COMPARISON OF BURNABLE ABSORBER ELEMENTS FOR VVER NUCLEAR FUEL

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ABSTRACT

Nuclear fuel containing burnable absorber (BA) significantly improves fuel utilization during reactor operation. BAs compensate for the initial excess reactivity and consequently allow for lower power peaking factors and longer fuel cycles with higher fuel enrichments.

Burnable absorber selection comprises of element selection, its weight content and space distribution in fuel assembly. Selection of burnable absorber element requires large amount of computer time for fuel depletion analysis, therefore, in the first step of BA analysis, only selected elements were analysed with state-of-art industry code.

The contribution compares three selected elements (Gd, Eu, Er) as burnable absorbers in VVER-1000 fuel assembly. Number of burnable absorber bearing pins, their location and BA weight content were used as input variables. Multiplication coefficient during duel depletion was calculated and compared. Fuel depletion calculations for burnable absorber evaluation was performed by TRITON/NEWT code sequence from SCALE code package.

INTRODUCTION

Computationally expensive fuel depletion calculations are necessary in fuel design development. Main property of burnable absorber, initial excess reactivity compensation, is discussed in the paper. SCALE 6.1.2 code package was used to execute number of cases that describes various BA placement inside VVER-1000 fuel assembly.

CALCULATION CASES

Gadolinium, europium and erbium BA was chosen as typical elements for reactivity compensation. Gadolinium nuclides with interesting burnable properties are Gd-155 and Gd-157 with natural abundances 14.80 at% and 15.65 at%. Europium has natural abundance of 47.81 at% Eu-151 and 52.19 at% Eu-153. Both europium nuclides behaves as a good burnable absorber nuclide, both nuclides have have high neutron capture cross sections with end-product nuclide characterized by low capture cross section. Erbium nuclides with interesting burnable properties are Er-166 and Er-167 with natural abundances 33.50 at% and 22.87 at%. Total cross sections of selected BA nuclides Gd-155, Gd-157, Eu-151, Eu-153, Er-166 and Er-167 are depicted in Figure 1. Total cross section for thermal energy 0.0253 eV are: 60801 barns for Gd-155, 253929 barns for Gd-157, 9190 barns for Eu-151, 367 barns for Eu-153, 31 barns for Er-166 and 652 barns for er-167.

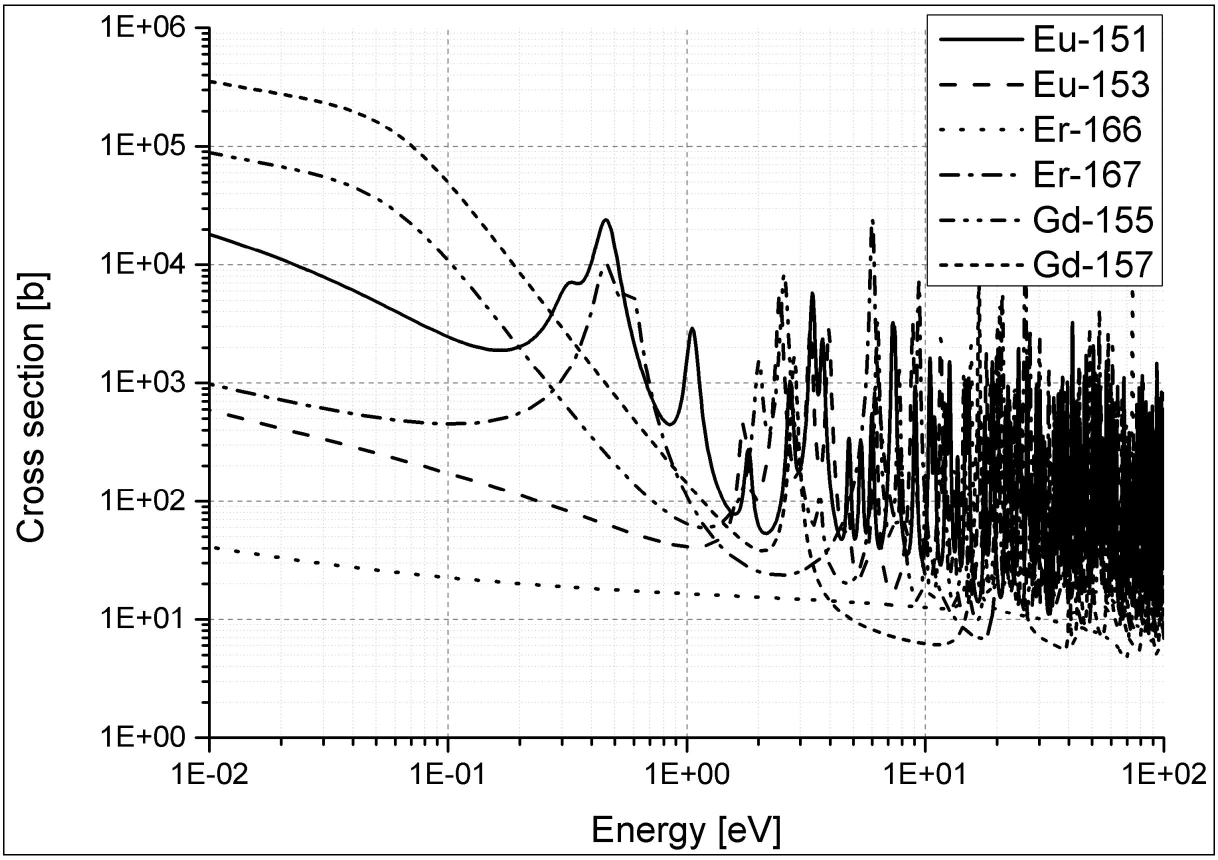


Figure 1: Gd, Eu and Er burnable nuclides - total cross sections.

Fuel depletion TRITON code sequence was used to calculate fuel inventory up to burnup of 20000 MWd/MTU. 2-D transport code NEWT was used to fuel depletion. Quarter part of VVER-1000 assembly model is depicted in Figure 2, whole assembly model was used in actual calculation. Notable depletion parameters: 28 time steps, 44-energy structure multigroup ENDF/B library, 4x4 space division of pin cell, boric acid 600 ppm, central hole and fuel-clad gap was neglected.

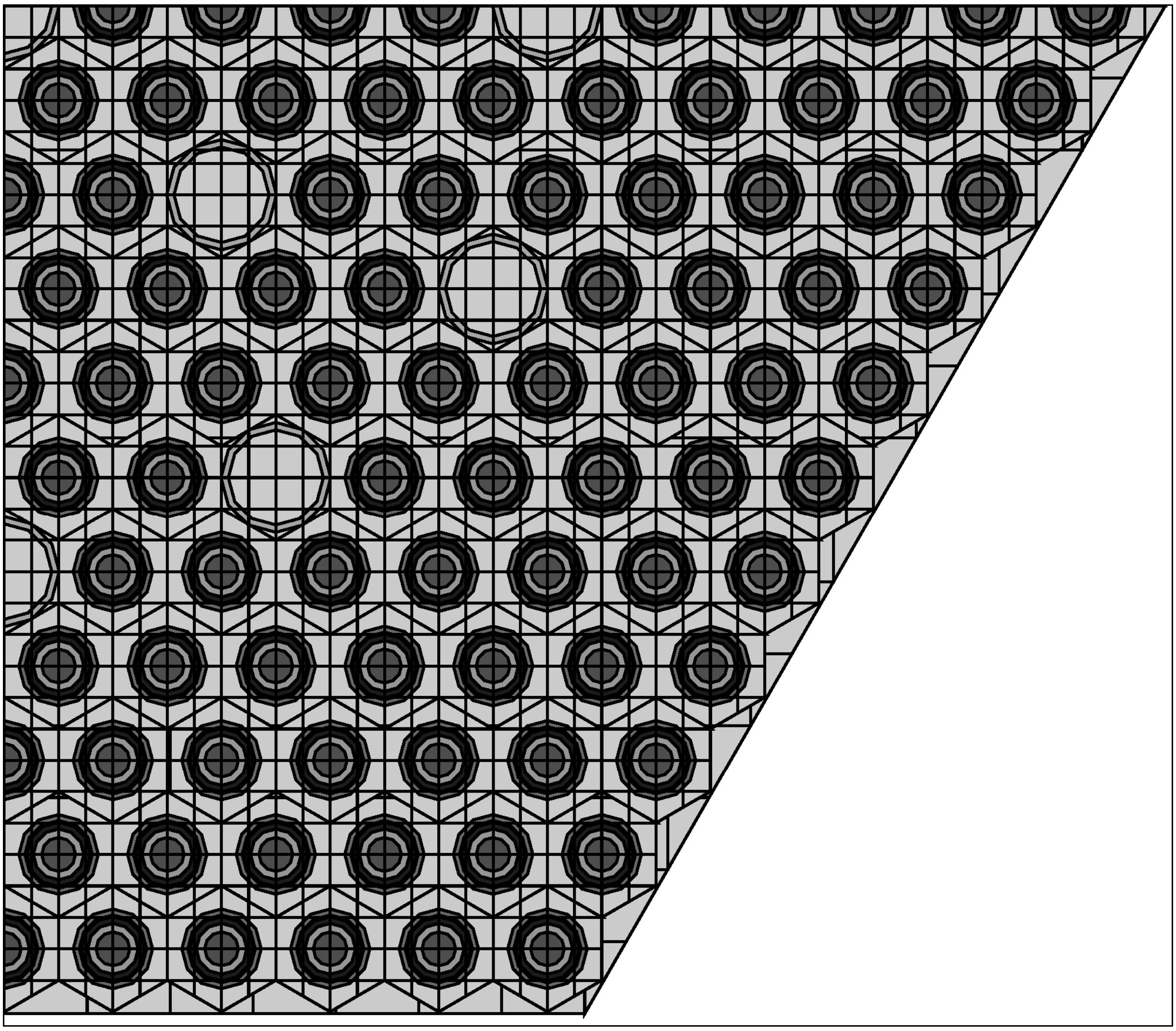


Figure 2: VVER-1000 fuel assembly model used in TRITON calculations

Calculation cases are described in Table 1. Geometry was used to define 18 cases, material to 6 cases and element to 3 cases. Adding one case without BA add together 325 cases. Geometry cases was divided according to number of BA bearing pins per assembly (6, 18, 36 and 312=all pins). One row of BA bearing pins was assumed in cases with 6 pins, 2 rows with 6 and 12 pins was modeled in cases with 18 pins and 3 rows with 6, 12 and 18 bearing pins was used to describe cases with 36 BA bearing pins. All 10 rows of pins was filled with BA in case of 312 BA pins. BA weight content in BA bearing pins was chosen to be at 6 levels from 0.05 wt % to 2.50 wt %. Weight content corresponds to content of BA compounds Gd_2O_3, Eu_2O_3 and Er_2O_3.

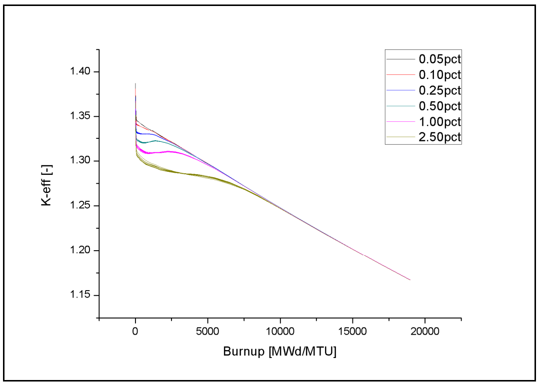
Table 1: Calculation cases parameters.

Geometry case [-]	Number of BA rows [-]	List of rows with BA pins [-]	Number of BA pins per row [-]	Total number of BA pins per assembly [-]
1	1	2	6	6
2	1	3	6	6

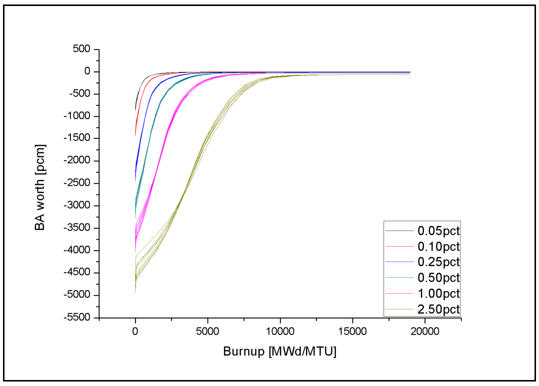
Geometry case [-]	Number of BA rows [-]	List of rows with BA pins [-]	Number of BA pins per row [-]	Total number of BA pins per assembly [-]
3	1	4	6	6
4	1	5	6	6
5	1	6	6	6
6	1	7	6	6
7	1	8	6	6
8	1	9	6	6
9	1	10	6	6
10	2	2--6	6--12	18
11	2	3--7	6--12	18
12	2	4--8	6--12	18
13	2	5--9	6--12	18
14	2	6--10	6--12	18
15	3	2--5--8	6--12--18	36
16	3	3--6--9	6--12--18	36
17	3	4--7--10	6--12--18	36
18	10	1..10	max	312
Material case [-]	**BA content [wt%]**			
1	0.05			
2	0.10			
3	0.25			
4	0.50			
5	1.00			
6	2.50			
Element case [-]	**Element [-]**			
1	gadolinium			
2	europium			
3	erbium			

RESULTS OF CALCULATIONS

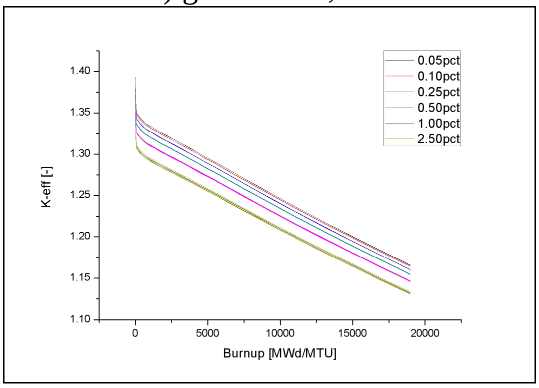
Multiplication coefficients during fuel depletion were calculated, see Figures 3, 4, 5 and 6. Cases were separated into 4 groups by number of BA bearing pins. In each figure, cases with same number of BA pins are depicted. Each color represents calculation cases with the same BA element and the same BA weight content, but different BA location, e.g. from 2nd to 10th row in case of 6 BA bearing pins. Both fuel assembly k-eff and BA reactivity worth are depicted in results figures.



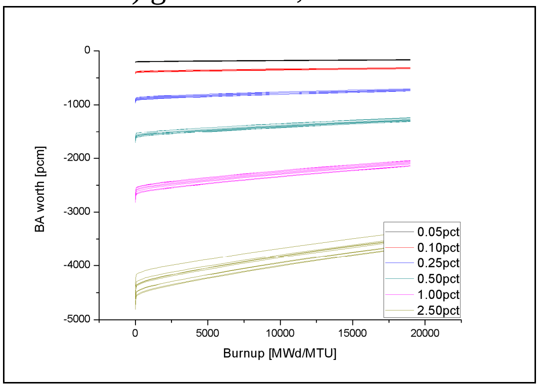
3a) gadolinium, k-eff



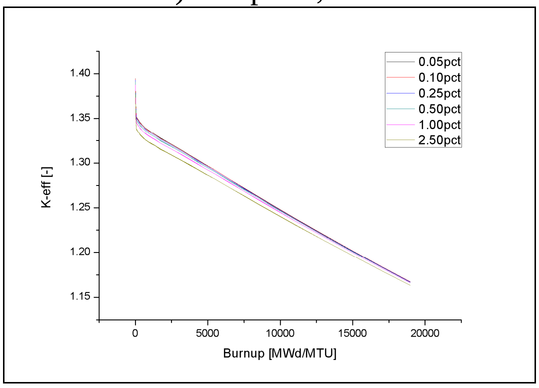
3b) gadolinium, BA worth



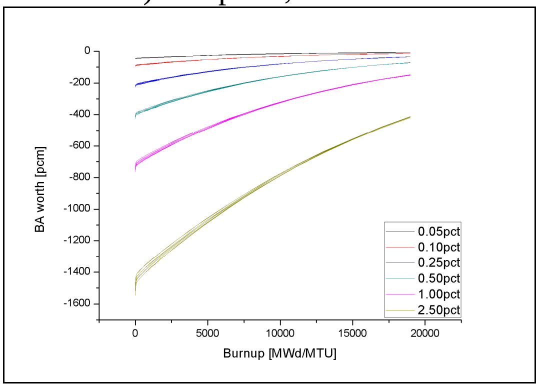
3c) europium, k-eff



3d) europium, BA worth

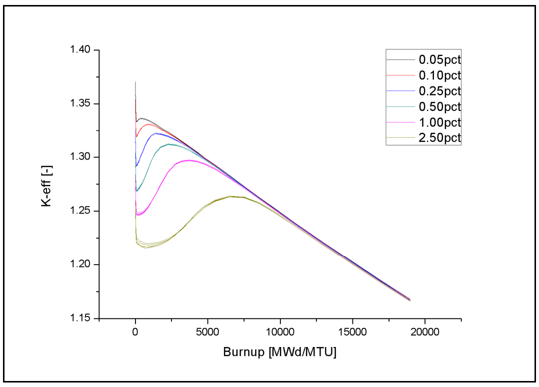


3e) erbium, k-eff

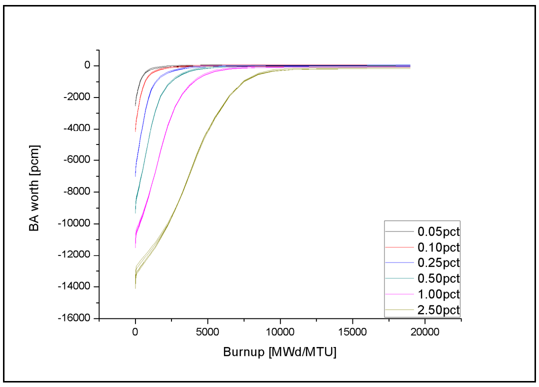


3f) erbium, BA worth

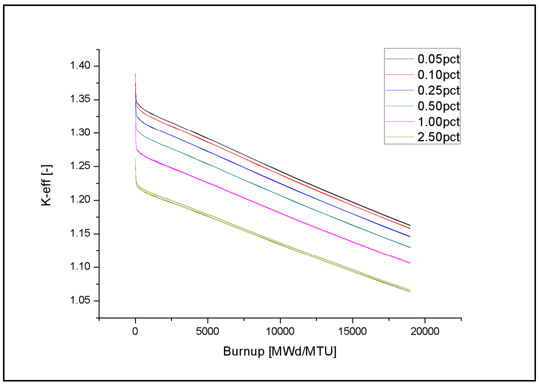
Figure 3: Multiplication coefficient during fuel depletion, 6 BA pins.



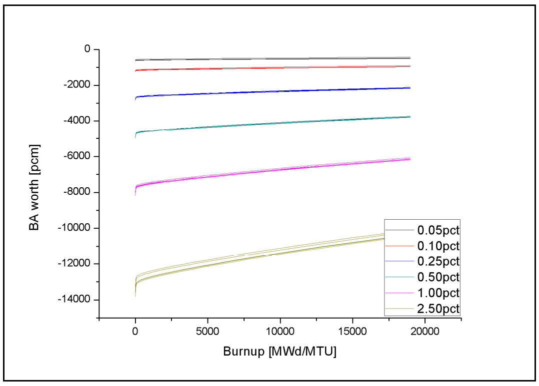
4a) gadolinium, k-eff



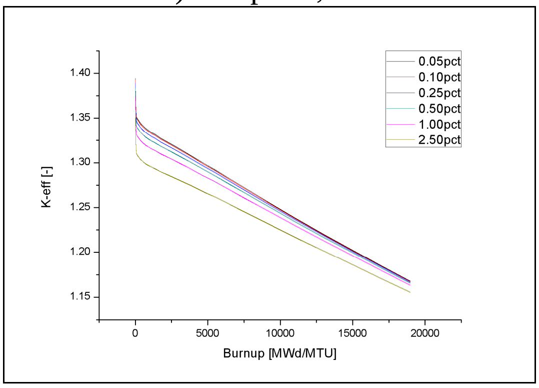
4b) gadolinium, BA worth



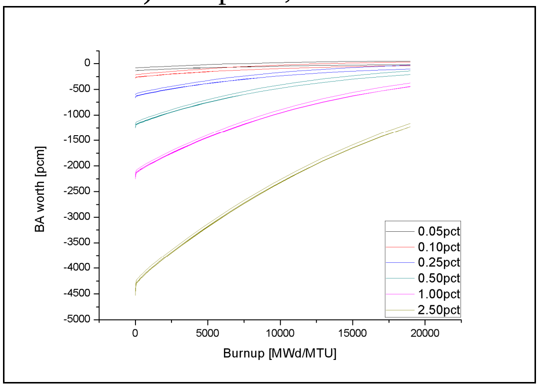
4c) europium, k-eff



4d) europium, BA worth

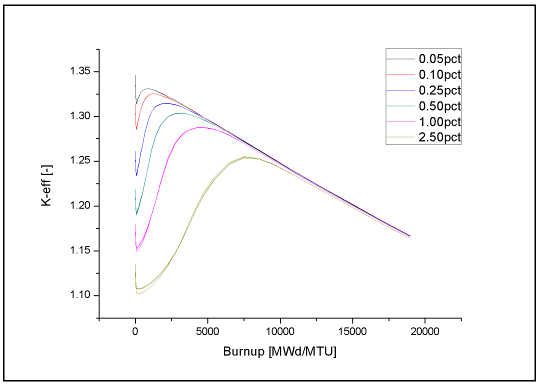


4e) erbium, k-eff

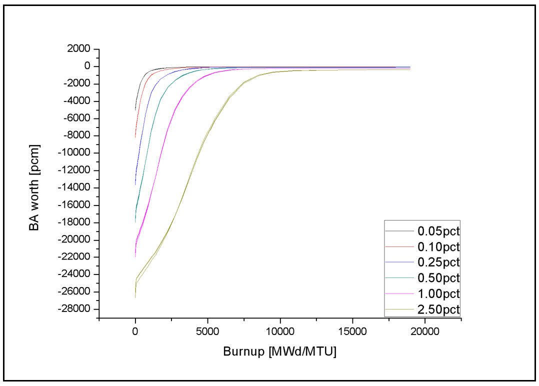


4f) erbium, BA worth

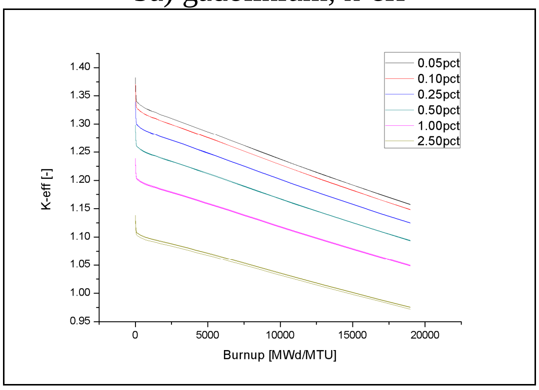
Figure 4: Multiplication coefficient during fuel depletion, 18 BA pins.



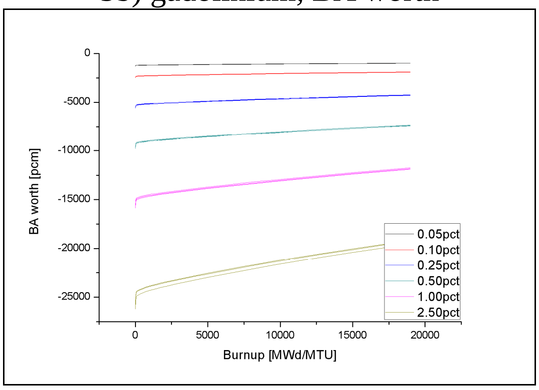
5a) gadolinium, k-eff



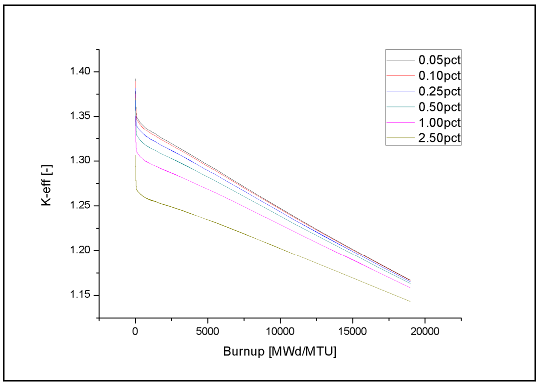
5b) gadolinium, BA worth



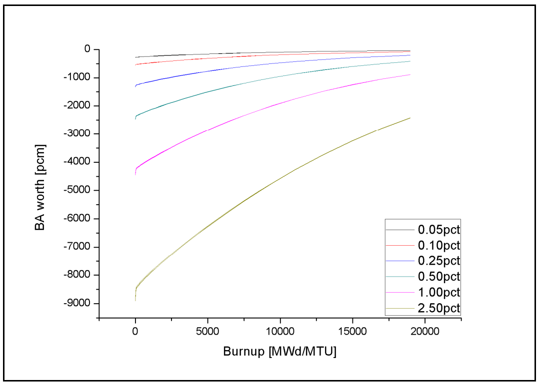
5c) europium, k-eff



5d) europium, BA worth

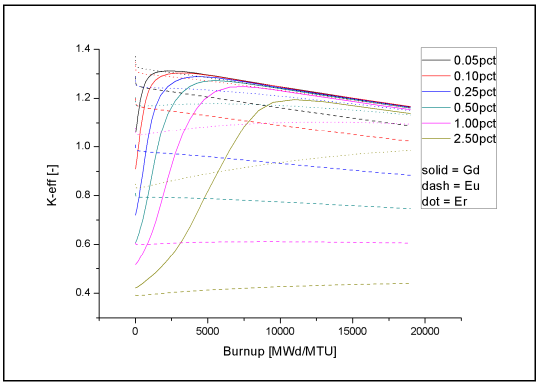


5e) erbium, k-eff

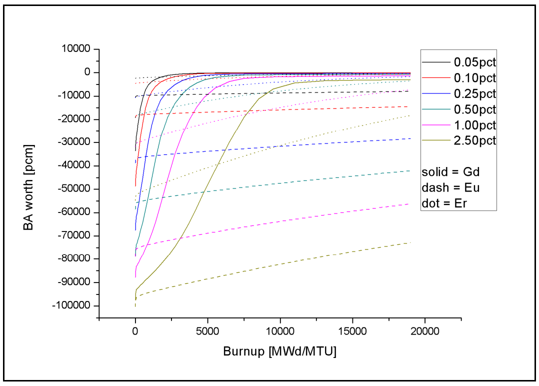


5f) erbium, BA worth

Figure 5: Multiplication coefficient during fuel depletion, 36 BA pins.



6a) k-eff



6b) BA worth

Figure 6: Multiplication coefficient during fuel depletion, 312 BA pins.

Calculation results showed that location of BA bearing pins is not of interest for reactivity excess evaluation. However, BA bearing pins location have large effect on power peaking values, but these values were not evaluated since they doesn't play significant role in question of BA element choice. Because of similar shapes of BA worth curves of each BA element, BA worth over BA content was chosen as output metric for BA element evaluation. For each depletion step, linear regression (BA worth)=(BA equivalent content)*m chose BA element metric *m* [-]

$$m = \frac{\text{BA worth}\,[\text{pcm}]}{\text{BA equivalent content}\,[10^{-3}\,\text{wt\%}]} \qquad (1)$$

BA element metric m is depicted on Figure 7. BA equivalent content is defined as fraction of BA oxide mass in whole assembly to fuel assembly mass.

Metric *m* seems to have linear behavior during fuel depletion and depends on BA element choice. Gadolinium burns out at approximately 10000 MWd/MTU burnup. At final analysed 20000 MWd/MTU burnup, only one quarter of europium is burned and about one third of erbium is still not burned.

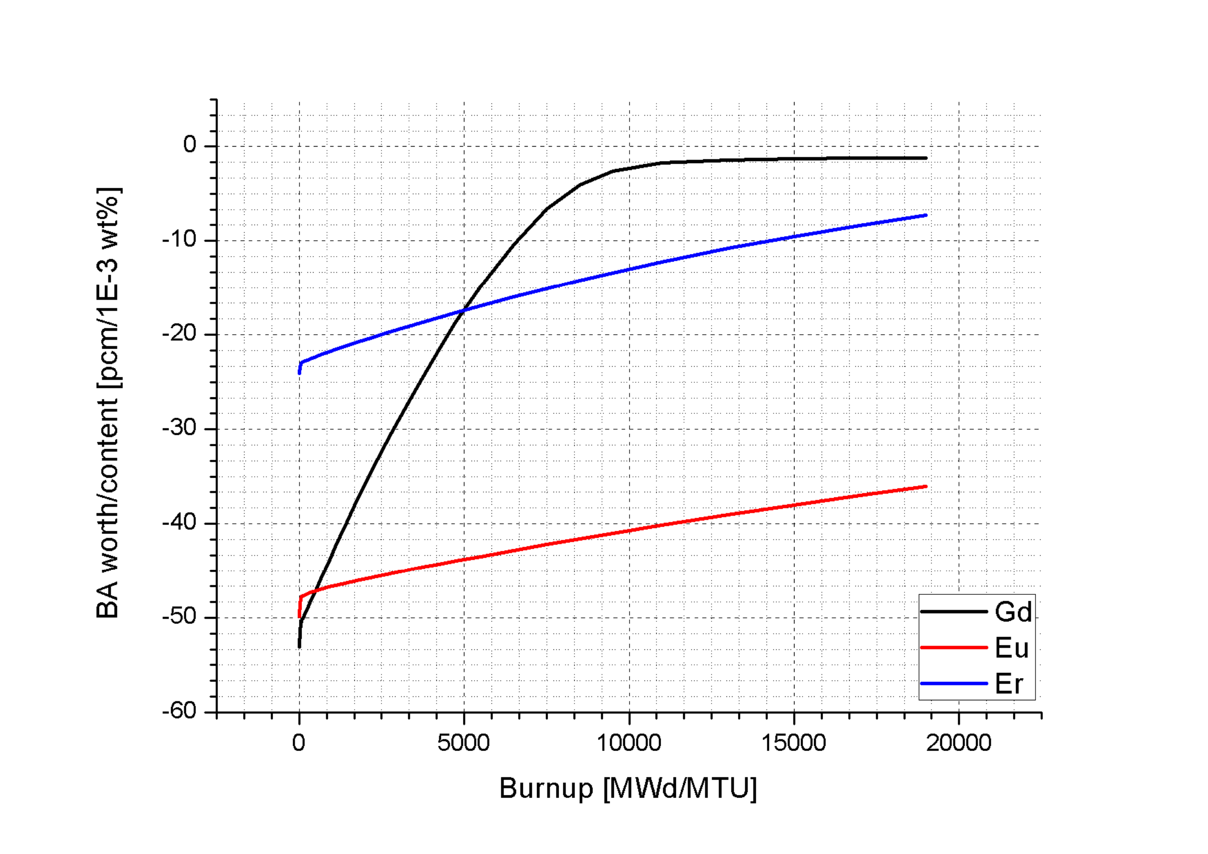


Figure 7: Burnable absorber worth over content comparison.

CONCLUSIONS

The contribution compares three selected elements (Gd, Eu, Er) as burnable absorbers in VVER-1000 fuel assembly. Number of burnable absorber bearing pins, their location and BA weight content were used as input variables. For k-eff values during fuel depletion, number of BA bearing pins and their location aren't important for BA element choice. Only BA weight content appears to be the main variable that significantly affects BA worth in fuel.

BA element metric m=(BA worth)/(BA equivalent content) was introduced and calculated for all selected elements. According to this metric, gadolinium burns out at approximately 10000 MWd/MTU burnup. At final analysed 20000 MWd/MTU burnup, only one quarter of europium is burned and about one third of erbium is still not burned.

ACKNOWLEDGMENTS

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REFERENCES

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