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A Development of Advanced Rigorous 2 Step System for the High Resolution Residual Dose Evaluation

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1. Introduction

In these days, an activation problem such as residual radiation is one of the important issues. The activated devices and structures can emit the residual radiation. Therefore, the activation should be properly analyzed to make a plan for design, operation, and decontamination of nuclear facilities. For activation calculation, Rigorous 2 Step (R2S) method [1] is introduced as following strategy: (1) the particle transport calculation is performed for an object geometry to get particle spectra and total fluxes; (2) inventories of each cell are calculated by using flux information according to irradiation and decay history; (3) the residual gamma distribution was evaluated by transport code, if needed. This scheme is based on cell calculation of used geometry. It can create bias of results due to gradient of particle flux and spectra in specific cells. To overcome this problem, Mesh-tally Coupled Rigorous 2 Step (MCR2S) method [2] is noted. In this method, the particle spectra and total fluxes are obtained by mesh tally for activation calculation. It is useful to reduce the effects of gradient flux information. Nevertheless, several limitations are known as follows: Firstly, high relative error of spectra, when lots of meshes were used; secondly, different flux information from spectrum of void in mesh-tally.

To reduce the relative error of flux spectra, R2Smesh [3] approach is developed by using fine/coarse mesh concept. The total particle fluxes are obtained by fine mesh-tally. The coarse mesh, which is including fine mesh, is applied for reducing relative error of particle energy spectra. The inventory calculation is performed at each coarse mesh. Then, the activity is weighted by total flux in fine mesh. Also, another approach called MCR2S unstructured mesh [4] is developed. Each cell or materials of object geometry are separated by unstructured mesh. Therefore, it can obtain the spectrum of each material without spectrum of void.

In this study, Advanced R2S (AR2S) system was developed by coupling MCNPX 2.7 [5] code and FISPACT-2010 [6] to combine the merits of R2Smesh and MCR2S unstructured mesh approach. Then, simple activation problem for residual radiation calculation was estimated to verify the developed system.

2. Methods and Results

2.1 AR2S System and General Methodology

The AR2S system is composed of four internal modules; (1) PTRAC Analyzer, (2) FISPACT Input Generator, (3) Residual Radiation Input Generator, and (4) Output Combiner. The workflow of the AR2S system is shown in Fig. 1.

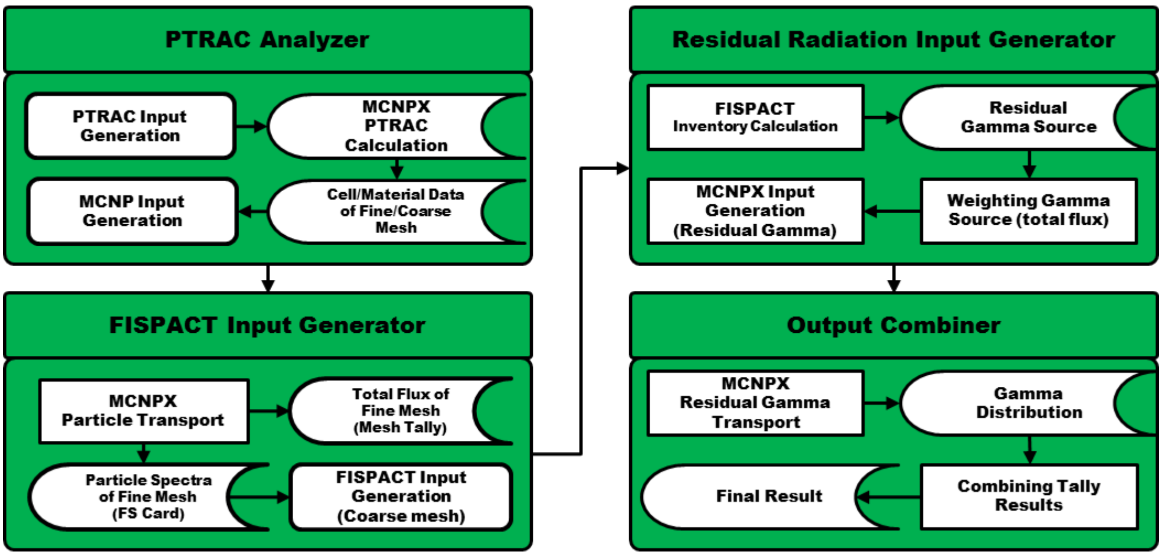


Fig. 1. The Workflow of the AR2S System

To get the material and cell information of each coarse/fine mesh element, Particle Track Output (PTRAC) option was used with void card in MCNPX code. The PTRAC sources were randomly generated in one side of mesh. The source particles move to the opposite side straightly. Then track lengths of each cell are recoded in PTRAC output. This process called as ray tracing treatment is illustrated in Fig. 2.

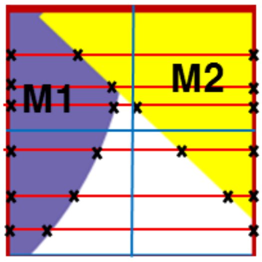


Fig. 2. Ray Tracing Treatment in a Coarse Mesh

Using the track length ratio, the cell/material volume of each mesh element is obtained. The statistical accuracy of the volume depends on the number of PTRAC source particles.

MCNPX input to calculate the particle spectra in coarse mesh and the total flux in fine mesh was automatically written by the AR2S system. To get the spectra, union tally for cell track length estimation (f4) was used to separate void material spectrum. Then, union tallies were divided by Tally Segment (FS) option according to coarse mesh division as shown Fig. 3. The volumes of each coarse mesh were inserted by using Segment Divisor (SD) cards from PTRAC calculation result. Also, mesh tally was used to get the total fluxes of fine mesh in MCNPX input.

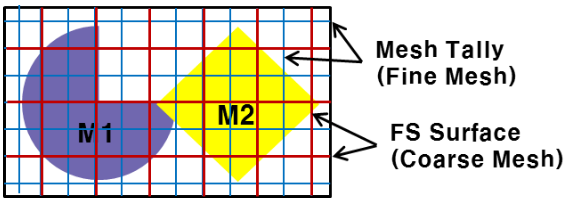


Fig. 3. Schematic Drawing of Fine/Coarse Meshes

The residual gamma sources are calculated by FISPACT for each coarse mesh and material except void material. The gamma source strength is properly weighted by total fluxes and material densities. Using calculated gamma source, lots of source card are needed to express distribution. In case of R2Smesh and MCR2S system, residual gamma distributions are expressed by using source routine (source.f). However, MCNPX must be recompiled for the source routine. Not to recompile, a number of MCNPX input are therefore generated depend on a number of source distribution. Then, the results are combined by Output Combiner module.

2.2 Verification of the AR2S System

To verity the AR2S system, a simple activation problem was evaluated by the AR2S system and cell based R2S method [1]. As shown Fig. 4, four cubical box, which have 50 cm × 50 cm × 50 cm size, consist of cooper (8.96 g/cm^3), STS316 (8.03 g/cm^3), concrete (2.3 g/cm^3), and graphite (1.8 g/cm^3) respectively. 1 MeV point neutron source was located in center of box with 1.48×10^{15} #/sec source strength. The irradiation time and decay time was set as 14 day. For the same condition, each coarse mesh of the AR2S has only one cell (material) as the blue lines in Fig. 4. For particle transport simulation, ENDF/B-VII [7] nuclear library was used. To compare the results, residual radiation was recorded by mesh tally, which has 20 × 20 × 1 division.

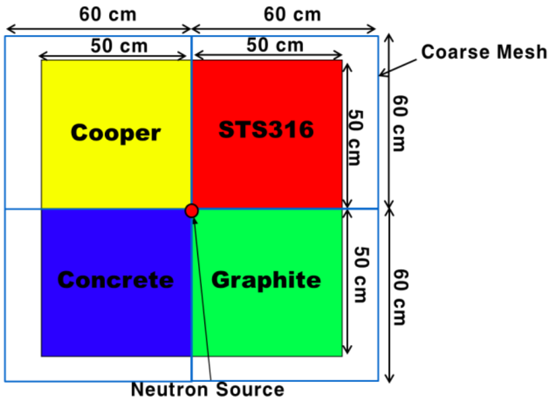
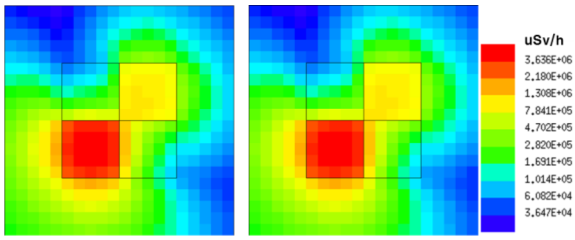


Fig. 4. Verification Model for the AR2S System

Fig. 5 and Fig. 6 are the residual dose distributions and a difference of both results at 14 day decay time. The residual doses from R2S and AR2S have good agreement within 0.83 % of relative difference. It shows that AR2S system can properly evaluate the residual radiation.



(a) R2S Method (b) AR2S System
Fig. 5. Residual dose from R2S and AR2S system

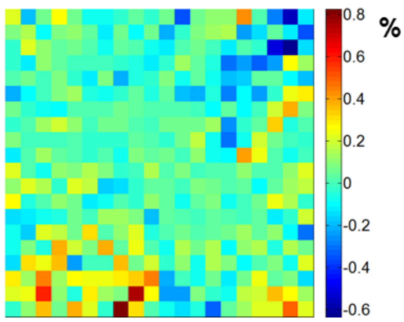


Fig. 6. Relative Difference of Residual Dose

Additionally, residual dose was estimated with 5 × 5 × 1 fine mesh to get a high resolution result. As well known, dense neutron flux can make high residual dose. The neutron source was situated on center of simulation area. Thus, maximum residual dose point will be existed in near the center. The maximum dose value of this simulation was located at near center position as shown Fig. 7. However, the maximum dose of Fig. 5 was center of concrete cell. Therefore, it was expected that more mesh division can give more realistic solution.

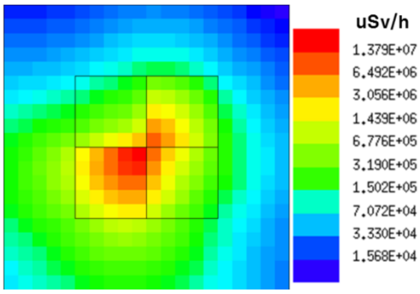


Fig. 7. Residual Dose Map with 5 × 5 × 1 Fine Mesh

3. Conclusions

To calculate high resolution residual dose, several method are developed such as R2Smesh and MCR2S unstructured mesh. The R2Smesh method products better efficiency for obtaining neutron spectra by using fine/coarse mesh. Also, the MCR2S unstructured mesh can effectively separate void spectrum. In this study, the AR2S system was developed to combine the features of those mesh based R2S method. To confirm the AR2S system, the simple activation problem was evaluated and compared with R2S method using same division. Those results have good agreement within 0.83 %. Therefore, it is expected that the AR2S system can properly estimate an activation problem.

Acknowledgement

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