MCNP Analysis to develop the Unified LWR Spent Fuel Attribute Tester

Ki Hyun KIM, Jae Bum PARK
Korea Institute of Nuclear Nonproliferation and Control, Yuseongdaero 1534, Yuseonggu, Daejeon, Korea, 305-348
**Corresponding author: khkim@kinac.re.kr*

1. Introduction

19 Light Water Reactors (LWR) have produced more than 12,000 spent fuel assemblies and stored them in its own spent fuel pool since Kori 1 Nuclear Power Plant (NPP) had been started its commercial operation. International Atomic Energy Agency (IAEA) has continuously required the application of IRradiated Assembly Attribute Tester (IRAT) for the verification of non fuel items in addition to the Spent Fuel Attribute Tester (SFAT) to verify LWR spent fuel assemblies in the SFP. It is anticipated that the IRAT verification will be partially performed during the IAEA inspection from 2012. Therefore increase of verification time and limited conditions of workplace should be taken into consideration.

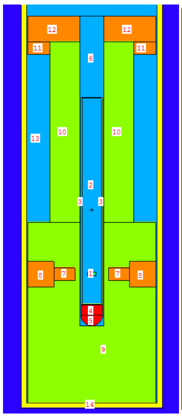
For the reasons of increase of spent fuel assemblies due to the operation of 19 NPPs and diversification of verification requirement by IAEA, it is necessary to develop the more efficient and effective verification technologies. The development of the integrated LWR spent fuel verification equipment, hereunder Unified Spent fuel Attribute Tester (USAT), started from the concept that is physical and functional integration between the SFAT and IRAT. Both of them have the same theoretical concept in respect of using a gamma spectroscopy that analyzes the specific spectrum of the gamma rays from the target. On the other hand, there are many differences between SFAT and IRAT such as the geometry, shielding method and material.

On this study, the modeling and measurement simulation, the confirmation of the main design parameters were conducted by using the well known analysis method Monte Carlo n particle code (MCNP). The manufacturing of the prototype equipment based on the result of MCNP analysis is under procedure recently.

2. The result of MCNP Analysis

2.1 Modeling and measurement simulation of IRAT

The characteristics and specification data for the modeling of IRAT are shown on the figure 2.1. The measurement simulation was conducted on the assumption that the distance between the detector and target (Cs-137 point source) is 30cm and the direction of measurement is horizontal. The spectrum result of simulation is shown on the figure 2.2. It presents 0.662MeV energy of photo peak, compton edge and back-scattering peak, those are typical Cs-137 gamma spectrum detected by the CZT detector.



Description	Material	Size(mm)		
		I.D(W)	O.D(D)	H
Crystal (1)	CZT20S	5	5	2.5
Detector (3)	SS	0.25 thickness		
End cap (4,5)	Teflon			
Lead Ring (7)	Pb	13	29	5
Lead Ring (8)	Pb	29	49	10
Shielding (9)	W	9	49	70
Shielding (10)	W	9	32	70
Shielding (11)	Pb	32	49	5
Shielding (12)	Pb	9	49	10
Housing (14)	SS 304	50	54	404

Fig. 2.1 Specification data for the modeling of IRAT

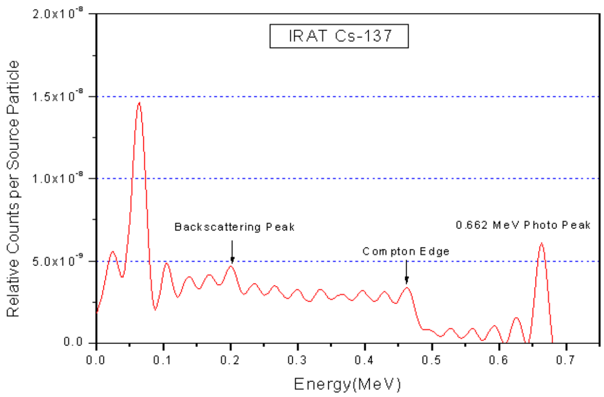
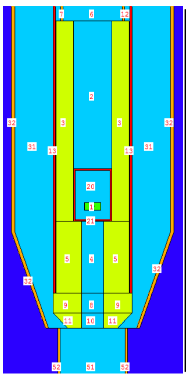


Fig. 2.2 The spectrum result of MCNP simulation of IRAT

2.2 Modeling and measurement simulation of SFAT

The characteristics and specification data for the modeling of SFAT are shown on the figure 2.3.



Description	Material	Size(mm)		
		I.D(W)	O.D(D)	H
Crystal (1)	CZT500S	10	10	5
Shielding (3)	W	24	34.75	126
Shielding (5)	W	12	34.75	45
Shielding (9)	W	12	36.35	12.5
Shielding (11)	W	12	36.35	9.5
Cylinder (13)	Al	1.6 thickness		
Detector (21)	Al	1.6 thickness		
Housing (32)	SS 304	1.6 thickness		
Air pipe (52)	SS 304	1.6 thickness		2554

Fig. 2.3 Specification data for the modeling of SFAT

The measurement simulation of SFAT was conducted to find the most similar measurement result with IRAT on the assumption that the distance between the detector and target (Cs-137 point source) is 30cm and the direction of measurement is vertical. The analysis results that are the radiation sensitivity and increase of the weight depending on the change of the thickness of the shielding are shown on the figure 2.4. The number of gamma rays that transfer its entire energy to the CZT detector decreased exponentially depending on the increase of the shielding. The most similar measurement result was appeared in the case of adding 25 mm thickness shielding. However, the weight increase due to the increase of the shielding thickness was 16.32kg. Those results make it worse to improve the portability and ease of handling so that the manufacturing unified verification equipment is anticipated negatively.

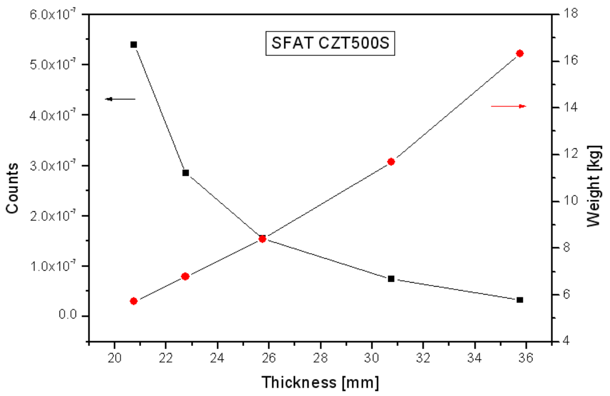


Fig. 2.4 The analysis result of MCNP simulation of SFAT

2.3 Modeling and measurement simulation of USAT

Most of the dimensions of USAT adopted the SFAT because the IRAT is not affordable to the volumetric increase of the shielding. In terms of detector, the SDP310/Z60 CZT detector is newly adopted. It has a better efficiency and poor resolution than the SDP310/Z20, the detector of IRAT, on the other hand, it has a better resolutions and poor efficiency than the CZT500S. The measurement simulation was conducted on the same assumption of the IRAT analysis except the detector of the SDP310/Z60 and the dimension of the shielding and housing. The most similar measurement result, 2.90×10^{-8} count to the one gamma ray, was appeared in the case of adding 12 mm thickness shielding. The weight increase due to the increase of the shielding thickness was 5.41kg that is quite acceptable. The results are shown on the table 2.5.

Shielding Thickness (3,5,9)	weight increase	Counts	error (%)
10.75 mm + 10 mm	4.19 kg	4.83×10^{-08}	7.69
10.75 mm + 12 mm	5.41 kg	3.30×10^{-08}	8.7
10.75 mm + 15 mm	7.05 kg	2.00×10^{-08}	7.91
10.75 mm + 20 mm	9.87 kg	1.77×10^{-08}	5.32
10.75 mm + 25 mm	12.07 kg	8.23×10^{-08}	6.36

Table 2.5 The analysis result of MCNP simulation of USAT

The measurement simulation to optimize the length of the air pipe that prevents radiation effects from the non-target surrounding a target was conducted. The counts are saturated below the 490 mm length of the air pipe. The most similar measurement result was appeared in the case of 900 mm length of air pipe. The results are shown on the table 2.6.

Length of Air Pipe	Counts	error (%)
1300 mm	6.30×10^{-3}	1.26
900 mm	1.14×10^{-2}	0.93
470 mm	1.31×10^{-2}	0.87
260 mm	1.32×10^{-2}	0.86
130 mm	1.33×10^{-2}	0.86
60 mm	1.33×10^{-2}	0.86

Table 2.6 The analysis result of MCNP simulation of Air pipe

3. Conclusions

The main design parameters are decided by the MCNP analysis and the manufacturing of a prototype USAT is under procedure. USAT will be applied to the verification work after several times of the field test. The design of the USAT will be improved through the field test and additional study. The result and experience of this study will be helpful to develop the evolutional verification equipment adopting the characteristics of the spent fuel assemblies, measurement environment and working condition.

REFERENCES

[1] Safeguards Techniques and Equipment 2003 Edition, IAEA Nuclear Verification Series No. 1(Revised), 2003

[2] X-5 Monte Carlo Team, “MCNP-A General Monte Carlo N-Particle Transport Code, Version 5," LA-UR-03-1987, April, 2003.

[3] R. Arlt, M. Aparo, H. Boeck, H. Zwickelstorfer, "Spectrum catalogue of gamma spectra taken with CdT and CdZnTe detectors", Nuclear Instruments and Methods in Physics Research A 458 (2001)

[4] K. H. Kim, Necessity of Development of Integrated γ Detector to Improve National Safeguards System, KNS, May. 2011

[5] K. H. Kim, A Study on the Conceptual Design for the Development of Integrated γ Detector to verify the LWR Spent Fuel Assemblies, KNS, Oct. 2011