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Application of Improved Air Transport Data and Wall Transmission/Reflection Data in the SKYSHINE Code to Typical BWR Turbine Skyshine

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Three basic sets of data, i.e. air transport data and material transmission/reflection data, included in the SKYSHINE program have been improved using up-to-data and methods, and applied to skyshine dose calculations for a typical BWR turbine building. The direct and skyshine dose rates with the original SKYSHINE code show good agreements with MCNP Monte-Calro calculations except for the distances less than 0.1 km. The results for the improved SKYSHINE code also have agreements with the MCNP code within 10 - 20 %. The discrepancy of 10 - 20 % can be due to the improved concrete transmission data at small incident and exit angles. We still improve the three sets of data and investigate with different calculational models to get more accurate results.

KEYWORDS : shyshine, gamma-ray, BWR, turbine building, ^{16}N, 6.2MeV, the SKYSHINE code, the EGS4 Monte-Carlo code, the Invariant Embedding (IE) method, air transport data, material transmission data, material reflection data

I. Introduction

The SKYSHINE program[(1)] is a skyshine calculation code for ^{16}N gamma-ray sources. This code is used in site boundary dose evaluations for Japanese boiling water reactor (BWR) turbine buildings. Three basic sets of data, i.e. air transport data for gamma rays $\leqq$ 6.2 MeV, and material transmission/reflection data for 6.2 MeV gamma-rays, are included in this program. We have been improving these data by using up-to-date data and methods to get more accurate results. In this paper, the overall study and performance evaluation this work are presented and discussed. Preparation of these new data is discussed in separate papers.

As a first step, the air transport data, which are air scattered dose rates for point monodirectional sources located in an infinite medium of air as a function of gamma-ray energy, source-receiver separation distance and the angle between the source emission direction and the source-receiver axis have been calculated with the EGS4 Monte-Carlo code[(2)] and approximated with a four-parameter formula. The parameters have been stored in the SKYSHINE code and tested by a sample problem representing a typical turbine building. The calculated results have been compared with those using the original data computed by the COHORT Monte-Carlo code[(3)].

As a second step, the material transmission/reflection data, which are given as a function of incident polar angle, slab thickness, exit polar angle and exit energy, incident polar angle, exit polar angle and exit energy respectively, have been calculated with the Invariant Embedding (IE) method[(4)] and tested with the same problem as mentioned above. The calculated results have been compared with those using the original data computed by the one-dimensional discrete ordinates transport code ANISN[(5)].

As a final step, the skyshine calculations with the original and the improved SKYHINE codes have been compared with MCNP[(6)] Monte-Carlo calculations.

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II. Improvement of Air Transport, Material Transmission and Reflection Data

1. Air Transport Data

The air transport data[(1, 7)] stored in the SKYSHINE code are given as a function of energy, source-receiver separation distance, and the angle between the source emission direction and

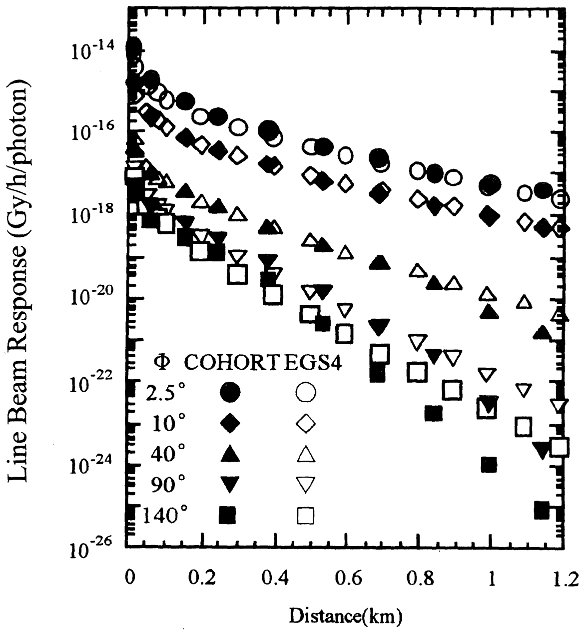

Fig. 1 Line Beam Response at Emitted Angles Ranging from 2.5 to 140 Degrees for 6.2MeV Gamma-ray.

the source-receiver axis. These have been computed for an air density of 1.239×10^{-3} g/cm^3 with the COHORT Monte-Carlo code at 4 gamma-ray source energies ranging from 0.6 to 6.2 MeV, 10 distances from 40 to 3750 feet and 18 angles from 0 to 180 degrees.

New air transport data have been computed for an air density of 1.225×10^{-3} g/cm^3 with the EGS4 Monte-Carlo code at 7 gamma-ray source energies ranging from 0.5 to 10 MeV, 24 distances from 10 to 2000 meters and 19 angles from 0 to 170 degrees and approximated with a four-parameter formula[8]. The approximated four parameters have been stored in the SKYHINE code.

Figure 1 shows the air transport data calculated by the EGS4 code at 6.2 MeV gamma-ray for example together with those by the COHORT code. The data of the EGS4 code are corrected to the air density used in the COHORT calculations with methods described by Zerby[9]. Both air transport data have good agreements at the angles between 2.5 and 10 degrees or the distances less than 0.3 km. The other data of the COHORT code get smaller than those of the EGS4 code with distances, possibly due to statistic problems. The updated air transport data were therefore improved at this point for each gamma-ray energy.

2. Material Transmission and Reflection Data

The material transmission and reflection data[1] are given as a function of incident polar angle, slab thickness, exit polar angle and exit energy, and incident polar angle, exit polar angle and exit energy, respectively. The transmission data computed with the one-dimensional discrete ordinates transport code ANISN and stored in the SKYSHINE code are given at 8 incident and 8 exit polar angle intervals ranging from 0.0 to 90 degrees, 10 thickness from 12.2 to 160 cm for concrete slabs

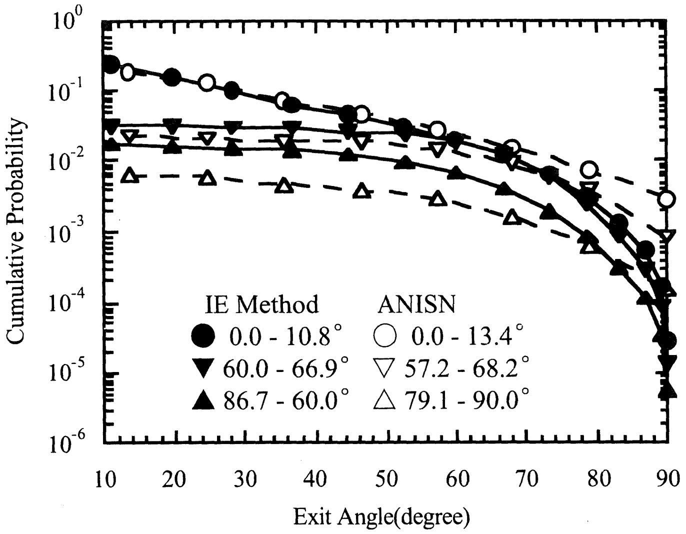

Fig. 2 Cumulative Probability for Exit Energies of Concrete Transmission Data for 12.2 cm Thick Concrete Slab (Parameter : Incident Angle).

and from 4.3 to 38.7 cm for steel slabs, and 16 exit energy intervals from 0.02 to 6.5 MeV. The reflection data computed with the OGRE Monte-Carlo code[10] and stored in the SKYSHINE code are given at 7 incident and 10 exit polar angle intervals ranging from 0.0 to 90 degrees, and 20 exit energy intervals from 0.02 to 6.2 MeV for the same materials as the transmission data.

New transmission data have been calculated with the IE method at 14 incident and 14 exit polar angle intervals ranging from 0.0 to 90 degrees, and 16 exit energy intervals from 0.02

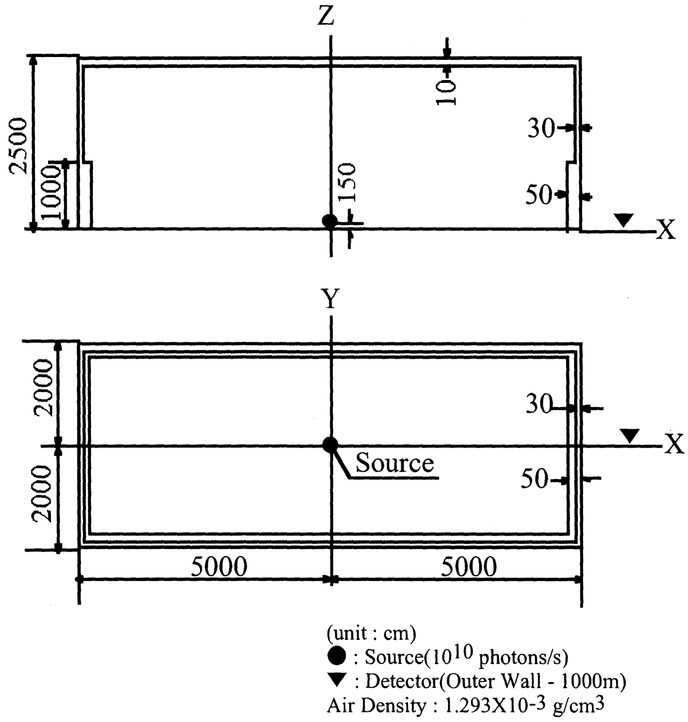

Fig. 3 Skyshine Calculational Model of a Typical BWR Turbine Building.

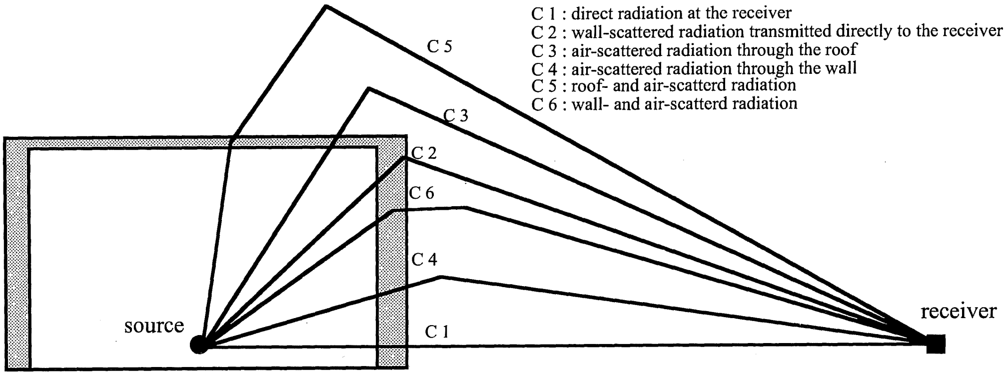

Fig. 4 Contributions of Direct and Skyshine Dose Rates Calclulated by the SKYSHINE Code.

to 6.5 MeV for the same slabs as the original data. New reflection data have been computed with the IE method at 14 incident and 14 exit polar angle intervals ranging from 0.0 to 90 degrees, and 20 exit energy intervals from 0.02 to 6.5 MeV for the same materials as the original data. Both data sets have been stored in the SKYHINE code.

Figure 2 shows the transmission data for the concrete slab calculated by the IE method at 6.2 MeV together with those by the ANISN code. The smooth and consistent differential transmission and reflection data over whole angle and energy have been compared with the original data.

III. Calculations

1. SKYSHINE Calculations

Figure 3 shows a skyshine calculational model for the SKYSHINE code. A 100 m x 40 m x 25 m BWR turbine building is used as the typical geometry. Each of the four walls is composed of concrete which thickness is 50 cm from the floor to 10 m height and 30 cm from 10 m height to the roof. The roof is also composed of concrete which thickness is 10 cm. An isotropic ^{16}N gamma-ray point source, emitting $1x10^{10}$ photons/s, is placed at 1.5 m height above the floor and at the center of the floor. An air density of $1.293x10^{-3}$ g/cm^3 is used. Calculations are done at distances up to 1 km. The reflection of the concrete slabs are not taken into account. The SKYSHINE code computes dose rates of six contributions shown in **Fig. 4**. Air scattered gamma rays (contributions without C1 and C2) are treated as "skyshine" contribution and "direct" contribution, i.e. gamma rays directly reach detectors without scattering (C1) or after scattering in the wall or in the roof (C2).

2. MCNP Calculations

The same calculational model shown in Fig. 3 and the same gamma-ray source are used in MCNP calculations. Reflections of the floor and the ground are not taken into account as the SKYSHINE code is not taken them into account. Point estimators are set at distances from the outer wall to 1 km. $5x10^7$ histories of gamma-rays are followed to get a standard deviation of the calculated dose rates within a 1 %.

IV. Results and Discussion

As a first step, direct and skyshine gamma-ray dose rates were calculated using the COHORT and EGS4 air transport data by the SKYSHINE code. **Figure 5** shows the comparison of the dose rates with both air transport data. The direct dose rates are the same for both cases because of using the same transmission data. The skyshine dose rates with the EGS4 air transport data are slightly higher than those with the COHORT data at distances from the outer wall to 0.1 km or over 0.6 km. Deviations of "skyshine" and "direct+skyshine" between each air transport data, however, are within 4 % and a 1 % maximum defference, respectively. The improved air trans-

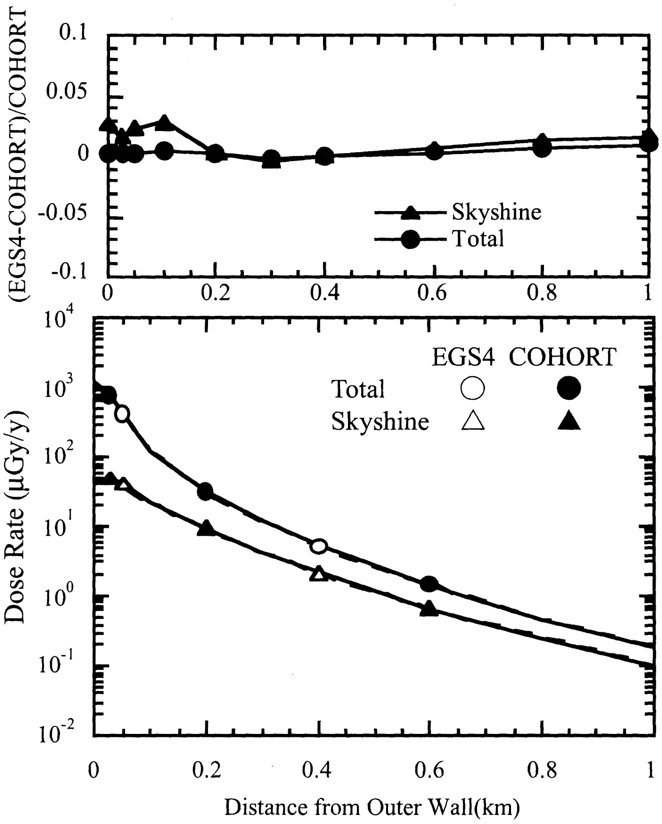

Fig. 5 Direct and Skyshine Dose Rates with EGS4 and COHORT Air Transport Data.

port data shown in Fig. 1 affect few for the skyshine dose rates, as the air scattered gamma-ray dose rates through the wall between the source and receivers are dominant for the calculational model.

As a second step, direct and skyshine gamma-ray dose rates with the concrete transmission data computed by the IE method were compared with those with the ANISN code. As shown in **Fig. 6**, the direct and the skyshine dose rates with the transmission data by the IE method are 10 - 20 % higher than those with the ANISN transmission data especially at distances from 0.05 to 0.1 km. This discrepancy can be due to the differences of the transmission data at small incident and exit angles as mentioned below.

As a final step, **Fig. 7** shows total gamma-ray dose rates with both original and improved SKYSHINE codes together with the MCNP calculations. The results with the original SKYSHINE code have good agreements with the MCNP calculations. The discrepancy of dose rates at distances less than 0.1 km is observed which may be due to the concrete transmission data because the direct dose rates (C1 and C2 contributions) are dominant at this distances. The results for the improved SKYSINE code also have agreements with the MCNP code within 10 - 20 %. The discrepancy of the calculations with both SKYSHINE codes can be due to the concrete transmission data at small incident and exit angles because the wall-scattered dose rates transmitted directly to the receivers (C2) and the wall- and air-scattered dose rates (C6) are main contributions and changed according to the transmission data shown in **Fig. 8**.

Improvements of the three sets of data are still needed to get more accurate results, especially the concrete transmission data at small incident and exit angles.

V. Conclusions

Air transport data, material transmission and reflection data in the SKYSHINE program have been improved with the EGS4 Monte-Carlo code and the IE method, and applied to skyshine dose calculations for a typical BWR turbine building.

The skyshine and the total dose rates with the EGS4 air transport data are slightly higher than those with the original COHORT data but their deviations are within 4 % and a 1 % maximum defference, respectively. Both direct and skyshine dose rates with the concrete transmission data by the IE method are 10 - 20 % higher than those with the original ANISN transmission data because of the differences of the transmission data at small incident and exit angles.

The results with the original SKYSHINE code have good agreements with MCNP Monte-Calro calculations except for the distances less than 0.1 km. The results with the improved SKYSINE code also have agreements with the MCNP code within 10 - 20 %.

Improvements of the three sets of data and investigations with different calculational models are still needed to get more accurate results.

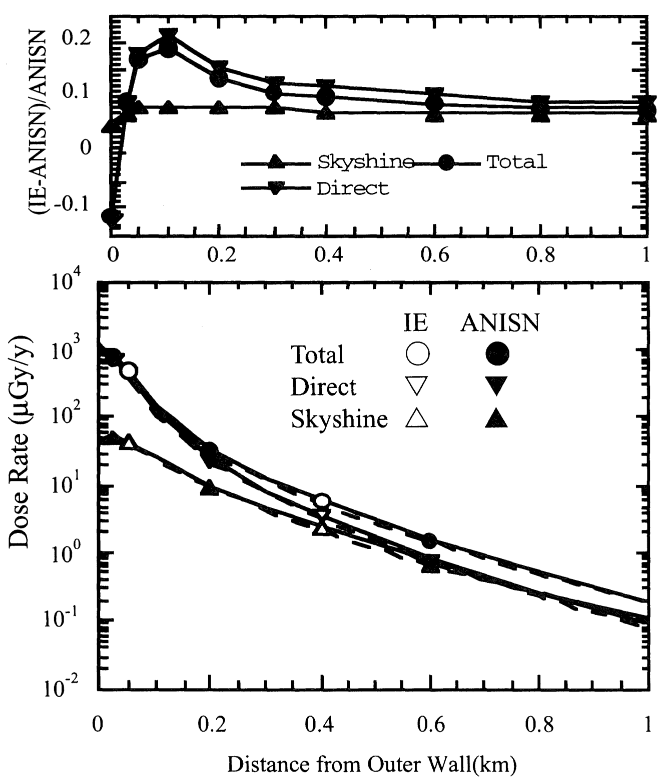

Fig. 6 Direct and Skyshine Dose Rates with IE Method and ANISN Transmission Data for Concrete.

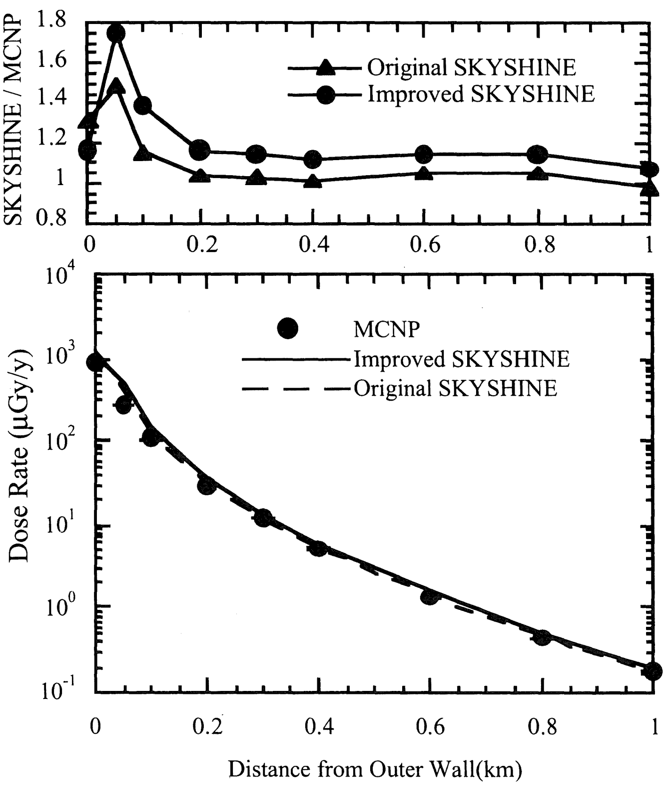

Fig. 7 Total Dose Rates Calculated by Original and Improved SKYSHINE Codes Together with MCNP Calculations.

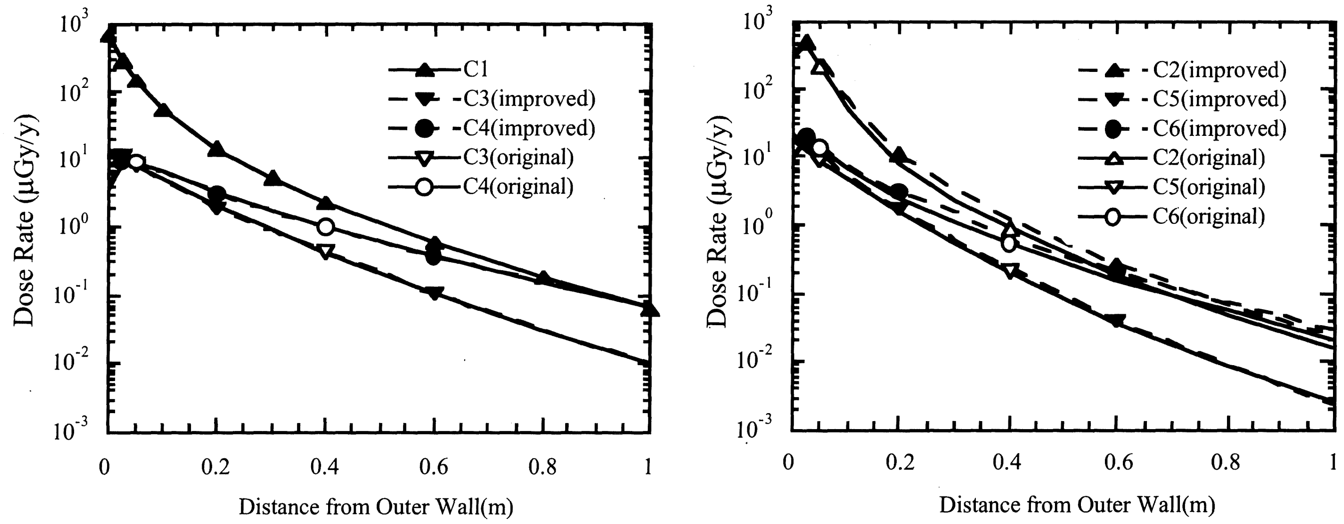

Fig. 8 Contributions of Direct and Skyshine Dose Rates Calculated by Original and Improved SKYSHINE Codes.

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