Verification of BWR Turbine Skyshine Dose with the MCNP5 Code Based on an Experiment Made at SHIMANE Nuclear Power Station*

Ryuichi TAYAMA**, Kenichi WAKASUGI**, Ikunori KAWANAKA***, Yoshinobu KADOTA*** and Yasuhiro MURAKAMI**

**Hitachi-GE Nuclear Energy, Ltd.,
3-1-1, Saiwai-cho, Hitachi-shi, 317-0073, Japan
E-mail: ryuichi.tayama.jc@hitachi.com
***The Chugoku Electric Power Co., Inc.,
4-33, Komachi, Naka-ku, Hiroshima, 730-8701, Japan

Abstract
We measured the skyshine dose from turbine buildings at Shimane Nuclear Power Station Unit 1 (NS-1) and Unit 2 (NS-2), and then compared it with the dose calculated with the Monte Carlo transport code MCNP5. The skyshine dose values calculated with the MCNP5 code agreed with the experimental data within a factor of 2.8, when the roof of the turbine building was precisely modeled. We concluded that our MCNP5 calculation was valid for BWR turbine skyshine dose evaluation.

Key words: BWR, Skyshine, Monte Carlo, MCNP5

1. Introduction
Accurate calculations of skyshine dose at the site boundary of Boiling Water Reactors (BWRs) are very important in Japan since the small site area has a possibility of resulting in a high radiation dose at the site boundary. Main contribution of the skyshine dose is photons emitted from the turbine building (T/B). The SKYSHINE code (1) is generally employed in the skyshine dose calculation, but it sometimes yields excessively conservative results due to the uncertainty resulting from code limitations, such as geometry modeling and the setting of source strength. We planned to use the MCNP5 code (2) in order to eliminate that uncertainty. However, few experimental data or benchmark calculations concerning the skyshine dose for BWRs have been reported (3).

In this study, we measured the following items for comparison with calculations using the MCNP5 code for NS-1 and NS-2 in order to confirm applicability of the code.

(1) Radioactivity concentrations in main units of turbine equipment, (i.e., high pressure turbine (HPT), low pressure turbines (LPT) and their inlet pipes) using an ionization chamber and a Ge semiconductor detector
(2) Dose equivalent distribution on the roof and outer walls of the turbine buildings using the ionization chamber and thermoluminescence dosimeters (TLDs)
(3) Skyshine dose distribution at the site using a NaI (Ti) scintillation detector
2. Experiments

2.1 Radioactivity concentrations in turbine equipment

Table 1 lists the radioactive nuclides detected around the turbine equipment. These nuclides are produced in a reactor core by neutron reaction, and then transferred to the HPT and LPTs. The nuclides emit photons through their decay and are the main source of radiation in turbine buildings.

Table 1 Radioactive Nuclides detected around the turbine equipment

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Reaction</th>
<th>Photon energy (MeV)</th>
<th>Photon emission rate</th>
<th>Half life (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N-16</td>
<td>O-16(n,p)N-16</td>
<td>7.12</td>
<td>0.049</td>
<td>7.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6.13</td>
<td>0.67</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2.74</td>
<td>0.0082</td>
<td></td>
</tr>
<tr>
<td>C-15</td>
<td>O-18(n,α)C-15</td>
<td>5.3</td>
<td>0.632</td>
<td>2.449</td>
</tr>
<tr>
<td>O-19</td>
<td>O-18(n,γ)O-19</td>
<td>1.36</td>
<td>0.504</td>
<td>26.88</td>
</tr>
</tbody>
</table>

Pulse height spectra around the equipment in each turbine building were measured in order to determine the radioactivity concentration in the equipment. Figures 1 and 2 show the experimental arrangement for NS-1 and NS-2, respectively. The Ge semiconductor detector employed is the trans-SPEC-100 with 40% efficiency, manufactured by Advanced Measurement Technology, Inc., and is collimated with 3-cm thick lead. The detector was set 5 to 7 m away from the inlet pipes of the HPT or LPTs to avoid a dead time problem. Dose equivalent values around the equipment were also measured with the VIC-95 ionization chamber manufactured by ALOKA Co., Ltd.

The radioactivity concentration for each nuclide was ultimately determined with the pulse height spectra and the dose equivalent values.

2.2 Dose equivalent on the roof and outer walls

The photon dose equivalent distribution on the roof and outer walls for NS-1 and NS-2 were measured as shown in Figs 1 and 2, respectively. The VIC-95 ionization chamber and the TLDs (UD200S) manufactured by Panasonic Corporation were used. The experimental dose equivalent values with the TLDs on the outer walls for NS-2 were background level, thereby indicating a negligible skyshine dose from the walls.

2.3 Skyshine dose in the site

Pulse height spectra at the site of the Shimane Nuclear Power Station were measured with a 3” x 3” cylindrical NaI(Tl) scintillation detector (1212/DM) manufactured by Ohyo Koken Kogyo Co., Ltd., surrounding a collimator with 5-cm thick lead to reduce background noise. Figure 3 shows the measurement points for NS-1 and NS-2. Experimental data were taken twice: once during plant operation and once during plant shutdown (background).

The $G(E)$ function method ($^4$) was applied to the conversion from pulse height spectra to air kerma.

The photon air kerma ($D$) is given by:

$$D = \sum_{I=1}^{n_{\text{max}}} N(I) \cdot G(I)$$

where, $N(I)$ is the pulse height spectrum and $G(I)$ the $G(E)$ function of photon energy $E$ at channel $I$ given in Ref. (4).
Fig. 1 Measurement points of dose equivalent and radioactivity concentration for NS-1.

Fig. 2 Measurement points of dose equivalent and radioactivity concentration for NS-2.
3. Calculations

The MCNP5 code was employed. The MCPLIB02 library (5) implemented in the code provided the cross-section data used in calculations.

The main units of equipment, concrete walls and roof including the deck-plate shown in Figs 1 and 2 were precisely modeled. The thickness of the concrete walls and roof, and their density were conservatively set according to the precondition of our radiation shielding design. The overhead traveling crane, its concrete girder, and the roof truss were not taken into account.

Table 2 summarizes the radioactivity concentrations in the equipment as determined by analysis described in § 2.1, and are used in the MCNP5 calculations. The concentration of N-16 used in our radiation shielding design is based on the recommended value at reactor pressure vessel (RPV) nozzle written in NEDO-20206 (6). The N-16 concentrations at each RPV nozzle of NS-1 and NS-2, which are calculated with the evaluated concentrations shown in Table 2 and decay time from the RPV nozzle to the HPT inlet pipe, are $8.73 \times 10^5$ and $8.82 \times 10^5$ Bq/g, respectively, and are approximately one-half of the recommended value. The concentrations of O-19 for NS-2 are lower than those for NS-1 because of the large statistical error especially for NS-2. The influence of the error on calculated dose equivalent values is negligible because the concentrations and photon energy of O-19 are lower than those of other nuclides.

Photon dose values were calculated using a point detector or surface tally. The photon fluence to dose equivalent and air kerma conversion factors are based on ICRP Publ. 74.

The $10^7 - 10^8$ photon histories were followed until the fractional standard deviation of the calculated values reaches within 5%. Weight windows with three energy bins were adapted as a statistical variance reduction technique.
Table 2 Evaluated radioactivity concentrations of main equipments for NS-1 and NS-2 used in the MCNP5 calculations

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Radioactivity Concentration (Bq/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NS-1</td>
</tr>
<tr>
<td></td>
<td>N-16</td>
</tr>
<tr>
<td>HPT inlet pipe</td>
<td>1.78E+04</td>
</tr>
<tr>
<td>HPT inlet</td>
<td>1.52E+04</td>
</tr>
<tr>
<td>exhaust</td>
<td>2.82E+03</td>
</tr>
<tr>
<td>LPT inlet pipe</td>
<td>2.44E+03</td>
</tr>
<tr>
<td>LPT inlet</td>
<td>2.28E+03</td>
</tr>
<tr>
<td>exhaust</td>
<td>1.50E+01</td>
</tr>
</tbody>
</table>

HPT: high pressure turbine, LPT: low pressure turbine

4. Results and discussion

Figure 4 compares the experimental and calculated dose equivalent distribution on each roof of NS-1 and NS-2. The dose equivalent values calculated with the MCNP5 code represent the experimental data within a factor of 2.4.

Figure 5 shows the experimental and calculated dose equivalent distribution on the outer wall for NS-1. The calculated dose equivalent at a height of 10.7 m from the floor is six times larger than the experimental data. This discrepancy is considered to be due to a radiation shielding effect of the concrete girder for the overhead traveling crane, which is not modeled in the calculation. Except for this point, the calculated dose equivalent values show good agreement with the experimental data within a factor of 1.7.

Figure 6 shows the calculated dose equivalent distribution on the north wall for NS-2 compared with the experimental data. The calculated dose equivalent values show good agreement with the experimental data within a factor of 1.5.

Figures 7 and 8 show the calculated skyshine dose distribution together with the experimental data for NS-1 and NS-2, respectively. The maximum statistical error of the experimental data is 16.3%. The calculated values are overestimated in the direction west of NS-2 especially at two points over 200m, distance from LPT (B). This is considered to be due to a radiation shielding effect of the overhead traveling crane and roof truss, which MCNP calculation does not take into account. The calculated dose values in the direction north of both NS-1 and NS-2 show good agreement with the experimental data within a factor of 2.8 - almost consistent with results obtained on the roof as previously described.

The radiation shielding effect of the deck-plate and additional concrete on the roof is normally not taken into account in radiation shielding calculations (simplified structure). Figures 9 and 10 compare the skyshine dose distribution using actual and simplified structures. The dose values calculated with the simplified structure are 1.5 times higher than those with the actual structure. This means that the calculated skyshine dose with the simplified structure has a 50% safety margin.

The present MCNP5 calculation with detailed turbine building model was found to be valid.

5. Conclusions

We concluded that the skyshine dose calculated by using MCNP5 showed good agreement with the experimental data within a factor of 2.8, when the radiation shielding effect of the deck-plate and additional concrete on the roof was precisely taken into account.

The MCNP5 code is therefore effective for accurate calculations of skyshine dose from the turbine building of BWRs.
Fig. 4 Experimental and calculated dose equivalent distribution on the roofs of each turbine building.

Fig. 5 Experimental and calculated dose equivalent distribution on the outer wall for NS-1.

Fig. 6 Experimental and calculated dose equivalent distribution on the north wall for NS-2.
Fig. 7 Experimental and calculated skyshine dose distribution for NS-1.

Fig. 8 Experimental and calculated skyshine dose distribution for NS-2.

Fig. 9 Comparison of calculated skyshine dose distribution with actual and simplified structures of turbine building for NS-1.
Fig. 10 Comparison of calculated skyshine dose distribution with actual and simplified structures of turbine building for NS-2.

References

(2) RSIC CODE PACKAGE CCC-710, MCNP5: Monte Carlo N-Particle Transport Code System.