Contribution ID: **193** Type: **Oral Presentation**

#5-193 Detection of 2.223 MeV γ Rays for Water Identification in Spent Nuclear Fuel Assemblies

Thursday, June 12, 2025 12:00 PM (20 minutes)

The detection of 2.223 MeV γ-ray emissions resulting from neutron capture on hydrogen, as a means to monitor water presence in spent nuclear fuel (SNF) assemblies is described. Water detection is crucial because water ingress into dry storage systems or other containment environments poses safety risks and potential criticality concerns. This study thus aims to explore the use of the characteristic 2.223 MeV γ rays for reliable detection of water within SNF assemblies, with a focus on understanding how neutron interactions, such as scattering and absorption, impact the γ-ray production and detection in different fuel configurations. This approach will provide a non-invasive and accurate approach for nuclear monitoring and maintaining nuclear safety. To achieve this objective, we employ a combination of experimental testing and computational modelling using Monte Carlo simulations. A GR5021 high-purity germanium (HPGe) detector has been used to measure γ-ray emissions from neutron capture events under controlled conditions. Several californium-252 (Cf-252) point neutron sources were used to provide a well-characterised neutron field representative of those in SNF environments. Various test configurations were created using high-density polyethylene (HDPE) blocks and 3D-printed metal foams such as SS316L stainless steel, zinc oxide, and tin oxide. The HDPE blocks serve as analogues to simulate the neutron moderation characteristics of water whilst the metal foams serve as analogues for fuel-containing materials. Water slabs of varying thicknesses between 2 mm and 40 mm were also introduced to allow for a controlled study of how neutron capture rates and γ counts varied with water content. Each of these materials was chosen to replicate the geometric and compositional characteristics of real fuel assemblies and to study neutron capture in the thermal and epithermal regions. Results consistently showed the detection of 2.223 MeV, with γ counts changing consistent with expectations as material thickness increased. In parallel with the experimental testing, MCNP simulations were performed to model neutron propagation and γ-ray production in identical configurations. Both thermal and epithermal neutron regions were examined to capture the full spectrum of neutron interactions. The simulation results showed strong agreement with experimental results and confirmed the accuracy of the computational approach. Both methods demonstrated that material composition and geometry significantly impact neutron behaviour and γ-ray emissions. Simulations of heterogeneous fuel assemblies, such as those in advanced gas-cooled reactors and prototype fast reactors were also performed. These simulations highlight the importance of considering specific assembly configurations, as material heterogeneity can cause localised variations in neutron flux and γ-ray production. The overall results suggest that the 2.223 MeV γ-ray is a reliable and sensitive indicator for detecting water in SNF assemblies, with significant implications for nuclear safety and fusion reactor environments.

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Session Classification: #05 - Nuclear Power Reactors and Nuclear Fuel Cycle

Track Classification: 05 Nuclear Power Reactors and Nuclear Fuel Cycle