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Calibration of a ^{137}Cs γ-ray beam irradiator using large size chambers

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Abstract

A ^{137}Cs γ-ray beam irradiator has been calibrated in terms of air kerma using large size chambers. The available air-kerma rates range between 1.8 μGy/h (0.2 mR/h) and 5.3 mGy/h (0.6 R/h). Large-volume chambers were used to characterize the source in terms of the radiation quantity air kerma (and exposure). Two types of chambers with significantly different characteristics and energy responses were used. This work shows that very good agreement can be obtained between the measurements performed with such different types of chambers. An agreement of 0.3% is observed between chambers even for the lowest air-kerma rates measured.
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Keywords: Ionization chamber; Cs-137; γ-ray; Scattered radiation; Secondary standard; Calibration coefficient; Air kerma

1. Introduction

A total of seven ^{137}Cs and ^{60}Co γ-ray irradiators are routinely used by the Radiation Interactions and Dosimetry Group at the National Institute of Standards and Technology (NIST) in support of the calibration program for disseminating the primary standards for air kerma (Minniti et al., 2006; Lamperti and O'Brien, 2001; Pibida et al., 2005). These facilities provide reference radiation γ-ray beams that have been characterized in terms of the radiation quantities air kerma and exposure using a suite of six graphite cavity air ionization chambers (Loftus and Weaver, 1974; Seltzer and Bergstrom, 2003). These chambers constitute the NIST *primary standard* instruments for the measurement of air kerma from γ-ray beams. These existing *primary standard calibration facilities* provide a broad range of air-kerma rates. Currently, the lowest air-kerma rate available for the ^{137}Cs γ-ray beams is approximately 4.4 mGy/h (0.5 R/h). Here, we report the development of a new calibration range that allows extending the air-kerma rate values down to approximately 1.8 μGy/h (0.2 mR/h).

The reference radiation γ-ray beams in the new facility were characterized using *secondary standard* ionization chambers of large volumes. The calibration range allows to position radiation detector equipment between 1 and 4 m from the source accurately. The source output was measured with four large-volume chambers that had been calibrated against the primary standard in the existing NIST primary standard calibration facilities. Large-volume chambers allow the measurement of low air-kerma rates. Chambers of two types with significantly different characteristics were used. The chambers of the first type are pressurized and sealed to the atmosphere. Their walls are made of stainless steel in order to contain the pressurized gas. The chambers of the second type are open to the atmosphere and have air-equivalent plastic walls. As a result of these different characteristics, the energy response of these chambers is very different over a photon energy range between 30 and 662 keV. The response of the air-equivalent plastic-wall chambers is constant within 5% over the entire energy range. The response of the pressurized chambers is relatively constant between 300 and 662 keV, too; however, it drops drastically below 300 keV (the difference between the responses at 300 and 100 keV is approximately 30%).

In this work, we used these two types of chambers to characterize the output of the source down to air-kerma rates as low as 1.8 μGy/h (0.2 mR/h). It was found that,

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despite the significantly different properties of the chambers, the lower air-kerma rates measured with them agree within 0.3%. For air-kerma rates above 8.78 μGy/h (1 mR/h), the differences become smaller.

There are many *secondary standard calibration facilities* throughout the world that are similar to the newly developed calibration facility described in this report. They provide air-kerma measurements traceable to primary standard calibration facilities (IAEA, 2005). In this paper, we report differences that can be expected in the measurements of air kerma with large volume chambers. Secondary standard facilities elsewhere may benefit from the data reported here.

A brief section on the calibration of secondary standard large-volume chambers is included in addition to a description of the calibration range and the measurement methods used. This is followed by a discussion of the results and conclusions.

2. Calibration of secondary standard large-volume chambers

Four large-volume chambers were calibrated against the primary standard in one of the existing NIST ^{137}Cs γ-ray primary standard calibration facilities. For each chamber, we determined an air-kerma calibration coefficient

$$N_{\mathrm{K}} = \frac{\dot{K}_{\mathrm{p}}}{I_{\mathrm{p}}}, \tag{1}$$

where $\dot{K}_{\mathrm{p}}$ is the air-kerma rate of the NIST reference radiation beam in the primary standard calibration facility (determined by applying a decay correction to the original air-kerma rate value) and I_{p} is the ionization current measured with one of the large-volume chambers in the primary standard calibration facility. The value of the ionization current I_{p} includes corrections to account for ion-recombination effects (Boag, 1987; Boutillon, 1998; Zankowski and Podgorsak, 1998) and for deviations of the ambient temperature and pressure from the NIST reference conditions of 22 °C and 101.325 kPa (1 atm), respectively (Lamperti and O'Brien, 2001).

Once all four secondary standard large-volume chambers were calibrated in the NIST primary standards calibration facility, they were used to determine the air-kerma rates at various distances from the ^{137}Cs source in the new secondary standard calibration facility. The air-kerma rates $\dot{K}$ measured with each chamber were determined using the expression

$$\dot{K} = N_{\mathrm{K}} \cdot I, \tag{2}$$

where N_{K} is the calibration coefficient for a given chamber and I is the measured ionization current in the secondary standard calibration facility. The value of the ionization current included a correction for recombination loss. In the case of chambers open to atmosphere, an additional correction was included to account for deviations of the ambient temperature and pressure from the NIST reference conditions.

3. Materials and methods

The new secondary standard calibration facility utilizes a ^{137}Cs irradiator made by Shepherd and Associates.[1] The irradiator is essentially a cylindrically shaped tower that has five ^{137}Cs sources mounted on a rod. The rod can slide vertically to position a single source, at a given time, in front of a collimator opening located approximately in the center of the tower. In the closed position, the sources are stored in the heavily shielded bottom part of the tower. Three of these sources were used in this work. For identification purposes only, each of these three sources will be referred to throughout the text of this manuscript using the manufacturer's nomenclature, i.e., by their nominal activities of 15 mCi, 300 mCi and 6 Ci (on October 15, 1994). The beam axis is located at a height of 1.4 m from the floor. The collimator opening provides a square radiation field of approximately 28 cm × 28 cm (defined by the 95% iso-intensity contour) at a distance of 1 m from the source.

A track system, designed and built at NIST, lies along the floor parallel to the beam center axis and allows for accurate positioning of radiation instruments at the distances between 60 and 430 cm from the source. Two lasers are used to align the instruments at the desired source-to-detector distance and beam axis height. A mounting stand, built of bakelite to minimize scattered radiation, is used for mounting the ionization chambers.

The data acquisition system is composed of an electrometer and a temperature and pressure transducers. A computer program, developed in Visual Basic, is used to acquire and simultaneously analyze the charge integrated over a given period of time and the temperature and pressure in the vicinity of the chamber.

Four large-volume spherical ionization chambers were used. The chamber specifications are summarized in Table 1. Two of the chambers were pressurized ionization chambers (PICs) and will be referred to throughout the text as PIC1 and PIC2. Both chambers are of the same type. The other two chambers are non-pressurized and are open to the atmosphere. These chambers will be referred to throughout the text by the manufacturer's models identification, i.e. A6 and A7. A bias of 1000 V was applied to the chambers A6 and A7, while 700 V was applied to the chambers PIC1 and PIC2. In all cases, only negative charge was collected.

All four chambers were calibrated in terms of air kerma (and exposure) at a higher air-kerma rate of approximately 4.4 mGy/h (0.5 R/h) in one of the existing NIST ^{137}Cs reference beams. An air-kerma calibration coefficient, N_{K}, was obtained for each secondary standard chamber. Each

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[1] Certain commercial equipment, instruments, and materials are identified in this work in order to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by NIST, nor does it imply that the material or equipment identified is the best available for the purposes described in this work.