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Independent verification of radioactivity by spent fuel assembly and independent verification program development

Ara Go[a*], Daesik Yook[a], Kyuhwan Jeong[a], GyeongMi Kim[b], GunHee Jung[b], Ser Gi Hong[b]
[a]*Korea Institute of Nuclear Safety, 62 Gwahak-ro Yuseong-gu, Daejeon*
[b] *Dept. of Nuclear Engineering, Kyung Hee Univ., 1732 Deogyeong-daero, Giheung-gu, Yongin, Gyeonggi-do*
[*]*Corresponding author: argo@kins.re.kr*

1. Introduction

Spent fuel (SF) pools in Korea are expected to be saturated after 2020s. Therefore, to prevent for the saturation of spent fuel pools, SF is transported form saturated pool to another unit spent fuel pool. According to Article 108 of the enforcement decree of the nuclear safety act, nuclear enterpriser, who intends to report the transport of radioactive material, etc. under the provisions of Article 71 (1) of the Act, shall file to the Commission a report on their transport, attached with document prepared in conformity with the Ordinance of the Prime minister, whenever he transports them [1]. In compliance with provisions of Article 12 of Notice of the Nuclear Safety and Security Commission No.2017-56 (waste.02), transport documents which are prepared by consignors shall be radioactive material transportation statement, and package inspection records. Radioactive material transport statements shall include maximum radioactivity of the radioactive content [2]. Independent verification is necessary to verify these radioactivity values calculated and submitted by applicant.

The purpose of this study is to independently verify radioactivity in statement on transport of radioactive materials for transported SF in Hanbit site in 2017. For this independent verification, AMORES (Automatic Multi-batch Origen Runner for Evaluation of Spent fuel) code was developed.

2. Materials and Methods

2.1 Information of spent fuel

Independent verification was performed using spent fuel that was transported in Hanbit site in 2017. These data were provided by Korea Hydro and Nuclear Power (KHNP). In Hanbit site, 144 assemblies were transported from unit 3 to unit 2 over 8 times during October and December in 2017. Fig. 1 shows discharge burnup and initial enrichment for transported assemblies. The average discharge burnup and initial enrichment of transported SF were 29 GWd/MTU and 2.46% respectively. The final discharge year was distributed from 1996 to 2006. 116 assemblies (81%) discharged before 2000, and 28 assemblies (19%) discharged after 2000.

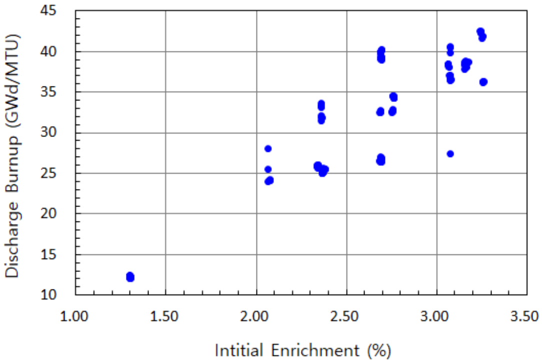

Fig. 1. Discharge burnup and initial enrichment

2.2 Calculation Radioactivity using AMORES code

To calculate radioactivity, AMROES code was used. The AMORES was developed using C++ and C# to generate the source terms of SNFs, making it possible to automatically generate ORIGEN-S input files and process their output files for a large number of SNF assemblies [3]. Fig. 2 shows the initial screen of the AMORES program.

The AMORES program has an express mode and a detail mode. The express mode assumed a single specific power 40 MW/MTU and used the irradiation time which is estimated by dividing the discharged burnup with the specific power for all the PWR spent fuel assemblies. On the other hand, the detail mode considered the irradiation and cooling histories. It calculated the irradiation time interval as the cooling time, and specific power was estimated by multiplying the discharge burnup and the total irradiation time.

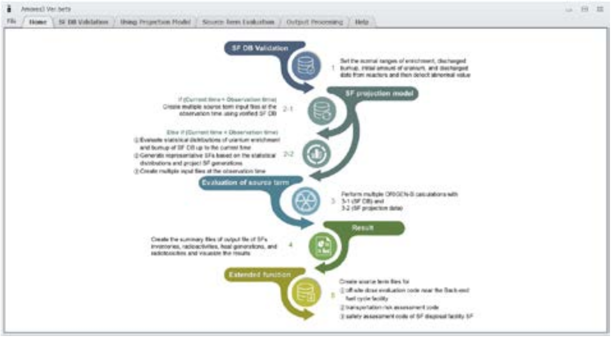

Fig. 2. Initial screen of AMORES program

3. Results and Discussion

Fig. 3 shows the radioactivity by assembly provided by KHNP and calculated using AMORES code. Radioactivity varied from 1,700 TBq to 7,000 TBq depending on the burnup, enrichment, and cooling time. Radioactivity increased with the increase of the burnup and enrichment, but some SF showed high radioactivity even though its burnup and enrichment were relatively low because of short cooling time. Radioactivity of about 1,700 TBq was found in 1.3% low enrichment SF.

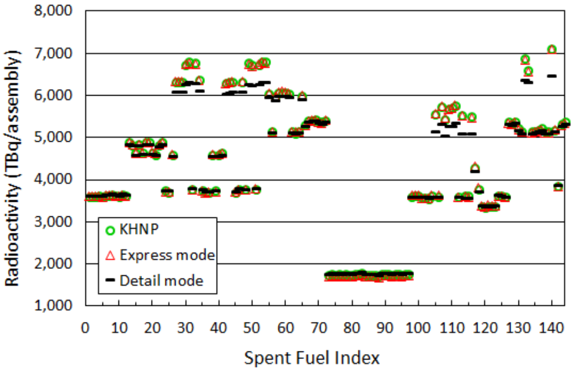

Fig. 3. The radioactivity by assembly provided by KHNP and calculated using AMORES code (The spent fuel index on the x-axis represents the SF of 144 assemblies transported in Hanbit site in 2017)

Table 1 shows the number of transported assemblies in several difference intervals between KHNP and AMORES results. As shown, it can be seen that the results of KHNP and AMORES were similar. In the case of the express mode, about 80% of the spent fuel had an error of less than 1%, and about 20% had an over than 2%. The causes of this error was due the cycle difference. In the calculation of radioactivity, KHNP reflected the actual cycle, but AMORES express mode assumed 2 cycle for the all case. The average error of 2.1% was found in 1.3% of low enrichment SF. This was because it was calculated that it was two irradiation cycle in AMORES express mode, although it was actually only one cycle irradiation. In ORIGEN, the radioactivity was different depending on the irradiation cycle. The difference between 1 and 2 cycle was 2.6%, and the difference between 2 and 3 cycle was 0.35%. These values were similar to the results of this study.

In the case of detail mode, about 80% of the spent fuel had an error of less than 2%, and about 10% had an over than 5%. These errors were caused by differences in the cooling time calculation method. KHNP calculated only the cooling time from final discharge date to the transport date, but AMORES detail mode also included the irradiation time interval in the cooling time. That is to say, the cooling time of AMORES was longer than or equal to KHNP. For 6.5 ~ 8% difference intervals, the time interval between 2 and 3 cycle was about 7 years, and 8 ~ 9.5% difference intervals, the time interval between 2 and 3 cycle was about 9 years. Therefore, it can be seen that the results of KHNP was more conservative than actual.

Table 1. the number of transported assemblies in several difference intervals between KHNP and AMORES results.

Difference interval between KHNP and express mode (%)	No. of assemblies (percent)	Difference interval between KHNP and detail mode (%)	No. of assemblies (percent)
-1 ~ -0.5	12 (8%)	-1 ~ 0.5	58 (40%)
-0.5 ~ 0	41 (28%)	0.5 ~ 2	58 (40%)
0 ~ 0.5	49 (34%)	2 ~ 3.5	1 (1%)
0.5 ~ 1	16 (11%)	3.5 ~ 5	9 (6%)
1 ~ 1.5	1 (1%)	5 ~ 6.5	0 (0%)
1.5 ~ 2	0 (0%)	6.5 ~ 8	17 (12%)
2 ~ 2.5	25 (17%)	8 ~ 9.5	1 (1%)

4. Conclusions

In this study, the radioactivity by assembly was verified independently using AMORES for transported SF in Hanbit site in 2017. As a result of independent verification, radioactivity results of KHNP and AMORES were similar. The cause and the maximum errors of each mode were as follows:
1) The express mode: cycle difference, up to 2.2%
2) The detail mode: cooling time difference, up to 9.2%
The maximum error values were 2.2% in express mode, and 9.2% in detail mode. Error in the detail mode may increase with the cooling time. The current conservative calculation has no problem in terms of transportation, but it is possible that the cost will be overestimated in design of the disposal facility. Reflecting these results, we plan to modify the AMORES to reflect the actual irradiation cycle even in the express mode.

REFERENCES

[1] Enforcement Decree of the Nuclear Safety Act, NUCLEAR LAWS OF THE REPUBLIC OF KOREA, 2018
[2] Regulations for the Packing and Transport of Radioactive Materials, etc., Notice of the Nuclear Safety and Security Commission No.2017-56, 2017.
[3] S. G. HONG et al., “Development of a Code for Regulation and Verification of Back-End Fuel Cycle Facilities,” KINS/HR-1613, Korea Institute of Nuclear Safety. 2017.