Modelling of the Spent Nuclear Fuel Assembly Using the Monte Carlo Method

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1. Introduction

After irradiation of a uranium fuel assembly during its operation in a fission nuclear reactor core, many radionuclides are generated by fission and activation of ^{235}U, ^{238}U and other nuclides present in the assembly. Thus spent nuclear fuel difficult to measure material because of the complexity of the isotopic composition and high neutron and gamma-ray emission rates. In particular, an independent determination of spent fuel assembly characteristics, such as initial enrichment, burnup, cooling time, and/or plutonium content, poses a challenging task [1-2].

The purpose of this paper is to develop and test simulated model to improve safeguards measurements of spent nuclear fuel. This model can be used to measure of gamma and alpha radiation emitted from a spent nuclear fuel assembly. A detailed combine modeling and evaluation of the additional instrument to independently assess spent fuel assembly characteristics will be performed in future work using GEANT4.

2. Method and Calculations

2.1 The GEANT4 simulation code

To simulate the passage of various particles emitted from the spent nuclear fuel, the GEANT4 Monte Carlo calculation code was selected. GEANT4 is a toolkit that simulates accurately the passage of particles through matter. It contains a complete range of functionalities including tracking, geometry, physics models and hit.

2.2 Characteristics of the spent nuclear fuel assembly

Generally, the fuel assembly consists of 265 fuel rods in a 17 by 17 square array. The center position in the fuel assembly has a guide thimble that is reserved for in-core instrumentation. The remaining 24 positions in the fuel assembly have guide thimbles. The guide thimbles are joined to the top and bottom nozzles of the fuel assembly and provide the supporting structure for the fuel grids.

We chose to consider the features of a spent nuclear fuel with a burnup of 47GWd. The fuel was initially enriched to 3.1wt%^{235}U and the most important radionuclides contributing to alpha activity are UO_2. They lead to an alpha activity of 4.73E+08Bq after 15 years of alpha decay and the average value of emitted alpha particles is 5.3MeV. The simplified chemical composition considered in the calculations is $^{238}UO_2$, with a mass density of 10.8 g/cm^3 [2].

2.3 Description of spent nuclear fuel

First, in order to be representative of the UO_2 fuel shape, we considered to geometrical shape of a single fuel rod. A single spent fuel rod was designed to consist of a three-layer cylindrical tube which is consist of Fuel, Gap, and Cladding. Where a single fuel rod consists of enriched uranium, in the form of UO_2 pellets, contained in Zircaloy-4 tubing. And rods are pressurized internally with helium during fabrication to reduce clad creepdown during operation and thereby prevent clad flattening.

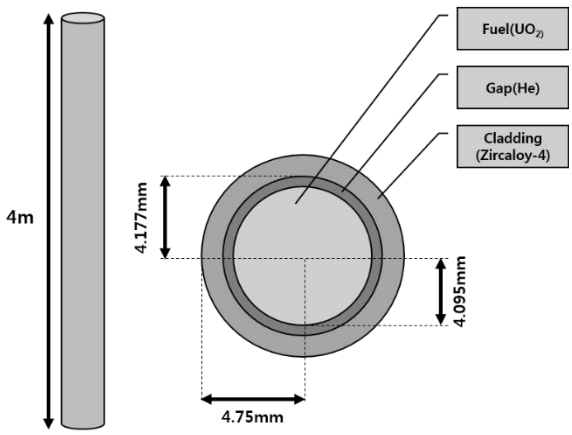

Fig. 1. Plant view of a single rod with the geometric characteristics.

Guide tube was designed to the cylindrical stainless steel tube. The designed single fuel rod and guide tube arranged 17 by 17 type.

Second, to give the simple approach to the spent fuel in the water, spent fuel was considered as a material which emission of alpha particle was isotropic and homogeneous.

A schematic layout of modeled systems is presented in Fig. 1. Also, the main parameters taken into account in the GEANT4 calculations are given in this figure.

3. Results

Fig. 2 shows the cross-sectional view of 17 by 17 spent nuclear fuel assembly model visualized using GEANT4. The red circles represent the guide tube and the white circles represent the spent nuclear fuel rods.

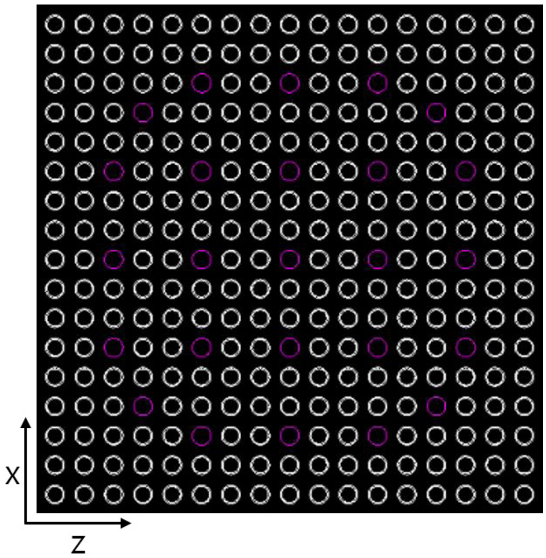

Fig. 2. GEANT4 geometry view of a 17 by 17 PWR Fuel Assembly.

As previously mentioned, the average energy of alpha particles was 5.3 MeV. Therefore, the effect of alpha particles on the spent nuclear fuel assembly was simulated using this model.

3.1 The effect of alpha particle emission

We observed the effect of alpha particle emission at 10, 100, 1000, and 10000, respectively.

The increase of alpha particles had more impact on the assembly area. These results are shown in Fig. 3. The yellow dots shown in this figure are result of the particles hitting each rod.

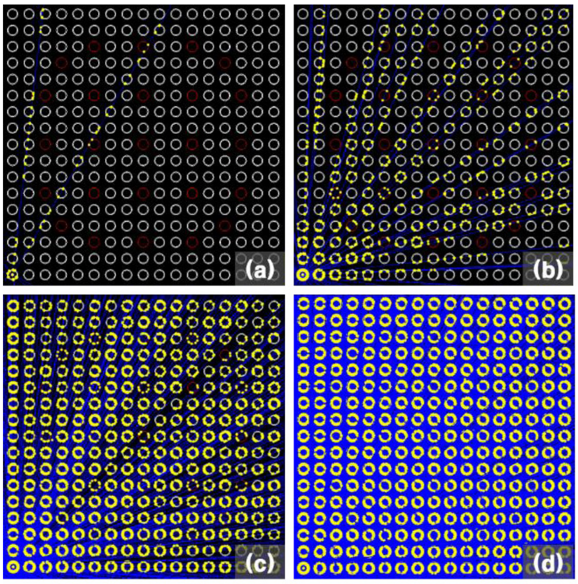

Fig. 3. Simulation results by amount of alpha particle emission (a) 10, (b) 100, (c) 1000, (d) 10000.

4. Discussion and Conclusion

In this work developed and test simulated fundamental model to improve safeguards measurements of spent nuclear fuel. The single fuel rod was modeled. And then the spent nuclear fuel assembly was created by arranging the designed fuel rod as 17 by 17. We investigated the effect of alpha particles emitted from fuel rods using the developed model. The simulation results showed that the increase of alpha particle effects more areas.

This work should be supplemented in the future. The model should be added the various physical processes and the detailed definition of radioactive source. In order to be suitable for the purpose, it is considered that further improvement of this model.

REFERENCES

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