Calculation of Surface Dose-Rate Profile of a Cask by Monte Carlo Method

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INTRODUCTION

It is important to obtain the dose-rate profile of a cask surface or 1m from the cask for evaluating the maximum dose-rate easily and precisely. So far two dimensional SN codes, such as DORT(Rhoades and Childs 1988) are used for this purpose, but the Monte Carlo code is a much better tool for the calculation of complicated geometrical shapes like a cask because any three-dimensional configuration can be modeled with the Monte Carlo code. The only problem in getting a dose-rate profile using the Monte Carlo code is the definition of estimators ; however, this is a serious problem. For example, if a thousand estimators are required, almost the same amount of additional geometry input is necessary to define the estimators when using the conventional method. It means that the calculation model becomes extremely complicated, and the complicated model makes the CPU time much longer. In this paper, a technique is presented to obtain surface dose-rate profiles of a cask surface or 1m from the cask by Monte Carlo code within a reasonable CPU time.

SELECTION OF ESTIMATOR

Commonly there are five estimators for Monte Carlo calculation as shown in Table 1. The Last Collision Estimator(LCE), which is a point detector, is very popular to use in Monte Carlo calculations, but the CPU time for using LCE is proportional to the number of detectors. Therefore, the LCE is not good for getting dose-rate profiles. As the Collision Density Estimator(CDE) and Track length Estimator(TLE) are volume detectors, these are not appropriate to express surface profiles, even though the CPU time is not sensitive for the number of detectors. When the dose-rate distribution inside or outside of cask is required, CDE or TLE is useful respectively.

For getting surface profiles the Surface Crossing Estimator(SXE) or the Next Event Surface Crossing Estimator (NESXE) are appropriate. As SAS4/MORSE-SGC/S(Tang et al. 1987) of SCALE code system is used to demonstrate the validity of this technique, the SXE is selected for estimator. This is because the NESXE is not specified in SAS4 and that takes much more CPU time than the SXE.

Table 1 Estimator of Monte Carlo Calculation

Detector	Estimator
Point Detector	Last Collision Estimator
Surface Detector	Surface Crossing Estimator
	Next Event Surface Crossing Estimator
Volume Detector	Collision Density Estimator
	Track Length Estimator

TECHNIQUE OF CALCULATION

The only problem using SXE in getting a dose-rate profile of cask surfaces or points of 1m from the surface is the definition of estimators; however, this is a serious problem. For example, if a thousand estimators are required, almost the same amount of additional geometry input is necessary to define the estimators when using the conventional method. This means that the calculation model becomes extremely complicated and the complicated model makes the CPU time much longer.

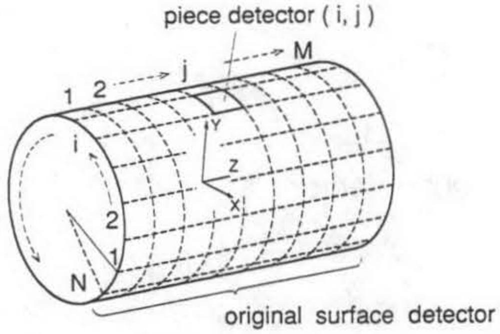
To overcome this problem, a technique, which does not use actual small detectors that are defined by using the additional geometry input data but use imaginary detectors, is introduced. This technique is very simple and easy. SAS4 /MORSE-SGC/S of the SCALE code system is modified to get dose-rate profiles using this technique. The SAS4 is a control module to calculate dose-rates exterior to a cask and uses adjoint fluxes from a one-dimensional discrete ordinate calculation with the XSDRNPM-S (Greene and Petrie 1990) to generate the biasing parameters for a Monte Carlo calculation by the MORSE-SGC/S code.

A. Imaginary Detectors

In the Monte Carlo calculation, a large surface detector that includes the outer surface of a cask or points of 1m from the surface is defined. The contribution to the dose-rate by a particle, neutron or gamma ray, across this large surface detector is stored separately according to the coordinate of the point that the particle crosses the surface as if there were a series of small surface detectors (we call it piece-detector).

Figure 1 shows the example of this technique, which is the case of radial surface detector. In this case the large detector is divided into N parts for azimuthal direction and into M parts for the axial direction. Then the total number of piece-detectors is N x M. The CPU time increasing for evaluating the location that a particle across this large detector is very small because the judgement is very simple. For example, if the large detector is divided into 360 parts for azimuthal direction, that means each piece detector has a 1.0 degree interval and is divided into the pitch of 1.0 cm width for the axial direction, the values of "i" and "j" are directly obtained from the coordinate of the crossing point of the particle. This means that it is not necessary to use N x M times DO loop at each surface crossing event to define the location. The size of each piece-detector is not essential for this technique, but it is better to use smaller piece-detectors as described in the example above.

For using this technique, subroutines BATCH and BDRYX of MORSE-SGC/S are modified, and a new file to store the dose-rate and the fractional standard deviation(FSD) of all piece-detectors is required. A very small modification described above gives much more information than the original calculation.



$i = \text{int}\,[\cos^{-1}(x/r) \cdot 180/\pi]$ (y>0)
$i = 360 - \text{int}\,[\cos^{-1}(x/r) \cdot 180/\pi$ (y<0)
$j = \text{int}[Z+1] - Z_0$

r : Radius of original surface detector
Z_0 : Lower boundary of original surface detector
(x,y,z) : coordinate of the crossing point of a particle

Figure 1 Concept of imaginary detectors technique

B. Postprocessing

After the Monte Carlo calculation has been done, the postprocessing procedure is made to produce dose-rate profiles of a cask surface using the data of piece-detectors stored in a file made by the Monte Carlo calculation. The concept of making a dose-rate profile of cask surface is as follows:

1. As shown in Figure 2, new larger detectors(we call them subdetectors) are defined by gathering the data of small piece-detectors around the center of a subdetector. The size of subdetector may be decided by the configuration of model, the FSD of results, or the purpose of calculation. One criterion, the size of actual detector that is used for a dose-rate measurement is applicable. In this study the size of subdetector is fixed to about 15cm x 15cm square, which is comparable to a size of a typical rem counter or ionization counter.

2. To express the three dimensional dose-rate profile, the data of subdetectors are transferred to the input data of a postprocessing software. In this study, a postprocessing software called AVS is used.

EXAMPLE OF CALCULATION

To demonstrate the validity of our method, two calculation models are chosen. The first one is a hypothetical small cask that has large voids in the main body or lid section. The other is a model that similar to TN24 transport/storage cask(Kakunai et al. 1995) that loads

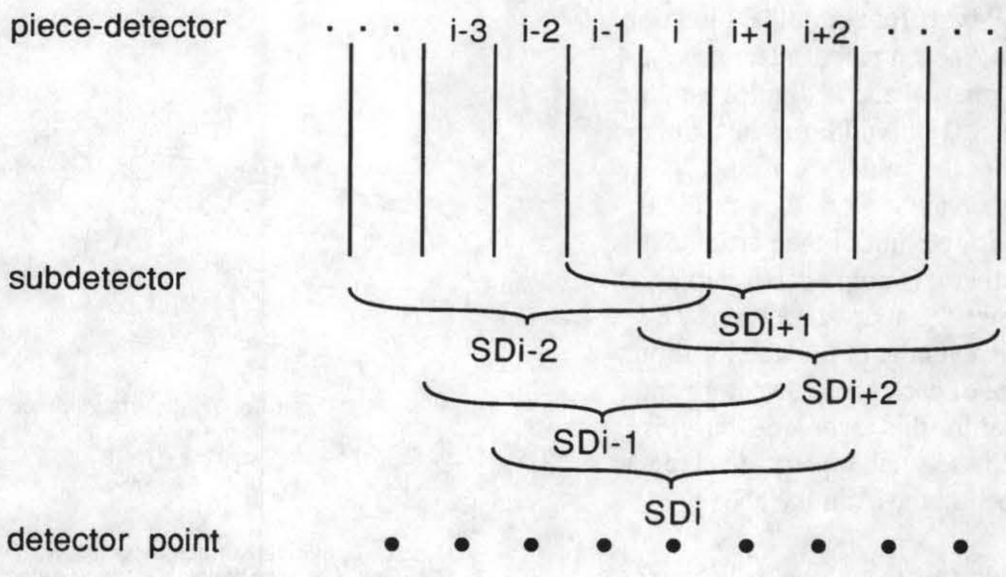


Figure 2 Concept of making subdetectors using piece-detectors

52 BWR fuel assemblies. The geometry of both cask models is assumed to be a combination of two cylinders as shown in Figure 3 in this study.

A. Hypothetical Small Cask

1. Description of model ; The configuration of model is shown in Figure 4. The source is assumed to be a Co-60 gamma ray. Voids of four different shapes are arranged in the main body at the pitch of 90 degrees, and a two-leg ring-shaped duct is in the lid. The total volume of the voids in each direction except the duct in the lid is same.

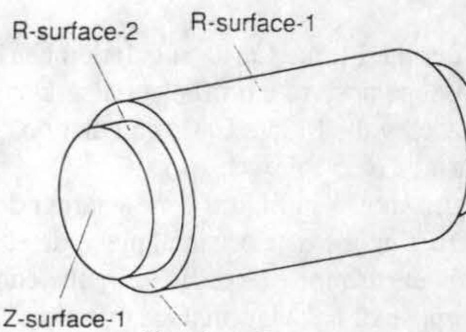


Figure 3 Typical geometry of cask

2. Dose-rate profile ; Figure 5 shows the dose-rate profile of the hypothetical small cask using iso-contour lines option in AVS. As these profiles are shown in monotone for publication reasons, it is a little difficult to see where the maximum and minimum dose-rate is. But the color copies of these profiles show clearly the effect of a two-leg ring-shaped duct in lid direction as a ring-shaped higher dose-rate peak. There is no such peak in the bottom direction as there is no duct in the bottom. The peak is on center at the bottom. The difference of dose-rate profiles caused by the existence of each void in main body is also clearly showed in the result. The maximum dose-rate is at 0 degree, where a large cylindrical void is, and is followed by 180 degrees, where a rectangular void is. The dose-rate at 270 degrees is lower than the other direction

but the higher dose-rate is spread wider than the others. The effect of the two voids in 90 degrees direction is shown as two small dose-rate peaks in this direction in Figure 5.

B. TN24 Cask

1. Description of model ; The configuration of model is shown in Figure 6. The source is assumed to be a FP gamma in the source region. In this model there is just one fuel assembly in the basket.
2. Dose-rate profile ; Figure 7 shows the dose-rate profile of TN24 model without using iso-contour lines. The highest dose-rate appears in the upper section of radial direction. This is caused by the lack of shielding material in this section. As the fuel assembly is at outer side of 135 degrees as shown in Figure 6, the higher dose-rate appears in this direction of outer surface of main body and this tendency is shown in the lid direction.

The additional CPU time caused by introducing a new technique to the original CPU time in these case is less than 10 %.

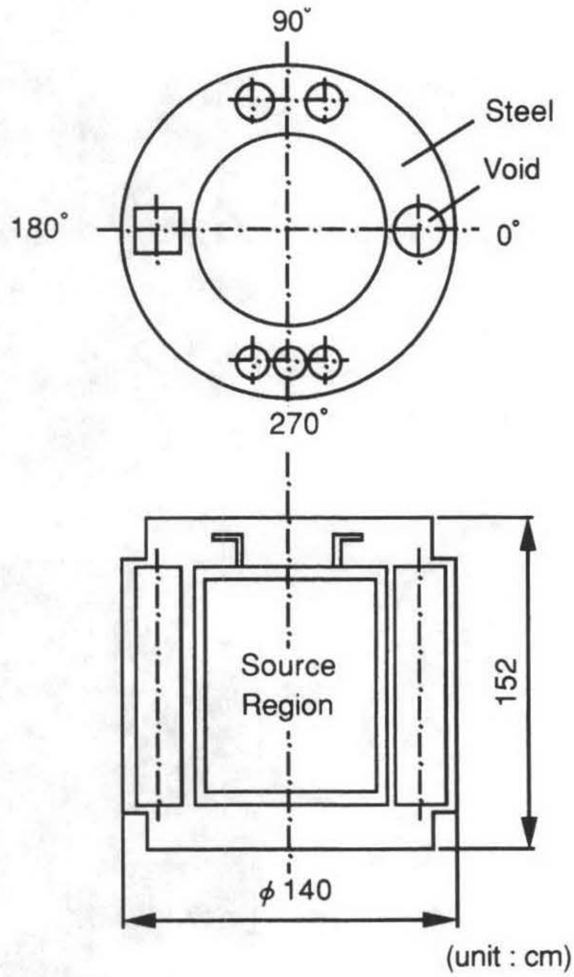
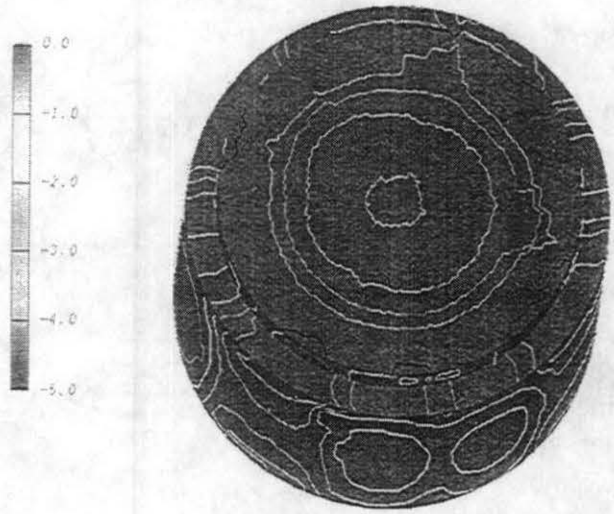


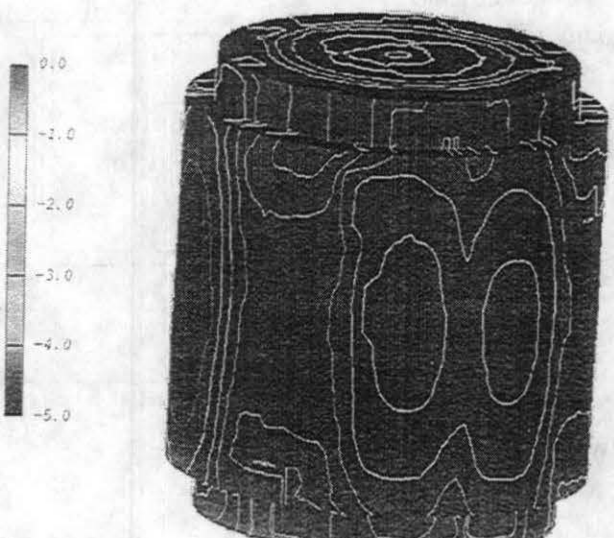
Figure 4 Geometry of hypothetical small cask

CONCLUSION

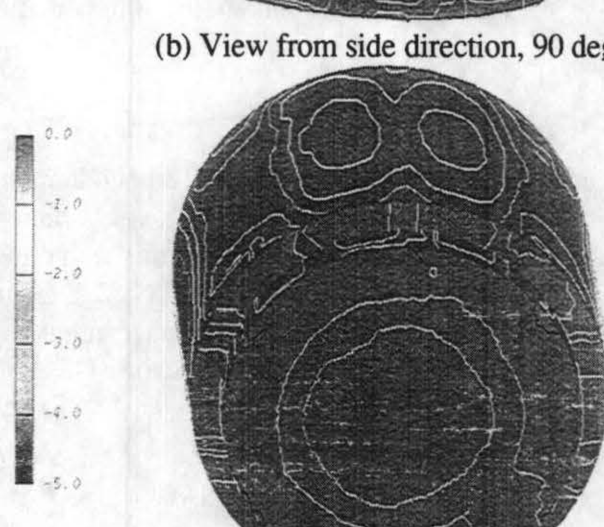
The surface dose-rate profile of a cask is obtained by Monte Carlo code with the proposed technique using SXE, and it is confirmed that this technique is a very efficient cost-saving method for getting dose-rate profiles around a cask. Of course, this technique is available for other objects. And the same technique can be applied using NESXE estimator. Also the same kind of technique can be applied using CDE or TLE volume estimator for getting dose-rate distribution inside or outside of cask. The technique using TLE volume estimator, which can show the dose-rate distribution outside of cask, will be presented in near future.



(a) View from upper direction



(b) View from side direction, 90 degree



(c) View from bottom direction

Figure 5 Dose Rate Profiles of hypothetical small cask(Iso-contour line)

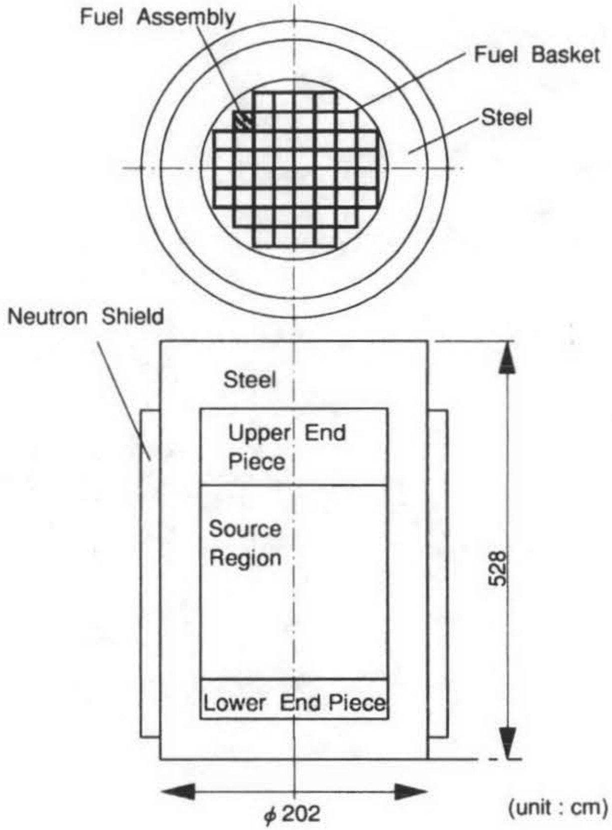


Figure 6 Simplified geometry of TN 24

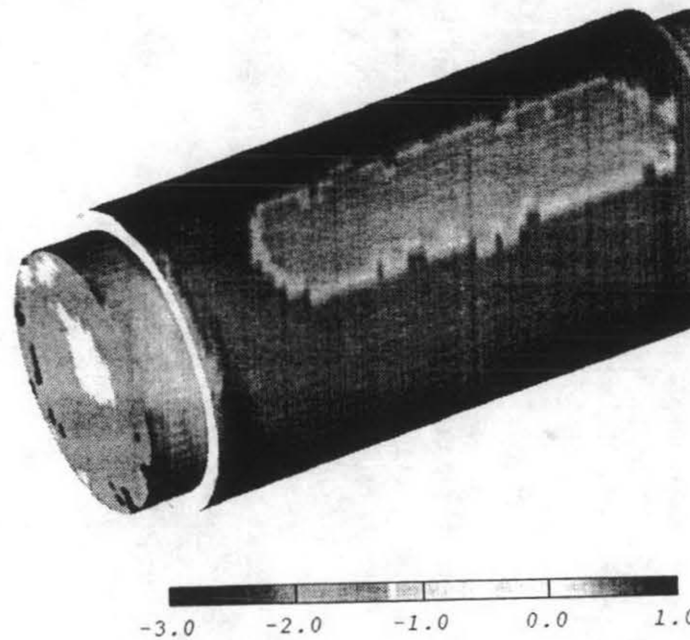


Figure 7 Dose rate profile of TN 24

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