The Spent Fuel Nondestructive Assay (NDA) project started in FY09 with the premise of developing NDA instruments to achieve the following technical goals: (1) verify the initial enrichment, burnup, and cooling time of fuel assemblies, (2) detect the diversion or replacement of pins, (3) estimate fissile mass, (4) estimate decay heat, and (5) determine the reactivity of spent fuel assemblies. One of the active instruments developed as part of the spent fuel NDA project is Differential Die-Away (DDA) which measures the response of a spent fuel assembly to a neutron pulse. The irradiated isotopic compositions of the assemblies were obtained using the SCALE/ORIGAMI code, and the DDA instrument was modeled with MCNP. The response can be analyzed to infer fissile mass, burnup, cooling time, and initial enrichment of a spent fuel assembly. For this study, only burnup and initial enrichment were estimated for 9 PWR assemblies with similar cooling times.

**Introduction**

The DDA instrument comprises three pods of four $^{3}He$ detectors positioned in pods on three sides of a fuel assembly with a neutron generator on the fourth side.

**Theory**

To simulate the expected response of DDA to spent fuel assemblies, a collection of 25 PWR and 25 BWR assemblies from SKB’s Clab interim storage facility were modeled. The PWR assemblies were split into three axial sections and the BWR assemblies were split into four axial sections. For each axial section, two fixed-source MCNP runs were performed:

1. A time-independent source containing source terms for each assembly. This model detects the response from spontaneous fission inside the SFA.
2. A time-dependent source from the NG consisting of a 20 μs square pulse of 14.1 MeV neutrons. The net multiplication $M_{\text{net}}$ in fixed source MCNP output files was found to equal

$$M_{\text{net}} = \text{source weight} + (\lambda_f - \lambda_i) \text{fission weight}$$

Twelve MC assemblies with known parameters and similar cooling times, the calibration curve becomes

$$f(\tau, \alpha) = 1.2079\alpha^3 + 14.495\alpha^2 - 0.2397\alpha \tau + 1.2893\tau + 77.220$$

Twelve $^{4}$He tallies with 2 μs time bins from 0 to 400 μs were also set up for each detector. Since very few histories survive into late time bins, a method of combining weight windows from different runs optimized for different time windows was developed. Combining weight windows spoil up simulations by a factor of up to 600 in late-time windows for the neutron generator runs.

**MCNP Modeling**

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**Calibration Curve**

With simulated time-dependent signals from each assembly, a calibration curve was created to estimate initial enrichment and burnup. The following steps were performed:

1. Find the time range in which the the DDA signal is dependent only on the multiplication.
2. Calculate time constants of the decaying DDA signal for each assembly using the optimal time window.
3. Use multiplication $M$ and time constant $\tau$ to calculate $\alpha$, a parameter describing the slope of the line each point lies on.
4. Use $\alpha$ to calculate initial enrichment $\lambda$.
5. Linearly interpolate between given values of $\tau$ and $\alpha$ to infer burnup for unknown values.

**Conclusion**

The results show that simulations of DDA are clearly capable of detecting differences in initial enrichment and burnup. DDA shows promise for helping to verify initial enrichment particularly in spent fuel assemblies that cannot be determined through passive gamma or fork detector measurements. However, the main challenge is in creating a calibration curve that can accurately quantify initial enrichment and burnup.