SHIELDING ABILITY OF A MODULAR SHIELDING HOUSE KEEPING SPENT FUEL TRANSPORTABLE STORAGE CASKS IN AN INTERIM STORAGE FACILITY

K. Ueki (1), K. Kawakami (2), D. Shimizu, (2), and M. Matsumoto (3)
(1) National Maritime Research Institute
6-38-1 Shinkawa, Mitaka, Tokyo 181-004, Japan
(2) OCL Corporation, Osaka Branch Office
1-15-8 Nishihonmach, Nishi-ku, Osaka 550-0005, Japan
(3) Nuclear Fuel Transport CO., LTD
1-1-3 Shiba Daimon, Minato-Ku, Tokyo 105-0012, Japan

ABSTRACRT

The shielding ability of a modular shielding house in which 2 unit of 4 spent fuel transportable storage casks are set aside is analyzed with the Monte Carlo coupling technique. 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". The effective dose rate distributions in an interim storage facility are obtained as far as 300 m from the center of the shielding house.

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, when the distance from the center of the shielding house to the site boundary of the storage facility takes 300 m at least, it might be possible to keep 600 casks approximately in the modular shielding houses, under the Japanese severe criterion of 50 μSv/y at the site boundary of an interim storage facility.

Moreover, it is cleared 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 it is produced from the water in the steel-water-steel shielding system of the house. The rest of the dose rate is mostly by neurons, 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.

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 (M. B. Emett, et al., 1973) was a typical code system to complement the two-dimensional discrete ordinates Sn code DOT (W. A. Rhoades, et al., 1973) and the Monte Carlo code MORSE (M. B. Emett, 1975) to treat a deep penetration and a complex shielding system. After that, the Monte Carlo coupling technique (K. Ueki, 1981) 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 (K. Ueki, et al., 1986). 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 (J. F. Briesmeister, 2000). 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 (T. Nakagawa, et al., 1995), ENDF/B (V. Mclane, 2001), are evaluated exclusively by the continuous energy Monte Carlo codes, now (N. Yamano, et al., 1995, and N. Yamano, et al., 2001).

In the present study, the shielding ability of a modular shielding house in which 2 units of 4 spent fuel transportable casks are set aside is analyzed by using the Monte Carlo Coupling technique. 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. Note that in the Monte Carlo calculation, the history of a particle is tracked in a shielding system in accordance with probability low, so that we are able to recognize each history of a particle passed through it. In addition, the detail 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 μSv/y and it is 1/5 of the criterion in USA. Accordingly, the advanced shielding analysis is required to evaluated or to verify the strict value in Japan, that is the exact arrangement of casks in a shielding house, the detailed shielding structures of it, and also the radiation sky-shine from atmosphere have to take into account in the shielding analysis.

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 kind 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 window boundary of each cell by referring the original weight for the next calculation.

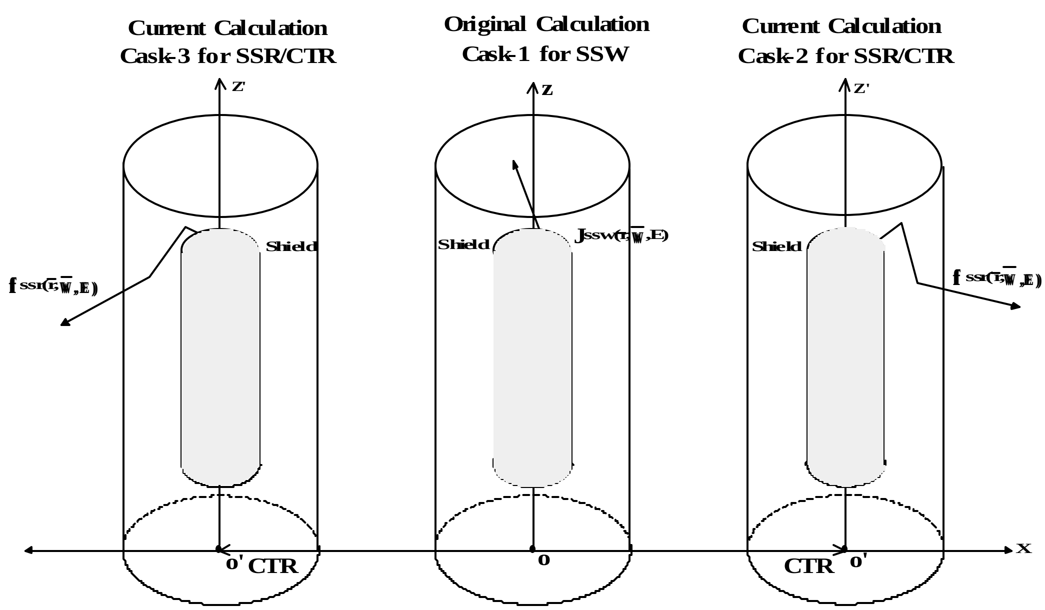

Fig.1 Concept of the SSW-SSR/CTR Calulation System.
SSW: Surface Source Write. SSR: Surface Source Read.
CRT: Coordinate Transformation.

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. The source intensity of neutrons and gamma rays in a spent fuel assembly depends strongly on the axial-direction specific burn-up distribution, so that the burn-up distribution is taken into account in the present calculation. The average specific burn-up of the spent fuels of 9 assemblies stored in the inner part of the basket is 55,000 MWD/MTU and the burn-up of 12 assemblies stored in the outer part of it is 50,000 MWD/MTU. The peeking factor of 1.15 is considered in the middle part of 10/12 for all the fuel assemblies. The source intensity of the spent fuels is calculated by ORIGEN2/82 code (A. G. Croff, 1983). The effective multiplication factor, keff, of the cask containing 21 PWR assemblies is calculated by KENO V.a code (L. M. Petrie, et al., 1998), and keff of 0.3 is employed to obtain the neutron source intensity of the cask. A modular shielding house in which 2 units of 4 spent fuel transportable storage casks are set aside is modeled as shown in Fig 2, in the Monte Carlo Coupling calculation. The cardinal shielding structure of the interim shielding house is a steel-water-steel multilayer shielding system, and it has a relatively large opening of intakes and outtakes system in the shielding house is inside steel of 6 cm-thick, middle water of 20 cm-thick and outside steel of 15 cm-thick. 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 the steel-water-steel shielding system, respectively.

On the other hand, the intakes are left and right sides, and the outtakes are upper part in Fig. 2. Because of the enhancement effect for neutrons is expected with steel-water-steel arrangement (K. Ueki, et al., 1996), the shielding system is an effective system for neutrons, in particular. However, some of neutrons penetrated through the casks and also secondary gamma rays produced in the multilayer system are to be stream through the opening system. The 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 the most important thing to evaluate the shielding ability of the shielding house. Those neutrons and gamma rays streamed out from the opening system are to form the sky-shine, and some secondary mamma rays are produced in the atmosphere and the round 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.

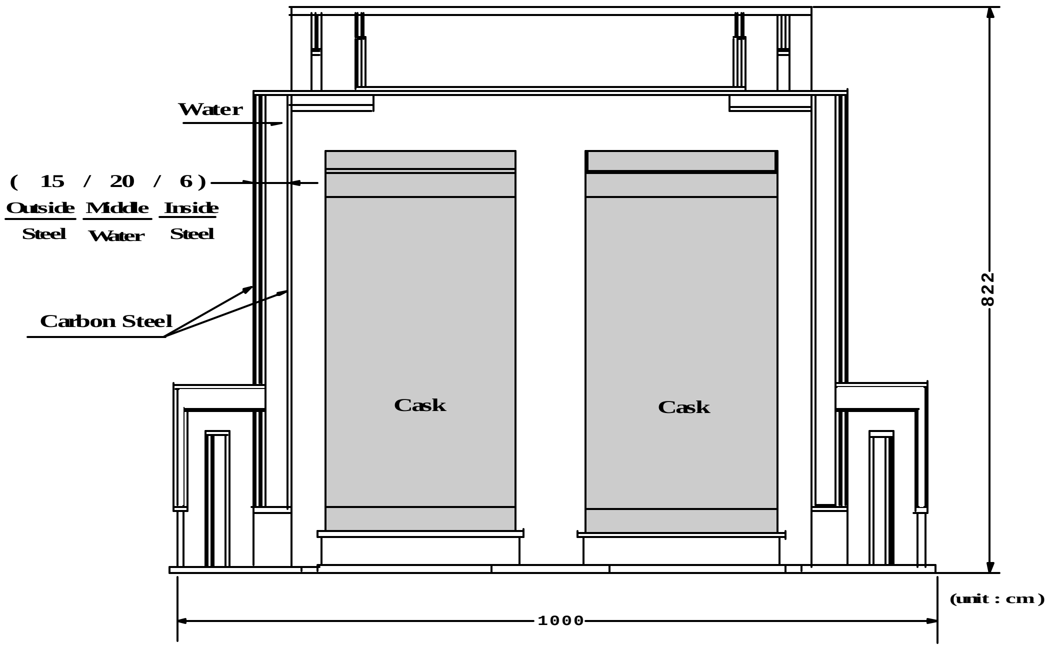

Fig. 2 MCNP 4C calculation model of shielding structures and arrangement of casks in a unit of the shielding house.

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 (μSv/y/4 casks). However, it reduces to 0.625 (μSv/y/4 casks) at 150 m, and it is 0.083 (μSv/y/4 casks) at 300 m from the center. Therefore, when the distance from the center of the shielding house to the boundary of the storage facility takes 300m at least, it might be possible to keep 600 casks approximately in the modular shielding house under the severe Japanese criterion of 50μSv/y at the site boundary of an interim storage facility.

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

CONCLUDING REMARKS

Following remarks can be made from the present analysis with the Monte Carlo coupling technique 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 (μSv/y/4 casks). Therefore, when the distance from the center of the shielding house to the site boundary takes 300m at least, it might be possible to keep 600 casks approximately in the modular shielding houses under the severe Japanese criterion of 50 μSv/y at the site boundary of an interim storage facility.

2. It must observe closely that the secondary gamma rays are account for more than 60 % of the total effective dose rate at all the calculated points around the modular shielding house. The 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 accounted mostly by neurons, and FP and ^{60}Co activation gamma rays are a few percents of it. Accordingly, the reduction of the secondary gamma ray is a critical matter to improve not only shielding ability but also 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 is able to apply to the shielding system in which more than several hundreds of transportable storage casks are set aside.

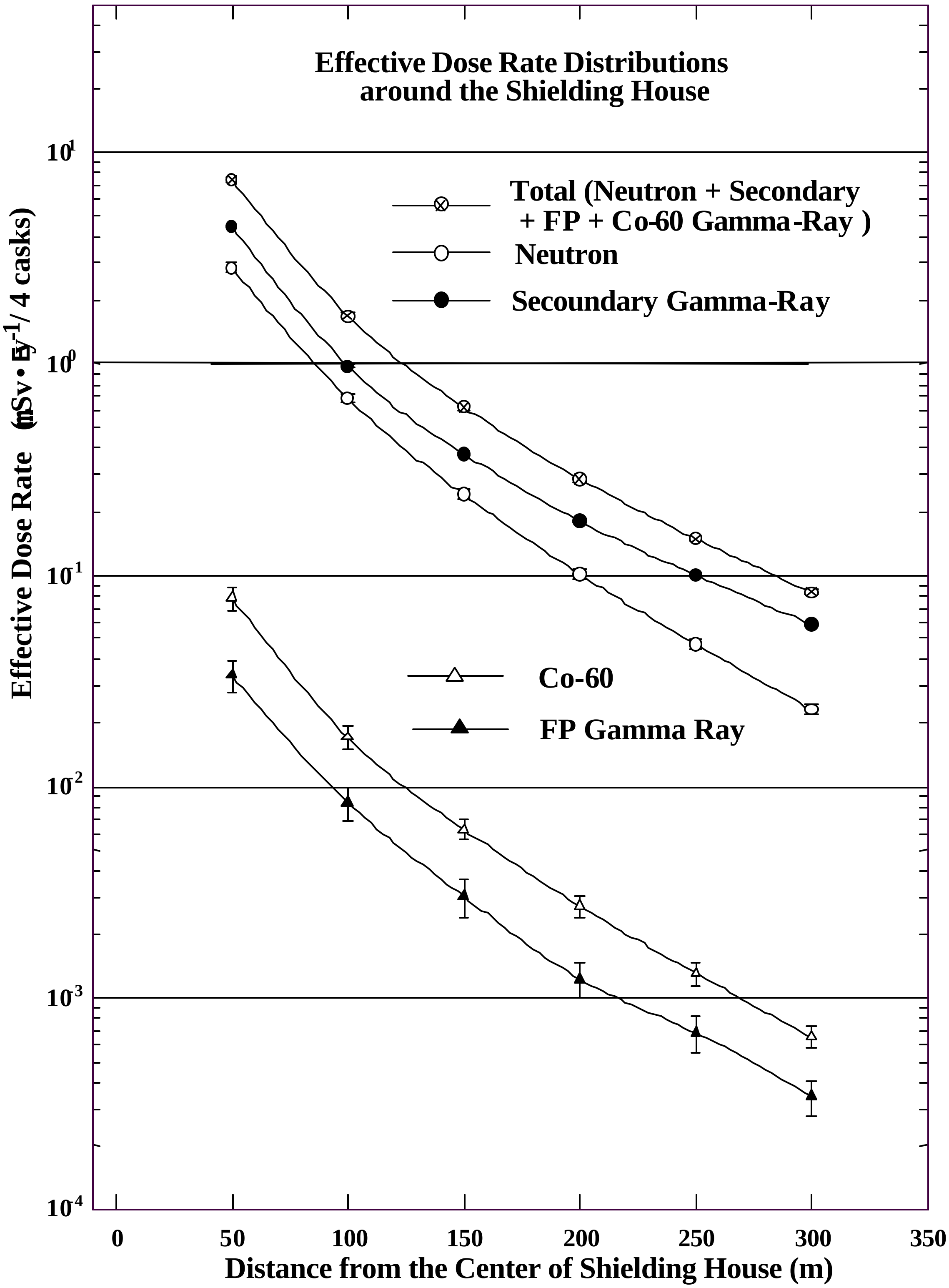

Fig. 3 MCNP calculated effective dose rate distributions around the shielding house keeeping 4 transportable casks.

REFERENCEES

[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, 253 (1981).

[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, 164 (1986).

[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, 1259 (1995).

[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, 32 (1995).

[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, 335 (1983).

[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, ORNL/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, 455(1996).