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Comparison of the Results of the Whole Core Decay Power Using the ORIGEN Code and ANS-1979 for the Uljin Unit 6

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1. Introduction

For a simulation of the fission products transport and the decay in a severe accident analysis, the RN package and DCH package in the MELCOR code are used. When a detailed tracking of the nuclide is not required-, i.e., only the whole core decay heat information is required, then the RN package is not activated and the DCH package is solely used, whereas both the RN and DCH packages are used when we need a fission product transport simulation and location information.

For DCH only mode, there are four options to calculate the whole core decay heat calculation for the time after a shut-down [1]. The first is using a summation of the decay heat data from ORIGEN-based fission product inventories for the representative BWRs and PWRs, which are scaled if necessary. The second is using the ANS-1979 standard for the decay heat power [2]. The third is using a user-specified tabular function of the whole-core decay as a function of time. The fourth is using a user-specified control function to define the decay heat.

In this research, for option 2, the ANS-1979 standard for the whole core decay heat calculation is compared with the result of the ORIGEN calculation for Uljin Unit 6 after arranging the ORIGEN result based on the mass, radioactivity, and decay heat for the elements and nuclides. Because the plant-specific characteristics are increasing these days, it is expected that a rough calculation of the ANS standard has a significant difference compared with the ORIGEN result.

It is expected that the reflection of plant specific data will greatly increase the accuracy of the nuclides information such as mass, radioactivity and decay heat based on the comparison results of the ORIGEN code and the ANS-1979. Also the ORIGEN calculation will greatly increase accuracy of the aerosol dynamics result by supplying accurate input.

2. ORIGEN Result for an Assembly

Uljin Unit 6 is a type of OPR 1000 with a CE type fuel assembly with 16 by 16 arrays. The enrichment of the fuel is 4.399wt%, a 44 group ENDF cross section is used for the neutron and gamma data, and the average burnup is 37154MWD/MTU for the end of the cycle with an operation period of 1009.5 days and power of 36.8045MW. The decay process proceeds for seven days after the shut-down of the reactor core.

2.1 Top 10 Nuclides and Elements for Mass

Of course, U-238 has the largest portion among the various nuclides, and the changes in mass are almost negligible for 7 days after a shut-down, as shown in Figs. 1, and 2 and Table I.

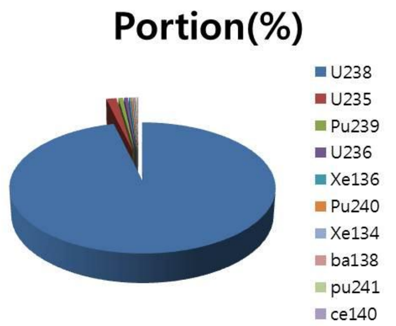

Fig. 1. Initial Mass Ratio of the Top 10 Nuclides

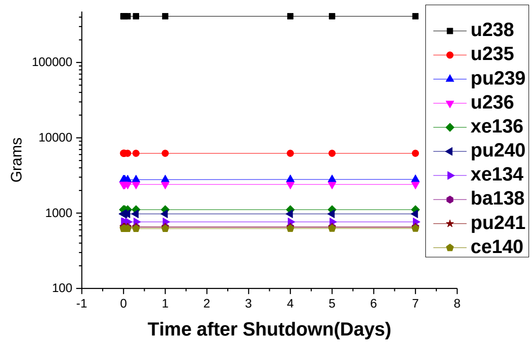

Fig. 2. The Change of the Mass of the Top 10 Nuclides

Table I. Information of Top 10 Nuclides on Mass

	Category	Charge (g)	Discharge (g)	Portion (%)	Half Life (year)
U238	Actinides	0.4172E+06	0.4112E+06	93.01	4.47E+09
U235	Actinides	0.1146E+05	0.6223E+04	1.41	7.04E+08
Pu239	Actinides	0.2178E+04	0.2772E+04	0.63	2.41E+04
U236	Actinides	0.1567E+04	0.2403E+04	0.54	2.34E+07
Xe136	Fis. Pro.	0.5469E+03	0.1112E+04	0.25	2.11E+21
Pu240	Actinides	0.4429E+03	0.9766E+03	0.22	6.5E+03
Xe134	Fis. Pro.	0.3858E+03	0.7636E+03	0.17	>1.1E+16
Ba138	Fis. Pro.	0.3333E+03	0.6535E+03	0.15	N/A
Pu241	Actinides	0.2832E+03	0.6525E+03	0.15	14 Year
Ce140	Fis. Pro.	0.3111E+03	0.6228E+03	0.14	N/A

Because the calculation for the operating period is done for two separate cycles, the charge means the beginning of the second cycle, or 504.750 days. The discharge implies the point of shut-down, which occurs at 1009.5 days. During the operation, it can be verified that the U-238 and U-235 portions are decreased and that fission products such as Pu-239, Pu-241, Xe-136, Xe-134, and Ce-140 are produced.

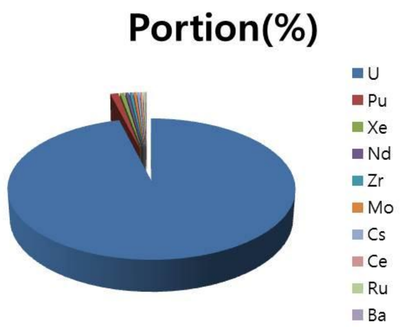

Fig. 3. Initial Mass Ratio of the Top 10 Elements

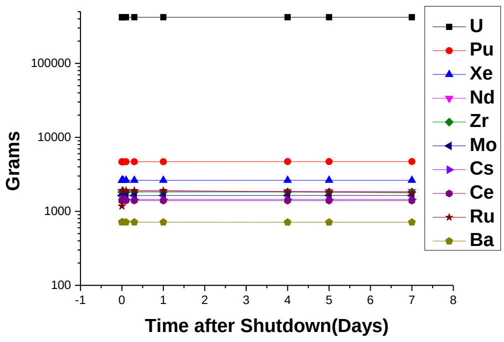

Fig. 4. The Change of the Mass of the Top 10 Elements

Table II. Information of Top 10 Elements on Mass

	Category	Charge (g)	Discharge (g)	Portion (%)
U	Actinides	0.4304E+06	0.4200E+06	94.99
Pu	Actinides	0.2954E+04	0.4677E+04	1.06
Xe	Fis. Pro.	0.1302E+04	0.2630E+04	0.60
Nd	Fis. Pro.	0.8942E+03	0.1854E+04	0.42
Zr	Fis. Pro.	0.9790E+03	0.1826E+04	0.41
Mo	Fis. Pro.	0.8066E+03	0.1637E+04	0.37
Cs	Fis. Pro.	0.7411E+03	0.1448E+04	0.33
Ce	Fis. Pro.	0.7840E+03	0.1399E+04	0.32
Ru	Fis. Pro.	0.5535E+03	0.1178E+04	0.27
Ba	Fis. Pro.	0.3555E+03	0.7147E+03	0.16

From the element point of view, zirconium is added to the list of the top 10 elements. Because of the usage of zirconium in the structure materials such as cladding and spacer, zirconium has the fifth mass portion among the various elements. It can be verified that the xenon is placed in the 3rd position in the list, as shown in Fig. 3 and Table II. The mass of the element also has no variation with time, as shown in Fig. 4.

This result is conversely implies that the most abundant materials in the reactor core do not vanish at all despite of the time scale of days.

2.2 Top 10 Nuclides and Elements for Radioactivity

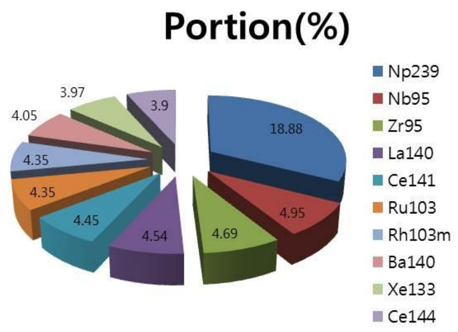

Fig. 5. Initial Radioactivity Ratio of the Top 10 Nuclides

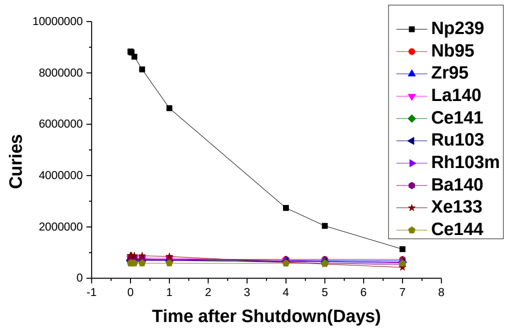

Fig. 6. The Change of the Radioactivity of the Top 10 Nuclides

Table III. Information of Top 10 Nuclides on Radioactivity

	Category	Charge (g)	Discharge (g)	Portion (%)
Np239	Actinides	0.7423E+07	0.8827E+07	18.88
Nb95	Fis. Pro.	0.8030E+06	0.7385E+06	4.95
Zr95	Fis. Pro.	0.7997E+06	0.7324E+06	4.69
La140	Fis. Pro.	0.8186E+06	0.7954E+06	4.54
Ce141	Fis. Pro.	0.7574E+06	0.7243E+06	4.45
Ru103	Fis. Pro.	0.5997E+06	0.7008E+06	4.35
Rh103m	Fis. Pro.	0.5987E+06	0.6999E+06	4.35
Ba140	Fis. Pro.	0.8013E+06	0.7670E+06	4.05
Xe133	Fis. Pro.	0.8887E+06	0.8785E+06	3.97
Ce144	Fis. Pro.	0.4891E+06	0.5867E+06	3.90

The radioactivity is listed in the unit of curies. It shows an exponential decrease, as indicated in Fig. 6. And from the viewpoint of radioactivity, the top 10 list consists of different nuclides compared with those in the top 10 list in terms of mass. It can be verified that Np-239 takes first place in the list and that Xe-133, Ce-144, Ce-141 and Zr-95 also appear in the list as shown in Fig. 5 and Table III.

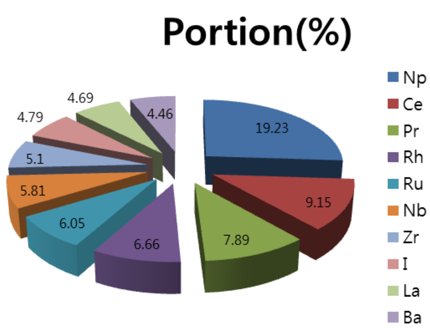

Fig. 7. Initial Radioactivity Ratio of the Top 10 Elements

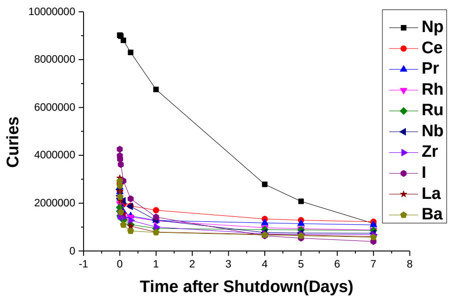

Fig. 8. The Change of the Radioactivity of the Top 10 Elements

Table IV. Information of Top 10 Elements on Radioactivity

	Category	Charge (g)	Discharge (g)	Portion (%)
Np	Actinides	0.7493E+07	0.9021E+07	19.23
Ce	Fis. Pro.	0.3485E+07	0.3441E+07	9.15
Pr	Fis. Pro.	0.2955E+07	0.2982E+07	7.89
Rh	Fis. Pro.	0.1839E+07	0.2703E+07	6.66
Ru	Fis. Pro.	0.1500E+07	0.2091E+07	6.05
Nb	Fis. Pro.	0.6629E+07	0.6600E+07	5.81
Zr	Fis. Pro.	0.4609E+07	0.4436E+07	5.10
I	Fis. Pro.	0.5330E+07	0.5331E+07	4.79
La	Fis. Pro.	0.4621E+07	0.4362E+07	4.69
Ba	Fis. Pro.	0.4644E+07	0.4383E+07	4.46

For the element list, xenon is now off the list, and iodine nearly appears the list newly. Neptunium still takes first place in the list, followed by cesium and neptunium, as shown in Fig. 7 and Table IV. Most of the elements show exponential behaviors, as indicated in Fig. 8. The portions of light elements are nearly negligible and do not appear on the list.

2.3 Top 10 Nuclides and Elements for Decay heat(Watts)

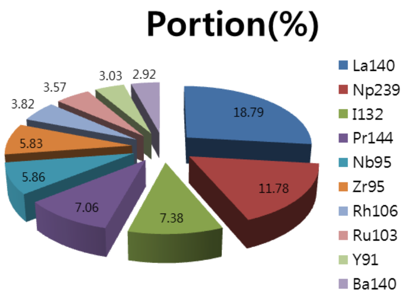

Fig. 9. Initial Decay Heat of the Top 10 Nuclides

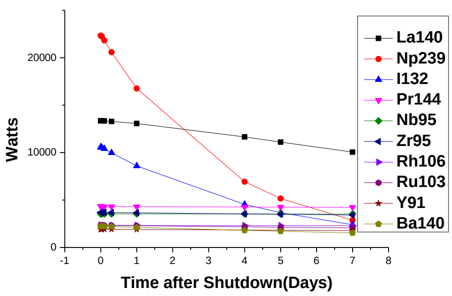

Fig. 10. The Change of the Decay Heat of the Top 10 Nuclides

Table V. Information of Top 10 Nuclides on Decay Heat

	Category	Charge (g)	Discharge (g)	Portion (%)
La140	Fis. Pro.	0.1374E+05	0.1335E+05	18.79
Np239	Actinides	0.1877E+05	0.2232E+05	11.78
I132	Fis. Pro.	0.1040E+05	0.1057E+05	7.38
Pr144	Fis. Pro.	0.3614E+04	0.4333E+04	7.06
Nb95	Fis. Pro.	0.3851E+04	0.3541E+04	5.86
Zr95	Fis. Pro.	0.4031E+04	0.3692E+04	5.83
Rh106	Fis. Pro.	0.1256E+04	0.2550E+04	3.82
Rh103	Fis. Pro.	0.1996E+04	0.2333E+04	3.57
Y91	Fis. Pro.	0.2309E+04	0.1917E+04	3.03
Ba140	Fis. Pro.	0.2342E+04	0.2241E+04	2.92

As a result of the radioactivity list, the decay heat released by the radioactive materials also shows exponential decay, as shown in Fig. 10, although some of the materials do not have a simple and basic exponential function. Familiar isotopes such as I-132 and Zr-95 can be found in Table 5 and Fig. 9. Similar to the results of radioactivity list, light elements are not found on the list.

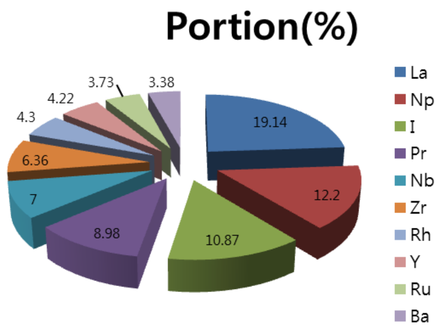

Fig. 11. Initial Decay Heat of the Top 10 Elements

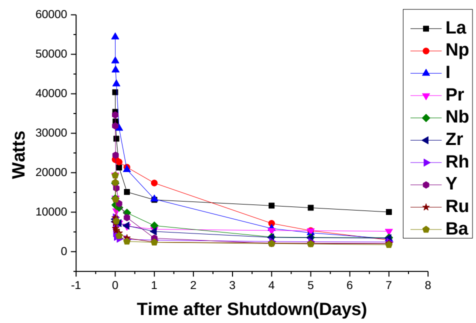

Fig. 12. The Change of the Decay Heat of the Top 10 Elements

Table VI. Information of Top 10 Elements on Decay Heat

	Category	Charge (g)	Discharge (g)	Portion (%)
La	Fis. Pro.	0.6897E+05	0.6503E+05	19.14
Np	Actinides	0.1917E+05	0.2335E+05	12.20
I	Fis. Pro.	0.7974E+05	0.7938E+05	10.87
Pr	Fis. Pro.	0.2357E+05	0.2419E+05	8.98
Nb	Fis. Pro.	0.8976E+05	0.9198E+05	7.00
Zr	Fis. Pro.	0.4564E+05	0.4433E+05	6.36
Rh	Fis. Pro.	0.7615E+04	0.1293E+05	4.30
Y	Fis. Pro.	0.1017E+06	0.9425E+05	4.22
Ru	Fis. Pro.	0.8235E+04	0.1154E+05	3.73
Ba	Fis. Pro.	0.4133E+05	0.3855E+05	3.38

The element list of the decay heat is much similar to the nuclide list of decay heat, as shown in Fig. 11 and

Table VI. In particular, the decay heat portion of Lanthanoid takes first place in Fig. 12 during most of the decay period. In addition, the decay heat generated by La is steadily maintained during the decay period a after a shut-down. Iodine is also a noteworthy element, and takes third place on the list.

3. Whole Core Decay Heat Result

To compare the results of whole core decay heat from the ORIGEN code and the ANS-1979 code for the Uljin unit 6 core, the total number of assemblies is multiplied by the ORIGEN result of one assembly calculation. In addition, by using default values for PWR from the MELCOR code, which follows ANS-1979, the whole core decay heat result can be produced for a PWR type reactor core.

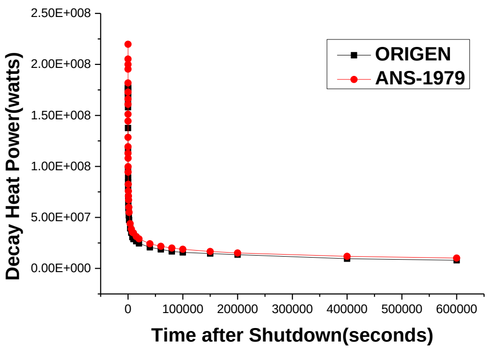

Fig. 13. Comparison of Whole Core Decay Heat Power with Time After Shutdown

The decay heat simulation was conducted for about 7 days and a total of 36 points during this period are plotted in Fig. 13 and Table VII. In Fig. 13, the initial decay heat for the shutdown of the ORIGEN code and ANS-1979 are 178MW and 220MW, respectively.

Table VII. Time Table

Index	Seconds	Days	Index	Seconds	Days
1	0	0.00000	19	800	0.00926
2	1	0.00001	20	1000	0.01157
3	1.5	0.00002	21	1500	0.01736
4	2	0.00002	22	2000	0.02315
5	4	0.00005	23	4000	0.04630
6	6	0.00007	24	6000	0.06944
7	8	0.00009	25	8000	0.09259
8	10	0.00012	26	10000	0.11574
9	15	0.00017	27	15000	0.17361
10	20	0.00023	28	20000	0.23148
11	40	0.00046	29	40000	0.46296
12	60	0.00069	30	60000	0.69444
13	80	0.00093	31	80000	0.92593
14	100	0.00116	32	100000	1.15741
15	150	0.00174	33	150000	1.73611
16	200	0.00231	34	200000	2.31481
17	400	0.00463	35	400000	4.62963
18	600	0.00694	36	600000	6.94444

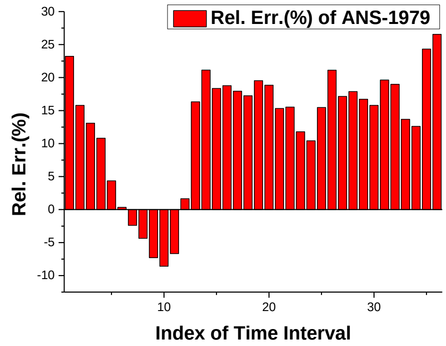

Fig. 14. Relative Differences of Whole Core Decay Heat Power for Each Time Interval

Although the two results look similar in Fig. 13, the relative differences of ANS-1979 compared with the result of ORIGEN as a reference solution are much higher in an absolute sense, as shown in Fig. 14.

Table VII. Time of Decay Heat Power Reduction Compared with the Initial Decay Heat Power

	ORIGEN(Seconds)	ANS-1979(Secons)
20%	0.07Days(5687)	0.05Days(3996)
10%	0.80Days(68722)	0.67Days(57475)
5%	5.49Days(474572)	5.81Days(501891)

In Table VII, decay power reductions are listed for three cases of 20%, 10%, and 5% reductions. The ANS-1979 predicts that the decay heat will decrease much faster than the ORIGEN code for 20% and 10% reductions. However, for the 5% reduction, the ORIGEN code gives a somewhat shorter time compared with the ANS-1979 result.

4. Conclusion

In this paper, one assembly calculation with the ORIGEN code for Uljin unit 6 of OPR 1000 type is reported, and the whole core decay heat results of the ORIGEN code and ANS-1979 are compared with each other.

Investigating the list of radioactive materials from the core with one assembly calculation based on the mass, radioactivity and decay heat, can help recognize the important materials for fission product transport and aerosol dynamics.

In addition, the necessity for the use of the ORIGEN code instead of the old standard for the decay power in a light water reactor is emphasized. Because the information for the radioactivity material such as the mass, radioactivity, and decay heat greatly dependent on the plant-specific characteristics, a rough calculation using a simplified assumption gives inaccurate information about the fission product, but a gives fast result compared with a detailed calculation.

The conclusion which is contained in this section is based on the particular solution, thus it is difficult to apply to the general situation. It is expected that many benchmark calculations are required for the the application of this result.

Because the MELCOR code is currently using the ANS-1979 standard, the lasted version for decay heat in ANS standards is not mainly dealt with in this research. The goal of the examination is to find the necessity of changing old standard for the enhancement of the accuracy. The ANS-1979 is an old standard about decay heat, thus recent standards which are ANSI/ANS-5.1-1994 and ANSI/ANS-5.1-2005 should be investigated in the long term research.

This research has certain drawback in that the mere multiplication of the number of assemblies is done for the whole core decay heat calculation in the arrangement of the ORIGEN result. Thus, the reflection of the detailed and information of various assembly types for a target period of the whole core should be considered in future research.

5. Acknowledgement

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