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Pin Weighting Factor Calculations for the Vanadium Incore Detector using MCNP5

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Ⅰ. Introduction

The electron flow from the emitter to the outer sheath produces an electrical current that is proportional to the number of neutron interactions in the emitter. Vanadium is one of several well known neutron detector materials and has been used in CANDU type reactors for many years. The vanadium based In-core Instrumentation (ICI) assembly design has been developing to displace the rhodium based ICI assemblies currently used in OPR1000. [1][2] Rhodium has been commonly used in Light Water Reactors because it produces a relatively large output signal. The magnitude of the output signal from the rhodium detector minimizes the need to use very sensitive signal processing electronics to measure the output signal.

The benefit of vanadium is its low depletion rate, which is about a factor of seven times less than rhodium, at the expense of smaller output current from the detector. The detector current can be increased by increasing the detector wire diameter and/or length. Due to a relatively small absorption cross section, and the lack of neutron resonance structure, the diameter can be increased efficiently and a simple self-powered detector model can still predict the output current very accurately.

The purpose of this study is to show that vanadium signals can be used as effectively as signals from the rhodium detectors to reconstruct the core power distribution and the peaking factors, and that the validation of a nodal three-dimensional code can be based on the analysis of vanadium detector signals as well as rhodium detector signals. This study represents one step in the overall validation of vanadium detectors.

II. Methods and Results

The vanadium detectors are sensitive to neutrons emitted by fuel rods in close proximity to the detector. Because of this selective response and because of power gradients in the assemblies, the actual power distributions in the core environment must be accounted for determining the detector response. This is done by the introduction of pin weighting factors Wi, which represent the contribution of the various pins to the signal. Wi are normalized such that:

$$\sum_{\mathrm{i}} \mathrm{W_i} = 1.0$$

The detector signals become proportional to

$$S = Q \times \sum_{\mathrm{i}} \mathrm{W_i} \times \mathrm{P}_i$$

in which P_i is the pin power distribution in the core environment and Q is the burn-up dependent sensitivity.

The factors W_i are obtained from Monte Carlo calculations performed by the MCNP5 code.[3] They depend on the fuel pins and assembly geometries, but not on the pin type, enrichment, burn-up or power. When tabulated as a function of the separation between the fuel pin and the detector, they show an exponential variation which is easily fitted. In order to obtain the detector neutron response from each individual fuel pin, several MCNP Monte-Carlo assembly calculations were performed, assigning a power of unity to the fuel pin of interest and of zero to all other fuel pins. MCNP calculates the neutron reaction rate in the detector wire per neutron emitted by a fuel rod. The neutron emission is proportional to the pin power. Thus the contribution of a single fuel pin to the detector signal can be isolated. By repeating this calculation for all fuel pins, one gets the response distribution W for each pin. These calculations were performed for OPR1000 fuel assembly, and extended to a checkerboard geometry to validate the extrapolation of W to the neighboring assemblies.

The radial MCNP assembly description was the same as used in general lattice code with a vanadium detector, i.e., a quarter of an assembly with reflective boundary conditions and the detector model. A flat axial power distribution was supplied. A full length detector was modeled to capture the reaction rates over each detector level and the spacing between levels. A total of 236 fuel pins has to be calculated to get the Wi for the OPR1000 fuel assembly. Figure 1 gives the assembly geometry of MCNP.

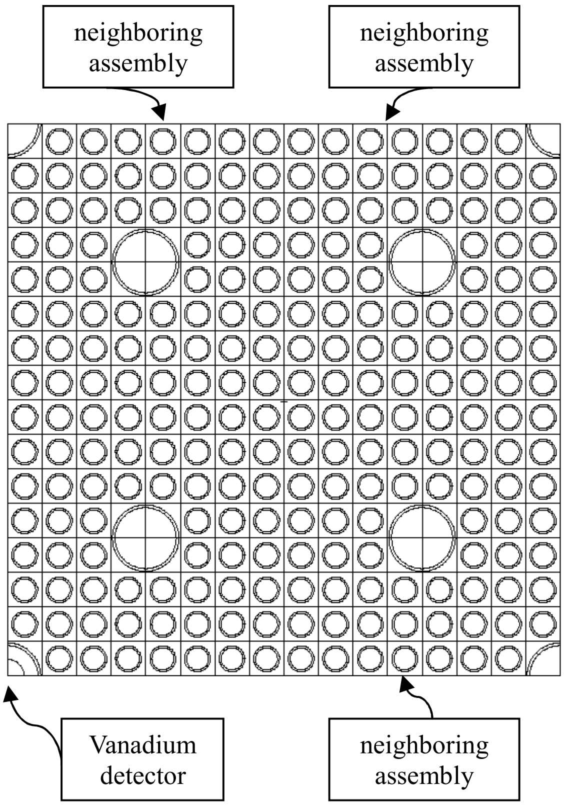

Figure 1. MCNP Geometry

It is not necessary to calculate every fuel pins, since the results will be fitted as the pin-detector separation and the fit can be used to fill-in the missing values. Some pins were calculated to determine the effect of the moderator. One can see that the moderator density has some impact on the weighting factors, because the neutron population will grow near the moderator.

Figure 2 shows the results for the OPR1000 fuel assemblies. Due to the computer running time 28 fuel pins were calculated. The results show a faster decrease of W as a function of the distance d, and can be fitted to the expression:

$$W = 0.00342 \times e^{-0.61d} + 0.00176 \times e^{-0.1d} + 0.00197$$

in which d is the distance between the centerline of the detector cell to the centerline of the fuel cell, in centimeter. W must be normalized to

$$\sum_i \mathrm{W_i} = 1.0$$

over the single assembly or assembly plus neighbors when applied to the core power distribution.

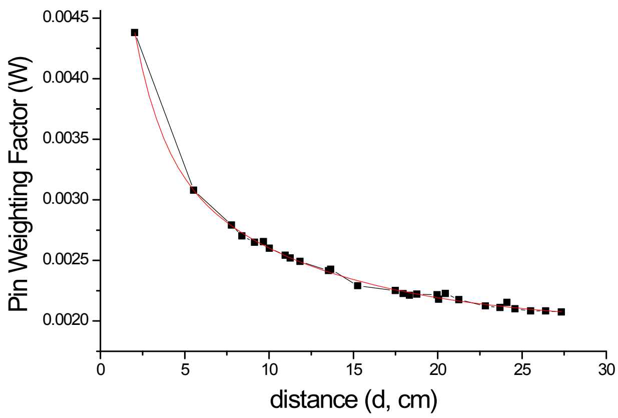

Figure 2. Pin Weighting Factor

III. Application of Pin Weighting Factors

Because the lattice code solution already contains a pin-by-pin power distribution, some of the importance weighting is already accounted for the calculation of the detector response, i.e., the power distribution of an infinite array of identical assemblies is accounted for. The effective weighting factor to apply in a core environment is the ratio of the value obtained in a core environment to that of a single assembly. In practice, centrally located assemblies do not need a weighting factor in the calculation of the detector response, but peripheral assemblies do. A systematic study of this effect is going to be performed near future.

References

[1] Kyoon Ho Cha, "Long-lived Hybrid Incore Detector for Core Monitoring and Protection," KNS Fall Meeting, October 2010
[2] Kyoon Ho Cha, "Sensitivity Calculation of Vanadium Self-Powered Neutron Detector," KNS Spring Meeting, May 2011.
[3] "MCNP: A General Monte Carlo N-Particle Transport Code, Version 5," Los Alamos 2005