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ScienceDirect

Nuclear Data Sheets 120 (2014) 242–245

Nuclear Data Sheets

www.elsevier.com/locate/nds

Benchmark Experiment of Dose Rate Distributions Around the Gamma Knife Medical Apparatus

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Dose rate measurements around a gamma knife apparatus were performed by using an ionization chamber. Analyses have been performed by using the Monte Carlo code MCNP-5. The nuclear library used for the dose rate distribution of ^{60}Co was MCPLIB04. The calculation model was prepared with a high degree of fidelity, such as the position of each Cobalt source and shielding materials. Comparisons between measured results and calculated ones were performed, and a very good agreement was observed. It is concluded that the Monte Carlo calculation method with its related nuclear data library is very effective for such a complicated radiation oncology apparatus.

I. INTRODUCTION

The gamma knife is one of the most popular radiation oncology apparatus which uses ^{60}Co radioisotopes. Since the amount of ^{60}Co in the apparatus is very high, shielding needs to be taken very seriously. In particular, the behavior around the focus point is very complicated due to multiple scattering. The precise estimation of dose rates around the gamma knife apparatus is very important not only for the shielding calculation, but to estimate the patients exposure. Even though the cobalt source is focused at the iso-center (focus point), it can not be considered a point source, since the iso-center is surrounded in all directions with cobalt sources. Because of the complicated nature of the problem, simple calculation methods, such as the point kernel method, can not be applied to estimate dose rates around the gamma knife apparatus. In this study we have performed precise calculation of dose rates distributions around the gamma knife apparatus by using the three-dimensional Monte Carlo code MCNP5 [1] with its related nuclear data library. The measurements of dose rates distributions around the gamma knife apparatus have also been performed and compared with the calculated results to verify the calculated results.

II. GAMMA KNIFE APPARATUS

A cross section view of the gamma knife apparatus is shown in Fig. 1. In the source region, there are 192 homogenized cobalt sources covered with aluminum cases. The activity of each cobalt source is 1.16 TBq and the total activity of the source is 222 TBq. In front of the source there are three kinds of collimators made of tungsten and lead, with diameters of 4, 8 and 16 mm. The shielding body is made of cast iron. In the rear there is a driving instrument for placing the source in "in" or "out" positions.

III. MEASUREMENT

A. Gamma Knife Oncology Room

The floor plan of the gamma knife oncology room with the gamma knife apparatus is shown in Fig. 2. The room is 753 cm long and 510 cm wide. The iso-center is located 145 cm and 198 cm from the left and top walls, respectively. The distance between the floor and the ceiling is 335 cm. The oncology room is shielded by concrete walls. The radiation field spans 45 degrees.

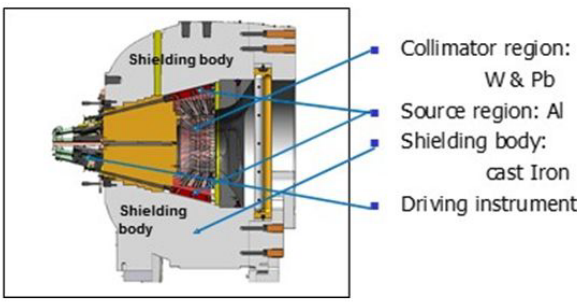

FIG. 1. Cross section view of the gamma knife apparatus.

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http://dx.doi.org/10.1016/j.nds.2014.07.057

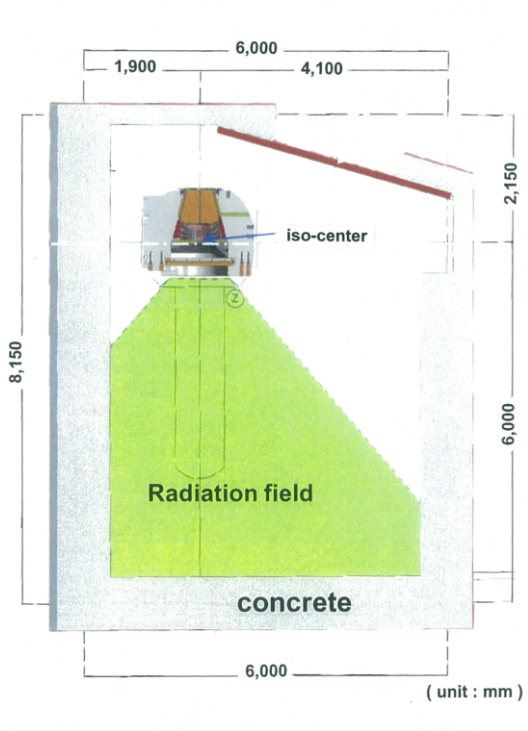

FIG. 2. Gamma knife oncology room.

B. Measured Results

We have adapted an ionization chamber, Aloka ICS 323C, for the measurement of the dose rates, which were measured nearly every 1 m in the horizontal plane (X-Z plane) and in some vertical plane positions (X-Y plane) every 50 cm. The measured dose results on the horizontal plane at the same height as the iso-center when the 16 mm collimator was used are shown in Fig. 3. The horizontal axis corresponds to X axis of Fig. 2 while the vertical corresponds to the Z axis. In the radiation field the dose rate varied from 5,740 to 24 μSv/h, but it decreased very rapidly outside of the radiation field. In the back of the gamma knife apparatus, the dose rate was at most 2 μSv/h, which is less than the radiation limit at the boundary of the controlled area.

Fig. 4 shows the measured results on the vertical plane when the 16 mm collimator was used. The horizontal axis corresponds to the X axis of Fig. 2 while the vertical corresponds to the Y axis of the room. Note that all the position are in the radiation field, since Z=170, 270 and 370 cm. Measured dose results varied from 184 to 7.6 μSv/h.

IV. CALCULATION

Calculations of the dose rate around the gamma knife apparatus were performed using the three-dimensional Monte Carlo calculation code MCNP5 with its related nuclear data library MCPLIB04 [2]. The source gamma ray energies of ^{60}Co were 1173 and 1333 keV. All the structures of the gamma knife apparatus such as aluminum cases of the cobalt source, collimators and shielding body, were included in detail in the geometry of the calculation, but the driving instrument was excluded, since it would be too complicated to model. The calculated gamma ray spectra were converted to the dose rate by using a flux to dose conversion factor based on ICRP-74 [3].

V. COMPARISON BETWEEN MEASURED AND CALCULATED RESULTS

The ratios of calculated to experimental values (C/E) of dose rates at the horizontal and vertical plane are shown in Figs. 5 and 6, respectively.

The C/E values varied from 0.8 to 2.1, except behind the gamma knife apparatus on the concrete wall. The average and standard deviation of C/E are 1.55 and 0.291, respectively. The reason behind the low C/E = 0.2 at the back is due to the lack of modeling of the driving instrument. There are very small gaps around the driving instrument and gamma rays from the cobalt sources leaked through these gaps by streaming effects. These gamma rays were detected in the measurement.

Fig. 6 shows the C/E values on vertical plane. The C/E values varied from 1.3 to 2.1. The average and standard deviation are 1.62 and 0.229, respectively. Some overestimation of calculated results at the Z = 270 cm position may be caused by the existence of a bed, which was not included in the calculation. This will cause shielding effects in the measurements.

VI. SUMMARY

The dose rate measurement around the gamma knife apparatus have been performed and compared with calculated results. Very good agreements between measured and calculated results were obtained within a factor of 2. It is concluded that the Monte Carlo calculation code MCNP5 with its related nuclear library MCPLIB04 is very effective not only for the estimation for the shielding calculation of the gamma knife facility but also for the estimation of exposure for patients during radiation therapy.

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