Development of the Computer Code for Multi-Calculations of Source Term of Spent Fuel - 15351

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ABSTRACT

Many PWR spent fuels have been transferred between the neighboring nuclear power plants at Kori, Hanbit, Hanwul site, and from nuclear power plant to the KAERI(Korea Atomic Energy Research Institute) for the research purpose in Korea. In case of the PHWR type spent fuels, these have been transferred from the spent fuel pool to an on-site dry storage facility. Total radioactivity of spent fuels has to be calculated before transport in advance by the regulation requirement. In case of PWR, KN-12 transport cask can transfer 12 spent fuel assemblies at one time and in case of PHWR, Hi-STAR 63 transport cask can transfer 120 spent fuel assemblies at one time. Therefore, total radioactivity of all transported spent fuel assemblies that are transported generally are calculated by using the ORIGEN-ARP to meet this regulatory requirement. Basically, ORIGEN-ARP calculates the one fuel assembly at one time. SCALE code including this code provides the batch mode to perform the multi-calculations of the source term. In this study, in order to use the batch mode of ORIGEN-ARP, ARP-auto program was developed to generate input files and batch file of ORIGEN-ARP automatically and to make the summary file extracting the result from output files of ORIGEN-ARP. This code enhances the efficiency at the field. The working time to complete the calculation of source terms of 120 spent fuel assemblies take only 20 minutes. In order to confirm the credibility of this code, total radioactivity of 12 spent fuel assemblies of 17x17 Westinghouse type were calculated and compared to the previous result. The initial enrichments of these spent fuels are 3.46 ~ 3.50 w/o and burnups are 29 ~43 GWD/MTU. As the results, the relative errors are about 0.9 ~ 3.0%.

INTRODUCTION

The Status of Spent Fuel Transport in Korea

Spent fuels generated from NPPs are stored in the spent fuel storage facility in each unit. The storage capacity for spent fuel has been expanded as a consequence of the delayed construction schedule of the Away-From-Reactor interim storage. As the storage capacity of the spent fuel pools at old NPPs became saturated, spent fuels have been transferred to the pools at relatively new neighboring NPPs. For PHWR at Wolsong site, an on-site dry storage facilities (Silo and MASCTOR) have been operating to resolve the shortage of capacity of the pre-existing spent fuel pools of Wolsong Units 1,2,3 and 4[1]. The table I is shown the status of transferring of spent fuels in NPPs in recent years. As shown in table I, many spent fuels have been transferred in every year by using the KN-12 PWR spent fuel transport cask and Hi-STAR 63 PHWR spent fuel transport cask.

THE DEVEOPMENT OF ARP-AUTO PROGRAM

The Development of ARP-Auto Program

According to the regulatory framework of Korea on the transport, an authorized party or those entrusted by the authorized party to pack or transport radioactive materials should be inspected by the Nuclear Safety and Security Commission in terms of their observance of technical standards pursuant to Article 72 (Technical Standards Concerning Package or Transport) of the Act. The packing and transport inspection consists of inspections performed periodically based on the object or inspection cycle as per Article 101 of the Enforcement Regulations of the Act (periodic transport inspection) and inspections conducted whenever “radioactive materials” set forth under Article 101 of the Enforcement Regulations of the Act

are to be packed or transported (individual transport inspection). This inspection is designed to confirm if the applicant or authorized party satisfies the technical standards under Article 72 of the Act. As the regulatory requirement of the nuclear safety act, Total radioactivity of spent fuels has to be calculated before transport in advance.

Table I. The status of transferring of spent fuel in NPPs in recent years. (unit : the number of times)

Site	2009	2010	2011	2012	2013
Kori	4,360	4,756	108	0	156
Hanbit	192	372	60	48	0
Hanul	492	720	132	144	0
Wolsong	9,960	12,480	21,000	21,600	21,600
Total	15,004	18,328	21,300	21,792	21,756

The ORIGEN-ARP program is used for this purpose but this program calculates the source term of spent fuel as a unit of fuel assembly at one time [2]. And this program provides the batch mode to calculate the multi-source terms of spent fuels as well. For using this characteristics of this program, in this study, ARP-auto program were developed. Basically, ARP-auto program is not an independent program to calculate the source term of spent fuel, but it use the ORIGEN-ARP program for easy-to-use when multi-source terms of spent fuels are calculated. ARP-auto program generate the multi input files and batch file for ORIGEN-ARP programs. And it can generate the summary result output file from the multi output file of ORIGEN-ARP programs. Figure 1 shows the procedure of ARP-auto program using the ORIGEN-ARP and Figure 2 shows the real execution features of this program.

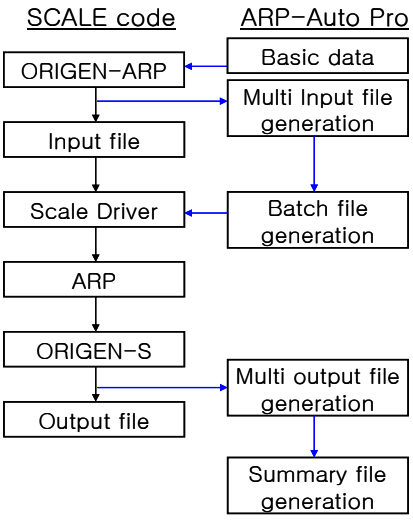

Figure 1. The procedure of ARP-auto program using ORIGEN-ARP

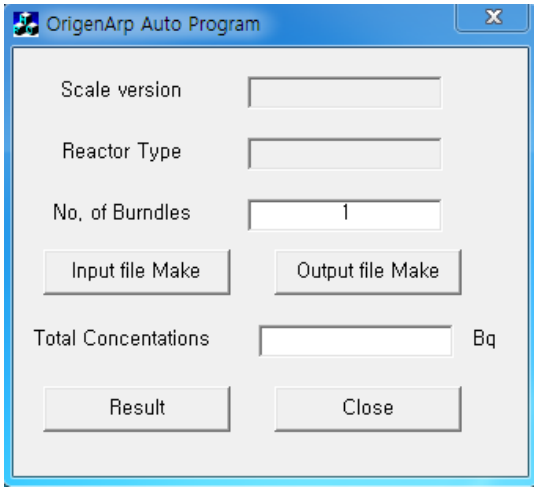

Figure 2. The execution features of ARP-auto.

Firstly, ARP-auto program read the basic information of spent fuel from the text file which is made in advance, that is, type of spent fuel, name of spent fuel assembly, initial enrichment of uranium(%), burnup(MWd/MTU), initial amounts of uranium (gram), cooling time of spent fuel (month), burning time(month). By reading information of spent fuel, ARP-auto program generate the multi input files and

batch file by clicking the button of ‘input file make’. By clicking the ‘output file make’, ARP-auto program call the scale driver to calculate the multi-source terms of spent fuel. Finally, by clicking the ‘result’ button, ARP-auto program generate the summary file which extract the result of the total radioactivity of each spent fuel from the multi output files of ORIGEN-ARP program and shows the total radioactivity of all spent fuels. Sometimes, the version of input file of ORIGEN-ARP is not compatible with the previous version. For that reason, ARP-auto program also distinguish the SCALE code version 6.0 and 6.1.

The Selection of Spent Fuels for Validation of ARP-Auto Program

In order to confirm and compare the results between the ORIGEN-ARP and ARP-auto program, PWR spent fuels and PHWR spent fuels were selected. In case of PWR, most of spent fuels which are transferred from old NPPs to neighboring NPPs are 17 x 17 spent fuels of Westinghouse type by using the KN-12 spent fuel transport cask in Korea[3,4]. Therefore, as shown in table II, 12 spent fuels of this type are selected. In case of PHWR, 120 spent fuels are transferred to the dry storage facility (Silo and MASCSTOR) by using the HI-STAR 63 after 6 years cooling. Average burnup is 7800MWD/MTU and the range of each spent fuel burnup is shown in figure 4.

Table II. Information of PWR spent fuels for validation of ARP-auto program

No. of spent fuel	Enrichment (w/o)	Burnup (MWD/MTU)	Amounts of U-235 (g)	Cooling time (Month)	Burning time (Month)
1	3.47	34720	423335	197	18
2	3.46	35027	423996	197	18
3	3.46	40857	420178	197	18
4	3.46	43187	418702	197	18
5	3.47	34805	424323	197	18
6	3.50	43371	417352	197	18
7	3.47	29115	426593	211	18
8	3.48	35172	422114	197	18
9	3.47	34926	424011	197	18
10	3.47	34890	424278	197	18
11	3.47	29207	428614	211	18
12	3.46	29214	427959	211	18

RESULTS AND CONCLUSION

The calculated results between ARP-auto program and ORIGEN-ARP are shown in table III. The activity results of ORIGEN-ARP were performed by KHNP(Korea Hydro & Nuclear Power Co., LTD) when this company transferred spent fuels from Hanbit unit 1& 2 to Hanbit unit 3 in compliance with the nuclear safety act[3]. Because KHNP has only the SCALE 5.1 code, the calculated results between ARP-auto program and ORIGEN-ARP were compared by using the different version of SCALE code in this study. Table III shows the radioactivity and relative error of each spent fuel calculated by both computer codes. The range of relative error is about 0.9 ~ 3.0%. It may cause from the difference of data libraries between SCALE 5.1 and SCALE 6.0 because the ARP-auto program uses the SCALE 6.0 or higher versions.

Table III. Comparison of the calculated activity of each spent fuel between ARP-auto and ORIGEN-ARP

No. of spent fuel	ARP-auto pro. (Scale 6.0) (Bq)	ORIGEN-ARP (SCALE 5.1) (Bq)	Relative error (%)
1	5.31E+15	5.40E+15	-1.66
2	5.36E+15	5.44E+15	-1.40
3	6.10E+15	6.18E+15	-1.30
4	6.38E+15	6.44E+15	-0.91
5	5.34E+15	5.40E+15	-1.20
6	6.39E+15	6.44E+15	-0.75
7	4.38E+15	4.51E+15	-3.01
8	5.36E+15	5.44E+15	-1.44
9	5.35E+15	5.44E+15	-1.64
10	5.35E+15	5.44E+15	-1.68
11	4.42E+15	4.51E+15	-2.22
12	4.41E+15	4.51E+15	-2.36
Total	6.42E+15	6.52E+15	-1.56

In this study, radioactivity of each nuclide in the bundle of spent fuel was calculated by using the PHWR spent fuel as shown in table IV, and the interrelation between total activity and burnup is evaluated as shown in figure 3 as well. In order to compare the results of ARP-auto program, the reference radioactivity of each nuclide is excerpted from the representative spent fuel of Wolsong unit 1 which transferred by HI-STAR 63[4].

Table IV. The comparison of radioactivity between HI-STAR 63 and ARP-auto program

Nuclide	SCALE 4.4 (Bq)	ARP-auto (Bq)	Relative error (%)
Sr-89	3.493E+01	3.477E+01	0.454
Sr-90	1.092E+13	1.094E+13	0.229
y-90	1.092E+13	1.094E+13	0.229
Ru-103	1.162E-02	1.168E-02	0.531
Ru-106	2.431E+12	2.483E+12	2.098
Cs-134	1.332E+12	1.295E+12	2.857
Cs-137	1.606E+13	1.622E+13	0.999
Ce-144	1.702E+12	1.713E+12	0.642
Pm-147	1.058E+13	1.041E+13	1.652
Pu-238	5.772E+10	5.832E+10	1.029
Pu-239	1.154E+11	1.136E+11	1.620
Pu-240	1.721E+11	1.682E+11	2.289
Pu-241	1.203E+13	1.408E+13	14.59
Cm-242	2.823E+08	3.452E+08	18.21
Cm-244	9.990E+09	1.021E+10	2.155

Source term of this spent fuel was evaluated using the SCALE 4.4 by KHNP. There is little difference about radioactivity in most nuclides except the Pu-241 and Cm-242. It may also cause from the difference of data libraries between SCALE 4.4 and SCALE 6.0. Figure 3 shows the direct interrelation between burnup and radioactivity of PHWR spent fuel. And the purpose of calculation of 120 spent fuels of PHWR is to confirm of the effectiveness and availability of ARP-auto program. The working time to complete the calculation of source terms of 120 spent fuel assemblies take only 20 minutes whereas it takes one or two days by hands even though using the batch mode of ORIGEN-ARP. But this code still has some challenging problem. This is instability of the execution of the code because this code was developed by using the function of macro in Visual C++. ARP-auto program execute the ORIGEN-ARP automatically and write each parameters at the express mode of this program. A malfunction is occurred while writing parameters from time to time. Nevertheless, ARP-auto program can be used when the regulatory body review or inspect to confirm the credibility of evaluated source term of spent fuel transport cask or storage cask.

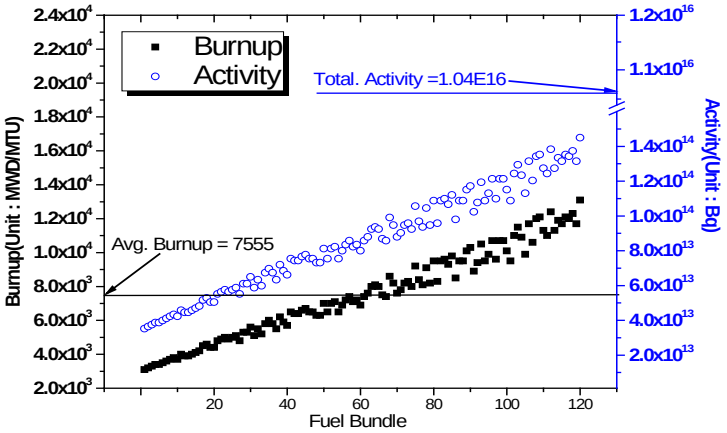

Figure 3. Interrelation between burnup and activity of PHWR SNF bundles.

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ACKNOWLEDGEMENTS

This work was supported by the Nuclear Safety Research Program through the Korea Radiation Safety Foundation (KORSAFe), granted financial resource from the Nuclear Safety and Security Commission(NSSC), Republic of Korea (No. 1305004)