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Development of "SKYSHINE-CG" Code : A Line-Beam Method Code Equipped with Combinatorial Geometry Routine

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A boiling water reactor (BWR) plant has a single loop coolant system, in which main steam generated in the reactor core proceeds directly into turbines. Consequently, radioactive ^{16}N (6.2MeV photon emitter) contained in the steam contributes to gamma-ray skyshine dose in the vicinity of the BWR plant. The skyshine dose analysis is generally performed with the line-beam method code SKYSHINE, in which calculational geometry consists of a rectangular turbine building and a set of isotropic point sources corresponding to an actual distribution of ^{16}N sources. For the purpose of upgrading calculational accuracy, the SKYSHINE-CG code has been developed by incorporating the combinatorial geometry (CG) routine into the SKYSHINE code, so that shielding effect of in-building equipment can be properly considered using a three-dimensional model composed of boxes, cylinders, spheres, etc. Skyshine dose rate around a 500 MWe BWR plant was calculated with both SKYSHINE and SKYSHINE-CG codes, and the calculated results were compared with measured data obtained with a NaI(Tl) scintillation detector. The C/E values for SKYSHINE-CG calculation were scattered around 4.0, whereas the ones for SKYSHINE calculation were as large as 6.0. Calculational error was found to be reduced by adopting three-dimensional model based on the combinatorial geometry method.

KEYWORDS: BWR plant, Turbine building, Skyshine dose, Line-beam method, Combinatorial geometry method, 6.2MeV gamma-ray

I. Introduction

A boiling water reactor (BWR) plant has a single loop coolant system, in which main steam generated in the reactor core proceeds directly into turbines. The main steam contains radioactive ^{16}N (6.2MeV photon emitter), which contributes to gamma-ray skyshine dose in the vicinity of the BWR plant.

The skyshine dose analysis is generally performed with the SKYSHINE[(1)] code. The code considers a rectangular building housing a set of isotropic point sources as a calculational model. The SKYSHINE code is widely used because of its simple and convenient calculation model.

However, in the SKYSHINE calculation, being difficult to model complicated structure geometry such as turbine, a safety margin is usually considered in order to get rid of underestimation of dose rate.

We have been developing SKYSHINE-CG code by incorporating the combinatorial geometry (CG) routine into the SKYSHINE code for the purpose of upgrading calculational accuracy. Skyshine dose rate from a 500MWe BWR turbine building was calculated with both the SKYSHINE-CG code and the SKYSHINE code. The results were compared with measured data obtained with a NaI(Tl) scintillation detector.

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II. Feature of SKYSHINE-CG Code

The SKYSHINE code considers a rectangular structure enclosed by a slab, four walls and a roof. Each of the walls and the roof of the building is subdivided into up to nine areas, representing different materials or different thickness. The shielding effect in the building, which is caused by interior walls and/or adjoining equipment, can be roughly considered by means of "projection method", in which extra shielding thickness corresponding to the shielding effect of the in-building equipment is added to the thickness of the building wall or roof.

The SKYSHINE-CG code incorporated with the CG routine describes three-dimensional geometry model as a combination of cylinders, spheres, boxes and so on. The code has the following four calculation steps.

Step 1: Determination of initial gamma-ray direction using a random number generator routine.

Step 2: Calculation of total transmission length from point source to the outer surface of the building wall along with the locus of the gamma-ray using the CG-routine.

Step 3: Calculation of gamma-ray spectrum and angular distribution at the outer surface of the building using data based on the ANISN[(2)] calculation.

Step 4: Calculation of dose contribution of each gamma-ray using propagation data based on Monte Carlo calculation. Skyshine dose rate is obtained by summing up the dose contribution from each gamma-ray.

III. Calculation of Skyshine Dose

We analyzed skyshine dose around a 500MWe BWR turbine

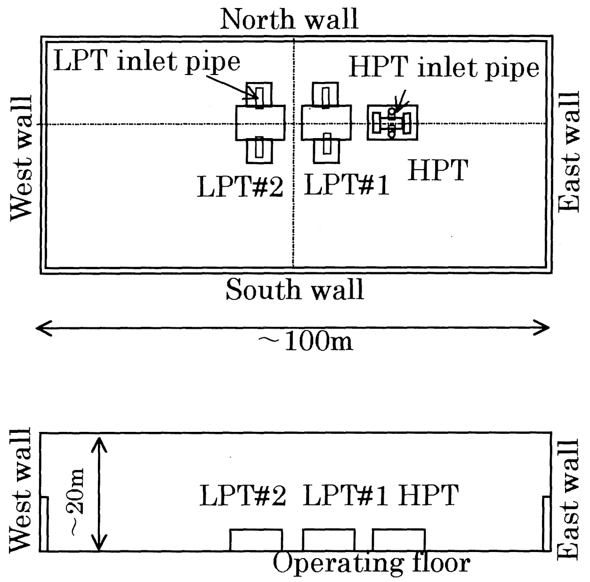

Fig.1 Layout of BWR turbine building

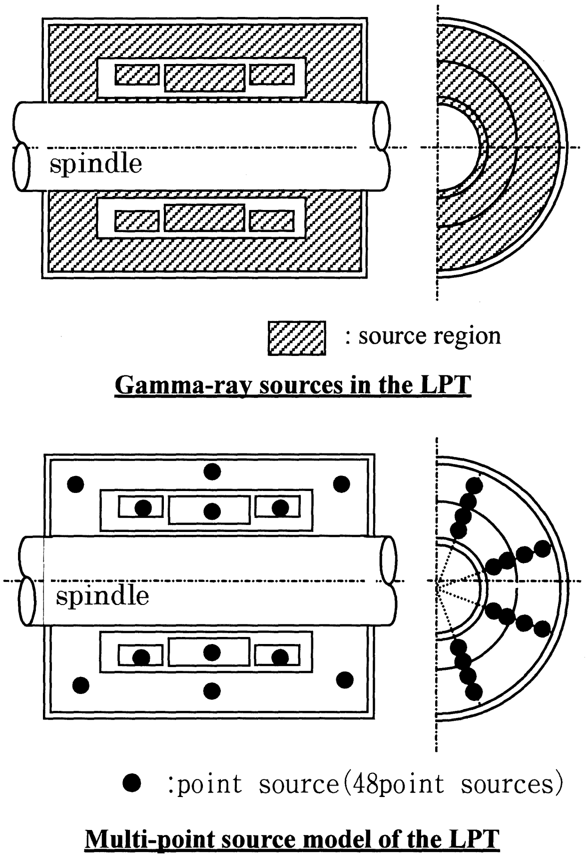

Fig.2 Gamma-ray source in the LPT and multi-point source model of the LPT

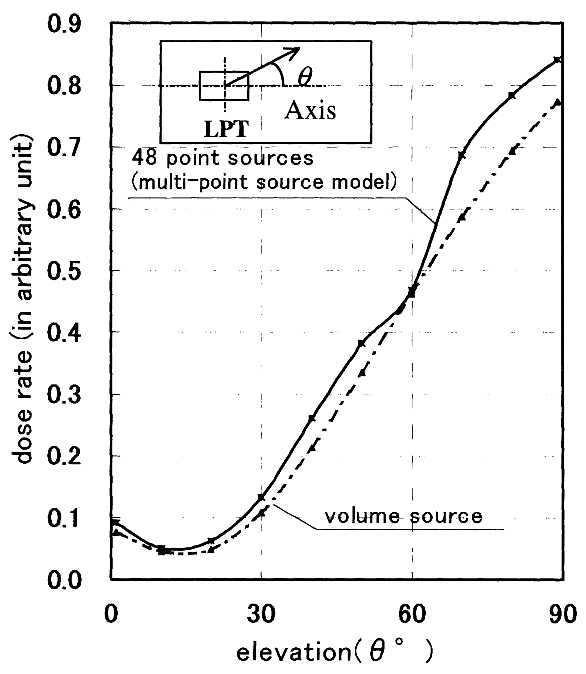

Fig.3 Angular distribution of dose rate from the LPT calculated with the QAD code with volume source and multi-point source model

building with the SKYSHINE-CG code and the SKYSHINE code.

1. The profile of Turbine Building

Figure1 shows layout of the 500MWe BWR turbine building. Main steam generated in the reactor is provided into a high pressure turbine (HPT) via HPT inlet pipes. And then, the steam exhausted from the HPT is provided into two low pressure turbines (LPTs) via LPT inlet pipes. The equipment to be considered in the calculation is one HPT, HPT inlet pipes, two LPTs and LPT inlet pipes.

2. Modeling of Sources

In both the SKYSHINE code and the SKYSHINE-CG code, gamma-ray source in the turbine building is modeled with a set of point sources. Gamma-ray source in the inlet pipes can be easily modeled because of their simple geometry. On the other hand, gamma-ray source in the turbine can not be easily modeled because of its complicated geometry.

In the SKYSHINE analysis, gamma-ray source in the turbine is modeled with an equivalent point source of which intensity is determined with point kernel method. In the SKYSHINE-CG analysis, gamma-ray source in the turbine is modeled considering geometry of the turbine brads room and density of the steam. The gamma-ray source in the turbine is usually translated into 30-50 point sources. Self-shielding effect of the turbine is considered as structure model assembled with the CG routine.

Figure2 illustrates gamma-ray source in the LPT and its multi-point source model consisting of 48 point sources. In order to verify the accuracy of the model, calculations of dose rate around the LPT was performed with the point kernel code QAD-CG[3] for the multi-point source model and for the exact volume source model. **Figure 3** compares the calculated angular distribution of dose rate around the LPT between the two

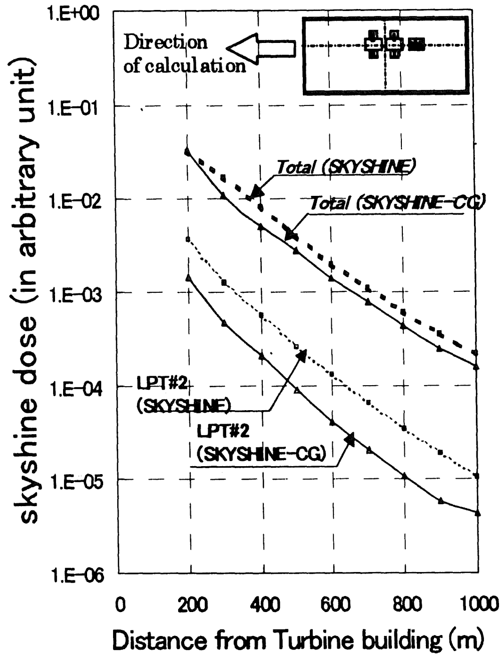

Fig. 4 Comparison of calculated skyshine dose between SKYSHINE results and SKYSHINE-CG results

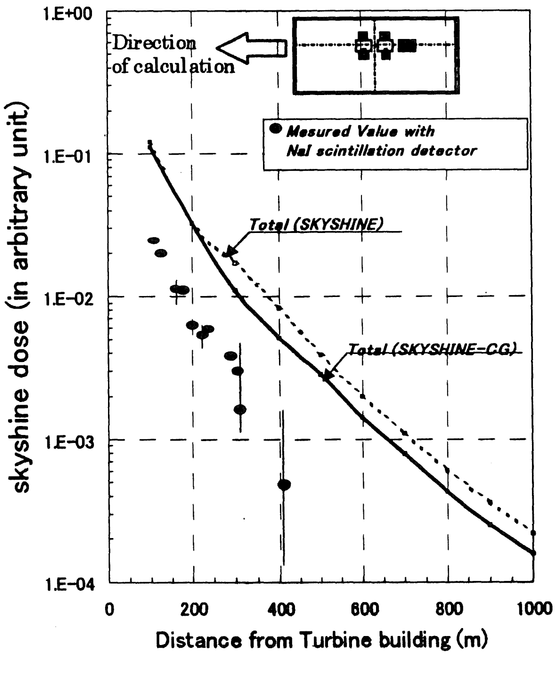

Fig. 5 Comparison of skyshine dose between measured data and calculated one.

models. The curve calculated with multi-point source model shows good agreement with one calculated with the volume source.

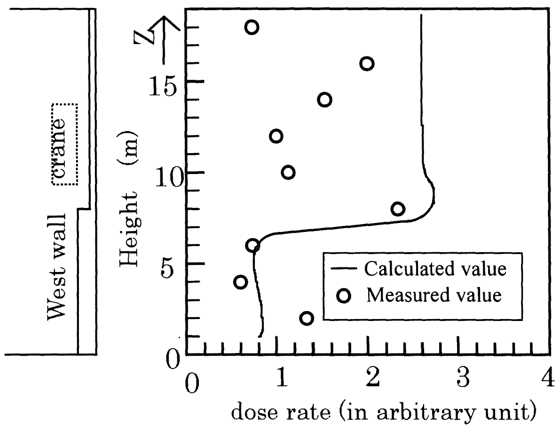

Fig. 6 Comparison of dose rate at outer surface of a building wall between calculation and measurement

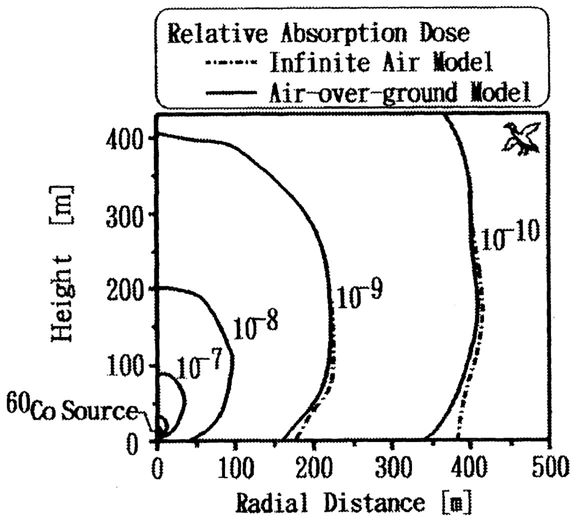

Fig.7 Iso-dose contours for 1.3MeV gamma-ray skyshine dose calculated with DOT3.5 code using two different models; infinite air model and air-over-ground model.

IV. Result and Discussion

Figure4 compares calculated skyshine dose rate between the SKYSHINE-CG results and the SKYSHINE results. The total skyshine dose rate calculated with the SKYSHINE-CG code is smaller than one calculated with the SKYSHINE code by factor 1.5. This resulted from the difference between turbine contributions. As for the LPT contribution, the SKYSHINE results are larger than the SKYSHINE-CG results by factor 2.0. In the SKYSHINE calculation, angular distribution of gamma-ray from turbine is assumed to be isotropic, whereas the actual distribution is anisotropic as shown in Fig.3. As the results, emission of gamma-ray to lower elevation (θ<40°) is overestimated.

Figure 5 shows comparison of skyshine dose rate between calculated results and measured one obtained with a NaI(Tl) scintillation detector. Calculational error was found to be reduced by adopting three-dimensional model assembled with the CG routine.

Discrepancy between the SKYSHINE-CG results and the measured data is considered to be caused by,

(1) calculational error of gamma-ray transmission from source to the outer surface of the building.

(2) Calculational error of gamma-ray propagation in the atmosphere.

The former was investigated by comparing dose rate on the outer surface of the building between calculated data and measured data obtained with TLDs. The calculated data was obtained with point kernel method using the same model as the SKYSHINE-CG calculation.

Figure 6 compares distribution of dose rate on the outer surface of the turbine building wall between measurement and calculation. The measured dose rate distribution shows a hollow in the area of Z=10m - 15m, which is considered to be caused by shielding effects of a ceiling crane, which was not modeled in the SKYSHINE-CG calculation. If a calculation including the ceiling crane model were done, the C/E value 4.0 would be reduced to 3.5.

The latter is ambiguity of the gamma-ray propagation data in the database incorporated in the SKYSHINE and the SKYSHINE-CG codes. The data are the ones prepared by Monte Calro calculation, of which model consisted of a infinite atmosphere region and a gamma-ray source at the center. The simplified model eliminating the existence of the ground may not yield enough accuracy in the analysis of dose rate near the ground surface.

Figure 7 shows an example of skyshine analysis performed for the purpose of investigating the influence of ground on the skyshine dose rate. The calculation was made with the DOT3.5[4] code using two different models; a uniform atmosphere model having a point source at the center, and an air-over-ground model consisting of the atmosphere and the ground expressed as a soil region having a thickness of 50cm. Figure 7 suggests that the dose rate near the ground surface is lower than predicted from the infinite air model calculation because of gamma-ray absorption in the soil.

If the influence of the ground on the skyshine dose rate were reflected in the gamma-ray propagation data, the accuracy of the calculation would be upgraded.

V. Conclusion

We have been developing the SKYSHINE-CG code by incorporating the CG routine into the SKYSHINE code for the purpose of upgrading calculational accuracy. Skyshine dose rate from a 500MWe BWR turbine building was calculated with both the SKYSHINE-CG code and the SKYSHINE code. As the results, the C/E values for the SKYSHINE-CG calculation were scattered around 4.0, whereas the ones for the SKYSHINE calculation were as large as 6.0. Calculational error was found to be reduced as factor 1.5 by adopting three-dimensional model assembled with the CG routine.

— References —

(1) SKYSHINE: RSIC Computer Code collection, *CCC*-289 (1976).
(2) Engle Jr.,W. W. : ANISN, *K*-1693 (1967).
(3) QAD-CG: RSIC Computer Code collection, *CCC*-307.
(4) DOT.3.5:RSIC Computer Code collection, *CCC*-276.