# APPLICABILITY OF THE MONTE CARLO METHOD TO THE EVALUATION OF DOSE EQUIVALENT RATES FROM METAL CASKS IN AN INTERIM STORAGE FACILITY

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## ABSTRACT

Dose equivalent rates at the premises of an interim storage facility have been evaluated by using the continuous energy Monte Carlo code MCNP-4B [1]. It is confirmed that the direct and skyshine dose equivalent rates are evaluated with sufficient accuracy by using the appropriate detailed source biasing and weight window parameters. The wall thickness required to meet a dose equivalent limit in Japan has been roughly estimated.

Furthermore, the shadow effects caused by other surrounding casks and streaming effects through an opening in the ceiling have been evaluated for realistic shielding design of such facility. The direct dose equivalent rates may reduce to about 1/3 by the shadow effects and the skyshine dose equivalent rate may increase by over 10 times by the streaming effects. These results show that neutron skyshine dose equivalent rates may be critical for the shielding design of it.

The coupling calculation method based on MCNP-4B code was applied to perform calculations efficiently. The calculation results by the coupling method well agreed with the ordinary method. It is confirmed that the coupling method based on MCNP code is useful to save the calculation time.

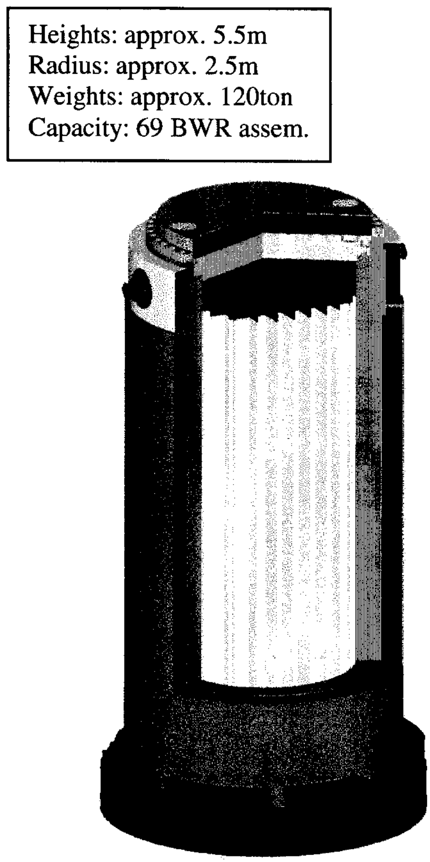



Fig.1 MMETS-69B cask

## INTRODUCTION

In Japan there is a plan to start to operate an interim storage facility with a capacity of about 5000 tonU around 2010 and metal casks to transport and storage spent fuels will be used in the facility. It is widely recognized that accurate and rational evaluation of the dose equivalent rate, especially skyshine, at the facility premises is needed because of the small site size and strict dose equivalent limits in Japan.

Although deterministic methods such as DOT3.5 [2] code and G33[3] code have been widely used for skyshine evaluations, G33 code can not be applied to neutron calculations. Coupling calculations based on DOT3.5 code may include some approximations and can not treat complicated models such as arrayed casks or openings in the ceiling directly.

Monte Carlo methods can treat large complicated models directly without any approximations. Developing the Monte Carlo codes and computers ability, some results using the Monte Carlo method applied to skyshine problems were recently reported[4],[5]. Applicability of the Monte Carlo method to the shielding calculation of an interim storage facility is investigated in this study. It is thought that the shadow effects and the streaming effects through openings are also important for the facilities. The quantitative evaluations of these effects for a typical interim storage facility have been evaluated in this study.

## CALCULATION CONDITIONS

(1) Cask & Facility

The view of a typical transportable storage cask: MMETS-69B (Mitsui MEtal cask for Transport and Storage cask) and its major properties are shown in Fig. 1. The cask is dry type and steel and resin (NS-4-FR) are used for the shielding. The basket of it is made of borated aluminum. In this study, a cask modeled after the MMETS-69B cask is used.

2 types of typical interim storage facilities are considered in this study. One is an AR (At Reactor) type small facility, the capacity of which is 500 tonU. The other is an AFR (Away From Reactor) type large one, the capacity of which is 5000 tonU. As the capacity of the cask is approximately 12 tonU, the capacity of casks in each facility is set to 45 and 450 respectively. The rough calculation model of the facility is shown in Fig.2. The pitch between arrayed casks is 4m and the ceiling and walls are made of ordinary concrete.

(2) Source condition

Two kinds of source conditions are considered. One is neutron source only (N-100% case) and the other is gamma-ray only (G-100% case). In both cases, source strength were normalized as the dose equivalent rates at 1m from the cask surface are 100 μ Sv/h. Dose equivalent rate of neutron induced gamma is included in the N-100% case. The Pu-239 spontaneous fission neutron spectrum and a 40 GWd/t BWR spent fuel (10 years cooling) gamma spectrum calculated by the ORIGEN2[6] code are used.

The effective dose equivalent rate limit at the premises of interim storage facilities is 50 u Sv/y which is same to nuclear power plants in Japan.

(3) Methods

The continuous energy Monte Carlo code MCNP-4B and JENDL-3.2 library are used in this study. Point tally estimators are used and source biasing and detail weight window parameters are adopted for the variance reduction.

The ground and air around it are modeled up to 2500m. Two kinds of dose equivalent rates are calculated separately. One is the direct dose equivalent rate, which is contributions

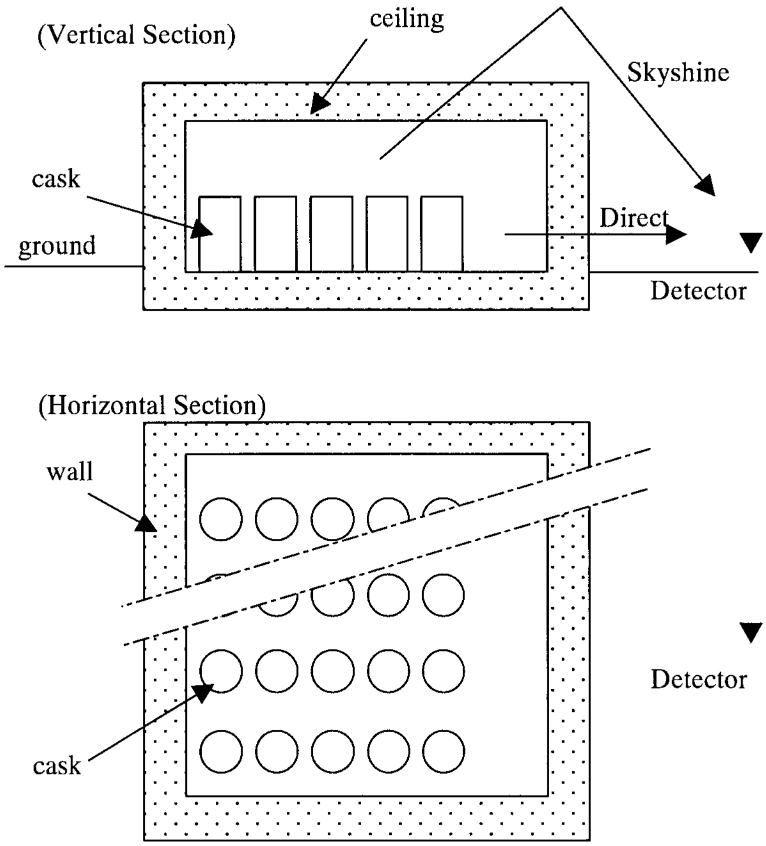



Fig.2 rough calculation model of the interim storage facility through walls of the storage building. The other is the skyshine dose equivalent rate, which is contributions through the ceiling of it, The ceiling is set to `black' (all particles are absorbed) and only particles through the walls are calculated for the direct dose equivalent rates. On the contrary, the walls are set to black and only particles through ceiling are calculated for the skyshine dose equivalent rates.

**RESULTS & DISCUSSION**

(1) Dependence on distance and wall thickness

Direct and skyshine dose equivalent rates have been evaluated separately as a function of the distance from the storage building and the thickness of its concrete wall and ceiling. Source biasing parameters and detailed weight window parameters are adjusted by trial and error to get accurate and reasonable results.

One of typical results is shown in Fig.3, which shows the relationship of dose equivalent rates from a cask and the distance from the storage building when its wall and ceiling thickness is 100cm. It shows that the direct and skyshine dose equivalent rates decrease rapidly with increasing distance. Although the F.S.D. (Fractional Standard Deviation) values which means the statistical error of the calculation results increase gradually with increasing distance, the most values at less than 1000m are about 5% and the values at over 1000m are about 10%. It is thought that the results have sufficient accuracy.

The direct dose equivalent rates are larger than the skyshine dose equivalent rate when the wall thickness is same to the ceiling. The dose equivalent rates of the N-100% case are larger than the G-100% case. Especially difference between the skyshine dose equivalent rates of the N-100% case and these of the G-100% case increases with increasing distance.

The wall thickness required to meet a dose equivalent limit has been estimated The dose equivalent rate at the facility premises are got by the total dose equivalent rate from a cask (= direct + skyshine dose equivalent) simply multiplied by the cask capacity in the facility in this section. Fig.4 shows a result of the N-100% and 5000 tonU (450 casks) case. As the dose equivalent rate limit is 50 $\mu$ Sv/year, it shows that about 100cm is necessary for the wall thickness when the distance from the storage building to the premises is 100m and about 50cm when the distance is 300m.

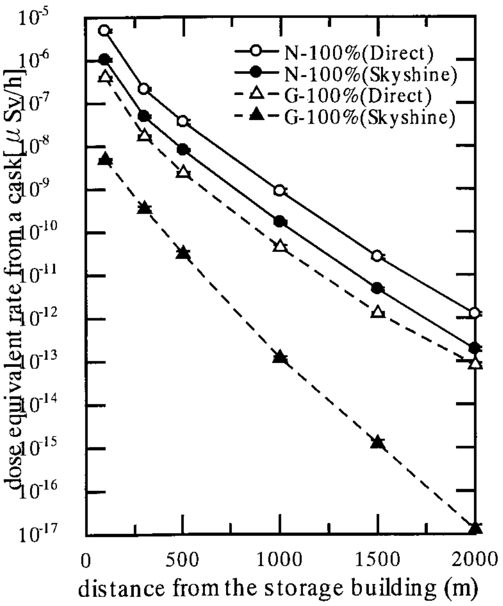



Fig.3 dose equivalent rates from a cask

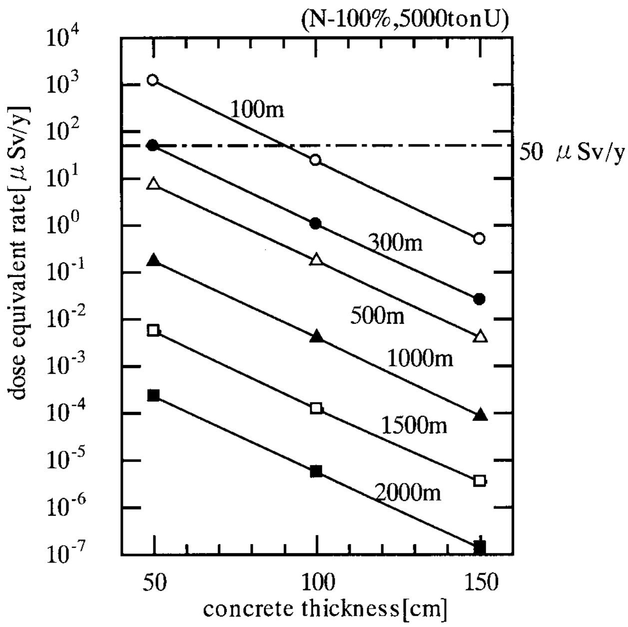



Fig.4 dose equivalent rates from 450 casks

(2) Shadow effects

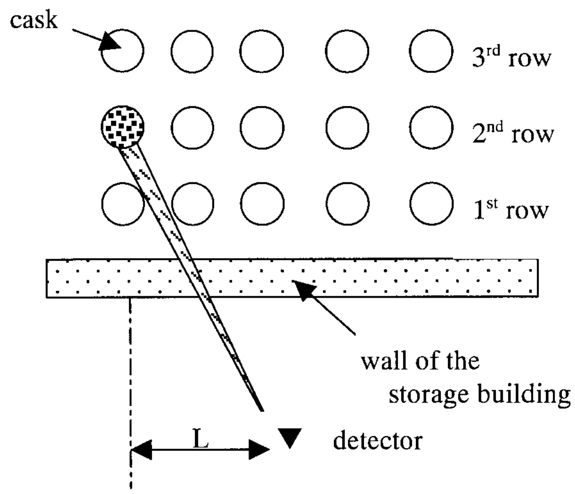
Fig. 5(a) shows typical arrangements of arrayed casks in an interim storage building. As the direct dose equivalent rates from a cask behind other arrayed casks may get smaller than that from a cask isolated, it is called "shadow effects" in this study. Two kinds of calculations have been performed to evaluate the shadow effects. One is a calculation modeled after an isolated cask with sources in the storage building and the other is a calculation modeled after a cask with sources and the surrounding casks without source. The difference of the two calculation results indicates the shadow effects.

The typical results show in Fig.5(b),(c) when the distance from the building is 300m and the wall thickness is 100cm. These results show the dose equivalent rate distributions from a source cask settled in the 2"d row and the 3`d row. These show that the dose equivalent rates decrease gradually with increasing distance (L) because the distance from the cask and effectively penetrating wall thickness increase. The shadow effects for the neutron seem to be almost independent on the distance from center L. On the contrary, the gamma dose equivalent rates with the shadow effects largely depend on the distance. Fig. 5(b) shows that the dose equivalent rates from the 2nd row cask decrease to approximately 25% for neutron and 15 - 40% for gamma by it. Furthermore Fig.5(c) shows that the dose equivalent rates from the 3rd row cask decrease to 10 - 20% for neutron and less than 10% for gamma.

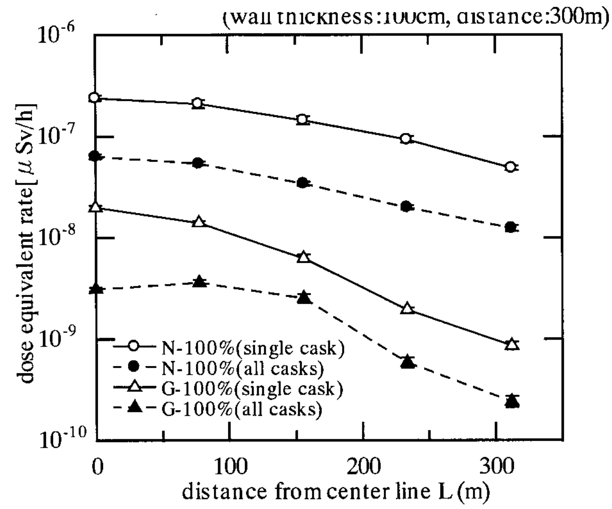
For the above 2 interim storage facilities, total shadow effects from all casks in the facility have been estimated because the total shadow effects are expected to depend on the arrangement of the arrayed casks in it. In this estimation, the N-100% case is considered and the shadow effects are conservatively assumed as follows:

| | |
|---|---|
| 1st row | : 1.0 |
| 2nd row | : 0.3 |
| 3rd row | : 0.2 |

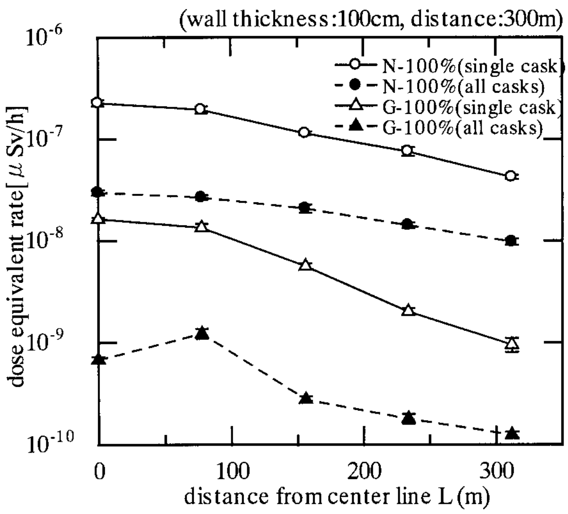
It is assumed that the effects of all the casks behind the 3`d row are equal to 0.2 of the 3rd row




(a) calculation model




(b) dose equivalent rates from the 2nd row




(c) dose equivalent rates from the 3rd row

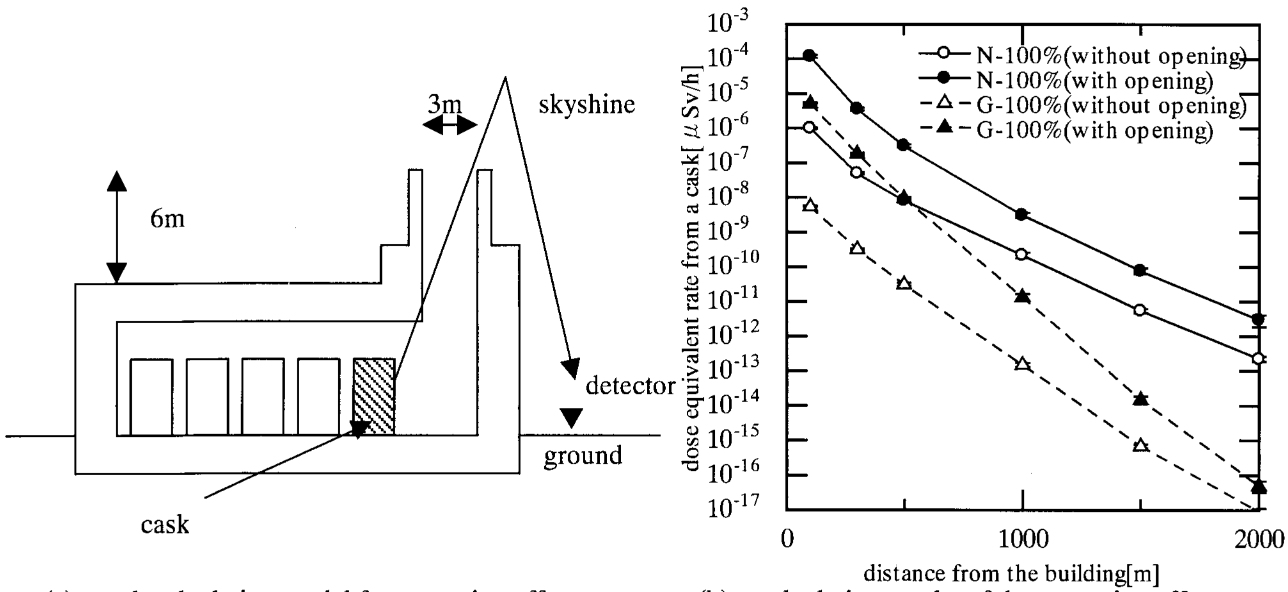
Fig.5 model and results of shadow shielding effects value and the effects of the 1st row are ignored conservatively. The estimated results are shown in Table 1. Casks are arrayed as 5 rows and 9 columns in the small facility (500tonU) and arrayed as 10 rows and 45 columns in the large facility (5000tonU). Table 1 shows that the direct dose equivalent rates decrease to less than 40% for small facility and less than 30% for large one by the shadow effects.

Table.1 direct dose equivalent rates (distance:100m,wall thickness:100cm)

| Capacity (number of casks) | dose equivalent rate[$\mu$Sv/y] | | Ratio (With /Without) |
|---|---|---|---|
| | Without shadow effects | With shadow effects | |
| 9×5(=45) | 1.94E+0 | 7.39E-1 | 0.38 |
| 45×10(=450) | 1.94E+1 | 5.64E+0 | 0.29 |

(3) Streaming effects

In general, interim storage buildings require large openings in ceiling for heat release because natural ventilation systems are adopted. It is thought that the streaming effects through the openings in ceiling are very important because the skyshine dose equivalent rates are shielded by the thick ceiling. In this study, a stuck type opening (width:3m, hights:6m) shown in Fig. 6(a) is considered and the quantitative estimations of the streaming effects through it have been performed. The skyshine dose equivalent rates from the nearest cask to the opening is used in this section.




(a) rough calculation model for streaming effects (b) calculation results of the streaming effects

Fig.6 model and results of streaming effects for skyshine

The calculation results were shown in Table2 and Fig. 6(b). These show that the dose equivalent rates get over about 100 times large for neutron and nearly 1000 times large for gamma by the streaming effects through the opening when the distance from the building is small. The increase of the dose equivalent rates is due to the increase of the particles by the streaming effects through the opening. Especially, increase of the gamma skyshine dose equivalent rate is large, it is because the shielding effects for gamma skyshine by the ceiling is more effective than that for neutron and affects of the opening of ceiling get larger. The streaming effects decrease with increasing distance.

Table 2 streaming effects through the opening for the skyshine

| distance [m] | N-100% | | | G-100% | | |
|---|---|---|---|---|---|---|
| | Dose(A)* [$\mu$Sv/h] | Dose(B)* [$\mu$Sv/h] | ratio (B/A) | Dose(A)* [$\mu$Sv/h] | Dose(B)* [$\mu$Sv/h] | ratio (B/A) |
| 100 | 9.96E-07 | 1.18E-04 | 118 | 5.53E-09 | 5.21E-06 | 943 |
| 300 | 5.00E-08 | 3.57E-06 | 71 | 3.20E-10 | 1.84E-07 | 574 |
| 500 | 8.24E-09 | 3.10E-07 | 38 | 3.09E-11 | 9.62E-09 | 311 |
| 1000 | 2.17E-10 | 3.12E-09 | 14 | 1.51E-13 | 1.36E-11 | 91 |
| 1500 | 5.46E-12 | 7.67E-11 | 14 | 6.94E-16 | 1.51E-14 | 22 |
| 2000 | 2.24E-13 | 3.00E-12 | 13 | 9.02E-18 | 5.03E-17 | 6 |

* A: without the opening, B: with the opening

In general, minimization of the ceiling thickness of a storage building is required from the point of the structure strength and construction costs. According to the above calculations, direct dose equivalent rates decrease by the shadow effects and skyshine dose equivalent rates increase by the streaming effects. It is thought that these results make the skyshine dose equivalent rate more important for the shielding design of the facilities and especially, the neutron skyshine dose equivalent rates including the streaming effects may be critical for it.

**COUPLING METHODS**

(1) Methods

The above calculations show the applicability of the Monte Carlo method (MCNP-4B) for the shielding design of such interim storage facility. But it takes much calculation time because shielding material of casks and building are very thick and calculation models are very large (up to several thousand meters). Furthermore if the shadow effects and the streaming effects are directly taken into account by modeling after detail arrangement of arrayed casks and openings, it takes much more time to calculate dose equivalent rate. To save calculation time, applicability of a coupling method based on the Monte Carlo code MCNP-4B has been investigated in this section. Two calculations are performed. One is called the 1st calculation, in which an isolated cask is modeled and particles from spent fuels in it are calculated. All particle information (weight, energy, direction, etc.) at the cask surface in the 1st calculation is stored. The other is called the 2nd calculation, in which all things including casks, the storage building, ground and air are modeled and the calculation of all particles is restarted from the cask surface. No approximations are included in the calculations.

The calculations have been done for a typical case (single cask, wall thickness: 100cm, no opening). The 'whole model' which is modeled after all (a cask, a building and so on) directly and the coupling method which is modeled after a cask and a building separately and coupling two calculations at the cask surface. Point tally estimators are used in the same way as the above calculations.

(2) Results

The calculation results are shown in Table 2. It shows that the calculated dose equivalent rate by the

coupling method well agree with the whole model. In general using point tally estimators is not appropriate in the coupling methods because contributions from inside casks can not be taken into account. But it is confirmed that the contributions are negligible by another calculation of the whole model. It shows that coupling method with point tally estimators can be used for such a calculation model with thick shielding wall.
In the coupling method, the total calculation time (1s` + 2"d calculation time) is similar to that of the whole model in a single cask case. When dose equivalent rates from arrayed multi casks must be calculated or the design of the storage building is changed (ex. Size of openings and ceiling thickness), only the 2"d calculations are necessary to perform by using the same surface sources calculated in the 1" calculation and only the calculation time for the 2"d calculation increase by using the coupling method. Table 2 shows that approximately 20% of the calculation time for above cases may be saved by the coupling method.

Table 3 comparison of the coupling calculation and the ordinary calculation
(distance:300m,wall thickness:100cm)

| | coupling method(A) | whole model(B)*** | Ratio(A/B) |
|---|---|---|---|
| Dose Equivalent rate [$\mu$Sv/y] * | 2.154E-7 (0.0739) | 2.198E-7 (0.0673) | 0.98 |
| calculation time** [min] | ($1^{st}$ calculation : 39.5)<br>$2^{nd}$ calculation : 277.1 | 340.3 | ~ 0.81 |

* : values in blanket mean F.S.D.
** : 5 million histories for both cases
***: without the contributions from inside casks

**CONCLUSION**

Direct and skyshine dose equivalent rates at the premises of an interim storage facility have been calculated by using the Monte Carlo code MCNP-4B. As source biasing parameters and detailed weight windows parameters are adjusted by trial and error, calculated results with sufficient accuracy are obtained. Furthermore, quantitative estimation for the shadow effects and the streaming effects has been performed. As the result, the direct dose equivalent rates decease to about 1/3 by taking the shadow shielding effects into account and the streaming neutron through the openings in the ceiling increased the neutron skyshine dose equivalent rates by over 10 times. Therefore it get clear that the neutron skyshine dose equivalent rates are very important for the shielding design of such facilities.
It is also confirmed that the coupling calculation method based on MCNP-4B code can be applied and save the calculation time to calculate the direct and skyshine dose equivalent rates for such interim storage facilities. The method is suitable for efficient and rational shielding design of the facilities.
The Monte Carlo method will be widely applied to the shielding design because it can directly and exactly treat complicated models (multiple casks, openings and so on) and calculation time may be saved by using the coupling methods. It is thought that developing the variance reduction technique is necessary for the Monte Carlo methods to be applied wider and wider.

**REFERENCE**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