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APPLICATION OF THE MONTE CARLO COUPLING TECHNIQUE FOR EVALUATING SHIELDING ABILITY OF A MODULAR SHIELDING HOUSE

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Abstract

The shielding ability of a modular shielding house in which 4 spent fuel transportable storage casks for 2 units are accommodated is evaluated by the Monte Carlo coupling technique with the coordinate transformation. The coupling technique is available with the SSW card and the SSR/CRT card in the continuous energy Monte Carlo code MCNP 4C as the "SSW-SSR/CRT calculation system".

In the present Monte Carlo calculations, the total effective dose rate at 300 m from the center of the shielding house is estimated as 0.083 (μSv/y/4 casks). Accordingly, if distance between the center of the shielding house and the site boundary of the storage facility takes 300 m at least, it is able to accommodate approximately 2400 casks in the modular shielding houses, under the Japanese severe criterion of 50 μSv/y at the site boundary.

Moreover, it become evident that the secondary gamma rays account for more than 60 % of the effective total dose rate at all the calculated points around the shielding house, and the most of which is produced from the water in the steel-water-steel shielding system of the shielding house. The rest of the dose rate is mostly by neutrons, and fission product and ^{60}Co activation gamma rays are a few percents of it. That is the reduction of the secondary gamma rays is a critical matter to improve not only the shielding ability of a shielding house but also the shielding safety of an interim shielding facility.

1 Introduction

The Monte Carlo method is a very useful tool for solving a large class of radiation shielding problems. In contrast to a deterministic method, geometric complexity is a much less significant problem, and the Boltzmann transport equation can be solved with any approximation. The accuracy of a Monte Carlo calculation is, of course, limited by the statistical deviation of the quantities to be estimated. In this turn, several techniques were proposed to reduce the statistical deviation, especially for a large or a complex shielding system. The DOT-DOMINO-MORSE code system[1] was a typical code system to complement the two-dimensional discrete ordinates Sn code DOT[2] and the Monte Carlo code MORSE[3] to treat a deep penetration and a complex shielding system. After that, the Monte Carlo coupling technique[4] with the multi-group Monte Carlo code MORSE was investigated and employed to analyze a radiation streaming problem in a large shielding system. The coupling technique with the MORSE code was employed successfully to analyze the neutron streaming problem of a large shielding system in a reactor and also to the effective dose rate distributions in a spent fuel transport vessel[5]. Nowadays, a computer performance is progressing day by day, and point-wise nuclear data is available in a continuous energy Monte Carlo code, like the MCNP code[6]. Due to employing point-wise nuclear data, the self shielding factor for the resonance reaction is not necessary to take into account, as considered in multi-group constants. Accordingly, not only the shielding problem but also the nuclear data, such as JENDL[7] (T. Nakagawa, et al., 1995), ENDF/B[8], are evaluated exclusively by the continuous energy Monte Carlo codes, now[9,10].

In the present study, the shielding ability of a modular shielding house in which 4 spent fuel transportable casks for 2 units are accommodated is analyzed by using the Monte Carlo Coupling technique with coordinate transformation. That is the SSW (Surface Source Write) - SSR (Surface Source Read) / CTR (Coordinate Transportation) calculation system of the MCNP 4C code. In the original calculation, neutron and gamma ray tracks are recorded on the outer surface of an interim storage cask with the SSW card. The particle track positions scored on a cask surface in the original calculation are transformed into the locations of the four casks in the shielding house with the CTR card. It should be noted that in the Monte Carlo calculation, the history of a particle is tracked in the shielding system in accordance with probability theory, so that we are able to recognize each history of a particle passed through it. In addition, the detailed shielding structures of the interim shielding house, the atmosphere and the ground around the shielding house are provided to take into account the sky-shine in the current Monte Carlo calculation with the SSR card.

In Japan, the criterion of an effective dose rate at an interim site boundary is 50 muSv/y, and it is 1/5 of the criterion applied in the USA. Accordingly, the advanced shielding analysis is required to evaluate and verify the rigid value applied in Japan, by reflecting exact arrangements of casks in the shielding house, detailed shielding structures, and also the radiation sky-shine from atmosphere in the shielding analysis.

2 Monte Carlo Coupling Technique

The concept of the Monte Carlo coupling technique with the SSW-SSR/CRT calculation system of the MCNP 4C code is shown in Fig. 1. In the original calculation, the particle location (x, y, z), direction (u, v, w), energy E, weight W, and the kind of it are scored when a particle crosses the surface indicated in the SSW card. In the current calculation, source particles are generated from the surface or the transported surfaces with the recorded quantities faithfully with the SSR/CRT card. The range of sampled source weights is indicated in the current calculation. Accordingly, it is possible to correct the weight w indow boundary of each cell by referring the original weight for the following calculation.

3 Shielding System

The main shielding structures of the transportable cask are carbon steel for gamma ray shielding and propylene-glycol-water-solution with boron for neutron shielding, and 21 PWR spent fuel assemblies are contained in the cask. Since the source intensity of neutrons and gamma rays in a spent fuel assembly depends strongly on specific burn-up distribution in the axial direction, burn-up distribution is taken into account in the present calculation. Average specific burn-up of the spent fuels of 9 assemblies stored in the interior of the basket is 55,000 MWD/MTU and the burn-up of 12 assemblies stored on the periphery is 50,000 MWD/MTU. The peaking factor of 1.15 is assumed in the middle part of 10/12 for all fuel assemblies. The source intensity of the spent fuels is calculated by ORIGEN2/82 code[11]. The effective multiplication factor, keff, of the cask containing 21 PWR assemblies is calculated by KENO V.a code[12], and keff of 0.3 is employed to obtain the neutron source intensity of the cask. A modular shielding house in which 4 spent fuel transportable storage casks for 2 units are installed is modeled as shown in Fig 2, in the Monte Carlo Coupling calculation. The cardinal shielding structure of the interim shielding house is the steel-water-steel multilayer shielding system, and it has relatively large opening for intakes and outtakes to cool the casks by natural air circulation. Main construction on the system in the shielding house is the steel-water-steel shielding system which consists of 6 cm-thick of inner steel, and 15 cm-thick of outer steel with 20 cm-thick of water sandwiched in between. The effective dose rate of fission neutrons is reduced to approximately 10-2 and it of 1.5 MeV gamma rays is approximately 10-4 with effect of the steel-water-steel shielding system, respectively.

On the other hand, the intakes are located both on the left and right, and the outtakes are upper part in Fig. 2. Because of the enhancement effect for neutrons is expected with steel-water-steel arrangement[13], the shielding system is effective particularly for neutrons. However, some of neutrons penetrated through the casks and also secondary gamma rays produced in the multilayer system are to stream through the opening system. Most of the secondary gamma rays are originated from $^{1}H(n,\gamma)$ and $^{56}Fe(n,\gamma)$ of thermal neutrons in the steel-water-steel shielding system. Therefore, the streaming analysis is most essential to evaluate the shielding ability of the shielding house. These neutrons and gamma rays streamed out from the opening system are to form the sky-shine, resulting in production of secondary gamma rays in the atmosphere and around the shielding house. Thereupon, those structures are take into account as far as 500 m from the center of the house. The dose conversion factor of ICRP Publication 74 is employed to calculate effective dose rates.

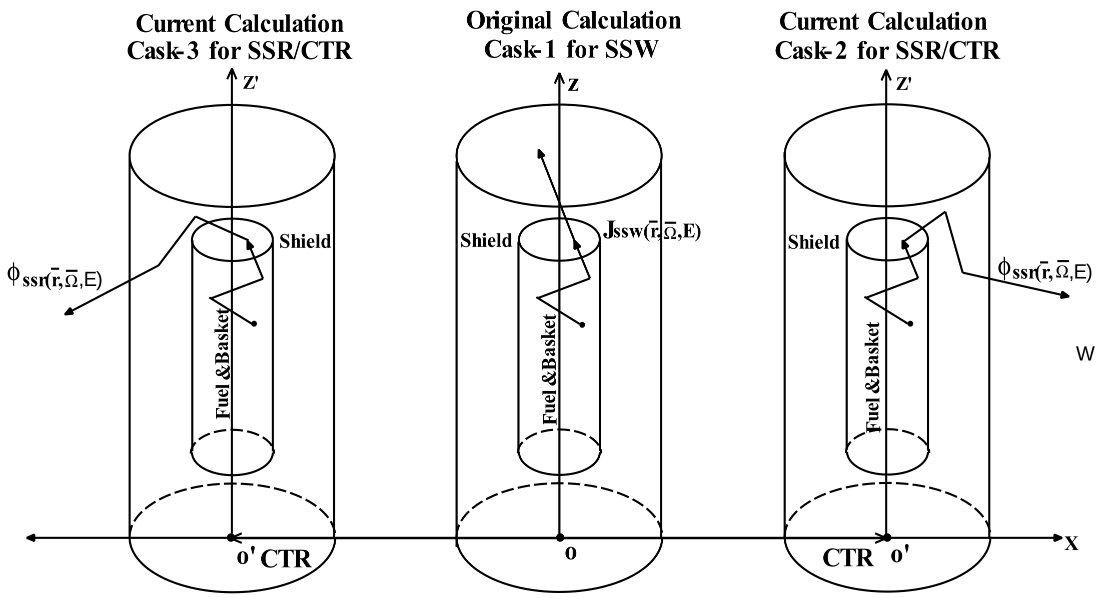

Fig.1 Concept of the SSW-SSR/CTR Calulation System.
SSW: Surface Source Write. SSR: Surface Source Read.
CRT: Coordinate Transformation.

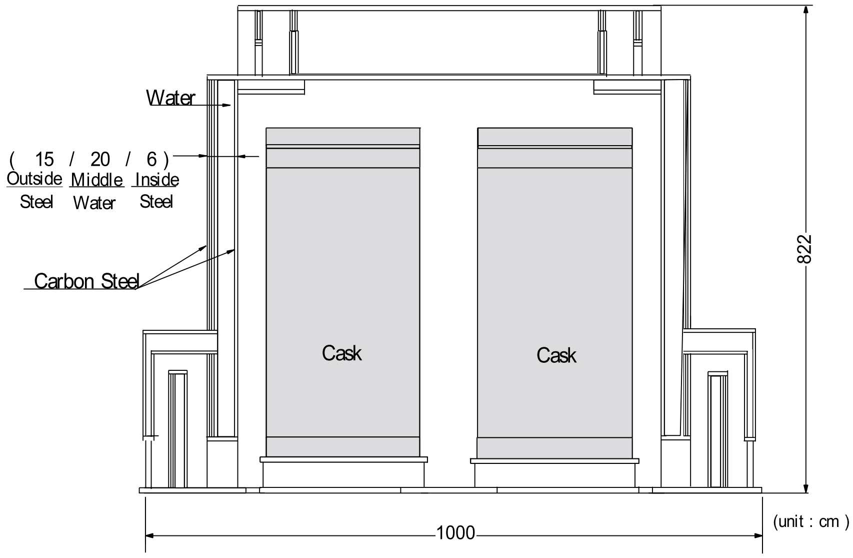

Fig. 2 MCNP 4C calculation model of shielding structures and arrangement of casks in a unit of the shielding house.

4 Results and Discussion

The Monte Carlo calculated effective dose rate distributions around the shielding house are shown in Fig. 3 as far as 300 m from the center of the house. The total effective dose rate (neutron, primary and secondary gamma rays) at 50 m from the shielding house is 7.44 (muSv/y/4 casks). However, it reduces to 0.625 (muSv/y/4 casks) at 150 m, and it is 0.083 (muSv/y/4 casks) at 300 m from the center. Therefore, if the distance between the center of the shielding house and the boundary of the storage facility takes 300m at least, it is able to accommodate approximately 2400 casks in the modular shielding house, under the severe Japanese criterion of 50 muSv/y at the site boundary.

Hereupon, it must be observed closely that the secondary gamma ray accounts for more than 60 % of the total effective dose rates at all the calculated points around the shielding house. Most of the gamma ray is produced from the water in the steel-water-steel shielding system of the house. The rest are mostly by neutrons and FP and ^{60}Co activation gamma rays makes up a few percents of the total. In consequence, reduction of the secondary gamma ray is a critical matter to improve not only shielding ability of the shielding house, but also the shielding safety of an interim storage facility.

5 Concluding Remarks

Following remarks can be made from the present analysis with the Monte Carlo coupling technique with the coordinate transformation for the modular shielding house in an interim storage facility.

1. The total effective dose at 300 m from the center of the shielding house is 0.083 (muSv/y/4 casks). Therefore, if the distance between the center of the shielding house and the site boundary takes 300m at least, it is able to accommodate approximately 2400 casks in the modular shielding houses, under the severe Japanese criterion of 50 muSv/y at the site boundary of an interim storage facility.

2. It must be observed closely that the secondary gamma rays account for more than 60 % of the total effective dose rate at all the calculated points around the modular shielding house. Most of the gamma rays are produced from the water in the steel-water-steel shielding system of the house. The rest of the dose rate is comprised mostly of neutrons, and FP and 60Co activation gamma rays make up a few percents. Accordingly, the reduction of the secondary gamma ray is a critical matter to improve not only the shielding ability, but also the shielding safety of the shielding house.

3. With the present knowledge of the Monte Carlo coupling technique with the "SSW-SSR/CRT calculation system" of MCNP 4C code, it is demonstrated that the coupling technique is a powerful and a unique tool to analyze shielding ability and safety of the modular shielding house. In addition, the coupling technique can be applied to the shielding system in which more than several hundreds of transportable storage casks are accommodated.

References

1) M. B. Emett, C. E. Burgart, and T. F. Hoffman, "DOMINO: A General Purpose Code for Coupling Discrete Ordinate and Monte Carlo Radiation Transport Calculations," *ORNL-4836*, Oak Ridge National Laboratory (1973).

2) W. A. Rhoades and F. R. Mynatt, "The DOT III Two-Dimensional Discrete Ordinates Transport Code," *ORNL-TM-4280*, Oak Ridge National Laboratory (1973).

3) M. B. Emett, "The MORSE Monte Carlo Radiation Transport Code System," *ORNL-4972*, Oak Ridge National Laboratory (1975).

4) K. Ueki, "Three-Dimensional Neutron Streaming Calculations Using the Monte Carlo Coupling Technique," *Nucl. Sci. Eng.* **79**(1982)253.

5) K. Ueki, Y. Namito, and T. Fuse, "Measurement of Dose Rates and Monte Carlo Analysis of Neutrons in a Spent Fuel Shipping Vessel," *Nucl. Technol.* **74**(1986)164.

6) "MCNP-A General Monte Carlo N-Particle Transport Code Version 4C," Judith F. Briesmeister, Ed., *LA-13709-M*, Los Alamos National Laboratory (2000).

7) T. Nakagawa, et al, "Japanese Evaluated Nuclear Data Library Version 3 Revision-2: JENDL-3.2," *J. Nucl. Sci. Technol.* **32**(1995)1259.

8) V. McLane (Ed.), "ENDF-102 Data Formats and Procedures for the Evaluated Nuclear Data File ENDF-6," *BNL-NCS-44945-01/04-Rev.* (2001).

9) N. Yamano and K. Ueki, "Validation of Gmma-Ray Production Data of Iron in JENDL-3.2 with Shielding Benchmark," *J. Nucl. Sci. Technol.* **614**(1995)32.

10) N. Yamano, et al., "Status on Testing of JENDL-3.3 with Shielding Benchmarks," Proceedings of the 2000 Symposium on Nuclear Data, *JEARI-Conf. 2001-006*, Japan Atomic Energy Research Institute (2001).

11) A. G. Croff, "ORIGEN2: A Versatile Computer Code for Calculating the Nuclide Cmpositions and Characteristics of Nuclear Materials," *Nucl. Technol.* **62**(1983)335.

12) Petrie and N. F. Landers, "KENO V.a: An Improved Monte Carlo Criticality Program with Super-grouping," NUREG/CR-02000, Revision 6, Volume 2, Section F11, O *RNL/NUREG/CSD-2/R6* (1998).

13) K. Ueki, A. Ohashi, and N. Nariyama, “Systematic Evaluation of Neutron Shielding Effects for Materials,” *Nucl. Sci. Eng.* **124**(1996)455.

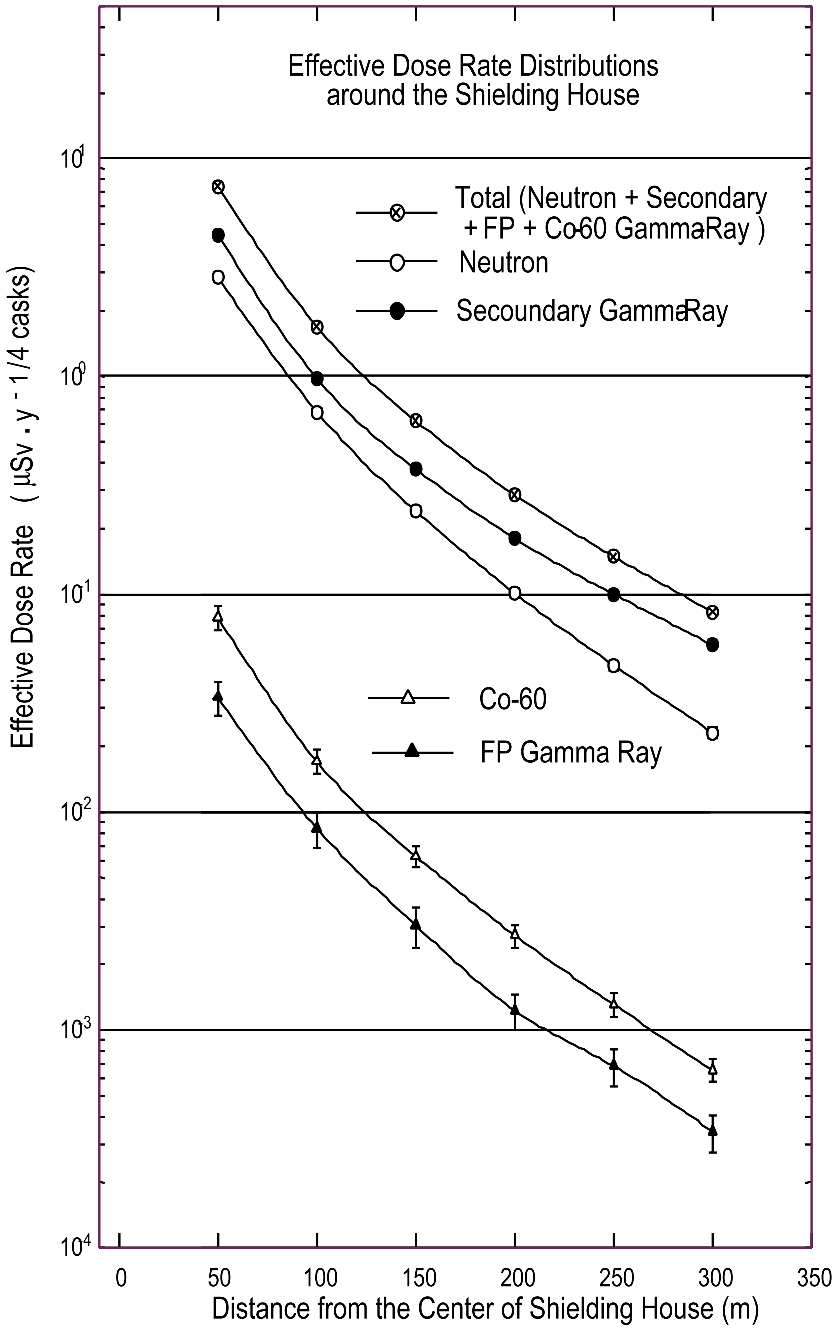

Fig. 3 MCNP calculated effective dose rate distributions around the shielding house keeeping 4 transportable casks.