Standardization of the absorbed dose at 3 mm depth in tissue in a $^{90}\text{Sr}/^{90}\text{Y}$ beta radiation field

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Abstract. The reduction of the dose limit for the eye lenses of occupational exposed workers drew the attention of authorities to review the monitoring, the calibration method and the performance of the individual dosimeters. Calibration laboratories are expected to perform dosimeter calibrations and tests in standardized and reliable conditions. In this work, the $^{90}\text{Sr}/^{90}\text{Y}$ beta radiation beam of the Beta Secondary Standard system was characterized. Beam standardization was achieved by measuring the absorbed dose rate at 3 mm in tissue, $D_T(3)$. A reliable procedure for calibrating eye lens dosimeters in terms of $H_p(3)$ in the $^{90}\text{Sr}/^{90}\text{Y}$ beta radiation field was established.

Keywords: absorbed dose in tissue, beta radiation standardization

1. Introduction

The International Commission on Radiological Protection, ICRP, reviewed epidemiological evidences of some late tissue reaction effects, which they suggested that the absorbed dose threshold for effects in the eye lens could be lower than that previously adopted. Reduction of the annual equivalent dose limit for the eye lens to 20 mSv was then recommended and it was immediately adopted by many countries, including Brazil [1].

The ICRP recommendation stressed the need of reviewing eye lens monitoring in order to control and optimize the exposure in radiation practices; workers who may get their eyes reached by radiation should be monitored in a reliable manner [2]. Besides interventional radiology procedures where x-ray exposures of the medical staff eye lenses are highly concerning, there are some practices when workers’ eyes may be exposed to beta particles or electrons that would contribute significantly to the absorbed dose in their eye lenses.

Ionizing radiation metrology laboratories should be capable to perform reliable calibrations and tests in dosimeters used to monitor eye lens exposures in terms of the personal dose equivalent in 3 mm depth in tissue, $H_p(3)$. In Brazil, Borges et al. [3] carried out calibration studies of an eye lens dosimeter for monitoring x-ray exposures in the interventional radiology and Da Silva et al. [4] studied the reliability of the worker dosimetry in a positron emission tomography radiopharmaceutical production facility.

The aim of this work was to standardize a $^{90}\text{Sr}/^{90}\text{Y}$ beta radiation field in terms of the absorbed dose in 3 mm depth in tissue, in order to provide a reliable standard condition for calibrating and testing
dosimeters to be used for monitoring \( H_p(3) \) at occupational workplaces, where beta radiation or electrons could reach the eye’s worker.

2. Materials and methods

Absorbed dose rate measurements in the \(^{90}\)Sr/\(^{90}\)Y beta radiation fields of the Beta Secondary Standard BSS2 system were done with a 23392PTW extrapolation chamber, in the CDTN Dosimeter Calibration Laboratory.

The 23392PTW extrapolation chamber uses the null volume extrapolation measurement method to determine the absorbed dose rate in tissue, \( D_T \), under Bragg-Gray cavity theory condition, according to Equation 1 [5].

\[
D_T = s_{T,\text{air}} \frac{W_e}{\Delta m_{\text{air}}} \left( \frac{\Delta I_c}{\Delta m_{\text{air}}} \right)_{BG}
\]  

(1)

where: \( s_{T,\text{air}} \) is the ratio between the average mass stopping powers of tissue and the dry air equal to 1.064 [6]; \( W_e \) is the energy required to produce an ion pair in air equal to \((33.97 \pm 0.12) \text{ J.C}^{-1} \) [6] and \( \Delta I_c \) is the variation of the corrected ionization current produced in the air mass increment \( \Delta m_{\text{air}} \) in the extrapolation chamber.

In terms of the distance between the collecting electrode and the entrance window of the extrapolation chamber, \( \Delta d \), which it is established by the micrometre of the chamber, the \( D_T \) can be determined by Equation 2.

\[
D_T = s_{T,\text{air}} \frac{W_e}{\Delta d} \left( \frac{\Delta I_c}{\Delta d} \right) \frac{1}{(\rho_0 A)}
\]  

(2)

where: \( \rho_0 \) is the dry air density at reference ambient conditions equal to \((1.19740 \pm 0.0005) \text{ kg.m}^{-3} \); \( A \) is the area of the collecting electrode equal to \((7.22 \pm 0.05) \text{ cm}^2 \) [7, 8] and \( \Delta I_c / \Delta d \) is the slope of the experimental obtained extrapolation curve.

To validate the experimental dosimetry procedure with the extrapolation chamber, the absorbed dose rates in air, \( D_{\text{air}} \), in the \(^{90}\)Sr/\(^{90}\)Y beta radiation fields were determined and compared to previous results. Ionization currents were measured with the constant electrical field of \( \pm 50 \text{ V.mm}^{-1} \) applied to the chamber for the gap between its electrodes from 2.0 to 5.0 mm with increments of 0.5 mm; all correction factors related to the chamber, to the radiation field and other influence quantities were adopted from Reynaldo [7]. All extrapolation curves were obtained and the angular coefficients were determined for the standard \(^{90}\)Sr/\(^{90}\)Y beta radiation fields.

For the determination of the absorbed dose rate in 3 mm depth in tissue, \( D_T(3) \), similar procedure was adopted but the 3 mm depth in tissue was simulated by attaching 1.032 g·cm\(^{-3}\) density solid water\® HE slabs on the surface of the 23392PTW extrapolation chamber (Figure 1).

![Figure 1 – Beta secondary standard BSS2 with the 23392PTW extrapolation chamber with the attached water solid slab for measuring the absorbed dose in tissue.](image-url)
3. Results

Table 1 compares the absorbed dose rates in air, $D_{\text{air}}$, on 2018-11-09 obtained in this work with previous values from Reynaldo et al. [7, 8] in the standard $^{90}\text{Sr}^{90}\text{Y}$ beta radiation fields. Considering the expanded uncertainties, results showed a good agreement between the values with the maximum difference of about 7.0%; this result suggested the reliability of the measurement procedure with the extrapolation chamber.

**Table 1 – Absorbed dose in air in $^{90}\text{Sr}^{90}\text{Y}$ beta radiation fields, on 2018-11-09, determined with the 23392PTW extrapolation chamber.**

| Beta standard radiation beam | Absorbed dose rate in air, $D_{\text{air}}$ ($\mu\text{Gy} \cdot \text{s}^{-1}$) | This work | Reynaldo [7, 8] |
|-----------------------------|-------------------------------------------------|----------|----------------|
| $^{90}\text{Sr}^{90}\text{Y}$ – 11 cm | 71.08 ± 4.92* | 74.56 ± 5.9* |
| $^{90}\text{Sr}^{90}\text{Y}$ – 20 cm | 21.33 ± 1.48 | 22.82 ± 1.8 |
| $^{90}\text{Sr}^{90}\text{Y}$ – 30 cm | 10.37 ± 0.72 | 10.27 ± 0.81 |
| $^{90}\text{Sr}^{90}\text{Y}$ – 30 cm (with filter) | 6.66 ± 0.46 | 6.71 ± 0.53 |
| $^{90}\text{Sr}^{90}\text{Y}$ – 50 cm | 3.79 ± 0.26 | 3.77 ± 0.31 |

*Expanded uncertainty k=2.

Table 2 compares the results of the absorbed dose rates in 3 mm depth in tissue on 2018-10-30 obtained in this work against the $D_{T}(3)$ values calculated by using the depth dependence factor $T(3;\text{source};\text{incidence angle})$ according to Equation 3 [9]; $D_{T}(0.07)$ values were considered as those provided in the BSS2 calibration certificate.

$$T(3;\text{source};0°) = \frac{D_{T}(3;\text{source};0°)}{D_{T}(0.07;\text{source};0°)}$$

**Table 2 – Absorbed dose in air in 3 mm depth in tissue, in $^{90}\text{Sr}^{90}\text{Y}$ beta radiation fields, on 2018-10-30, determined with the 23392PTW extrapolation chamber and compared to the calculated values.**

| Beta standard radiation beam | Absorbed dose rate in 0.07 mm depth in tissue, $D_{T}(0.07)$ ($\mu\text{Gy} \cdot \text{s}^{-1}$) | $T(3;{^{90}\text{Sr}^{90}\text{Y}};0°)$ [9] | Absorbed dose rate in 3 mm depth in tissue, $D_{T}(3)$ ($\mu\text{Gy} \cdot \text{s}^{-1}$) |
|-----------------------------|-------------------------------------------------|---------------------------------|---------------------------------|
| $^{90}\text{Sr}^{90}\text{Y}$ – 11 cm | 88.11 ± 1.6** | 0.5008 ± 0.0050** | 44.13 ± 0.91** 44.86 ± 3.13** |
| $^{90}\text{Sr}^{90}\text{Y}$ – 20 cm | 27.28 ± 0.5 | 0.4949 ± 0.0050 | 13.50 ± 0.28 13.87 ± 0.86 |
| $^{90}\text{Sr}^{90}\text{Y}$ – 30 cm | 12.09 ± 0.2 | 0.4759 ± 0.0048 | 5.75 ± 0.11 5.90 ± 0.42 |
| $^{90}\text{Sr}^{90}\text{Y}$ – 30 cm (with filter) | 7.75 ± 0.14 | 0.4311 ± 0.0044 | 3.34 ± 0.06 3.44 ± 0.21 |
| $^{90}\text{Sr}^{90}\text{Y}$ – 50 cm | 4.29 ± 0.08 | 0.4397 ± 0.0044 | 1.89 ± 0.04 1.87 ± 0.12 |

*BSS2 calibration certificate.

**Expanded uncertainty k=2.

Results from Table 2 showed that $D_{T}(3)$ determined in this work showed differences that varied from -1.1% up to 3.0% in comparison to the calculated values; these are acceptable values considering that the expanded uncertainty was estimated about 7.0%. One may conclude that the Beta Secondary Standard system is reliable to calibrate personal dosimeters used for monitoring $H_{p}(3)$. 
Acknowledgments
Luciana Teles is thankful to FAPEMIG for her master fellowship. Sibele Reynaldo is also thankful to CNEN for the post-doctorate fellowship. Teógenes Da Silva is grateful for the financial support from FAPEMIG APQ-02277-15 and PPM XI-00397-17f and to CNPQ for the PQ2 304985/2018-0 fellowship.

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