during its physical start-up was used. The stabilised state of EMO Unit 2 is described in Chapter 2, Table 1; Evaluation of Mochovce NPP Unit 2 physical start-up tests, reg. No. 24/2000, VUJE Trnava [3]. Stabilised parameters: the position of the 6th group of SCR h_6=144.4 cm; primary circuit temperature T_{PO}=200.3 °C; primary circuit pressure p_{PO}=12.09 MPa; the median of H_3BO_3 critical concentration c_{Bkrit}^{exp}=8.11g/kg. For the validation of calculations of H_3BO_3 critical concentration, we consider it to be experimentally determined by three more independent methods. Using the potentiometric method the value reached c_{Bkrit1}=8.12 g/kg; using the coulometry method - c_{Bkrit2}=8.14 g/kg [3]; using the titration method, SE a.s. – EMO o.z. determined c_{B3krit}=8.08 g/kg and using the method 716 DMS Titrino, SE a.s. – EMO o.z. determined the critical concentration of H_3BO_3 with the value c_{B4krit}=8.11 g/kg. The above methods of H_3BO_3 concentration measurement provide the concentration with a tolerance of $\pm$ 0.05 g/kg.

For the above state, the input file MCNP5 1.60 was created, which contained all the materials and geometric arrangement of the first fuel loading into the reactor core of EMO Unit 2.

3. Results

The H_3BO_3 critical concentration for the first fuel loading of EMO Unit 2 was calculated for the described state by means of the iteration method. During the calculation, the accuracy of the calculation k_{eff}^{MCNP} was adjusted to the value better than ξ_N = 0.00005. The calculated H_3BO_3 critical concentration c_{Bkrit}^{MCNP}=8.45023 g/kg differs from the experimentally determined H_3BO_3 critical concentration c_{Bkrit}^{exp}=8.11 g/kg during the physical start up tests of Unit 2. This deviation will be considered to be the systematic error of calculations and will be reflected in the results in the form of correction $\Delta_{c_{Bbias}}$. The value of correction of the calculation of H_3BO_3 critical concentration is:

$$\Delta_{c_{Bbias}} = c_{Bkrit}^{exp} - c_{Bkrit}^{MCNP} = -0.34023 \text{ g/kg} \qquad (1)$$

The median of H_3BO_3 experimental critical concentration was c_{Bkrit}= 8.11 g/kg determined with a tolerance of ±0.05 g/kg. For the purpose of determination of values of the systematic bias Δ_{bias} we consider the above value of H_3BO_3 critical concentration to be an experimentally specified value c_{Bkrit}^{exp} with the known tolerance of determination. Conservatively, we presumed a uniform distribution of the value c_{Bkrit}^{exp} in the whole interval of tolerance, and we specified the standard uncertainty:

$$\sigma_{c_{Bkrit}}^{exp} = \frac{a+b}{2\sqrt{3}} = \frac{0{,}05 + 0{,}05}{2\sqrt{3}} = 0.02887 g/kg. \qquad (2)$$

In the described state, the reactor is critical, i.e. $k_{eff}^{exp} = 1$ with the uncertainty of σ_{exp}, whose value was determined by means of calculations using the code MCNP5 1.60. During the calculation, we took into account a uniform occurrence of H_3BO_3 critical concentration in the whole tolerance interval from 8.05 – 8.16 g/kg. The calculated values of k_{eff}^{MCNP} and k_{eff}

corresponding to the uniform occurrence of the value of boric acid critical concentration were in the range of k_{eff} =<1.00114;0.99909> and k_{eff}^{MCNP} =<1.00781±0.00008; 1.00576±0.99909>. For the stabilized median of H_3BO_3 critical concentration 8.11, the value of Δ_{bias} defined by term (3) is equal to 0.00667.

$$\Delta_{bias} = k_{eff}^{\exp} - k_{eff}^{MCNP} \tag{3}$$

The uncertainty of bias Δ_{bias} will be determined by means of the relation:

$$\sigma_{bias} = \sqrt{\sigma_{MCNP}^2 + \sigma_{\exp}^2} = 6.14x10^{-4} \tag{4}$$

According to the assignments and above methodology, for the reactor core loading with fuel of the 2nd generation, with the primary circuit temperature increase from 200 to 260°C, the critical concentration of H_3BO_3 drops from $c_{B1krit200}$ = 7.09898 g/kg to $c_{B2krit200}$ = 7.05211 g/kg at the position of the 6th SCR h_6=200 cm. Similarly, with an increase in the primary circuit temperature from 200 to 260°C, the critical concentration of H_3BO_3 also drops for the position of the 6th SCR h_6=125 cm from $c_{B1krit125}$ = 6.92121 g/kg to $c_{B2krit125}$ = 6.81498 g/kg.

4. Conclusion

The drop of H_3BO_3 critical concentration suggests the expectation of a negative value of the summarized thermal reactivity coefficient of the first fuel loading into the reactor core using the 2nd generation fuel. These results will allow exact determination of summarized thermal reactivity coefficients which are fundamental requirements of National Regulatory Authority in license process.

Implementation of methodology based on automatic computation of given parameter using iteration method can be used for calculation of any other variable including control rod position, fuel pellet diameter or appropriate water density.

Acknowledgement

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5. References

[1] X-5 Monte Carlo Team, "MCNP – A General N – Particle Transport Code, Version 5 – Volume I: Overview and Theory“, LA-UR-03-1987, Los Alamos National Laboratory, April 24, 2003 (Revised 2/1/08).

[2] Pre-Operational Safety Report for the EMO NPP Revision 1 – Amendment No. 3, Units 1 and 2, Федеральное агентсво по атомной енергии, ФГУП ОКБ ГИДРОПРЕС, ФГУ РНЦ Курчатовский институт, У213-ТИ-1768, 10/2005

[3] Evaluation of Mochovce NPP Unit 2 physical start-up tests, reg. No. 24/2000, VUJE Trnava.

[4] E. MacFarlane, D. W. Muir : RSICC PERIPGERAL SHIELDING ROUTINE COLLECTION - NJOY99.0, Code System for Producing Pointwise and Multigroup Neutron and Photon Cross Sections from ENDF/B Data, Los Alamos National Laboratory, Los Alamos, New Mexico

[5] ENDF library - Evaluated Data Libraries including INDF/B-VII.0, ordered from IAEA http://www-nds.iaea.org/cd-catalog.html, (April, 2011).

[6] International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03, OECD Nuclear Energy Agency (2007)