Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2017

Characteristic Analysis of Accident Source Term for PLUS7 and CE 16 by 16 Fuel Assemblies

Eun Hyun Ryu [a*], Hae Sun Jeong [a], Kwang Soon Ha [a] and Dong Ha Kim [a]
[a]*Korea Atomic Energy Research Institute, Daedeok-daero 989-111, Yuseong-gu, Daejon, 34057, Korea*
[*]*Corresponding author: ryueh@kaeri.re.kr*

1. Introduction

The ORIGEN code calculates the inventory, radioactivity and thermal power of the fission product for various assemblies, operating time, power and so on. In addition, most of the known fuel assemblies are already packed into the ORIGEN code itself, thus one does not need to think about the details regarding the specific assembly. However, the user should generate their own library if the library for the target assembly if a calculation does not exist. For example, there are pre-existing libraries such as the Westing house type, vver, candu, combustion engineering, and so on.

Because the OPR-1000 uses the CE 16 by 16 type assembly, the user does not need to make their own library. However the APR-1400 uses the PLUS7 library which has an enhanced fuel performance, average discharge burnup of over 55MWD/kgU, 10% increased overpower margin, over a 0.3g ground acceleration of seismic resistance and no foreign material-induced or fretting wear-induced rod failure. Thus, a library generation should be conducted for the new assembly type of PLUS7 [1].

Because there were minor modifications to the dimensions of the fuel assembly, material, moderator density and enrichment, it is expected that there are not many differences between the results, such as the mass, radioactivity and thermal power between the two assemblies.

However, the types of assemblies are rigorously different with each other, and should be verified quantitatively. In this paper to evaluate the newly generated PLUS7 library, same ORIGEN input data are used for the ORIGEN-ARP calculation [2]. By generating new ORIGEN library of plus7 and CE 16 by 16, the effect for three parameters, mass, radioactivity and thermal energy is evaluated. During this procedure, the element grouping of the MELCOR code is used.

2. PLUS7 Library Generation with the SCALE Code

To generate the ORIGEN-ARP library for the PLUS7 assembly, a SCALE code calculation should be applied. The current release of the SCALE code is up to 6.2 version and the TRITON code and ORIGEN code are included in this version [3].

2.1 Detailed Dimensions

The major change to PLUS7 fuel is not related with the reactor physics parameters. Despite this fact, the actual dimensions that are used in the calculation for a library generation are listed here.

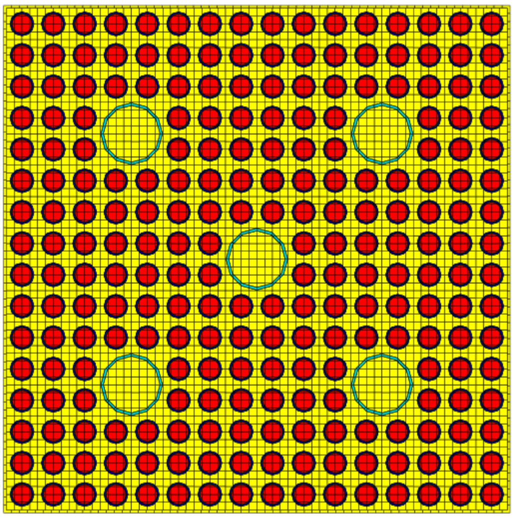

Fig. 1. Assembly Drawing of TRITON

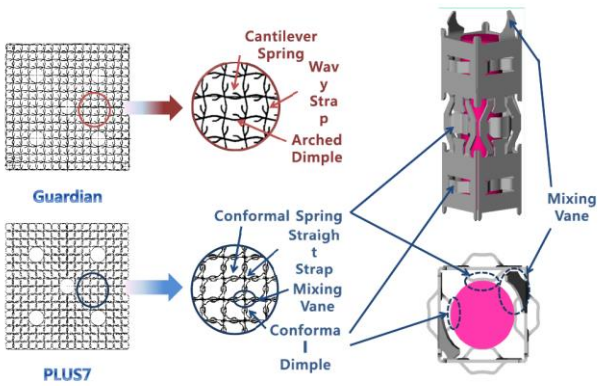

Fig. 2. Difference of Guardian and PLUS7 Fuel Assemblies

Table I. Fuel Dimensions

Region	Fuel	Gap	Clad	Cell Pitch
Diameter /Pitch(cm)	0.819	0.836	0.95	1.285
Material	3.14wt% En. U	O_2	ZIRLO™	H_2O
Temp. (Kelvin)	960.95	585.37	612.04	585.37
Density (g/cm^3)	10.96	0.001	6.522	0.6996

Table II. Guide Tube Dimensions

Region	Moderator	Clad	Guide Tube Pitch
Diameter /Pitch(cm)	2.27528	2.46	2.57
Material	H_2O	ZIRLO^{TM}	H_2O
Temp. (Kelvin)	585.37	612.04	585.37
Density (g/cm^3)	0.6996	6.522	0.6996

The assembly pitch is 20.23cm and the gap spacing is 0.549. Thus the summation of the assembly pitch and gap spacing is 20.779 and the gap is filled with light water. Note that in tables I and II, the dimensions of the fuel and moderator density are different from the assembly of the OPR-1000. The overall scale and structure can be confirmed in Fig. 1.

2.2 TRITON Calculation

The TRITON code was developed from Oak Ridge National Laboratory and was utilized for various depletion calculation based on the ORIGEN-S code with 2-D NEWT and 3-D KENO. The TRITON code provides us with five basic combinations of depletion sequence; among these combinations, the T-NEWT and T-DEPL combinations are mainly used for library generation for ARP's depletion nuclear cross section. The corresponding combination generates three group adjusted nuclear cross sections by deriving the volume averaged flux for each part in model from NEWT. The library, which follows the above mentioned procedure, is reflected in ORIGEN-S by the COUPLE code [4].

The SCALE code package contains ORIGEN code. In addition, the ORIGEN-ARP is often used for fast fission product inventory calculation. The ORIGEN-ARP contains express mode which make ORIGEN input easily. Thus actual information which ORIGEN requires is much less than expectation. We need the amount of uranium, enrichment, fuel type, burnup, number of calculation step for irradiation, number of libraries which will be used for one calculation step, decay time, power history and average specific power for one assembly.

2.3 MELCOR Isotope Grouping

A severe accident simulation code such as the MAAP code and the MELCOR code usually simulate the radioactive element with several groups which have similar chemical properties.

While simulating the severe accident, the individual element ratios will be forgotten, and it is assumed that the initial ratio will be maintained during the simulation.

Table III. MELCOR Element Grouping

Class Number and Name	Member Elements
1. Noble gases	Xe, Kr, (Rn), (He), (Ne), (Ar), (H), (N)
2. Alkali Metals	Cs, Rb, (Li), (Na), (K), (Fr), (Cu)
3. Alkaline Earths	Ba, Sr, (Be), (Mg), (Ca), (Ra), (Es), (Fm)
4. Halogens	I, Br, (F), (Cl), (At)
5. Chalcogens	Te, Se, (S), (O), (Po)
6. Platinoids	Ru, Pd, Rh, (Ni), (Re), (Os), (Ir), (Pt), (Au)
7. Transition Metals	Mo, Tc, Nb, (Fe), (Cr), (Mn), (V), (Co), (Ta), (W)
8. Tetravalents	Ce, Zr, (Th), Np, (Ti), (Hf), (Pa), (Pu), (C)
9. Trivalents	La, Pm, (Sm), Y, Pr, Nd, (Al), (Sc), (Ac), (Eu), (Gd), (Tb), (Dy), (Ho), (Er), (Tm), (Yb), (Lu), (Am), (Cm), (Bk), (Cf)
10. Uranium	U
11. More Volatile Main Group Metals	(Cd), (Hg), (Pb), (Zn), As, Sb, (Ti), (Bi)
12. Less Volatile Main Group Metals	Sn, Ag, (In), (Ga), (Ge)
13. Boron	(B), (Si), (P)
14. Water	(Wt)
15. Concrete	(Cc)

The elements that will be simulated are listed in Table III. In practical terms, an element with an extremely low concentration is excluded in advance. The element in brackets in Table III is also excluded because it is already known that the contribution is extremely small.

3. Calculation Results

As mentioned in the introduction, three parameters are investigated in this research. Only the values at shut down are listed.

Table IV. The FP Inventory at Shut Down for Groups

Group	CE16[2] (grams)	PLUS7 (grams)	Abs. Diff. (grams)	Rel.Err. (%)
1	1.69E+03	1.70E+03	1.00E+01	0.59
2	9.53E+02	9.44E+02	8.90E+00	-0.93
3	7.13E+02	7.14E+02	6.00E-01	0.08
4	6.52E+01	6.53E+01	1.19E-01	0.18
5	1.54E+02	1.54E+02	3.40E-01	0.22
6	1.09E+03	1.09E+03	2.00E-01	0.02
7	1.22E+03	1.22E+03	1.30E+00	0.11
8	2.15E+03	2.14E+03	8.20E+00	-0.38
9	1.97E+03	1.98E+03	4.90E+00	0.25
10	4.28E+05	4.29E+05	2.00E+02	0.05
11	4.83E+00	4.84E+00	1.02E-02	0.21
12	3.20E+01	3.22E+01	1.50E-01	0.47

Table V. The Radioactivity at Shut Down for Groups

Group	CE16[2] (curies)	PLUS7 (curies)	Abs. Diff. (curies)	Rel.Err. (%)
1	6.15E+06	6.09E+06	5.50E+04	-0.89
2	6.42E+06	6.39E+06	3.10E+04	-0.48
3	8.65E+06	8.62E+06	3.40E+04	-0.39
4	6.33E+06	6.32E+06	1.46E+04	-0.23
5	4.14E+06	4.13E+06	1.33E+04	-0.32
6	4.35E+06	4.38E+06	3.37E+04	0.78
7	1.54E+07	1.54E+07	8.00E+03	0.05
8	1.69E+07	1.68E+07	9.00E+04	-0.53
9	1.47E+07	1.46E+07	5.50E+04	-0.37
10	9.19E+06	9.10E+06	9.10E+04	-0.99
11	1.85E+06	1.84E+06	6.70E+03	-0.36
12	8.62E+05	8.62E+05	2.00E+02	-0.02

Table VI. The Decay Heat at Shut Down for Groups

Group	CE16[2] (watts)	PLUS7 (watts)	Abs. Diff. (watts)	Rel.Err. (%)
1	7.23E+04	7.17E+04	5.80E+02	-0.80
2	1.36E+05	1.35E+05	7.90E+02	-0.58
3	9.97E+04	9.92E+04	5.10E+02	-0.51
4	1.05E+05	1.05E+05	4.50E+02	-0.43
5	4.35E+04	4.32E+04	2.50E+02	-0.58
6	2.15E+04	2.18E+04	2.56E+02	1.19
7	1.83E+05	1.83E+05	1.40E+02	0.08
8	8.39E+04	8.35E+04	4.30E+02	-0.51
9	1.94E+05	1.93E+05	6.90E+02	-0.36
10	2.47E+04	2.45E+04	2.30E+02	-0.93
11	3.65E+04	3.63E+04	2.00E+02	-0.55
12	9.39E+03	9.34E+03	4.70E+01	-0.50

In Tables IV, V, and VI, the relative error of the PLUS7 result lies within 1% except for the decay heat result for group 6. In terms of the absolute amount, group 10 has the largest absolute mass and radioactivity difference because of its original large mass. For the decay heat, group 2 has the largest differences. However, the differences between the two types of fuel assemblies looks negligible.

4. Conclusions

In this research, the difference between two types of assemblies are examined with the ORIGEN code for three kinds of parameters, such as mass, radioactivity, and decay heat. As a result, the relative errors for all groups for every parameter are extremely small. In addition, the absolute difference is not meaningful. Thus, the use of a CE 16 by 16 library is possible for an APR1400 in a macroscopic sense. However, the PLUS7 library was already generated. Thus, it can be suggested that any choice regarding a library will be acceptable for the ARP1400 fission product inventory calculation.

5. Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (Ministry of Science, ICT, and Future Planning) (No. NRF-2017M2A8A4017283).

REFERENCES

[1] Y. H. Kim and K. T. Kim, Advanced Spacer Grid Design for the PLUS7 Fuel Assembly, Proceedings of the Korea Nuclear Society Autumn Meeting, Yongpyong, Korea, Oct., 2002.

[2] E. H. Ryu, H. S. Jeong and D. H. Kim, Comparison of the Results of the Whole Core Decay Power using the ORIGEN Code and ANS-1979 for the Uljin Unit 6, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May, 2015.

[3] Gauld, I. C., ORIGEN-S: SCALE SYSTEM MODULE TO CALCULATE FUEL DEPLETION ACTINIDE TRANSMUTATION, FISSION PRODUCT BUILDUP AND DECAY, AND ASSOCIATED RADIATION SOURCE TERM, Oak Ridge National Laboratory, ORNL/TM-2005/39, ORNL, 2009.

[4] H. S. Jeong and K. S. Ha, The generation of ORIGEN Library for Accident Analysis of OPR1000 Nuclear Reactor, KAERI, TR-5419, 2013.