A Study on the Conceptual Design for the Development of Integrated γ Detector to verify the LWR Spent Fuel Assemblies

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1. Introduction

According to the World Nuclear Association (WNA) report "World Nuclear Power Reactors & Uranium Requirement" issued 2011, there are 21 Nuclear Power Plants (NPPs) under operation, 5 NPPs under construction, and 6 NPPs under the planning in the Republic of Korea (ROK). The nuclear electricity generation is 141.9 billion kWh which takes 40% of the total electricity generation in the ROK as of 2010. Due to the increase of the spent fuel assemblies by the operation of a large number of NPPs, the verification requirement by the International Atomic Energy Agency (IAEA) is increasing as well.

The IAEA has insisted that NPPs in ROK should accept the new verification equipment to verify the non-fuel items in the spent fuel pond. However, there are some technical problems such as direct handling of the spent fuel assemblies or non fuel items, the application of the new equipment has not been decided yet and discussed between the ROK and the Agency continuously. For these reasons, the integrated nuclear material verification equipment that could cover the increasing verification quantity by minimizing the inspection time and verify the non fuel items effectively as well is under developing in Korea Institute of Nuclear nonproliferation And Control (KINAC).

The development of the integrated nuclear material verification equipment started from the concept that is physical and functional integration between the Spent Fuel Attribute Tester (SFAT) for the spent fuel assembly verification and the IRradiated Assemblies Attribute Tester (IRAT) for the non fuel item verification. Both of them have the same theoretical concept in respect of using a gamma spectrometry that analyzes the specific spectrum of the gamma ray from the target. On the other hand, there are many differences between SFAT and IRAT such as the meaningful intensity of the gamma ray, collimator geometry, shielding method and material. On this study, the conceptual design of the integrated equipment being proceeded until now and the future plan, for example the modeling of each equipment (SFAT and IRAT), functional verification by the simulation method, are discussed.

2. The conceptual design of the integrated equipment

2.1 Measurement Scheme of the SFAT and IRAT

Spent fuel assemblies of the Light Water Reactor (LWR) could be verified by measuring the gamma ray from the fission products and analyzing spectrum of the specific gamma ray (661.7kev) from Cs-137. The SFAT generally used for the spent fuel verification is consisting of a multichannel analyzer electronics unit and a NaI or CdZnTe (CZT) detector. The SFAT is used for taking measurements from the top of a fuel assembly as it sits in the storage rack. A watertight collimator pipe is attached below the detector housing to permit only radiation from the principal assembly rather than from adjacent assemblies to reach the detector.

Non fuel items also could be verified by using the gamma spectrometry because the verification of the non fuel items in the spent fuel pond is identifying the absence of the nuclear materials in target items. Therefore, most of the components and measurement system of the IRAT are very similar with the SFAT. However, the IRAT uses a smaller detector compared to the SFAT that is well-fitted to the low intensity gamma ray measurement.

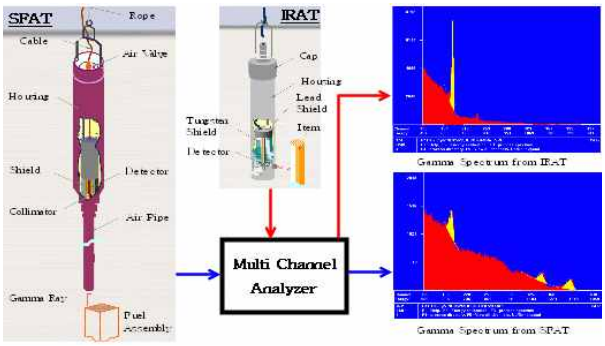

Fig. 1. Schematic Diagram of the SFAT and IRAT

The IRAT has not a vertical collimator but a horizontal collimator to acquire the signal directly from the target without air collimator pipes so that the item should be lifted up and moved to the side of the equipment. Furthermore, due to the direct signal acquisition, there is a ring-shaped tungsten shield around the detector to prevent signal saturation by the high radiation from the irradiated metal such as Co-60.

2.2 Main factors of the conceptual design

The first factor of conceptual design is a type of the detector. Both SFAT and IRAT are adopting the CZT detector to measure the gamma ray. Comparing the CZT detector with the NaI detector suitable for the gamma ray detection, the CZT detector has a relatively small volume that helps to reduce the weight and size of the equipment. Besides, the CZT detector has a better resolution when the crystal size is similar. The gamma ray intensity from the spent fuel assemblies is very high compared to gamma ray from non fuel items though it is up to the burn-up of the spent fuel assemblies. The detector which has a large volume of the crystal has a good efficiency on the other hand it means low resolution. The smaller one has a better resolution but it also means low efficiency. The bigger one is well-fitted to the SFAT and the smaller one is well-fitted to the IRAT.

The second factor is the geometry of the collimator and radiation shied. The IRAT collimates signals from the side of the equipment in contrast with the SFAT that collimates signals from the bottom of the equipment. The advantage of the collimator geometry of the IRAT is identifying the middle or low section of the non fuel items where is not able to be verified with the SFAT. However, the signal is subject to saturate by the effect of the gamma ray from highly irradiate metal so that the more complex shielding system is required to prevent the saturation in case of the IRAT. A watertight air collimator pipe system of the SFAT permits only radiation from the target assembly rather than from adjacent assemblies to reach the detector. For these reasons, the effect without air collimator pipes and ring-shaped shied around the detector have to be considered to enhance the quality of the conceptual design.

The third factor is the mobility of the target item in a direct or indirect manner. The IRAT gets signals from the side of the equipment so that the target items have to be lifted up or moved close to the IRAT. However, Operators of the facility pay their attention to the probability of safety accidents that could be happened during the lifting or movement of the items. Thus, the mobility of the target items should be minimized to facilitate the application of the integrated equipment to the facilities.

2.3 Draft conceptual design of the integrated equipment

The frame of the integrated equipment based on the SFAT to take advantages of the experiences of developing the K-SFAT. The detector of the integrated equipment will be the CZT that make it possible to reduce the size of body and lighten the weight of the shield. The size of the crystal in the detector will be decided by the analysis using the MCNP or MCNPX code. The air collimator pipe will be adopted to prevent the neighboring effect. Furthermore, The radius and length of the air collimator pipe will be adjusted to enhance the mobility and control convenience. The air-holed and ring-shaped tungsten shield around the detector also will be installed to collect proper intensity of the signals and to minimize the saturation effect. Air holes in the shield could assist the gamma collection from the side of the detector.

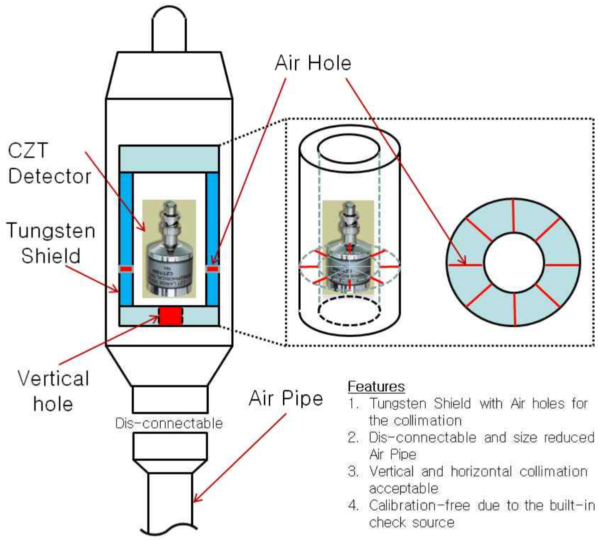

Fig. 2. Draft conceptual design of the integrated equipment

The thickness of the shied, the shape of collimator, the number and size of the air holes will be decided by using the MCNP or MCNPX simulation code. The functional verification will be performed after the modeling work regarding each of the equipment is completed by using the same code. Following the simulation, a prototype equipment production and field test will be conducted to improve and confirm the design of the integrated equipment.

3. Conclusions

In this study, the integration has a relatively small progression in the respect of the physical and functional combination without theoretical or fundamental concept changes. On the other hand, improved field applicability is looked for because the technologies and equipment used are verified and well-known. It makes us take the advantageous position to acquire the certification from IAEA. It is anticipated that this development project contributes to enhance the effectiveness and efficiency of the national safeguards inspection system.

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