Analysis of Errors in Albedo Monte Carlo Calculation due to Errors in Albedo Data

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Abstract

The error analysis method, which enables one to make an estimation of errors in the streaming neutron flux due to errors in the albedo data in the albedo Monte Carlo calculation, is described. The proposed method is based on a perturbation model which follows the same neutron path as in the unperturbed case, and estimates the flux error as a deviation in the neutron weight each time a neutron has a collision.

As an example of the application of the proposed method, neutron duct streaming problems in 2-m long concrete ducts are analyzed. The importance of neutron scattering in each energy group to the streaming neutron flux is quantitatively described by the method.

I. Introduction

The albedo Monte Carlo method is widely used[1-3] in nuclear facility design for estimating the radiation field in complex geometries which include a void region. This method saves much computing time as compared with the ordinary Monte Carlo method to obtain the same results. This is because the multiple scattering inside wall in the ordinary method is replaced in the albedo method with a single reflecting collision on the wall. However, trouble is very often caused in the albedo Monte Carlo calculation with the albedo data which requires troublesome efforts for data generation. Hence, the albedo data are usually calculated and stored in advance of the actual transport calculation. However, the compositions of materials in the actual geometry sometimes vary a little from case to case. For example, concrete which is usually used as material for the wall, contains different type ingredients in case to case, and its water content differs from time to time. Moreover, it sometimes has a thin iron lining on its surface, the thickness of which may be different. All of these things affect the albedo values of the concrete. It is very important to check errors in the

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results of the transport calculation due to errors that may be in the albedo data, especially to know the possible range in which the results will fall.

There has been no attempt so far to make an estimation of such errors which might be generated by the albedo data errors. Here, we propose a simple method which allows one to make an estimation of the accumated errors due to albedo data errors in the random walk process during the albedo Monte Carlo calculation. The method is based on the perturbation model, where the neutron weight is changed in accordance with the deviation in the albedos at each reflecting point instead of the varing neutron trajectory which takes place in an analogue model calculation.

II. Calculational Method

Scattering media around void regions are considered as reflectors in the albedo neutron transport calculation. Usually, the reflectors are assumed to reflect neutrons at the boundaries. A neutron generated at a source with a certain weight arrives at a point of crossing the reflecting boundary, and then is reflected to a certain direction with its weight reduced by the total albedo.

The albedo is generally described as a function of the incident neutron energy E and the incident polar angle θ_o, reflecting energy E', reflecting polar angle Θ, and azimuthal angle ϕ:

$$\alpha\,(E, \theta_o\,;\,E', \Theta, \phi) = \alpha_t\,(E, \theta_o)\,h\,(E,\theta_o\,;\,E')\,f\,(E, \theta_o\,;\,\Theta, \phi), \qquad (1)$$

where α_t =total albedo,

h =energy distribution of reflected neutrons,

f =angular distribution of reflected neutrons,

and

$$\int_0^{2\pi}\int_0^{\pi/2} f\,(E, \theta_o\,;\,\Theta, \phi)\,\sin\,\Theta\,d\Theta\,d\phi = 1, \qquad (2)$$

$$\int h\,(E, \theta_o\,;\,E')\;dE' = 1. \qquad (3)$$

Let us consider a neutron whose weight is $W_{n-1}(E_{n-1})$ after its $(n-1)$-th reflection. After the n-th reflection, the energy and direction are determined, based on the functions h and f, respectively, while the new weight is determined by multiplying the total albedo to the old weight;

$$W_n(E_n) = \alpha_t(E_{n-1}, \theta_{n-1}) \cdot W_{n-1}(E_{n-1}). \tag{4}$$

This process is repeated until either the weight or energy is reduced below a predefined cutoff value, or the neutron leaks out of the system.

The contribution to the detector flux is scored by using the point detector estimation each time the neutron makes a reflecting collision. The calculated neutron flux at the detector is summarized as

$$\phi(E) = \frac{1}{N}\sum_{k=1}^{N}\sum_{n=1}^{\infty} P_n \alpha_n (E_{n-1}, \theta_{n-1}\,; E_n, \overline{\Theta}_n, \overline{\Psi}_n)/ l_n^2, \tag{5}$$

$$P_n = W_o^k \prod_{i=1}^{n-1} \alpha_i \ (E_{i-1}, \theta_{i-1}\,; E_i, \Theta_i, \Psi_i), \tag{6}$$

where N = total history number,

W_o = initial weight of the k-th source neutron,

P_n = probability of the neutron entering into the n-th collision with parameters E_{n-1}, θ_{n-1},

l_n = distance between the detector and the n-th collision,

$\bar{\Theta}_n, \bar{\Psi}_n$ = direction of the neutron reflection from the collision point to the detector.

Let us consider a small deviation $\delta\alpha_n (E_{n-1}, \theta_{n-1}\,; E_n, \Theta_n, \Psi_n)$, introduced in $\alpha_n (E_{n-1}, \theta_{n-1}\,; E_n, \Theta_n, \Psi_n)$. The actual neutron trajectory will be changed a little by this deviation. However, we follow the same trajectory of the unperturbed case and estimate the accumulated deviation in ϕ, which will be introduced by the change in α, along the trajectory.

The probability P_n in Eqs. (5) and (6) after the $(n-1)$-th collision will be varied to the value $P_n + \delta P_n$ due to $\delta\alpha$,

$$P_n + \delta P_n = W_0^k \prod_{i=1}^{n-1} (\alpha_i + \delta\alpha_i), \tag{7}$$

then

$$(P_n + \delta P_n)/P_n = \prod_{i=1}^{n-1} (\alpha_i + \delta\alpha_i)/\alpha_i, \tag{8}$$

$$= \prod_{i=1}^{n-1} (1 + \delta\alpha_i / \alpha_i), \tag{9}$$

If the energy and angular distributions h and f are not changed, $\delta\alpha_n$ is written by the change in the total albedo as

$$\delta\alpha_n = \delta\alpha_t^n hf. \tag{10}$$

Then, the deviation in the flux ϕ of Eq. (5) is written as

$$\phi + \delta\phi = \frac{1}{N}\sum_{k=1}^{N}\sum_{n=1}^{\infty}(P_n+\delta P_n)\ (\alpha_t^n + \delta\alpha_t^n)\ hf/l_n^2, \tag{11}$$

$$= \frac{1}{N}\sum_{k=1}^{N}\sum_{n=1}^{\infty}(P_{n+1} + \delta P_{n+1})\ hf/l_n^2. \tag{12}$$

And

$$(P_{n+1} + \delta P_{n+1})\ /\ P_{n+1} = \prod_{i=1}^{n}(1 + \delta\alpha_t^i/\alpha_t^i), \tag{13}$$

or

$$\delta P_{n+1}/P_{n+1} \sim \sum_{i=1}^{n}\delta\alpha_t^i/\alpha_t^i, \tag{14}$$

when the deviation $\delta\alpha_t^n$ is small as compared with α_t^n. Therefore,

$$\delta\phi = \frac{1}{N}\sum_{k=1}^{N}\sum_{n=1}^{\infty}P_{n+1}hf\sum_{i=1}^{n}(\delta\alpha_t^i/\alpha_t^i)/l_n^2. \tag{15}$$

This is easily estimated along the neutron trajectory during the albedo Monte Carlo calculation process.

III. Application of Error Analysis Method

i) Description of Geometry and Data Preparation

The error analysis method derived in the above chapter is applied to typical neutron duct streaming problems. Fig. 1 shows duct systems of concrete which are selected here as typical examples of streaming paths frequently encountered in actual nuclear facilities. Both the straight and bent ducts are 20 cm in diameter, and 200 cm in length. The bent duct has a bent of 90 deg. at its center, each branch being 100 cm long. A point neutron source of 14 MeV is assumed at the center of the duct mouth for each duct.

For the calculation of the albedo data, multigroup cross secion data were generated first by the RADHEAT-V3 code system[4] from nuclear data stored in the ENDF/B-IV file[5]. The group constants were in 12 groups with P_8 approxima-

Table I Energy Group Structure

Group	Boundary (eV)
1	1.5 + 7*
2	1.3 + 7
3	5.49 + 6
4	2.47 + 6
5	9.07 + 5
6	3.34 + 5
7	1.11 + 5
8	9.12 + 3
9	7.49 + 2
10	6.14 + 1
11	5.04 + 0
12	4.14 − 1
	1.00 − 3

* Read as 1.5×10^7.

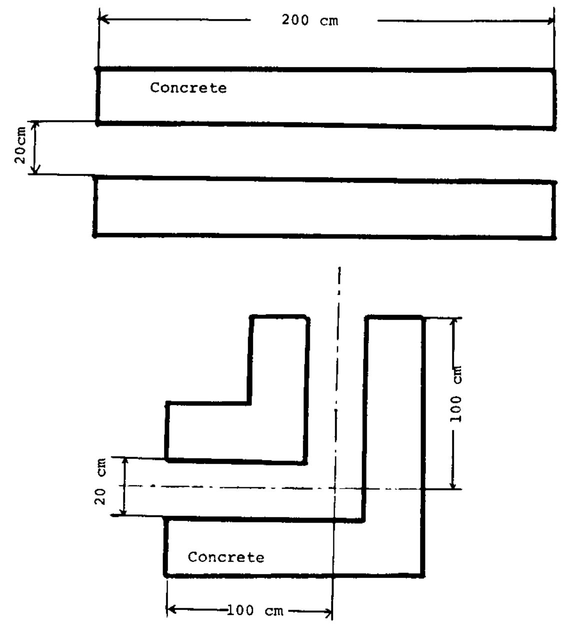

Fig.1 Concrete duct arrangements for the test calculation.

tion, whose group structure is shown in Table I. Then, one dimensional ANISN[6] calculations were performed with the P_8S_8 approximation based on the generated group constants in an infinite slab geometry, at the front boundary of which the parallel beam source was imposed. The ANISN calculation was repeated with the source energy group being scanned 1 through 12 and the incident direction 6 through 9. Note that the S_8 approximation was used in the calculation, and that the angles 6 through 9 were in the forward (slab side) hemisphere.

Finally, the albedo data were calculated by the following equation from the output data of the ANISN calculations.

$$\alpha(E_o, \theta_o ; E_i, \Theta_j) = \phi_{ij} \mid \cos \Theta_j \mid / (4\pi\phi_o W_o \mid \cos\theta_o \mid), \qquad (16)$$

where $\phi_{ij}/4\pi$ =reflected neutron angular flux per steradian,

ϕ_o =incident neutron flux per weight,

W_o =angular quadrature weight corresponds to the angular mesh $\cos\theta_o$.

Note that the ϕ dependence of the albedo was neglected in Eq. (16), since the one dimensional ANISN calculation was adopted.

ii) Results of Test Calculation

The spectra of streamed neutrons are shown in Fig. 2 for both the straight and bent ducts. The results were obtained by the albedo Monte Carlo calculation for the points located at the center of the duct's exit mouth. The spectra are expressed in the lethargy unit. The spectrum for the straight duct has a sharp and dominant peak at the source energy due to direct neutrons from the source. The spectrum then gradually decreases to the epithermal group, and finally increases a little at the thermal energy. The spectrum of the bent duct has, as opposed to the straight duct, no prominent peak near the source energy, and has a flat spectrum down to the epithermal group. The flux values at these energies are about one to three order of magnitude smaller than the cor-

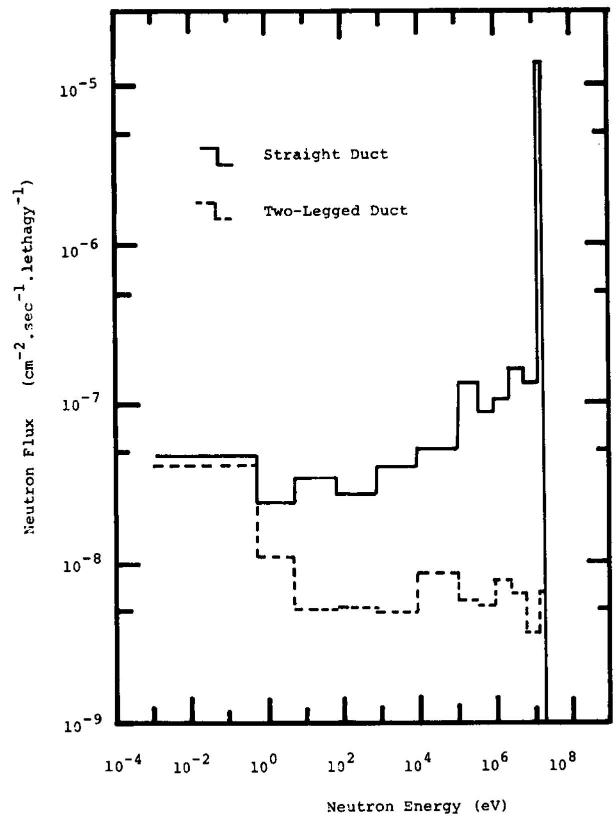

Fig.2 Results of the albedo Monte Carlo calculation.

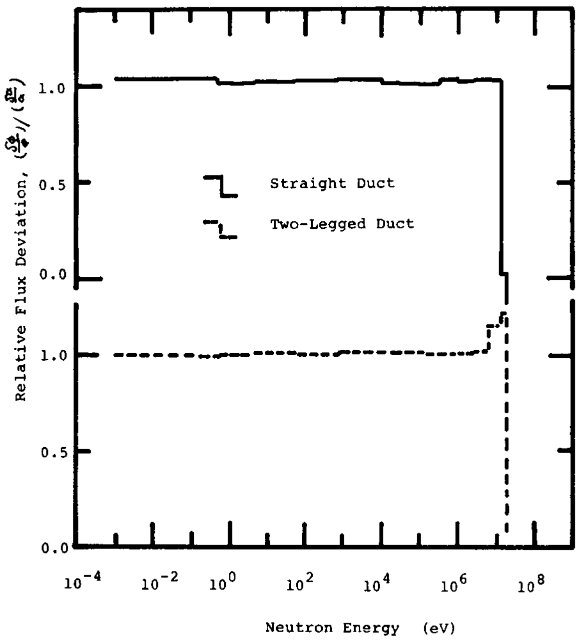

Fig.3 Flux deviation caused by the 10% deviation in the total albedo data of the 1st group.

respoding values of the straight case. However, the thermal group fluxes have about the same values for both cases. Most neutrons arriving at the exit of the bent duct have been slowed down due to multiple scattering. This is not the case in the straight duct geometry.

The total albedos a_t $(E, \theta_0 ; E')$ of the 1st group were all increased by 10%, and the deviation in the flux at the duct exit was evaluated by Eq. (15). Fig. 3 shows the results of the flux deviation due to the above data change, where the deviation is expressed by the ratio of the relative flux deviation to that of the albedos; $(\delta\phi/\phi)/(\delta a_t/a_t)$. The relative deviation in the flux of both ducts is almost equal to unity except near the source energy. The fluxes were changed by about 10%. This means that most of the neutrons which arrived at the duct exit suffered a single scattering in the 1st group and slowed down to lower energies as a result of the scattering. Ingroup scatering within the source group is rare, although this is seen as the small bump near the source energy in the bent duct data. The depression at the 1st group of the straight duct data is the result of the inclusion into the $(\delta\phi/\phi)$ evaluation of the direct neutrons which dominate the 1st group flux but are not affected by the albedo data deviation.

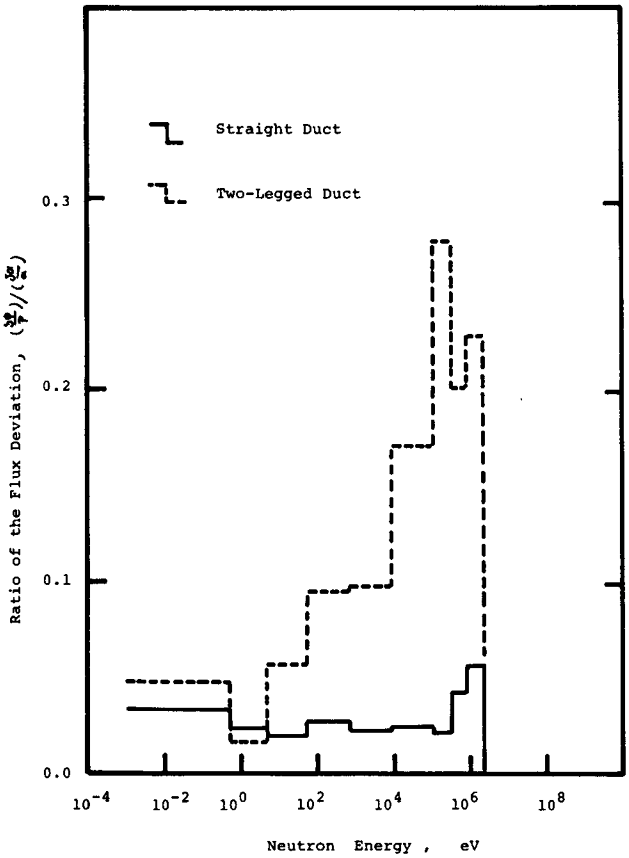

Fig.4 Flux deviation due to the 10% deviation in the total albedo data in the 4th group.

The second is the case where the 4 th group total albedos are all changed by 10%, while the rest of the albedos remain unchanged. The results of the calculations are shown in Fig. 4. Further, less change is seen in both duct cases than the change in the albedo data. Especially the change in the straight duct flux is only about 0.4%. This means that most of the neutrons jumped over the 4 th group during the slowing down process. In the bent duct, the fact that the neutrons generally scattered more often than in the straight duct resulted in a higher flux change than the straight one.

Finally, the total albedos over the whole energy groups were uniformly increased by 10%. The results are shown in Fig. 5. It is seen in the figure that the flux deviation increases quickly as the neutron energy decreases. It's values are 15 or 23 times as large as the albedo deveation at the thermal energy. The

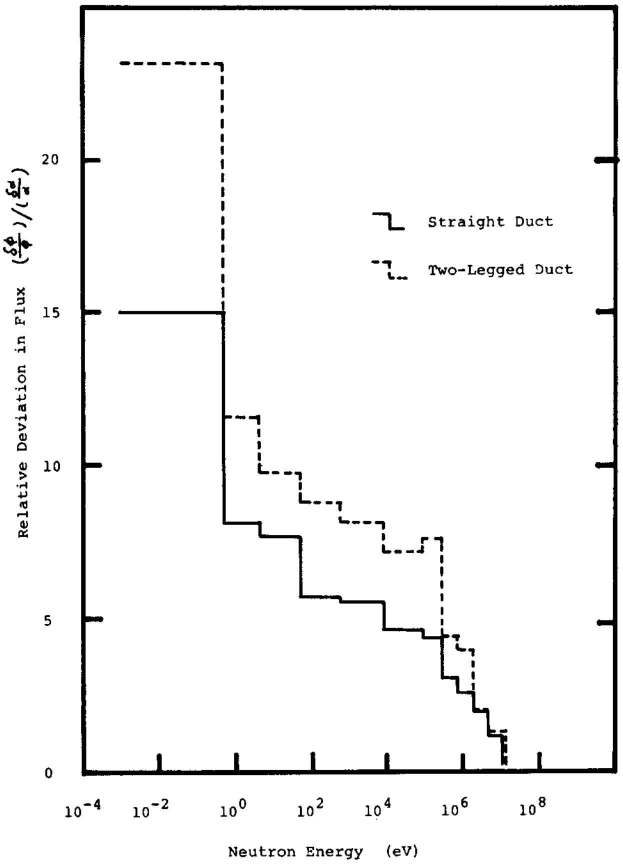

Fig.5 Flux deviation introduced by the 10% deviation in the total albedo data in all groups.

effect is very large. The two-legged duct shows more flux deviation than the straight duct does. These are explained by considering the number of scatterings in the ducts, i. e. the neutrons which suffered more time scattering resulted in more flux deviations.

Conclusion

A simple analysis method was proposed for the evaluation of errors in the albedo Monte Carlo results due to errors in the albedo data. The validity of the method was tested through the application of the method to typical duct streaming problems in concrete ducts.

It was clarified that the proposed method gave physically reasonable results. Moreover, the physical process of the duct streaming was better understood than before by the results of the method, i. e. the importance of neutron scattering in each energy group to the streamed flux was first quantitatively estimated by this method.

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