A SKYSHINE BENCHMARK EXPERIMENT

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I. INTRODUCTION

The requirement for the calculation code accurately predicting the skyshine radiation from nuclear facilities has been recently raised with the necessity of shielding design appropriate to the reduction of dose objective to the public. Then many calculation codes have been developed(1,2,3) and benchmark experiments have been performed to make sure of the accuracies for such calculation codes(4,5). The present report describes a skyshine benchmark experiment with the ^{60}Co source distributed in the reactor pressure vessel wall which was activated by neutrons during reactor operation. The γ-rays were emitted upward, and the energy spectrum and the exposure rate up to 300 m from the source were measured with a NaI(Tℓ) spectrometer and a high pressure ionization chamber, respectively. In addition, the vertical distribution of exposure rate up to 500 m of height was measured with a small ionization chamber. On the other hand, the two-dimensional discrete ordinates transport calculation was performed, and consequently compared with the experimental results.

II. EXPERIMENT

Operation of the JPDR, Japan Power Demonstration Reactor, of JAERI has been stopped for several years, however, a fairly large amount of radioactivities induced by neutrons remains in the reactor pressure vessel wall. The principal nuclide is ^{60}Co and it has enough γ-ray strength to perform the present experiment. The schematic view of the JPDR is given in Fig. 1. Usually, the reactor pressure vessel is filled up with water for radiation shielding. In this experiment, the γ-rays were emitted upward and collimated into about 30-deg. conical beam by lowering the water and taking off the shielding plugs.

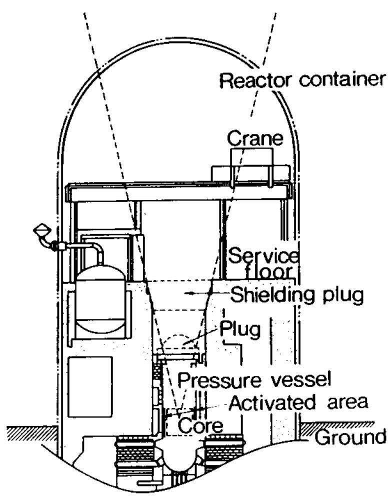

Fig.1 Schematic view of JPDR used as skyshine source

The energy spectrum and the exposure rate were measured with a spherical NaI(Tℓ) spectrometer and a high pressure ionization chamber at a height of 1.5 m above the ground. Measuring points were located at 15, 50, 100, 200 and 300 m on a straight line from the center of the reactor core. The sphericity of the NaI(Tℓ) detector provides for a flat directional sensitivity within 3.5% except for the bottom part. Measured spectra were unfolded with a set of response matrix and converted to the values in exposure rate unit. The high pressure ionization chamber has a spherical stainless steel shell, in which argon gas is filled at 8 atm. The spherical shape provides for the isotropic sensitivity except for the bottom part due to shielding by the electrometer.

A vertical distribution of exposure rate was measured with a small ionization chamber packed with a recorder in a box which was lifted by a 70 m³ kite - balloon at heights of about 50, 100, 150, 200, 300, 400 and 500 m above a point positioned about 100 m from the reactor core. The ionization chamber has a cylindrical shape and a flat energy response more than 60 keV. Two transits observed exact locations of the ionization chamber in each measurement.

III. CALCULATION

The discrete ordinates transport Sn calculation was performed in two stages with the DOT3.5 code. In the first stage, the photon flux inside the reactor container was calculated and then converted into a virtual anisotropic point source on the service floor after normalization to a measured value in terms of exposure rate. The source area in the reactor pressure vessel was specially divided into small meshes. A set of asymmetric Sn constants (166 angles) was used. In the next stage, the skyshine calculation outside the reactor container was performed with the source defined in the previous stage and a set of symmetric S_8 constants (48 angles) was used. In each stage, the photon energy was divided into 11 groups.

IV. RESULTS

The unfolded spectral shapes have no complicated structure and no significant difference each other for all horizontal locations. The spectrum consists of two parts, one has a peak at ∿70 keV and the other at ∿200 keV. The former becomes increasingly shifted to lower energy and the latter to higher energy being inconspicuous with increasing source-to-detector distance. It can be said from brief spectral analysis that the former is due to the photons multiply scattered by air and the latter to the photons scattered by the media nearby the source; e.g. the reactor container and crane in it. From the comparisons of the calculated and measured spectra, it is shown that the accordance between each spectrum becomes to be good

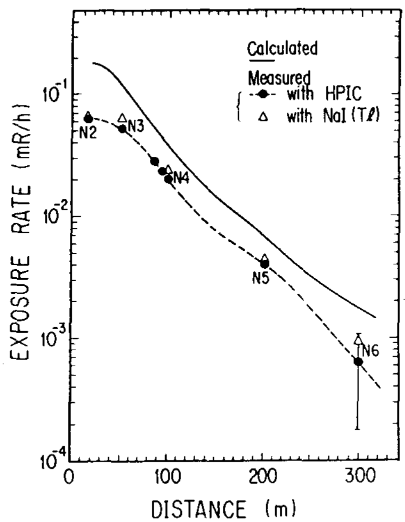

Fig.2 Comparison of calculated and measured horizontal distribution of exposure rate

with increasing source-to-detector distance.

The horizontal distribution of exposure rates decreases in a manner of exponential function with increasing source-to-detector distance in both cases of measurement and calculation, as shown in Fig. 2. From the comparison of the calculated and measured distributions, it is found that the DOT calculation overpredicts the exposure rates by 35 % for the NaI(Tℓ) detector and 50 % for the high pressure ionization chamber. As mentioned before, the virtual point source was used in skyshine calculation instead of the actual source distributed in the reactor pressure vessel wall. Nevertheless, the difference between each result is not so great.

The vertical distributions of exposure rates obtained by measurement and calculation are shown in Fig. 3 as a function of height. The exposure rate decreases with increasing height and its manner is gentle as compared with the horizontal case. From the comparison, the DOT calculation underestimates the exposure rates at all heights more than 100 m. However, the agreement between each result is generally good.

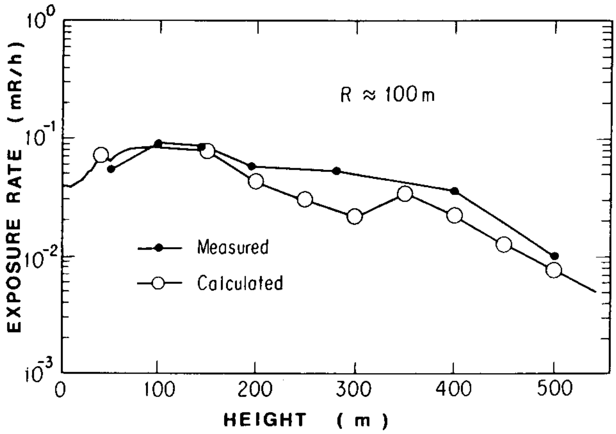

Fig.3 Comparison of calculated and measured vertical distribution of exposure rate. R is distance from reactor axis.

V. CONCLUSION

A skyshine benchmark experiment was carried out in order to make sure of the accuracies for the DOT code and the calculation gave the agreement with the measurement within 50 % in both horizontal and vertical directions. It was shown from this experiment that the DOT calculation predicts appropriately the skyshine exposure rates.

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