Development of an Optimal Program for Spent Nuclear Fuel Placement in Canister to Minimizing Total External Dose by Using View Factor Matrix

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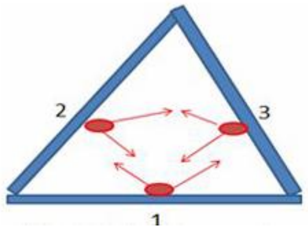
1. Introduction

Spent nuclear fuel canister requires balancing heat removal, criticality safety, shielding, and operational practicality [1]. During handling and transfer, worker dose near the canister is a primary concern. In typical operations, multiple withdrawals and reloads may occur during transporting from wet storage to dry storage facilities, compounding dose accumulation to workers. To reduce near-field dose, assemblies with higher activity can be preferentially placed toward the canister interior, utilizing self-shielding among assemblies.

This paper analyzes the optimized in-canister placement of fuel assemblies using a View Factor Matrix. This method enables rapid evaluation of many candidate layouts with less computational resources.



R/E	1	2	3	S
1	F_{11}	F_{12}	F_{13}	=1
2	F_{21}	F_{22}	F_{23}	=1
3	F_{31}	F_{32}	F_{33}	=1

Fig. 1. View Factor Matrix [2]

2. Methods and Results

In this section some of the techniques used to model the detector channel are described. The channel model includes a SiC detector, cable, preamplifier, amplifier, and discriminator models.

2.1 Problem definition and assumptions

Lattice: Assembly locations inside the canister basket are fixed and known.

External tally points: Dose is tallied at 16 equally spaced azimuthal points surrounding the canister.

Source model: Each assembly is treated as an isotropic emitter whose source strength scales with its activity (from input data).

Objective: Minimize the total external dose metric defined as the sum over 16 points of the superposed contributions from all assemblies.

2.2 View Factor Matrix formulation

Let N be the number of lattice positions. Define a column vector $s \in R^N$ of assembly source strengths (activities) and a matrix $V \in R^{16\times N}$, where entry V_{ij} quantifies the geometric coupling ("view factor") from assembly position j to external point i. For a given placement permutation π, the predicted dose vector at the 16 points is $d(\pi)=V s_\pi$, where s_π reorders s according to placement π. The scalar objective is $J(\pi)=1^\top d(\pi)=1^\top V s_\pi$. The optimal placement π^* yields the minimum J. This deterministic superposition avoids particle transport sampling while capturing geometric effects through V.

2.3 Computational approach

We precompute V from canister geometry and tally locations. For each candidate placement (e.g., all permutations or a pruned subset), we compute $J(\pi)$ via matrix–vector products. The minimal configuration is selected. This lends itself to vectorization and batched evaluation on modern CPUs/GPUs. The codebase is written in Python with automation assistance from an LLM.

2.4 Input and outputs

Input is provided via a comma-separated values (CSV) file (activities.csv) specifying the activity of each spent fuel assembly. Based on these inputs, the program generates two files. First, result_min.csv reports a numerical summary of the optimal placement and key statistics on the external dose indicators. Second, layout_min.png visualizes the directional dose distribution and the radiation dose for each assembly at 16 azimuth measurement points around the canister. Consequently, the program user can easily verify the optimized fuel placement and its resulting values.

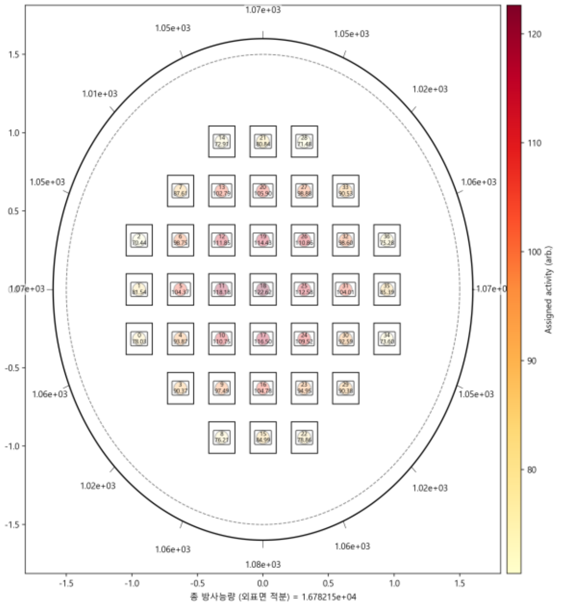


Fig. 2. Output Image File Example

2.5 Single Channel Analyzer (SCA) Model

A SCA is required to distinguish the pulses induced by neutrons from those arising from gamma-ray interactions. A MATLAB SCA model was written that simply records those counts which are above the discrimination level. A discriminator dead time is an important parameter for the SCA and is a limiting factor establishing the system count rate. The output of the discriminator model is presented in Fig. 2, as a graph of the fraction of counts that are lost versus the true count rate, with voltage and charge sensitive preamplifiers. As can be seen from the figure, due to the dead time associated with the SCA, even with a voltage sensitive preamplifier, accurate dead time corrections are necessary to achieve large and accurate count rates.

3. Conclusions

A VFM-based optimization program was developed using Python code to minimize external radiation dose around SNF canisters by arranging assembly layouts in a fixed basket grid. The program quickly calculates and visualizes the optimal layout for minimizing radiation dose outside the canister when loading spent nuclear fuel of various activity levels. This can minimize worker exposure during the transport of spent nuclear fuel from wet storage to dry storage facilities and during storage in dry storage facilities.

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