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SKYSHINE OF SYNCHROTRON RADIATION

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ABSTRACT

The skyshine of synchrotron radiation was measured at the 5-GeV electron storage ring at KEK. There was a broad peak at 30-70 keV in the measured photon spectra. The photon angular flux from above was 30-200 times larger than that from the floor, though the spectra from both directions were similar. The doses were measured using TL dosimeters and were compared with the calculated results using the G-33[1] code and the Monte Carlo code EGS4.[2] The calculated dose was increased by 30% due to the effect of linear polarization on the scattering.

I. INTRODUCTION

In high-energy electron synchrotrons the shielding of synchrotron radiation (SR) is an important problem because low-energy photons are very intense. There have been a few measurements of doses by scattered SR into air. However, their geometries are complicated and difficult to compare with the calculated results. The SR is emitted tangentially to the beam direction, and is linearly polarized. The scattering is not uniform in the azimuthal angle. The skyshine is affected by this effect because scattering in the vertical direction is enhanced rather than in the horizontal direction.[3] However, such transport calculations are rarely carried out because polarized photon scattering has not been treated in the shielding calculations.

In this work, measurements were made at the experimental hall of the TRISTAN Accumulation Ring of the National Laboratory for High Energy Physics (KEK). Straight vacuum pipes in the hall were not shielded and were located far from the dipole magnets; the scattering geometry was thus simple. Transport calculations were also carried out using the gamma-ray scattering code G-33[1] and Monte Carlo code EGS4.[2]

II. EXPERIMENTAL

In this work, measurements were made at the north experimental hall where a 17-m-long straight section of the electron accumulation ring at KEK is located. A stored current of 5 GeV electrons was between 10 and 20 mA. The vacuum beam pipes in the arc sections were covered with the sufficiently thick lead shield, though the straight aluminum pipe in the hall was not shielded. The bending radius was 23.2 m and the critical energy of the SR was 12.0 keV. The photon spectrum is shown in Fig.1. The degree of linear polarization of the SR was 0.9. The SR was injected to the inside of a straight cylindrical pipe at a very shallow angle of about 5 mrad. Schematic plane views of the vacuum pipes are shown in Fig.2. Both the arc and straight sections are shown, and a side shield wall is parallel to them. In Fig.2 a cross-sectional view of the pipe is also shown. The inner diameter was 108 mm and the aluminum thickness was 5 mm.

The pipe was placed 4.9 m above the floor. The ceiling was 22 m high and the photon scattering in the ceiling was negligible. A 9-m-high shield wall was placed parallel to the pipe. The wall was made of 20-cm thick concrete; there was no additional shielding in the hall.

Both inside and outside the shield wall the absorbed doses to air in free air were measured using thermoluminescence dosimeters (Matsushita UD-170L and 200S) and ionization chambers (Applied Engineering, AE-133). Because photons from 30 to 70 keV were dominant, TL dosimeters, especially the UD-170L type, overestimated the doses by $40 \pm 20\%$. They were therefore corrected using ionization chamber readings. Vertical cross-sectional views of the hall and measurement points are shown in Fig.3, which are 12.5 m distant from the last dipole magnet. The shield wall was sufficiently thick to attenuate single scattered photons from the beam pipe. Outside of the wall the doses were due to skyshine. The photon energy spectra were measured using a 2-mm-thick NaI(Tl) scintillator with a 0.15-mm-thick Be window. A 20-cm-long lead collimator was placed in front of the scintillator, and photons from each direction were measured.

III. CALCULATIONS

Primary-source photons were produced at the arc section. The photon spectrum along the electron beam orbit for a single radiating electron is given as follows:

$$\frac{d^2N}{d\varepsilon dL} = 1.775 \times 10^{-3} E^{-2} \int_r^\infty K_{5/3}(\eta)d\eta \quad \text{(photons per eV per meter)}, \qquad (1)$$

where

r $=\varepsilon/\varepsilon_c$,

ε_c :Critical energy,

E :The electron energy in GeV.

At a distance of between X_0 and $X_0 + \Delta X_0$ from the straight section entrance (Note Fig.2), photons incident on the straight pipe are as follows:

$$\text{Incident photons} = \frac{d^2N}{d\varepsilon dL}\Delta L \text{ (photons per eV)}, \quad (2)$$

where

L $=R\sin\theta_0$,

$L+\Delta L$ $=R\sin(\theta_0+\Delta\theta_0)$,

R : Bending radius.

The vacuum pipe was divided into 1-m-long sections and the SR source spectrum in each section was calculated using Eq(2). The gamma-ray scattering code G33-GP2[1] was used for each photon source, and each dose was summed. Then, the absorbed doses inside the shield wall were calculated since single-scattered photons from the pipe are dominant there.

Another calculation was carried out using the EGS4 Monte Carlo code and the same source spectra from Eq(2). Coherent scattering was included in the calculation. The binding effect for Compton scattering (incoherent scattering) was also considered. The linear polarization effect was considered in the scattering. The absorbed dose to air in free air was calculated using the next event surface crossing estimator and energy-absorption coefficients of air.[4] In each calculation, 10^9 cases ware followed, and the doses were calculated both inside and outside of the shield.

IV. RESULTS AND DISCUSSIONS

The measured photon spectra at point A (in Fig.3) are shown in Fig.4. The spectra from above and those from back are shown. Though the former was 30-times larger than the latter, both shapes were similar. There was a broad peak at 30-70 keV, and no photon above 150 keV. Below 20 keV, photons attenuated rapidly in air. A small peak about 10 keV was due to iodine K X-rays escaping from the detector. The photon spectra were also measured at some other points from different directions; and their shapes were all similar to that shown in Fig.4.

The vertical angular distribution of the photon flux at point A is shown in Fig.5. In the hall, photons from above were 30-200 times more than that from the floor. The photon flux was very anisotropic. Because the angular response of the TL dosimeters is not uniform, this caused an error of up to 60%.

The measured absorbed doses to air were normalized to one mA of the stored electron current, and shown in Fig.6. When the dosimeters were covered with 1-mm-thick lead, the doses were reduced to about 1/200. The calculated doses are also shown in Fig.6. On the whole, they agree with the measured results within a factor 4. The results using G-33 are smaller than those by EGS4. This is partly because coherent scattering is ignored in the former.

This effect was studied using EGS4. When coherent scattering and the binding effect for Compton scattering were ignored, the doses were reduced to 60%. On the contrary, the doses outside the shield were increased by 30% due to the effect of linear polarization on the scattering.

REFERENCES

1. ORNL, RSIC, *G33-GP code package*, CCC-494 (1986). Y.Sakamoto and S.Tanaka, JAERI-M 90-110 (1990).

2. W.R.Nelson, H. Hirayama and D.W.O. Rogers, *The EGS4 code system*, Stanford, California, Stanford University, SLAC-265 (1985).

3. Y.Namito, S.Ban and H.Hirayama, "Implementation of Linearly-Polarized Photon Scattering into the EGS4 Code," *Nucl. Instr. Meth.*, A332, 277-283 (1993).

4. J.H.Hubbell, "Photon Mass Attenuation and Energy-absorption Coefficients from 1 keV to 20 MeV," *Int.J.Appl.Radiat.Isot.*, 33, 1269 (1982).

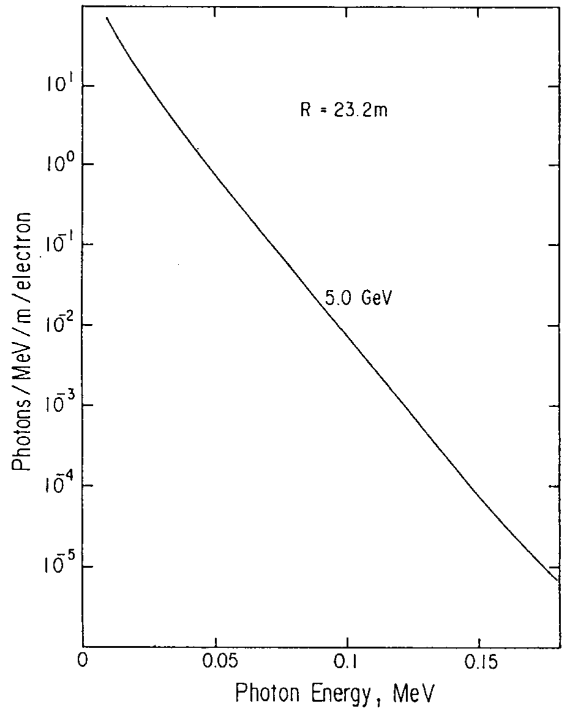

Fig.1 Primary synchrotron radiation spectrum.

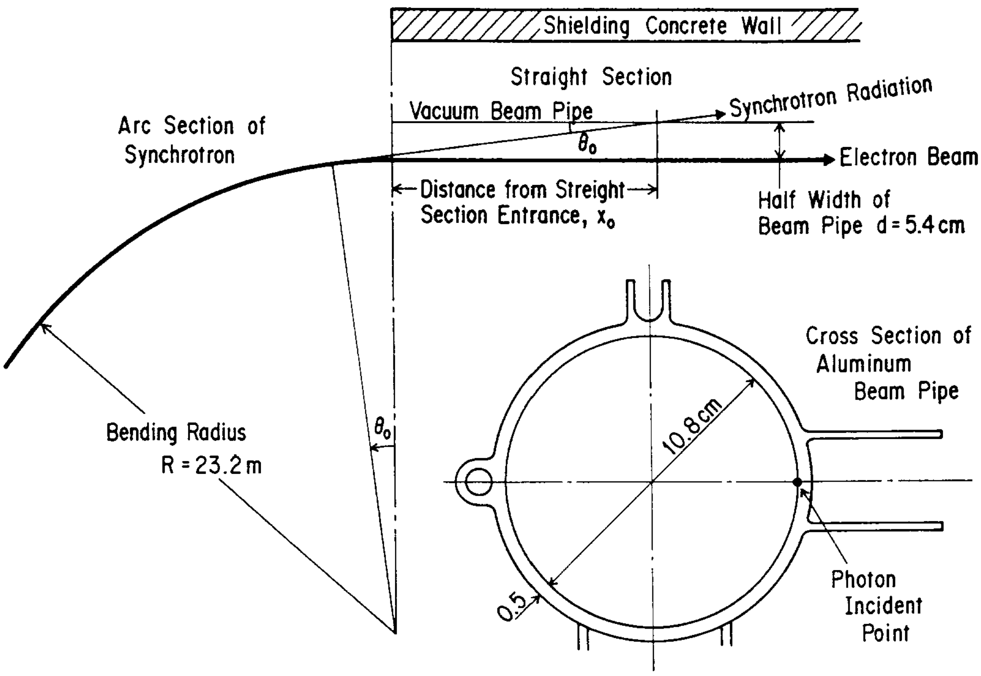

Fig.2 Schematic plane view of the vacuum pipe and a side shield wall. A cross-sectional view of the pipe is also shown.

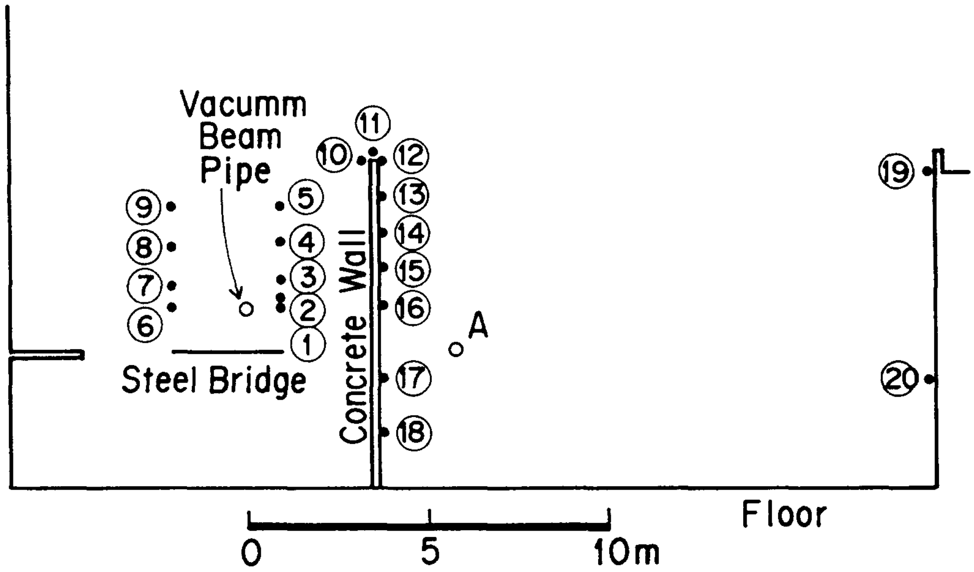

Fig.3 Vertical cross-sectional view of the hall and measurement points.

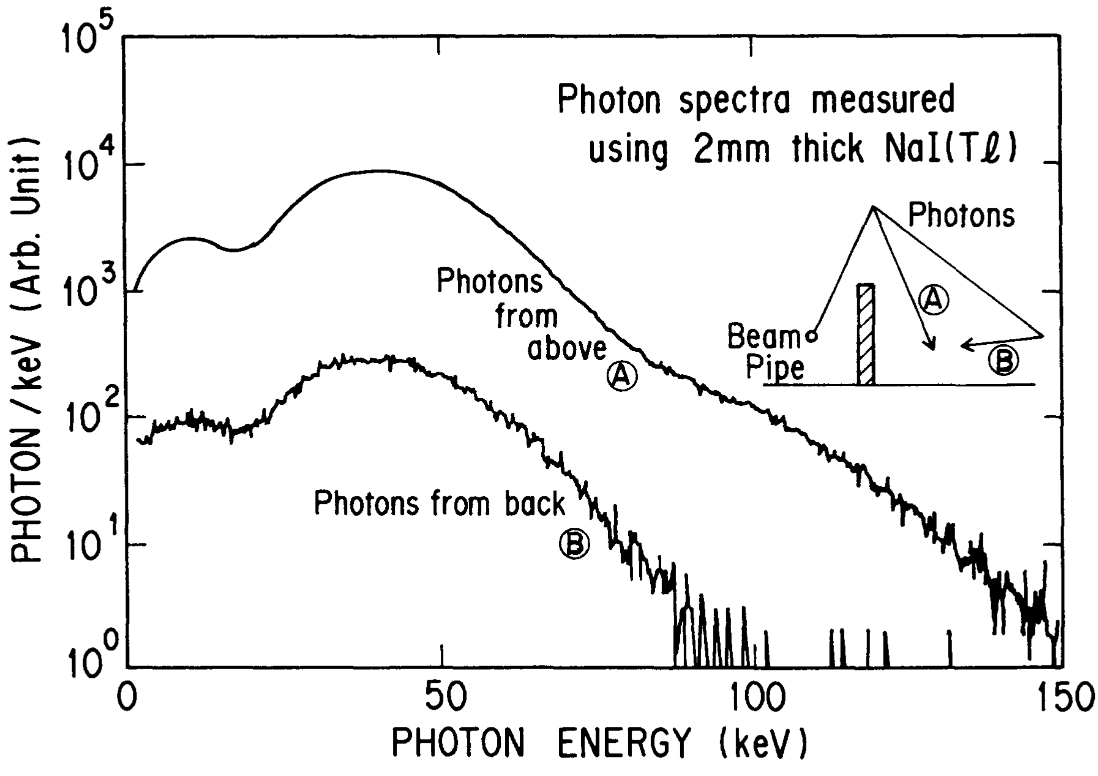

Fig.4 Measured photon spectra at point A in Fig.3. The photon spectra were measured using a 2-mm-thick NaI(Tl) scintillator with a Pb collimator. The spectra from above and those from back are shown.

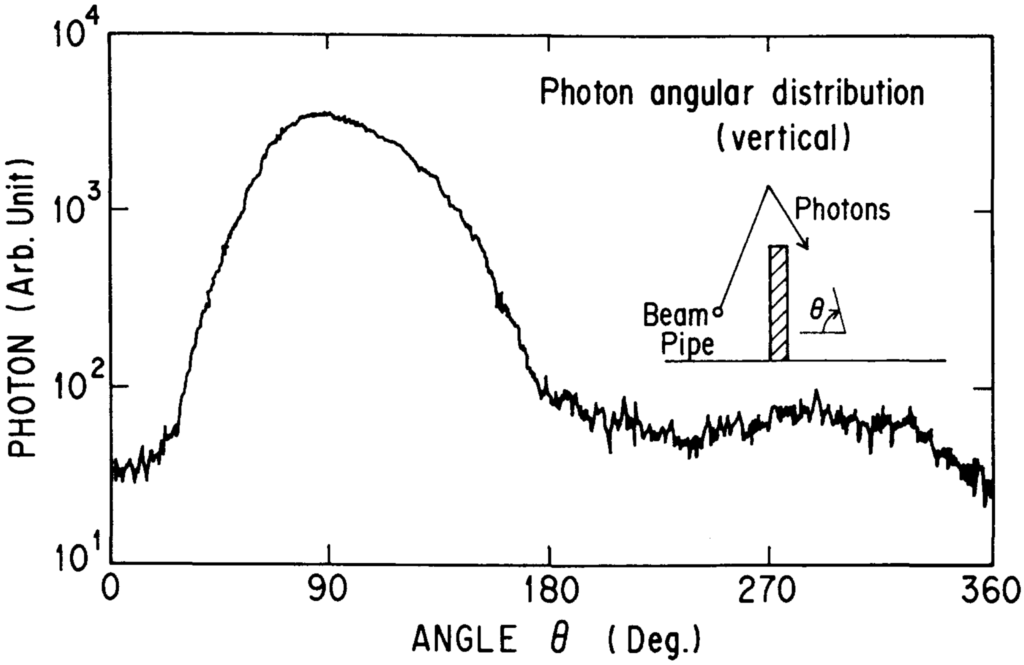

Fig.5 Vertical angular distribution of the photon flux at point A.

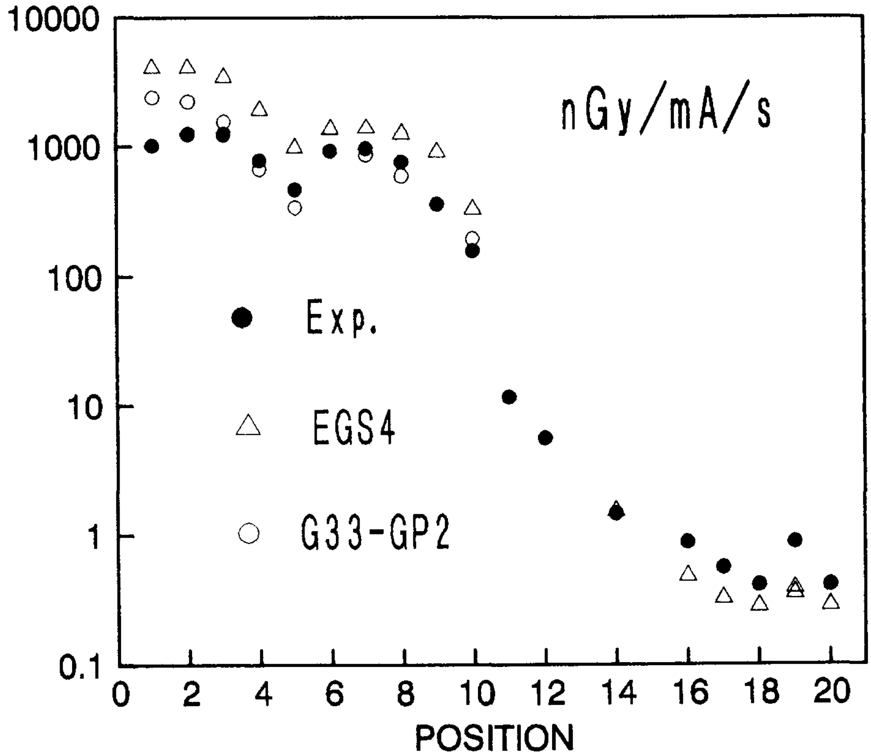

Fig.6 Measured and calculated absorbed doses to air in free air. The measurement points are shown in Fig.3.