Conference Paper

Features of Burnup Calculations in the SERPENT 2 Software Package Using the Example of a BWR Fuel Assembly

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Abstract

In this paper, we used the data from "**OECD/NEA Burnup Credit Criticality Benchmark Phase IIIB: Nuclide Composition and Neutron Multiplication Factor of BWR Spent Fuel Assembly**" ([1]) for the verification of the **SERPENT 2** code. The results obtained which were compared with the results of other authors, which were also given in "**OECD/NEA Burnup Credit Criticality Benchmark Phase IIIB: Burnup Calculations of BWR Fuel Assemblies for Storage and Transport**" ([2]). Investigations of the influence of the detailed model of pins and pins with gadolinium, as well as various methods of burn-up calculations were also carried out.

Keywords: SERPENT2, BWR fuel assembly, burnup calculations.

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1. Introduction

Considering that recently the SERPENT 2 code begins to be widely used in reactor calculations. The SERPENT software package is written in the standard ANSI-C language. Basically, the complex is designed for the Linux operating system. "SERPENT" uses the Monte Carlo method, which is a resource-intensive method.

In this work, we compared the burnup calculations of the BWR reactor fuel assembly using this code with the results obtained by other authors. At the present time, we have carried out only a part of the necessary calculations (see [1]) - the calculation of neutron multiplication factor (K_{inf}) and nuclei concentrations along burn-out time. Further calculations are planned for the case of partial and completed dehydration of fuel assemblies, etc.

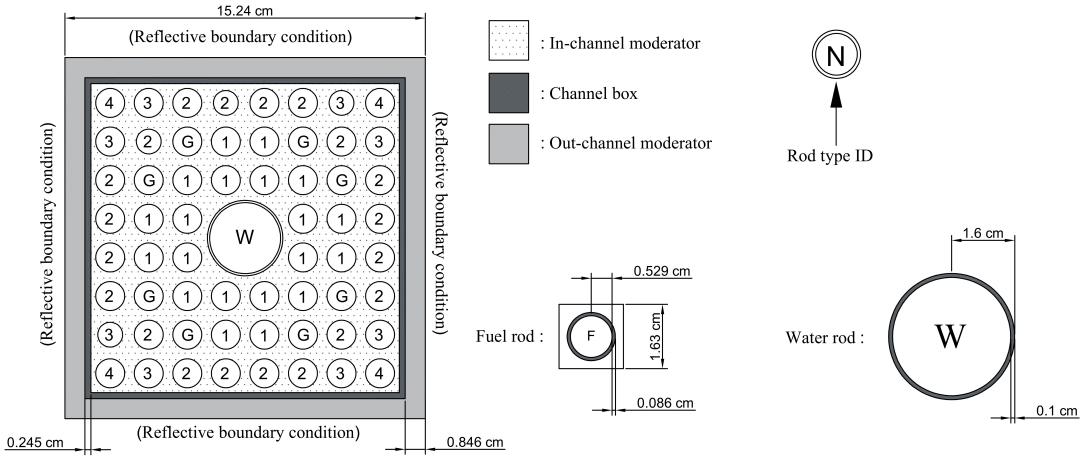


Figure 1: Fuel assembly of BWR.

2. Specification of fuel assembly (see [1])

Figure 1 shows the horizontal cross-section of the fuel assembly of the BWR reactor. A large water rod is located in the center of the fuel assembly. The dimensions of the fuel assembly are shown in Table 1.

Table 1: Dimensions of assembly, fuel and water rods [cm].

Assembly pitch	15.24
Thickness of channel box	0.254
½ thickness of water cap	0.846
Cell pitch	1.63
Outer radius of fuel rod	0.615
Inner radius of fuel rod	0.529
Cladding thickness of fuel rod	0.086
Outer radius of water rod	1.6
Inner radius of water rod	1.5
Cladding thickness of water rod	0.1

The fuel assembly of the BWR reactor consists of five kinds of fuel rods, 4.9(1), 3.6(2), 3.0(3) and 2.3(4) wt % U-235- enriched UO2 rods without Gadolinium (Gd) and 3.0(G) wt% U-235 - enriched UO2 rods with 4.5 wt% Gd, and a water rod. (Temperature: Fuel rods at 900 K, water rod at 559 K)

In-channel and out-channel moderator are water with 0% void fraction at 559K. Cladding and channel box are Zircaloy-4 at 559K.

3. Parameters of the Calculation (see [1])

Specific power is 25.6 MW/tHM, fuel burnup is 40* GWd/tHM, and the cooling time after burnup is 0 years. And we use the library "endfb7". (* Assembly value)

We will consider K_{inf} for the burnup of 0, 0.2, 10, 20, 30, 40 GWd/tHM and benchmarked nuclides after burnup. Table 2 shows nuclides that should be benchmarked are 12 actinides and 20 FPs.

Table 2: Benchmarked Nuclides.

Actinide	U-234,235,236,238; Pu-238,239,240,241,242; Am-241,243; Np-237
FP	Mo-95; Tc-99; Ru-101,103; Ag-109; Cs-133; Sm-147,149,150,151,152; Nd-143,145; Eu-153,155; Gd-155,156,157,158; Xe-131

4. Results from SERPENT2

The dependence of K_{inf} on the method of solving the burnup problem was studied for the following methods:

- **Nor**: Calculated with the normal options.
- **LEQI**: Calculated with use the LEQI.
- **LEQI-10**: Calculated with use the LEQI and pins with Gadolinium (Gd) divided into 10 radial parts.
- **LEQI-F10**: Calculated with use the LEQI and all pins divided into 10 radial parts.

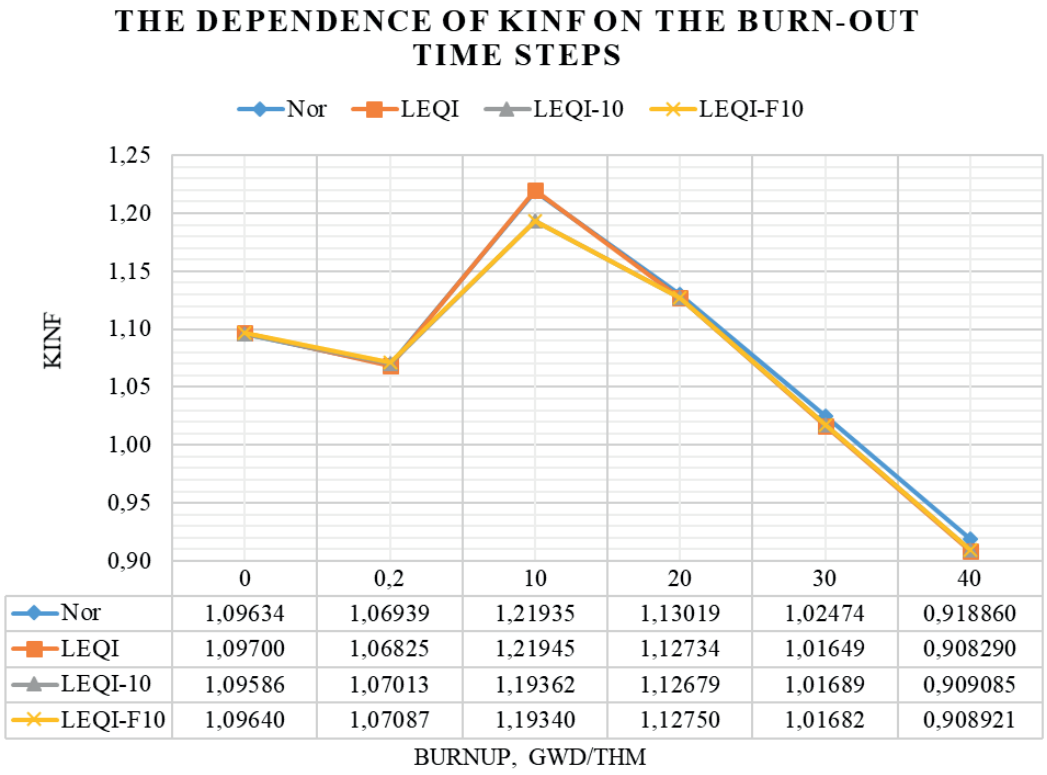
(**LEQI**: Linear extrapolation with quadratic interpolation)

Figure 2 shows the results of K_{inf} from SERPENT 2 and its the dependence on the burn-out time steps with different calculation methods.

Figure 2 shows that K_{inf} strongly depends on the degree of detailing on pins with Gd at 10 GWd/tHM, and also shows a strong impact of the calculation methods on the results.

As for nuclear density of benchmarked nuclides after burnup, the cases give almost same results with very small differences so we do not compare them here. But we will show you the dependence of Gd-157 nuclear concentrations ($10^{24}/cm^3$) on the burn-out time steps and its difference through different calculation methods.

Figure 3 shows the dependence of Gd-157 nuclear concentrations ($10^{24}/cm^3$) on the burn-out time steps.



	0	0,2	10	20	30	40
Nor	1,09634	1,06939	1,21935	1,13019	1,02474	0,918860
LEQI	1,09700	1,06825	1,21945	1,12734	1,01649	0,908290
LEQI-10	1,09586	1,07013	1,19362	1,12679	1,01689	0,909085
LEQI-F10	1,09640	1,07087	1,19340	1,12750	1,01682	0,908921

Figure 2: The dependence of K_{inf} as function of different options in SERPENT 2.

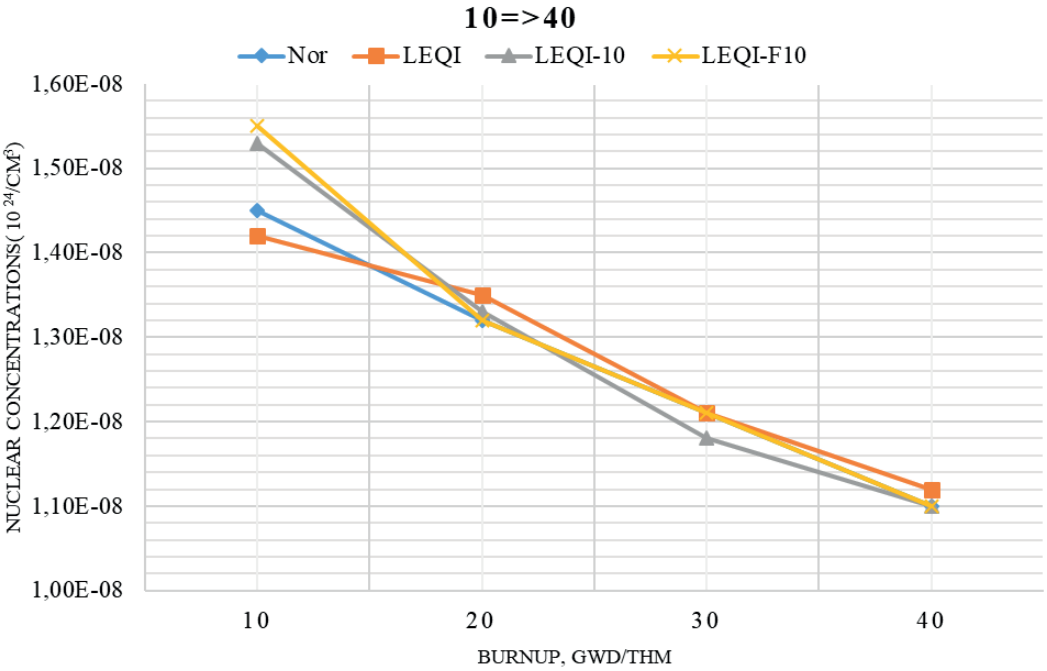


Figure 3: The dependence of Gd-157 nuclear concentrations ($10^{24}/cm^3$) on the burn-out time steps: 10; 20; 30; 40 (GWd/tHM)..

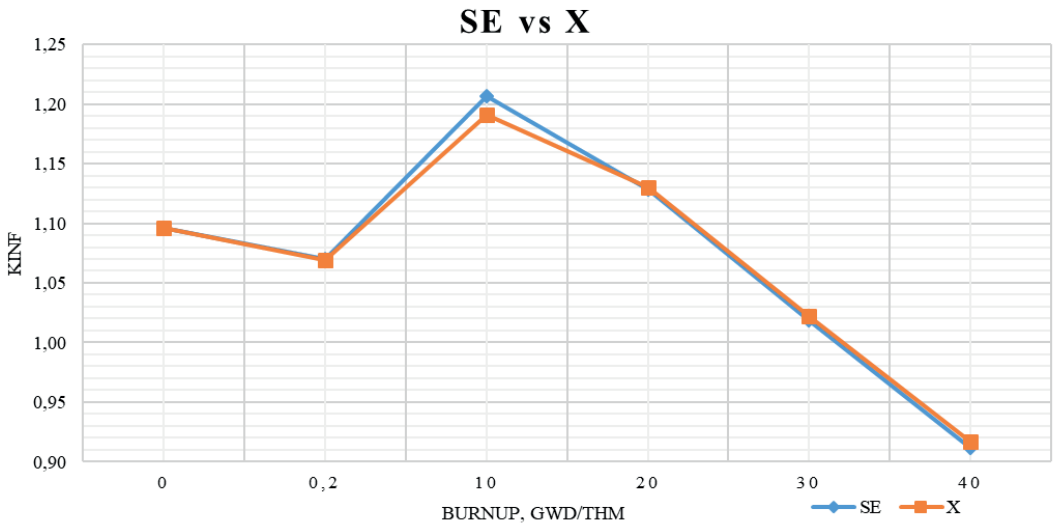


Figure 4: The dependence on the burn-out time steps of K_{inf} average values from SERPENT2 (**SE**) and from some other codes (**X**).

5. Comparison of results

Now, we will compare the results of SERPENT 2 with the results of some different codes extracted from [2]. We do not take all the results in [2] for comparison, because of which special cases result in very large deviations.

Table 3 shows the average values of K_{inf} from SERPENT2 (**SE**) and from some authors (**X**) in [2] computed by different codes, and deviation between them. Figure 4 shows the dependence on the burn-out time steps of **SE** and **X**.

Table 3: The average values of K_{inf} from SERPENT2 (**SE**) and from some authors (**X**) in [2].

Burnup (GWd/tHM)	0	0.2	10	20	30	40
SE	1.09640	1.06966	1.20646	1.12796	1.01874	0.91129
X	1.09608	1.06887	1.19081	1.12995	1.02207	0.91695
Deviation (%)	0.02891	0.07348	1.30519	0.17706	0.32725	0.61896

From Figure 4, we can see K_{inf} of **SE** and **X** approximately coincide and the biggest deviation is 1.31% at 10 GWd/tHM

Table 4 shows the deviation from average values of nuclear concentrations for benchmarked nuclides after burnup from SERPENT2 (**SE**) and some different codes in [2]. (%)

Notation: (codes used in [2])

- B: WIMS7
- C: APOLLO2

Table 4: The deviation of nuclear concentration for benchmarked nuclides after burnup (%).

Nuclide	SE	B	C	E	G	H	J	M	Q	R
U-234	0,11	0,54	1,84	1,62	0,32	0,76	-8,11	-4,00	3,35	3,57
U-235	-0,13	-0,13	0,50	-2,64	-3,27	0,50	3,02	-3,90	6,17	-0,13
U-236	-1,37	0,34	1,20	-0,52	1,20	-0,52	-2,23	2,06	-2,23	2,06
U-238	0,05	0,05	0,05	0,05	0,05	0,05	0,05	0,05	-0,42	0,05
Pu-238	5,19	12,64	-1,97	-4,95	7,27	-3,16	-4,95	6,68	-10,32	-6,44
Pu-239	8,76	-1,48	1,26	-1,59	-4,09	3,76	2,21	1,02	-4,93	-4,93
Pu-240	-2,04	-1,27	-0,12	-3,97	0,65	-1,46	3,54	-3,39	1,42	6,62
Pu-241	4,18	2,83	2,83	2,38	1,48	1,48	2,38	-3,01	-7,51	-7,06
Pu-242	-5,70	4,94	1,90	6,46	6,46	1,14	1,90	-1,90	-7,98	-7,22
Am-241	4,04	1,46	12,48	5,92	-1,00	0,76	-0,18	-7,44	-10,25	-5,80
Am-243	-14,34	10,10	4,56	9,64	5,49	3,18	7,33	2,72	-24,94	-3,73
Np-237	0,75	15,97	-3,09	-1,38	9,58	-3,09	-6,50	2,34	-8,63	-5,96
Mo-95	0,72	0,52	2,17	-7,53	0,93	2,37	-0,31	0,93	-0,52	0,72
Tc-99	1,05	-0,67	0,67	0,67	1,05	-0,29	0,29	-0,86	0,10	-2,01
Ru-101	-0,38	-0,78	-1,59	-0,78	-0,38	0,82	1,23	1,03	-0,18	1,03
Rh-103	0,00	1,54	0,38	2,31	1,92	-3,08	1,92	-0,77	-0,38	-3,85
Ag-109	29,38	5,91	-0,66	3,33	6,85	-1,13	-2,06	-14,03	-14,03	-13,56
Cs-133	-0,11	1,16	-0,65	2,07	2,98	0,07	-0,65	-2,11	-2,29	-0,47
Sm-147	-1,41	-1,41	10,03	-2,73	1,67	-0,31	-3,61	-3,83	0,13	1,45
Sm-149	4,41	4,61	-0,51	-5,24	2,64	2,64	5,01	5,40	-10,37	-8,59
Sm-150	-0,17	3,23	-1,87	-2,72	4,07	-6,11	2,38	7,47	-4,41	-1,87
Sm-151	8,54	6,51	2,75	9,70	1,59	-13,75	8,83	-3,04	-21,27	0,14
Sm-152	10,09	5,45	4,15	11,75	0,07	-5,30	-5,67	-11,23	-5,67	-3,63
Nd-143	2,40	1,15	1,15	1,47	1,15	-0,72	-4,46	-1,03	-1,03	-0,09
Nd-145	1,28	-0,36	0,30	-0,03	-0,36	0,95	-0,69	-0,69	-0,69	0,30
Eu-153	0,81	-4,31	-7,51	-2,60	-2,82	6,36	10,84	6,78	-4,31	-3,24
Eu-155	-1,52	20,30	21,63	16,67	18,98	-57,74	10,71	3,77	26,59	-59,39
Gd-155	-23,42	-12,92	-16,42	-30,43	90,11	-6,79	-14,67	-28,68	86,78	-43,56
Gd-156	-23,98	-21,56	-23,12	-23,81	95,19	-21,04	-23,12	-23,29	94,25	-29,52
Gd-157	-12,54	-28,91	-4,36	-14,59	78,11	-22,77	-19,71	-33,01	78,51	-20,73
Gd-158	-23,83	-25,32	-22,78	-23,68	98,92	-24,57	-24,13	-24,72	99,02	-28,92
Xe-131	-0,14	0,81	-1,09	-0,14	2,23	2,23	-4,41	-2,52	1,28	1,76

- E: BOXER
- G: WIMS7
- H: TGBLA/ORIGEN2.1
- J: VMONT
- M: SWAT

• Q: SCALE4.4

R: KENORESTОшибка! Ошибка связи. Table 4 shows that the differences in nuclear concentrations obtained by different codes vary significantly, especially for burnable absorbers (Gd).

6. Conclusion

The results obtained from the SERPENT 2 code are in good agreement with the results obtained from other codes. The discrepancies that were given by SERPENT2 can be caused by constants, the method of calculations, libraries, and others. And not only K_{inf}, the results for burnable absorbers essentially depend on the method of solving the burnup problem. So we need to give several calculation methods in order to get the best estimate for the solution.

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