Comparison of ORIGEN-2 and ORIGEN-ARP for Spent Fuel Management

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1. Introduction

Radiation source terms such as radioactivity, decay heat, nuclide concentration, and hazard index deduced from nuclear spent fuel are used to perform radiation shielding analysis, thermo-mechanical analysis, and safety performance assessments in the designing step of deep geological repository. ORIGEN2[1] has been widely used for the source terms analyses. However, ORIGEN2 only applies one-group-collapsed built-in cross-section library without library modification for each problem. Therefore, in case the dimension and enrichment of the fuel assembly to be analyzed are different from those considered when the built-in cross section library was generated, less reliable results would be expected. This constraint can be released by using ORIGEN-ARP[2].

In this paper, the results from ORIGEN2 and ORIGEN-ARP were compared to judge how much bias in the results calculated by ORIGEN2 in the previous study would come. And then, radiation source terms were generated using ORIGEN-ARP.

2. ORIGEN2 vs. ORIGEN-ARP

2.1. Features of ORIGEN-ARP

ORIGEN-ARP is a sequence of SCALE system to perform point-depletion calculations with the ORIGEN-S using problem–dependent cross sections. This sequence allows the ORIGEN-S multi-burnup library for different assembly designs by interpolation over pre-generated SAS2 cross-section libraries. The code can also provide user-specified energy groups for neutron and gamma spectra. Explicit ENDF/B-VI fission product yields were implemented for 30 actinides. Master photon library was completely updated based on ENDF/B-VI for 2,100 nuclides. The capabilities of cross-section generation and comprehensive neutron sources are superior features of ORIGEN-ARP. Code development and V&V have been performed extensively by Oak Ridge National Laboratory under the support of DOE and NRC.

2.2. Comparison of Results from Each Code

Two inputs describing representative PWR low-bunrup and high-burnup fuels were set up to compare results from each code. As shown in Fig 1, ~6% difference was shown in total decay heat within 1,000 year cooling period in case of low burnup PWR fuel with initial enrichment of 4.0w/o and discharge burnup of 45GWD/MTU. Similar trends were revealed for CANDU and high-burnup PWR spent fuels.

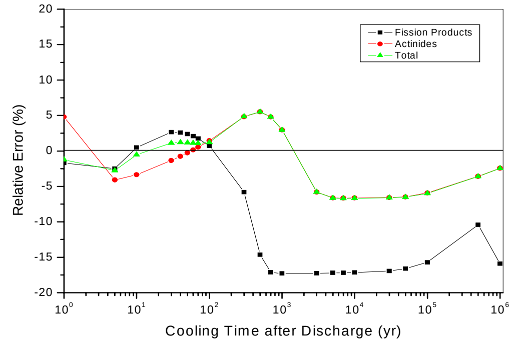

Fig. 1. Comparison of Decay Heat for Low-burnup PWR fuel

For total radioactivity, ~10 percent difference was expected, especially within 20-year cooling period. Major nuclides concentrations important in terms of disposal were also compared. About 10 percent difference occurred for actinides. However, in case of fission product the results agreed well within ~4 percent difference. For ingestion hazard, Sr-90 revealed severely different beheavior for both cases.

3. Source Term Analysis Using ORIGEN-ARP

3.1. Reference Spent Nuclear Fuel

17×17 KOFA with initial enrichment of 4.0wt% and discharge burnup of 45GWD/MTU was chosen as the reference low-burnup PWR spent fuel (PWR45). 16×16 KSFA(Korean Standard Fuel Assemblies) with initial enrichment of 4.5w/o and discharge burnup of 55GWD/MTU was chosen as a representative of high-bunup spent fuel (PWR55). CANDU spent fuel was also considered in this study.

3.2. Preparation of Cross Section Library

ORIGEN-ARP cross-section library was generated using the SAS2 module, because 16×16 KSFA cannot be solved using ORIGEN-ARP built-in library. A verification of the new library was performed. As a result, the former library was confirmed to have 0.3% error compared to the reference calculation. 17×17 KOFA was analyzed with built-in ORIGEN-ARP library.

3.3. Calculation Results

3.3.1 Source Intensity and Spectra

Source intensities and spectra were calculated as a function of time for each respective spent fuel. Photon and neutron intensities need for shielding analysis is listed in Table 1. Photon intensity of PWR45 is ~6 times higher than that of CANDU, while neutron intensity of PWR45 is ~80 times higher than that of CANDU at the time of 40 years after discharge. In view of photon spectra the intensity from 2 to 3MeV efficiently decreases after 20 years, as shown in Fig. 2.

Table 1. Photon and Neutron Intensities (particles /sec-tHMU)

	Time(yr)	1	30	40	50
Photon	PWR45	9.447E+18	3.859E+17	3.094E+17	2.498E+17
	PWR55	1.051E+19	4.569E+17	3.657E+17	2.947E+17
	CANDU	3.033E+18	6.405E+16	5.124E+16	4.119E+16
Neutron	PWR45	9.272E+08	2.815E+08	1.974E+08	1.399E+08
	PWR55	1.601E+09	4.973E+08	3.468E+08	2.440E+08
	CANDU	5.847E+06	2.611E+06	2.449E+06	2.330E+06

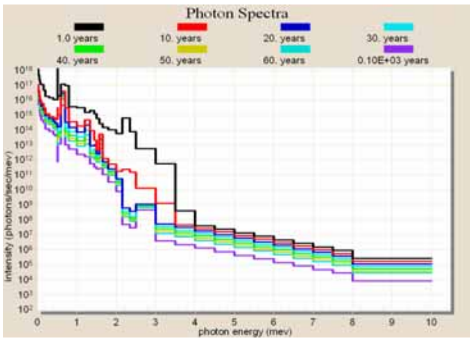

Fig. 2 Spectra variation with Cooling Time

3.3.2 Decay Heat

Decay heat emitted from spent fuel is treated important input parameter in the thermo-mechanical analysis, because it can decrease the safety performance of engineering and natural barrier. Figure 3 shows the trend of decay heat as the nuclides decay out. It can be shown that fission products dominates total decay heat up to several decades, ~60yrs. This behaviour can be expressed by Eqs (1) and (2). The coefficients which best represent the calculated values were obtained by statistical analysis, as shown in Table 2. This correlation formula will be used future thermo-mechanical analysis.

$$P(t) = C1EXP(\frac{1}{C2 + C3t}) \quad for \quad 1 \le t \le 30yr \qquad (1)$$

$$P(t) = C1t^{-c2} \quad for \quad 30 \le t \le 1 \times 10^6 yr \qquad (2)$$

Table 2. Coefficients for Each Correlation Formula

	t	C1	C2	C3	R^2
PWR45	1 ~ 30	881.99	0.23990	0.141124	0.99997
	30~ 10^6	14545.68	0.75756	-	0.99857
PWR55	1 ~ 30	1094.58	0.25711	0.135363	0.99994
	30~ 10^6	20020.55	0.78692	-	0.99847
CANDU	1 ~ 30	121.03	0.15755	0.141336	1
	30~ 10^6	1524.68	0.67603	-	0.99635

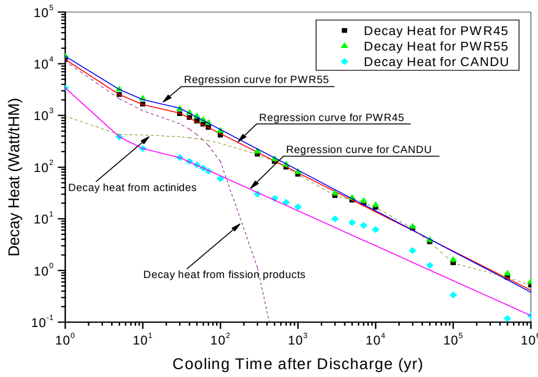

Fig. 3. Decay Heat for Three Representative Spent Fuels as a Function of Cooling Time

3.3.3 Nuclide concentration and Irradiation Hazard

All nuclide concentrations including actinides and fission products were estimated to be used as a reference in the experiment related with dissolution beheavior. Pu content and vector were also calculated. Ingestion hazard was also evaluated for long-term safety assessments.

4. Conclusions

Source terms needed for the design of repository were calculated using ORIGEN-ARP. About 10% difference in the results from ORIGEN2 and ORIGEN-ARP were shown in decay heat, radioactivity and nuclides concentrations. Source terms evaluated in this study can be used as input parameters in many calculations with more reliability.

ACKNOWLEDGEMENTS

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REFERENCES

[1] A. G. Croff, “A User’s Manual for the ORIGEN2 Computer Code,” ORNL/TM/7175, Oak Ridge National Laboratory, 1980.

[2] I.C. Gauld, et. al, “ORIGEN-ARP: Automatic Rapid Processing for Spent Fuel Depletion, Decay, and Source Term Analysis,” NUREG/CR-0200, Oak Ridge Nationnal Laboratory, 2004.