Fast Neutron Detection for Spent PWR Fuel in Dry Storage

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1. Introduction

Nuclear safeguards is of fundamental importance for any country operating nuclear power plants. The management of spent nuclear fuel (SNF) recently became important concern in S. Korea due to nuclear-free energy policy and out of pool storage capacity. These would lead to require the accelerated plan how to secure SNF in dry storage.

SNF in dry storage is notoriously difficult to accurately verify with nondestructive methods, so it is necessary to develop nondestructive techniques for ensuring and verifying the integrity of spent nuclear fuel.

Several techniques based on gamma and thermal neutron detection have been developed and applied for the monitoring and certification of SNF. However, there are very limited technologies available due to the influence of shielding materials and interference of background radiation.

Therefore, Korea Institute of Nuclear Non-proliferation and Control (KINAC) currently proposed a novel SNF monitoring technique using He-4 scintillation fast neutron detectors.

2. Methods and Results

2.1 Proposed Method via Fast Neutron Measurement

The ultimate goal of this approach is to verify integrity of SNF in dry storage via comparing the computational and experimental results [Fig. 1].

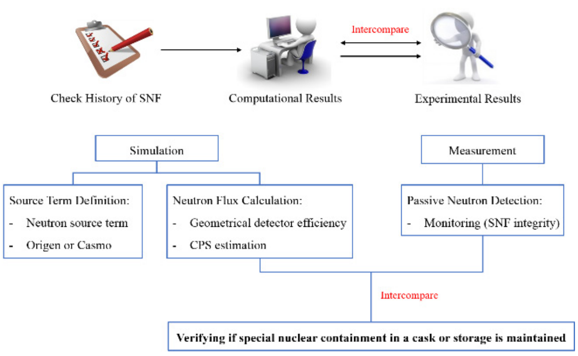

Fig. 1. Logical pathway of the proposed method.

2.2 Neutron Flux Evaluation

In order to evaluate neutron flux on the surface of a dry cask or storage, two separated steps are typically required such as; 1) source term evaluation via ORIGEN or CASMO code and 2) neutron flux calculation via MCNP code.

These two steps are so complicated and time consuming since it is not easy to write inputs, analyze outputs, and transfer data for each code without some specialized knowledge. The present authors have thus developed a new algorithm, coupled ORIGEN-ARP and MCNP, and the graphical user interface (GUI). It was designed for that a user can easily communicate with the GUI [1].

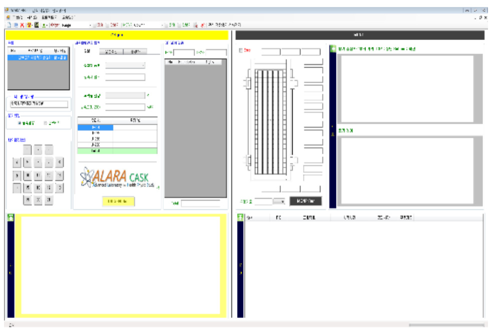

Fig. 2. GUI coupled ORIGEN-ARP and MCNP.

Through this GUI, the estimated neutron source term can be automatically transferred into MCNP inputs. The final outputs can also be graphically presented like Fig. 3.

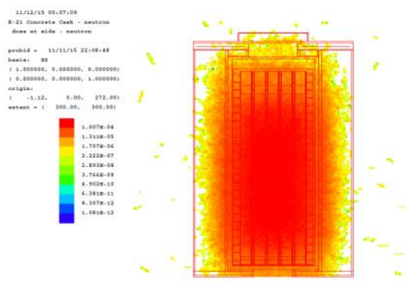

Fig. 3. Graphical result presented by the developed GUI.

2.3 Development and Evaluation of Trial Apparatus

Prototype He-4 gas scintillation detectors were employed as a fast neutron spectroscopy tool for monitoring SNF in a dry cask or storage. These prototype detectors (S670E) were developed by Arktis Radiation Detection Ltd. in Switzerland. They can simultaneously detect fast and thermal neutrons within the same device. Thermal neutrons react with Li-6 coated on the inner surface of the tube and fast neutrons are elastically scattered by He-4 gas [Fig. 4].

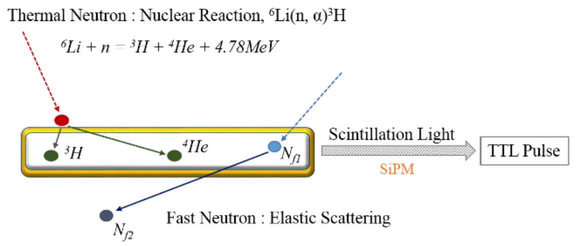

Fig. 4. Reaction mechanism in a He-4 gas scintillation detector.

The generated scintillation light is converted into an electrical signal by SiPMs, dispersed inside the active volume of the detector.

Vertically daisy-chained He-4 gas scintillation detectors were employed to build a new trial apparatus. The output signal can be analyzed individually and obtained counts from each detector will be used to map 2D neutron flux outside a cask or storage [Fig. 5].

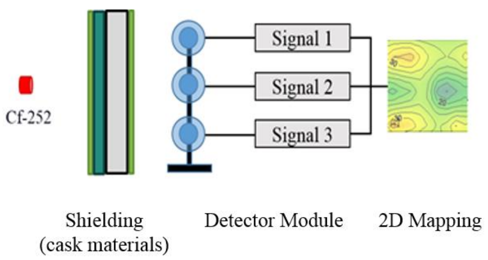

Fig. 5. Concept of experimental design.

The feasibility test of this new apparatus has been performed with a Cf-252 neutron source and the laboratory scale model cask, minimized by a factor of ten compared to the actual dimension of a KN-21 cask [Fig. 6].

KN-21 is a dual purposed cask newly developed by Korea Radioactive Waste Agency with the purpose of storing and transporting 21 spent nuclear fuel assemblies.

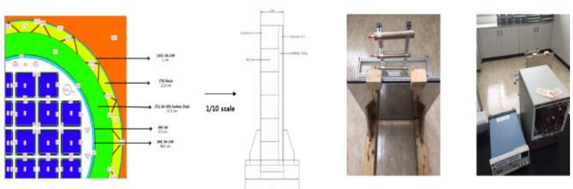

Fig. 6. Experimental setup at KINAC.

2.4 Neutron Detection via a He-4 Detector

Considering the experimental setup and results, the total counts from only prompt fission neutrons detected by a He-4 scintillation detector can be written as:

$$C_F = S \cdot \varepsilon \cdot T \cdot V \cdot e^{-\Sigma_t \cdot d} \qquad (1)$$

where S is the neutron source, ε is the detector efficiency, T is the acquisition time, and V is the sample volume [2]. The exponential term accounts for the attenuation in a sample.

However, the fast neutron signal directly has proportionality to its incident energy and angle so the detector efficiency term (ε) has to be written in energy function, R(E).

$$\mathrm{R(E)} = \int_E P_\mu(\mu, E)\sigma_s(E)dE \qquad (2)$$

Where $P_\mu(\mu, E)$ is the angular distribution and $\sigma_s(E)$ is the elastic scattering cross-section.

3. Conclusion

Currently, the new proposed study for SNF neutron monitoring is ongoing at KINAC. Based on the proposal, the present authors have designed, optimized, and built an experimental apparatus and computation tool capable of verifying SNF integrity in a dry cask or storage.

The groundwork such as energy discrimination, gamma rejection, and others for a new approach has been laid. The next step will be sensitivity studies of parameters which have non-negligible contributions.

REFERENCES

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