Optimal Design of Co-60 Single Source Radiation Facility With Monte Carlo Method

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1. Introduction

Radiation Metrology Division of China Institute of Atomic Energy (CIAE) obtains many photon sources with different activity values for calibration, metrological research and design new dosimeters for detection and measurement of photon-related quantities. With these sources e.g. cesium-137, colbalt-60 and americium-241, it is possible to obtain air kerma rate from 0.2μGy/h up to 54Gy/h sufficient for all of commonly used dosimeters. The development of computer technology made it possible to use sophisticated mathematical models to calculate relative parameters of the irradiation fields. In this study, a Monte Carlo code model was used for beam profiles verification and for the assessment and analysis of scattered air kerma, which are very important for optimal design of a new of Co-60 single source radiation facility. **The new Co-60 single source radiation facility has been produced in CIAE and will be used in nuclear power station.**

2. Principle

Co-60 gamma rays reference radiation filed is necessary for calibration of radiation dose meter. The Co-60 source radiation is made of lead which is thick enough to make sure the leaking radiation through the container decreases to **0.1%**. When the Co-60 source radiation facility is closed, the surface dose rate must be limited to an acceptable level (usually **2.5μSv/h**). **Fig. 1 is principle figure of radiation facility.**

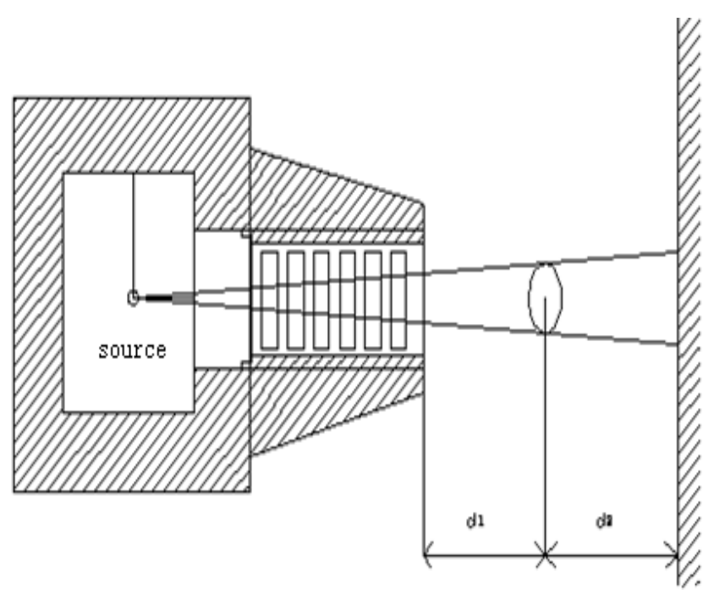

Fig.1 Principle figure of radiation facility

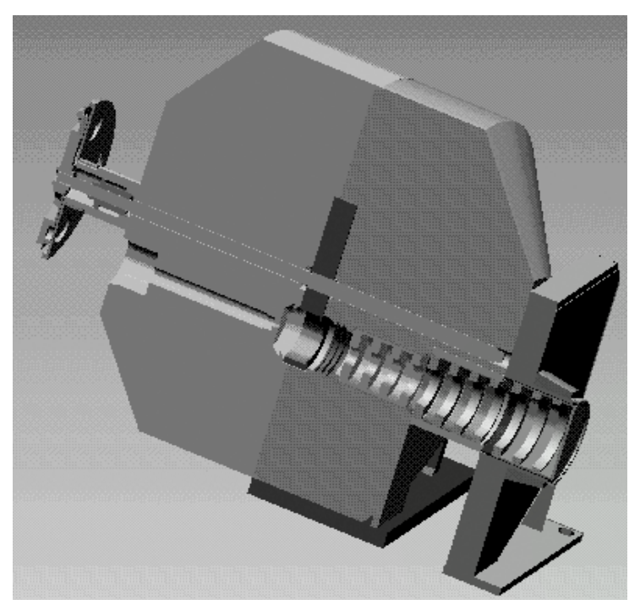

Fig.2 A simulation model of the lead shielding facility including the lead ring-collimator (right) and scatter hall (middle) used for reducing scatter photons of the facility

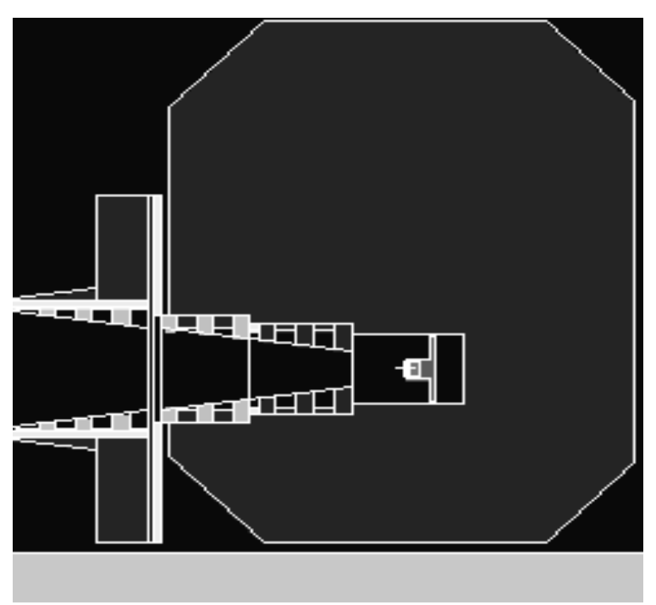

Fig. 3 Radiation facility model

3. Monte-Carlo Model

The source model consist of an active ^{60}Co volume, a steel and aluminum capsule, and an aluminum holder. **The encapsuled source was positioned inside a lead shielding facility with wall thicknesses up to 30cm.** The shielding closely surrounding the source on all sides except for a collimator pyramid, the lead ring-collimator of 30cm in length with an opening angle of **16°** was integrated in the lead shielding, as shown in Figure 2 and Figure 3.

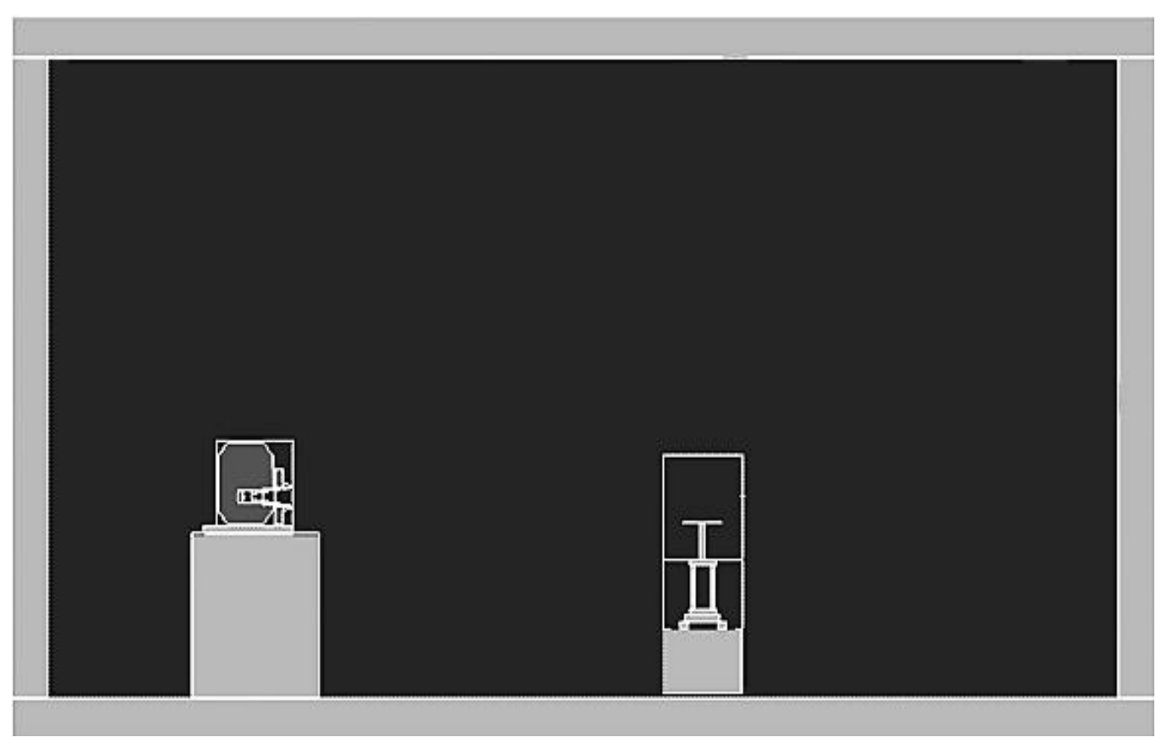

Fig. 4 Side view of calculation model showing the lead shielding facility, mobile platform, walls, floor, ceiling and the air environment.

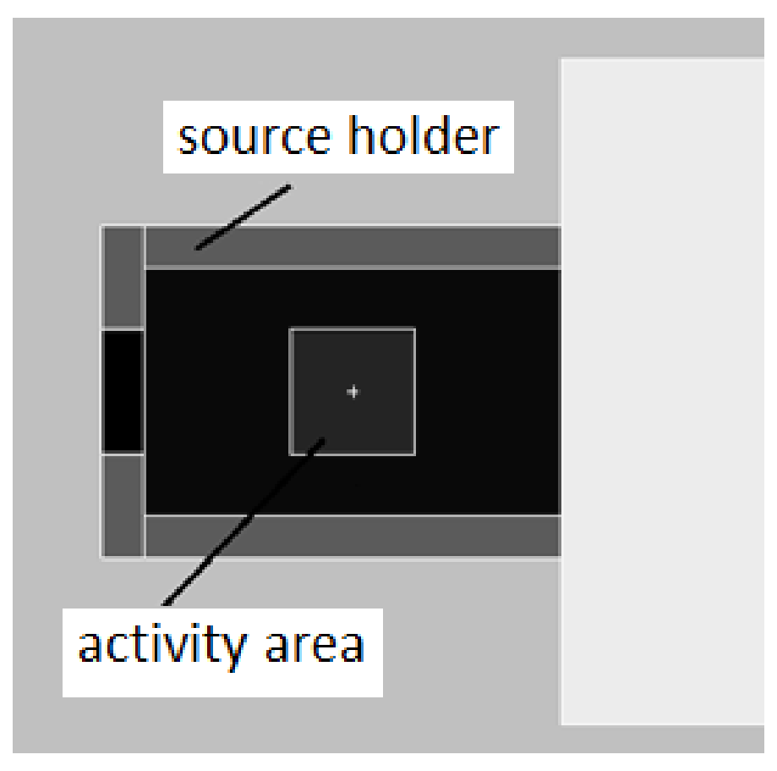

Fig. 5 Radiation source model

Around the lead shielding facility, a number of concrete and other structures are included, i.e., walls, blocks, ceiling and the mobile platform. The concrete floor of 0.5m thickness, and the air environment are also part of the simulation model, as shown in figure 4.

Four different kinds of surface were necessary for defining the calculation models (number of the used surface in brackets): planes(109),cylinders(34), spheres(1) and cones(2). Seven different materials, elements and compositions are used (mass densities in units of g/cm^3 in brackets): lead (11.3), air(0.001293), aluminum(2.78), source(3.988), steel(7.85), collimator(18) and concrete (2.35). The ^{60}Co source activity area is ϕ3 mm×6mm, mass densities 8.9 g/cm^3,The holder of source is ϕ6mm×11mm shown in figure 5.

In the Monte Carlo simulation, air kerma was calculated by folding the simulated photon fluence energy distribution by log-log interplotaed the air-kerma conversion coefficients provided by ICRU. Just as the experiments, longitudinal profiled in air-kerma rate at distances from 1.16m to 4m from the ^{60}Co source were simulated. In the Monte Carlo calculations, fluence is detected in spherical air volumes along the central beam axis.

Owing to statistical reasons, the diameters of air detector spheres have to be increased from 5cm to 20cm for increasing source-detector distance.

4. Scattering Cavity Design

The scattering cavity is used to reduce the scattered radiation of the irradiation device, and the bigger the scattering cavity is, the more obvious the effect is. **Monte Carlo code** was useed to simulate the spherical and cylindrical scattering cavities of different sizes, the calculated scattering cavity structure is shown in Figure 6.

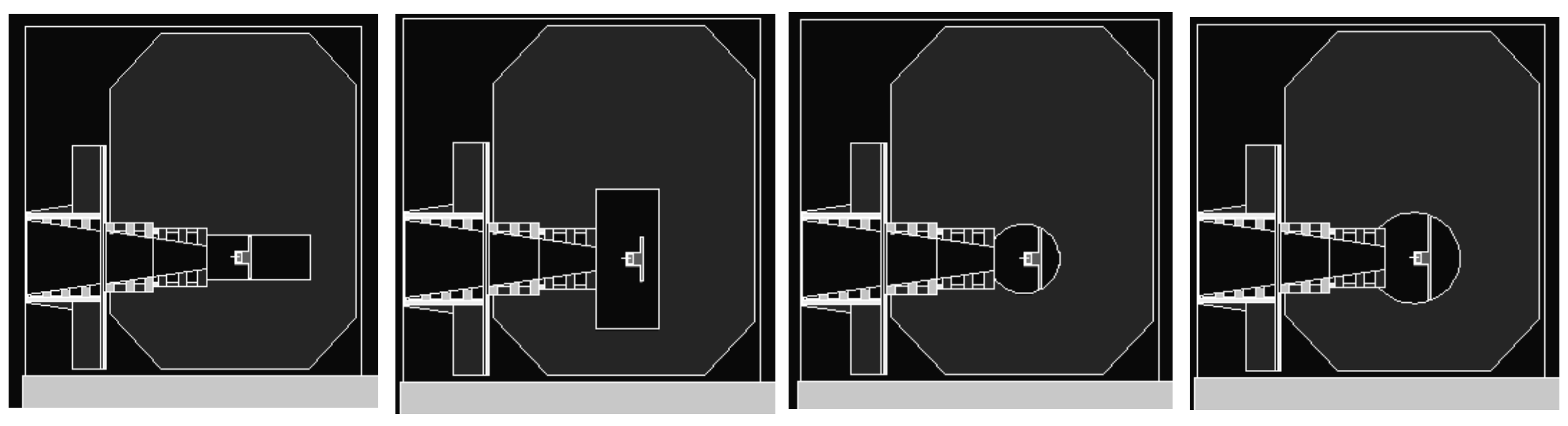

Figure 6 Radiation facility model with different scattered chambers

5. Collimator Design

The lead ring-collimator of 30cm in length with an opening angle of **16°** was integrated in the lead shielding. The transversal beam profiles were also simulated in a horizontal line perpendicular to the beam axis at two distances of 1m and 2m from the ^{60}Co source, the cubic air detectors were used for its lager sensitive volume compared to spherical detectors and columned detectors among the same intervals, as shown in figure 7. As the activity value of the ^{60}Co source is not available exactly, only relative air-kerma results are compared in this study. The simulation result is shown in figure 8.

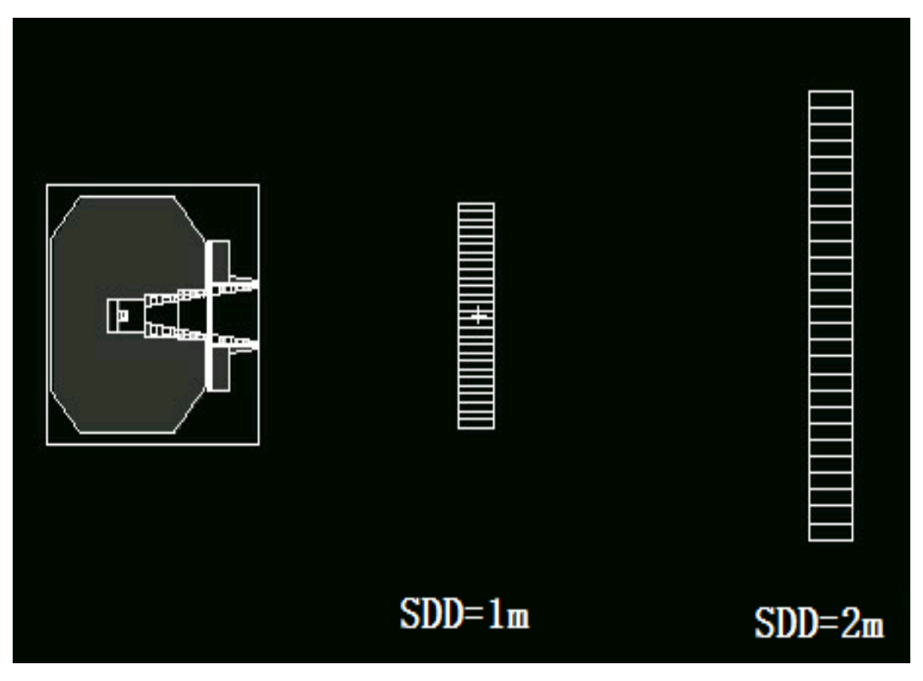

Figure 7 Top view of Monte Carlo calculation model showing the lead shielding facility(left), cubic air detectors(middle and right) at two different source-detector distance(SDD) of 1m and 2m.

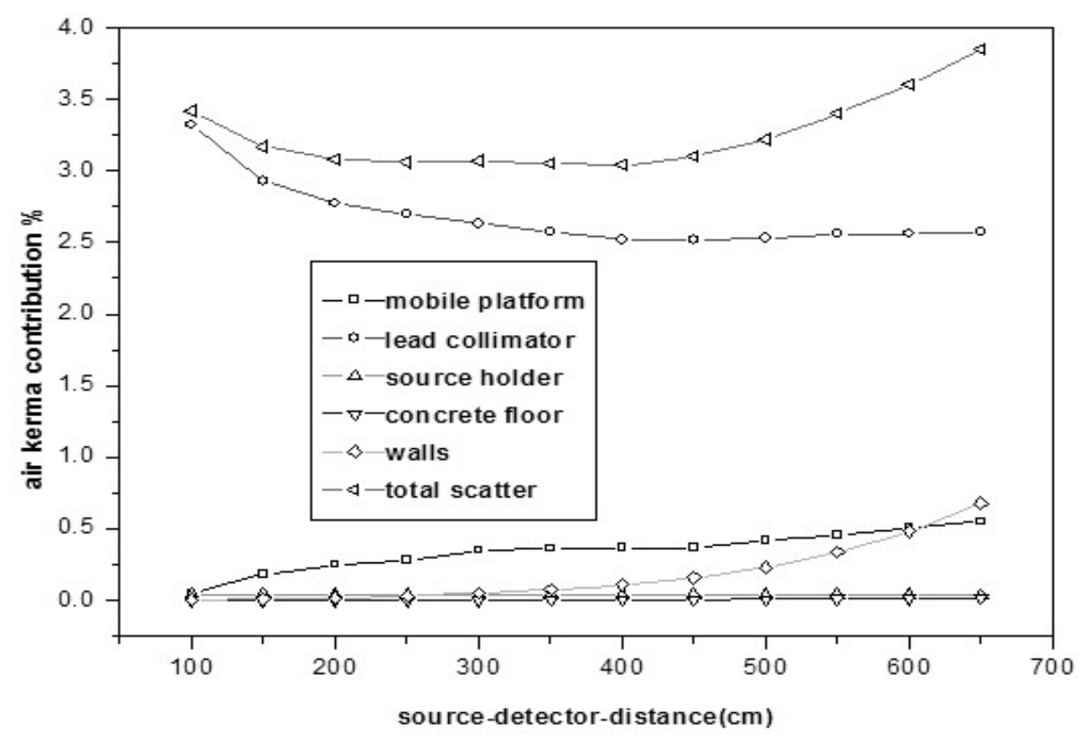

Figure 8 Relative air-kerma contribution of main calibration facility components to the total air-kerma depending on the source-detector-distance. Main components are collimator(circles), mobile platform (squares), walls (diamonds), source holder (triangles) and concrete floor(inverse triangles).

Figure 8 summarizes the scattered air kerma of all individual parts to the total air kerma at the distance from 1m to 6.5m. The total scattered contribution is increasing from 3.2% to 4.0% (fulfills the ISO 4037-1 requirement of a maximum scatter of 5%) toward the end of the calibration hall. The lead collimator with nine apertures (total thickness is 30cm) contributing most to the scattered air kerma, the maximum simulated contribution of the collimator is about 3.3% at the source-detector-distance of 1m,i.e., 63cm from the exit surface of the collimator and the minimum is about 2.6% at the source-detector-distance of 6.5m. At the distance of 6.5m,raising contributions of mobile platform and walls can be seen, as the beam broadens, more photons scattered on walls and mobile platform are detected, the contribution of them up to 0.6% and 0.5%. Scatteded contributions from the source holder and concrete floor are less than 0.1%, can be neglected.

6. Conclusions

In this study, the Monte Carlo code was used to simulate the scatter air-kerma of ^{60}Co source in the calibration hall which has been built by China Institute of Atomic Energy. The simulation models were tested by the experiments of longitudinal and transveral beam profiles in air kerma. **Good agreement between the simulation and the ionization chamber measurements has been shown**, but the observed deviations in the simulated results show the need to improve the simulation model. Furthermore, experiment of the scattered photons to the total air kerma on the beam axis should be carried out. The results presented in this paper confirmed the models' accuracy, and hence, these models can be used to learn more about the scattered informations of the calibration hall in the future.