# Determination of transmission factors for an $^{85}Kr$ beta radiation beam using an extrapolation chamber.

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## Abstract

The $^{85}Kr$ isotope is a beta-ray emitter (gas) with a half-life of 10.76 years. It is produced in the fission of Uranium and Plutonium. The origins of this isotope are the nuclear tests, the nuclear reactors and the reprocessing of nuclear fuel. In the gas release events around reactors, the $^{85}Kr$ may represent a major hazard. In beta emitters, in order to evaluate the absorbed dose rate at different tissue depths, it is necessary to determine the transmission factors. In this work, the preliminary results of the determination of transmission factors of the $^{85}Kr$ source of a BSS2 beta secondary standard are presented. For this purpose, an extrapolation chamber was used. The results obtained were considered acceptable, and they are within the uncertainties in comparison with the values provided by the source calibration certificate. The maximum difference between the results obtained in this work and those from the calibration certificate was 3.8%.

**Index Terms**: Transmission factors, extrapolation chamber, beta radiation, $^{85}Kr$ source.

## Introduction

Beta emitters can represent a hazard in gas release events around the reactors. One of these gases is the $^{85}Kr$ beta emitter (ICRU, 1997). The $^{85}Kr$ source is used in electric lamps and electronic devices of various types, in health physics and for the calibration of high resolution gamma-ray spectrometers. Beta radiation is a weakly penetrating radiation. The skin is the organ that most frequently receives significant doses. This occurs because the skin is considered the basal layer of epidermis. Its cells are at a shallow depth (POOK and FRANCIS, 1975; ICRU, 1997).

For calibration of beta sources and detectors, the transmission factors in the tissue must be determined (BÖHM, 1986). Transmission factors are very important for the determination of the absorbed dose rates at different tissue depths. To determine the transmission factor, the ionization current for different absorber thicknesses must be measured ($I_a$). Subsequently, this current is extrapolated to a null thickness representing the skin surface ($I_0$). The transmission factor is the ratio of the current $I_a$ and the current $I_0$ (CALDAS, 1980; ANTONIO et al., 2013).

Some transmission factors have been determined for Beta Secondary Standard sources (OWEN, 1973; POOK and FRANCIS, 1975; HEINZELMANN, 1975; CALDAS, 1980; BÖHM, 1986; ANTONIO et al., 2013). These standards did not use the $^{85}Kr$ source. This source started to be used instead of the $^{204}Tl$ source in the BSS2 secondary standard because the energy spectra of the beta particles are similar (BSS2, 2005). Transmission factors for this source were first calculated at the Nuclear Technology Development Center in Minas Gerais, Brazil (REYNALDO, 2015).

The objective of this work was to determine the transmission factors for an $^{85}Kr$ beta radiation beam. The results were compared with the transmission factors of the source calibration certificate and with the transmission factors determined by Reynaldo (2015). In addition, the uncertainties of the factors were calculated. The results of this work are of great importance for the LCI/IPEN in the establishment of this radiation standard.

**Materials and methods**

In this work, a commercial extrapolation chamber Physikalisch-Technischen Werkstätten Freiburg, PTW type 23392 of the LCI/IPEN was used. It was developed by Böhm (1986), and built by PTW. It is considered as the primary standard for the determination of the beta radiation absorbed dose rate in the tissue (BÖHM, 1986). Figure 1 shows a cross section view of the Böhm extrapolation chamber. The collecting electrode, the guard ring, a PMMA block and the entrance window constitute its main components.

Charge measurements with this extrapolation chamber were taken with a Keithley model 6517B electrometer.

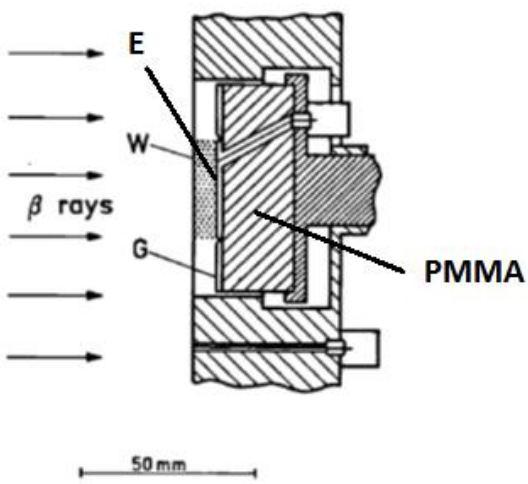


**Figure 1. Cross section of the Böhm extrapolation chamber. E: collecting electrode; W: guard ring; W: entrance windows; PMMA: PMMA block (ICRU, 1997).**

For the development of this work, the $^{85}Kr$ source was used. This source is part of the LCI/ IPEN beta secondary standard BSS2. The main features of this source are nominal activity, 3.7 GBq; mean beta energy, 0.24 MeV; and calibration distance, 30 cm (BSS2,2005). For use of this source in the BSS2 system, a Hostaphan filter must be used. The calibration date of this source is 30/11/2004 (PTB, 2005).

According to the Caldas procedure, to determine the transmission factors, the extrapolation chamber was covered by thin sheets of different thicknesses (CALDAS, 1980). These sheets shall be made of a material equivalent to the tissue and they shall be placed as close as possible to the chamber entrance window (OWEN, 1973). Tissue-equivalence is the property of a material whose mass stopping power and the diffusion properties of the radiation are identical to those of the tissue. The material of the absorber sheets is Polyethylene Terephthalate, commercially known as Hostaphan with density of 1.40 g/cm$^3$. To determine the transmission factors, an equivalence ratio between the material of the absorbent sheets and the tissue must be used. The relationship between the Hostaphan and the tissue is *10.8 mg/cm$^2$ of Hostaphan = 10.0 mg/cm$^2$ of tissue* (OWEN, 1973).

In addition to this, it is necessary to convert the surface density of the chamber entrance window to the tissue. According to Caldas, for each absorber sheet the following expression was used (CALDAS, 2017):

$$t_T = \left(d_j * c_j\right) + \left(e_H * \rho_H * c_H\right) \tag{1}$$

where $d_j$ is the thickness of the absorbing sheet that is equivalent to the tissue; $c_j$ is the conversion coefficient of the material of the chamber entrance window to the tissue; $e_H$ is the thickness of the absorber sheet; $\rho_H$ is the volumetric density of the absorber sheet and $c_H$ is the conversion coefficient of the material of the absorbent sheet to the tissue.

As previously mentioned, the transmission factor is the ratio of currents $I_a$ and $I_0$:

$$T' = I_a / I_0 \tag{2}$$

Taking into account the source-detector distance and the thickness of the absorber sheet, a correction factor $k_a$ shall be introduce.

$$k_a = (a - a_1)^2 / a_2 \tag{3}$$

where $a$ is source-detector distance and $a_1$ is the absorber sheet thickness.

Finally, transmission factors can be determined by the final expression:

$$T = T' * k_a \tag{4}$$

According to Caldas, the values of $T$ are plotted as a function of surface density.

Through a computer program, the graph is adjusted and an equation is obtained. From this equation, the transmission factors corresponding to the surface densities that appear in the calibration certificate of the radiation source can be determined. Subsequently, the values obtained experimentally are compared with the values of the calibration certificate (CALDAS, 1980).

The chamber entrance window was covered with 8 Hostaphan absorber plates, identified as RN 8, RN 25, RN 36, RN 50, RN 75, RN 100, RN 250 and RN 300. The number corresponds to the plate thickness in µm. Figure 2 shows the extrapolation chamber covered with a Hostaphan absorber plate.

**Figure 2. Extrapolation chamber entrance window covered by a Hostaphan absorber sheet.**

**Results**

To determine the transmission factors of the $^{85}$Kr source, the extrapolation chamber was positioned at a source-detector distance of 30 cm. The bias voltage and the chamber depth were maintained at ± 25 V and 2.5 mm, respectively.

The ionization current was measured with the absorber plates and without them. The ionization current varied in the range of (1.0950 ± 0.0012) pA and (0.5488 ± 0.0007) pA with a variation coefficient less than 0.41%. The current $I_0$ was obtained by adjusting the curve of the ionization current versus the surface density in the tissue. A computer program fitted polynomials to the points of graphic. A third degree polynomial was obtained adequate to fit the experimental values. Figure 3 shows the curve corresponding to the determination of the current $I_0$.

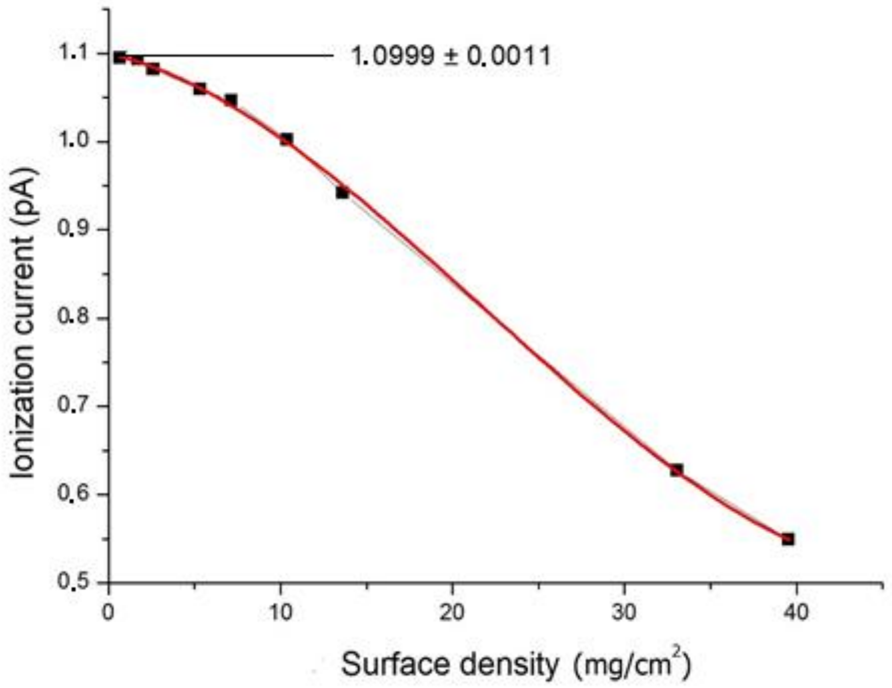


**Figure 3. Determination of the $I_0$ current for the [85]Kr source.**

From the current value $I_0$, it was possible to determine the transmission factors *T´*, the coefficient $k_a$ and the transmission factors *T* for the source. These values are shown in Table 1.

**Table 1. Transmission factors for the $^{85}$Kr source**.

| Absorber plate | Tissue Surface Density (mg/cm$^2$) | Transmission Factor $T^{\prime}$ | Correction Factor for Distance $K_a$ | Transmission Factor $T$ |
|---|---|---|---|---|
| | 0.67 | 0.9956 ± 0.0011 | 1.0000 ± 0.0200 | 0.996 ± 0.020 |
| RN 8 | 1.70 | 0.9936 ± 0.0013 | 0.9999 ± 0.0200 | 0.994 ± 0.020 |
| RN 25 | 2.61 | 0.983 ± 0.004 | 0.9999 ± 0.0200 | 0.983 ± 0.020 |
| RN 36 | 5.33 | 0.9632 ± 0.0011 | 0.9998 ± 0.0200 | 0.963 ± 0.019 |
| RN 50 | 7.15 | 0.951 ± 0.004 | 0.9997 ± 0.0200 | 0.950 ± 0.019 |
| RN 75 | 10.39 | 0.9114 ± 0.0009 | 0.9995 ± 0.0200 | 0.911 ± 0.018 |
| RN 100 | 13.63 | 0.8561 ± 0.0014 | 0.9993 ± 0.0200 | 0.856 ± 0.017 |
| RN 250 | 33.07 | 0.5701 ± 0.0012 | 0.9983 ± 0.0200 | 0.569 ± 0.011 |
| RN 300 | 39.56 | 0.4990 ± 0.0007 | 0.9980 ± 0.0200 | 0.498 ± 0.010 |

From the values for the transmission factors of Table 1, the curves to determine the transmission factors for the tissue-equivalent surface densities presented in the calibration certificates of the sources were obtained. The curve was adjusted following the same criteria as for the curve of Figure 3. Figure 4 shows the final curve for the transmission factor of the $^{85}$Kr source. Table 2 presents the final transmission factors determined in this work. The surface densities of the tissue corresponding to the thicknesses of the source calibration certificates of the $^{85}$Kr were taken into account. The factors were normalized to the thickness of 0.07 mm. The uncertainties were propagated, and the coefficient k = 2.

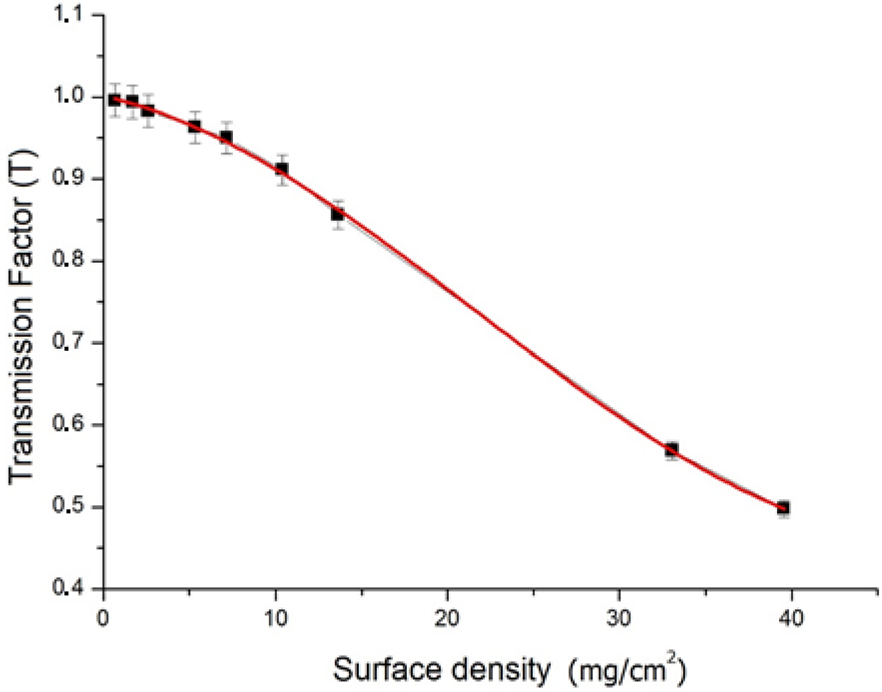


**Figure 4. Final curve of the transmission factors corresponding to the $^{85}Kr$ source (Third-order polynomial fitting).**

**Table 2. Final transmission factors for the $^{85}Kr$ source and certain values of tissue thickness, normalized for a thickness of 0.07mm.**

| Thickness (mm) | Tissue Surface Density (mg/cm$^2$) | Experimental Transmission Factors | Calibration Certificate Factors | Difference (%) |
|---|---|---|---|---|
| 0 | 0 | 1.06 ± 0.06 | 1.05 ± 0.01 | 0.9 |
| 0.02 | 2 | 1.05 ± 0.06 | 1.04 ± 0.01 | 0.9 |
| 0.04 | 4 | 1.03 ± 0.06 | 1.03 ± 0.01 | 0 |
| 0.05 | 5 | 1.02 ± 0.06 | 1.02 ± 0.01 | 0 |
| 0.07 | 7 | 1.00 ± 0.06 | 1.00 | 0 |
| 0.10 | 10 | 0.96 ± 0.06 | 0.96 ± 0.01 | 0 |
| 0.20 | 20 | 0.81 ± 0.06 | 0.78 ± 0.01 | 3.8 |

The transmission factors in the tissue obtained in this work are in agreement with the values of the transmission factors of the PTB source calibration. The maximum difference between them was 3.8% at a tissue depth of 0.20 mm.

In 2015, Reynaldo (2015) reported maximum differences of 2.6% for depths greater than 0.05 mm and differences of 5.4% for depths less than that value.

## Conclusions

In this work, the transmission factors for an $^{85}Kr$ radiation beam were determined using an extrapolation chamber.

These factors allow the determination of absorbed dose rates at different tissue depths.

The agreement of the transmission factors obtained and those from the PTB calibration certificate show that the results of this work are suitable for the establishment of a primary standard for beta radiation at LCI/IPEN using the PTW extrapolation chamber.

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