Optimalizace vyhořívajících absorbátorů pro reaktor EPR

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EPR Burnable Absorber Optimization

Abstract – **The research of burnable absorber (BA) is a very important issue, due to BA influence on regulation and control of reactivity in the reactor. Burnable absorbers compensate initial excess reactivity. This paper deals with the depletion calculation of Evolutionary Power Reactor (EPR) nuclear fuel with different types of BA, and with optimization of the BA. The main objective of this paper is to calculate burnable absorber composed of 2 elements. Based on depletion calculation, elements are divided into two groups, fast and slow BAs. Several combinations of two BA elements are then calculated based on this division. The evaluation of each BA combination is made, and the most appropriate one is selected.**

Keywords – Burnable absorber; Depletion calculation; EPR; IBA

I. INTRODUCTION

A. UWB1 depletion code

UWB 1 is a fast depletion code developed at the University of West Bohemia. The main reason for developing this program was to decrease computational time. In order to decrease the computational time, UWB1 skips the calculation of Boltzmann transport equations in fuel burnup calculation. However, if the UWB1 would skip the calculation of Boltzmann transport equation entirely, the estimate of the neutron multiplication factor would not be accurate enough. That is why it calculates the neutron flux and the effective cross section by implemented Monte Carlo transport solver at the beginning and at the end of fuel depletion. Burnup solver uses matrix exponential method and Chebyshev Rational Approximation Method (CRAM) for calculation of the next-step inventory of chosen geometric regions. The code is supported by data libraries that are based on ENDF/B-VII.1 nuclear data library [10] [1][8][9]

B. Burnable absorber

Burnable absorbers are materials with high neutron absorption cross section that are used in a reactor to compensate excess reactivity. The daughter nuclide needs to have low absorption cross section. Mother nuclide, thanks to its high absorption cross section, causes neutron absorption. Due to the fact that nuclide resulting from neutron absorption has a lower neutron absorption cross section, the absorber is burnable and the reactivity worth of inserting burnable absorber decreases with the fuel depletion. The greater the difference of cross section between mother-daughter nuclides, the faster the absorber will be burned. [2][6]

II. CALCULATION

C. *Initial step calculation*

In this part, 11 elements with appropriate burnable absorber properties were chosen. For those elements calculations of initial step (fresh fuel) were made. Due to this calculation, the initial drop of multiplication factor for each individual element was obtained. Then the reactivity was calculated and the reactivity difference from the case without BA was set. After this analysis, six elements were selected for further examination. In the Table I. , the data obtained from initial step calculation are shown.

TABLE I. COMPARISON OF INDIVIDUAL ELEMENTS.

Element	Nuclide with the highest cross section	Concentration [wt%]	Multiplication factor k_{eff} [-]	Reactivity difference [pcm]
Cd	Cd-113	0.0125	1.301	2709
Gd	Gd-157	0.0125	1.222	7640
B	B-10	0.0125	1.278	4123
Eu	Eu-151	0.0125	1.318	1703
Er	Er-167	0.0125	1.343	271
Hf	Hf-177	0.0125	1.343	309
Sm	Sm-149	0.0125	1.278	4080
Dy	Dy-164	0.0125	1.338	554
Ir	Ir-192	0.0125	1.341	404
Hg	Hg-199	0.0125	1.347	88
Lu	Lu-176	0.0125	1.345	193

D. *Depletion results for single element BA*

Results of the calculation with single BA from UWB1 code is shown in Fig. 1 to Fig. 6. The concentration was set from 0.0125 wt% to 0.5 wt%.

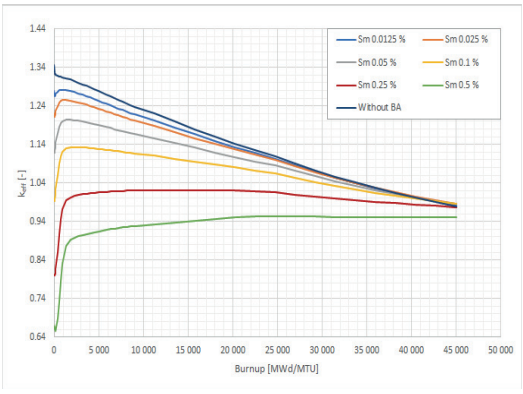

Figure I. **Multiplication factor Sm**

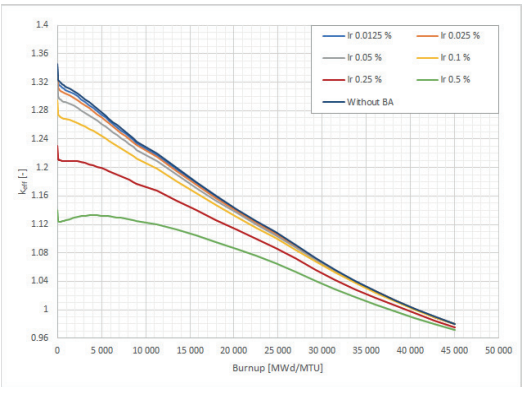

Figure II. **Multiplication factor Ir**

From these graphs, the difference between individual elements is shown. The graphs also show that the concentration 0.25 wt% and 0.5 wt% are inappropriate for all elements. In the case of Sm, at the end of the fuel cycle, the curves with BA are slightly above the curve without BA. This means, that positive reactivity is released, which is good, for the prolongation of the fuel cycle.

E. Depletion results for double elements BA

The calculation was made for total 9 combinations. It was set that the multiplication factor should be k_{eff} = 1.2 at 2250 MWd/MtU. The fraction of each element was selected from 1 to 0 with a step of 0.2. The total concentration of each combination was calculated using simple weight function.

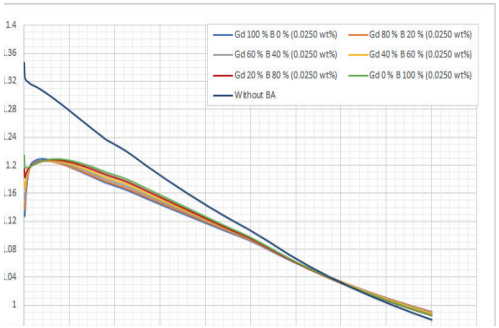

Figure III. **Multiplication factor Gd/B**

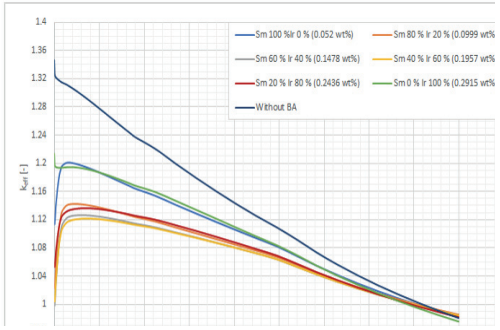

Figure IV. **Multiplication factor Sm/Ir**

F. Use of double element ba in 3, 4, 5-year fuel cycle

Usually, in the power plant 3, 4 or 5-year fuel cycle is used. In following graphs, the progress of multiplication factor is described for different fuel cycle lengths. Only the most suitable BA combination is shown here.

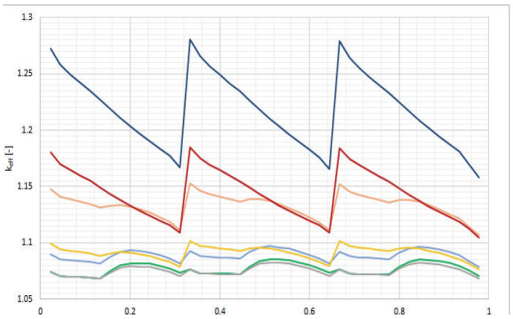

Figure V. **Multiplication factor - 3 year fuel cycle Sm/Ir**

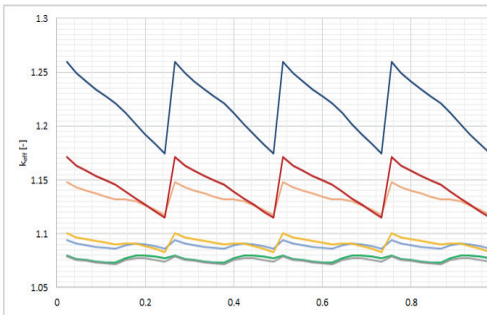

Figure VI. **Multiplication factor - 4 year fuel cycle Sm/Ir**

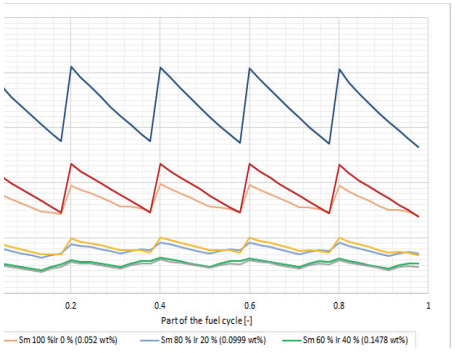

Figure VII. **Multiplication factor - 5 year fuel cycle Sm/Ir**

G. Evalution

For the evaluation of calculated data, a set of parameters was established. First, the initial multiplication factor decrease compared to the state without BA was examined. As a second parameter, the difference of the multiplication factor from the state without BA at the end of the fuel cycle was selected. In this case, it is desirable that the curve with BA is above the curve without BA. If so, the fuel cycle can be prolonged. The next parameter was the reactivity peak difference. The peak difference should be as low as possible. Next parameter of the evaluation was the difference of the peaks with and without BA. Here the desirable state is a large difference. And last, the concentration of each BA was separately evaluated. The desirable state here is to have as low concentration as possible.

III. CONCLUSIONS

The idea behind this paper was to calculate several burnable absorbers composed of 2 elements and evaluate it. After the evaluation, the two most suitable BA combinations were Sm/Ir and Gd/B. The Sm/Ir combination was selected as the most appropriate one based on the evaluation. Specifically, the concentration of 60 % Samarium and 40 % of Iridium is recommended for the EPR as the most suitable one. This combination is the best one from all 9 combinations. The use of this combination allows the prolongation of the fuel cycle and the possibility to use less boric acid, due to the lower peaks between the fuel changes.

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REFERENCES

[1] M. Lovecký, "UWB1 User's Manual," University of West Bohemia, 2015.

[2] M. Lovecký, J. Jiříčková and R. Škoda, "Assessment of burnable absorber fuel design by UWB1 depletion code," Acta Polytechnica CTU Proceedings 4:43–49, 2016.

[3] IAEA, "Thermal Cross Sections,Resonance Integrals and Westcott g factor.," [Online]. Available: https://www-nds.iaea.org/relnsd/NdsEnsdf/neutroncs.html.

[4] AREVA NP & EDF, FUNDAMENTAL SAFETY OVERVIEW, 2007. [Online]. Available: https://www.nrc.gov/reactors/new-reactors/design-cert/epr/reports.html.

[5] D. G. Cacuci, Handbook of nuclear engineering, London: Springer, 2010.

[6] M. Lovecký, J. Jiříčková and R. Škoda, "Monte Carlo solver for UWB1 nuclear fuel depletion code," Annals of Nuclear Energy, 2015.

[7] M. Lovecký, L. Piterka, J. Prehradný and R. Škoda, "UWB1 – Fast nuclear fuel depletion code," Annals of Nuclear Energy [online], no. 71, 2014.

[8] Chadwick, M.B.. (2011). ENDF/B-VII. 1 nuclear data for science and technology: Cross sections, covariances, fission product yields and decay data. Nucl. Data Sheets. 107.