Generation of Spatial Weighting Functions for Ex-Core Detectors of SMART PPE

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1. Introduction

This paper has been developed to evaluate the ex-core detectors response to the neutrons emitted from the reactor core (mainly nearby fuel assemblies) and from the reactor cavity. There are three main factors dominate the response rate of the ex-core detectors; reactor total power, reactor power distribution, and reactor configuration. The special weighting function establishes corresponding between the power distribution and the detector response. The special weighting function does not depend on core power distribution; however, it is more representative of the physical configuration of the core and the detector. The importance of the spatial weighting function is that it can estimate the core power distribution from the ex-core detectors. This is an essential factor to be used in SMART COre Protection System (SCOPS).

The analysis of spatial weighting function could be performed by two different methods; forward transport calculation and adjoint transport calculation. Both methods provide aligned results; however, the adjoint transport calculation provides more detailed data and much faster computing time.

In this paper DORT code has been used to evaluate the spatial weighting function for the ex-core detectors.

2. Methods and Results

The forward and adjoint transport problem can be defined as follows:

$$\begin{aligned} H\psi &= Q \\ H^{+}\psi^{+} &= \Sigma_d \end{aligned} \qquad (1)$$

where H, H^{+} = Forwad and Adjoint transport operator

ψ, ψ^{+} = Foward and Adjoint flux

Q = Source term

Σ_d = Total macroscopic cross-section of ex-core detector

The response of the ex-core detector can be expressed by the following equation by summarizing forward and adjoint transport equation using adjoint identity.

$$R = \left\langle \psi^{+} Q \right\rangle \qquad (2)$$

where $\langle\ \rangle$ = inner product= $\iiint dV dE d\Omega$

To calculate the spatial weighting function of the ex-core detectors, adjoint problem shall be solved first to obtain adjoint flux, thus calculating the response of the ex-core detector using source term Q. The isotropic point fission source at arbitrary location r_i in the core can be expressed as follows:

$$Q(r,\Omega,E) = \frac{1}{4\pi}\chi(E)\delta(r - r_i) \qquad (3)$$

where $\chi(E)$ = ^{235}u Fission energy spectrum

$\delta(r)$ = Three dimensional Dirac delta function

Then, the response (R) of the ex-core detector with regard to isotropic point fission source at arbitrary location r_i in the core can be expressed as follows:

$$R(r_i) = \frac{1}{4\pi}\int dE\,\chi(E)\phi^{+}(r_i, E) \qquad (4)$$

Where ϕ^{+} refers to adjoint scalar flux at arbitrary location r_i with regard to adjoint source $\Sigma_d(E)$.

Since the ex-core detector consists of ^{235}U fission chamber, a source term of adjoint transport calculation is proportional to the fission reaction rate of ^{235}U (n,f). Hence, macroscopic cross section $\sum_f$ of ^{235}U, is used as a source term of adjoint transport calculation. The response of the ex-core detector with regard to a single fuel assembly from the ex-core detector response R_i for each mesh expressed as follows:

$$R_n = \frac{\sum_{i=1}^{I} \Delta V_i R_i}{\sum_{i=1}^{I} \Delta V_i}, \qquad (5)$$

where I : Total number of meshes in each of fuel assembly

n : Index of fuel assembly

ΔV_i : Area of each mesh $[\frac{1}{2}\theta(r_2^2 - r_1^2)]$

R_i : Response of ex-core detector at i mesh.

In regards with assembly wise spatial weighting function (Assembly Weighting Factor), the relative segment of the ex-core detector response in each of the fuel assemblies can be expressed as follows:

$$AWF_n = \frac{R_n}{\sum_{n=1}^{N} R_n}, \qquad (6)$$

where n : Index of fuel assembly

N : Total number of fuel assemblies to be calculated

AWF_n: Assembly Weighting Factor

For the core height wise spaital weighting function (Shape Annealing Function), it is defined as the reaction fraction of the ex-core detector in the core height due to each horizontal spot of the core volume including neutron source. The core height wise spaital weighting function response can be expressed as follws:

$$SAF_j^k = \frac{\left[\dfrac{\sum_i R_{i,j}^k \pi \left(r_{i+1}^2 - r_i^2\right)\left(z_{j+1}^2 - z_j\right)}{\sum_{k-1}^{3}\sum_j \sum_i R_{i,j}^k \pi \left(r_{i+1}^2 - r_i^2\right)\left(z_{j+1}^2 - z_j\right)}\right]}{\left[\dfrac{\left(z_{j+1}^2 - z_j\right)}{H} \times 100\right]} \qquad (7)$$

Where i,j : radial and axial mesh in the core region.

k : upper, middle and lower ex-core detectors.

$R_{i,j}^k$: reaction of ex-core detector at mesh(i,j) of ex-core detector k.

H : effective core height.

2.1 DORT Modeling

For DORT calculation, the spatial weighting function was divided into two parts, assembly wise spatial weighting function (Assembly Weighting Factor), and core height spatial weighting function (Shape Annealing Function).

The assembly wise spatial weighting function was performed with regard to reactor structure which is converted into R-θ coordinate system. SMART PPE was modeled with 1/4 symmetry, void condition, which was used in the right side and reflected condition was used for the other sides as boundary conditions.

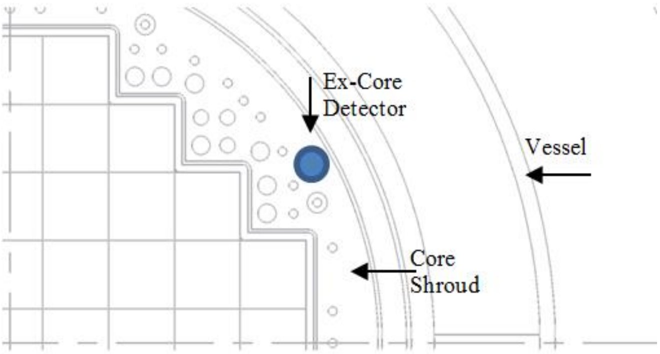


Figure 1: DORT Quarter Core Model for Assembly Weighting Factor

Fig.1 shows the core's configuration and the location of the ex-core detector. As it can be seen SMART has the ex-core detector inside the vessel and it is within the shroud area.

In regard with the core height spatial weighting function (Shape Annealing Function), SMART reactor was modeled in the R-Z coordinate system and half core symmetry was used for DORT calculation model. DORT model includes a lower core support plate via part up to upper core grid region in the axial direction.

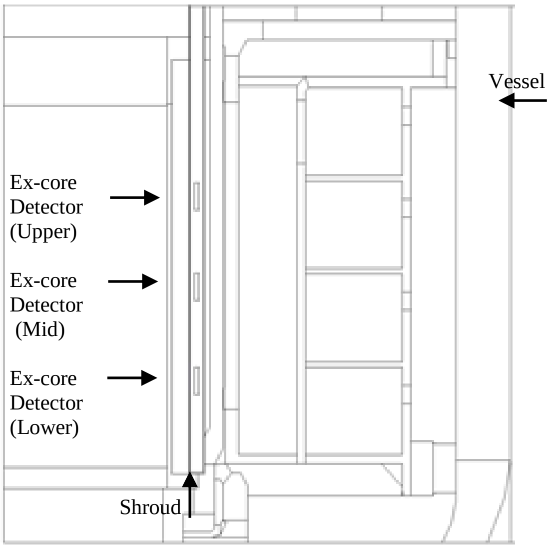
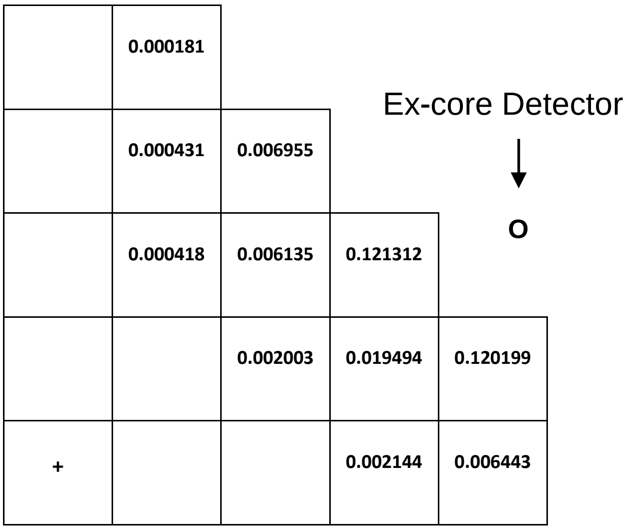


Figure 2: DORT Half Core Model for Shape Annealing Function

As it can be seen in Fig.2 the core has been divided axially into two symmetrical parts. Three ex-core detector levels are placed in the shroud area; bottom, middle and top.

2.2 Results

Fig.3 shows the values of the assembly wise spatial weighting function (Assembly Weighting Factor). AWF is distrbuted among the nearest eleven fuel assemblies to the ex-core detector.



	0.000181			
	0.000431	**0.006955**		
	0.000418	**0.006135**	**0.121312**	
		0.002003	**0.019494**	**0.120199**
+			**0.002144**	**0.006443**

Figure 3:Aassembly wise spatial weighting function (Assembly Weighting Factor)*

***All values are normalized**

Fig.3 ilistrates that the maximum, assembly wise spatial weighting function (Assembly Weighting Factor), values were found to be “0.121312” and “0.120199” which are the closest to the ex-core detector.

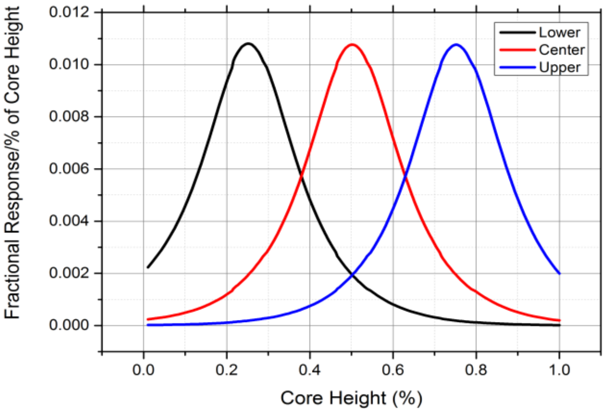


Figure 4: Core height wise spatial weighting function (Shape Annealing Function)

Fig.4 shows the Core height wise spatial weighting function (Shape Annealing Function), and it can be seen that the lower, center and upper fractional responses are identical in magnitude and different in location. Three adjoint calculations were executed (one in each height level) to obtain the response of the ex-core detectors.

3. Conclusions

DORT uses two dimensional discrete ordinate adjoint transport calculation model and it was used to obtain both of the Aassembly wise spatial weighting function (Assembly weighting factor) and the Core height wise spatial weighting function (Shape Annealing Function). The spatial weighting function is sensitive to the geometry of the reactor core, cavity and the vessel. Generally the core and the fuel assembly are the most critical factors for the ex-core detector response.

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