National Standard for $\Phi_{air}(0)$ in Beta Radiation Fields of $^{90}Sr/^{90}Y$ and Calibration of Contamination Superficial Monitors at SSDL-ININ-Mexico

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Abstract. In the Metrology Department at ININ, there is a Secondary Standard Dosimetry Laboratory SSDL, since 1987 it has an Alpha-Beta calibration room. In this room there are: the Beta Secondary Standard BSS Nr. 86 with traceability to the primary laboratory Physikalisch-Technische Bundesanstalt PTB and a reference class extrapolation chamber EC, which had been accredited as Mexican National Standard for realizing the unit of absorbed dose rate to air $\Phi_{air}(0)$ for $^{90}Sr/^{90}Y$. The developed activities with these standards are: a) Calibration of ophthalmic applicators with the EC for the determination of $\Phi_{air}(0)$; b) Measurement of $\Phi_{air}(0.07)$ at the equivalent tissue deep 0.07 mm, for $^{90}Sr/^{90}Y$ sources of the BSS; c) Monte Carlo MC simulations for $\Phi_{air}(0)$ with the Penelope algorithm; d) Construction of control charts of $\Phi_{air}(0)$ for the BSS of $^{90}Sr/^{90}Y$, (Shewhart technique); e) Calibration of personnel dosimeters and ionization chambers in terms of: personal dose equivalent $Hp(0.07)$ and directional dose equivalent $H'(0.07,a)$ with the BSS; f) Testing of personnel dosimetry performance for beta particles in terms of shallow dose equivalent $H_s(0.07)$ for Laguna Verde Mexican Nuclear Power Plant. Also, the expanded uncertainties U are presented, in agreement with the BIPM recommendations, and the percent deviations respect to PTB values.

In the other hand, the SSDL-ININ (Nuclear Centre of Mexico) is located at 3 000 meters over the sea level, at Salazar town where $P_{\text{eq}}=71,0$ kPa, $P/T \approx 0,24$ kPa K$^{-1}$; therefore it was necessary to apply the correction factors: $k_{\text{ad}}$ and $k_{\text{ab}}$; the first one, in order to correct the measurements for atmospheric reference conditions $T_0$ and $P_0$, the second one to take account the attenuation and scattering radiation in the external air to EC. However, for SSDL atmospheric conditions this later factor is out to the range of conditions considerate at PTB. That is why we used correction methods with a broad range, mainly: the NIST procedure and others employed for European laboratories. Additionally, the SSDL-ININ had taken in account another correction factor $k_{\text{dis}}$, this to correct the attenuation and scattering radiation in the air inside the EC volume. Finally, the SSDL has been doing calibration services for contamination superficial monitors by the determination of instrument efficiency $\epsilon$, and for these services, we utilized reference sources calibrated in terms of surface emission rate $q_{2\pi}$.

1. Introduction

The Alpha-Beta calibration room at SSDL-ININ has an EC brand PTW model 30-360, serial 2392-040 with 30,00 mm for collecting electrode diameter and electrodes with variable separation L; so it is possible to determine the $\Phi_{air}(0)$ by the current I produced by the ionization, as a function of L. This I vs. L, is known as an extrapolation curve ExC. With the measurements for $\Phi_{air}(0)$ realized since 1988 to 2003, the EC has been accredited as Mexican National Standard in beta field radiation of $^{90}Sr/^{90}Y$ for $\Phi_{air}(0)$ [1]. However, because we had problems with the measurement of $^{204}Tl$ and $^{147}Pm$ due to the correction for high altitude over the sea level of the SSDL-ININ only presents results for the $^{90}Sr/^{90}Y$ sources.

Additionally, the calibration room has the BSS Serial No. 86, with four standard sources for beta radiation. This group of sources is known as BSS of type 1, series 1: for sources of low activity, and series 2 for sources of high activity. Which radiation fields were calibrated by the primary laboratory PTB, (Germany), in terms of the absorbed dose rate in the air on the surface $\Phi_{air}(0)$ for several distance source detector DSD, see Table I [2].

1.1 Bragg Gray Theory

Using this EC $\Phi_{air}(0)$ is determined as [3]:
\[
\Phi_{\text{air}}(0) = \frac{\bar{w}}{e} \cdot \frac{1}{\rho_0 \cdot A_{\text{eff}}} \cdot \prod_{i=1}^{n} k_j \cdot d \cdot \prod_{j=1}^{m} k_j \cdot dL
\]

where

\(\bar{w}/e\) is the quotient of the mean energy expended in air dry per ion pair formed by elementary charge;

\(\rho_0 = 1.1995 \text{ kg m}^{-3}\) air density at: \(T_0 = 20.0 ^\circ \text{C}, P_0 = 101.3 \text{ kPa and 45 \% for the relative humidity};\)

\(A_{\text{eff}}\) is the effective area for EC’s collecting electrode, and for our chamber is: \(7.1617 \times 10^{-4} \text{ m}^2\) [4];

\(\prod_{i=1}^{n} k_j\) is the product of correction factors, which depend on electrode’s separation \(L\);

\(\prod_{j} k_j\) is the product of correction factors, which are not depend on \(L\).

The detail definition of these correction factors is given in [3].

1. 2 Atmospheric conditions correction factor at Salazar SSDL-ININ-Mexico

We had two problems when they are measured the \(\Phi_{\text{air}}(0)\), with BSS type 1 sources, at high altitudes following the methodology of PBT for such EC [3]:

(a) The correction factor for attenuation and scattering of radiation between the source and the EC window \(k_{ab}\), pertaining to the \(k_j\), is only valid in the interval of atmospheric conditions:

\[0.34 \leq P/T \leq 0.35 \text{ kPa K}^{-1}\];

(b) This factor is recommended only for the \(^{147}\text{Pm}\) source, no for \(^{90}\text{Sr}/^{90}\text{Y}\) [2].

To solve both problems the National Institute of Science and Technology NIST recommends to apply this factor to all sources of BSS type 1, [5], in the interval of the relative density of air: 0.6 < \(\rho/\rho_0 < 1.0\), (note that the NIST takes 22°C as the reference temperature). In particular, the SSDL-ININ is located at an elevation of 3000 m over the sea level: \(P \approx 71.0 \text{ kPa, P}/T \approx 0.24 \text{ kPa K}^{-1}\), \(\rho/\rho_0 \approx 0.7\). For this reason the measurements of variable \(I\) are corrected by the factor \(k_{ab}\) indicated by the NIST [5]; it is convenient to remark that European laboratories recommend a similar correction mainly for measurements for \(^{147}\text{Pm}\) [6]. It is clear that the remaining correction factors indicated in the equation (1) were also applied.

Table I. Values of \(\Phi_{\text{air}}(0)\) reported by the PTB for the \(^{90}\text{Sr}/^{90}\text{Y}\) BSS Nr. 86 [2].

<table>
<thead>
<tr>
<th>Activity MBq</th>
<th>DSD cm</th>
<th>Date</th>
<th>(\Phi_{\text{air}}(0))</th>
<th>Random Error</th>
<th>Systematic Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>1850</td>
<td>11</td>
<td>07-04-1986</td>
<td>547.4</td>
<td>0.6%</td>
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<td>1850</td>
<td>30</td>
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<td>0.1%</td>
<td>1.0%</td>
</tr>
<tr>
<td>1850</td>
<td>50</td>
<td>07-03-1986</td>
<td>26.78</td>
<td>0.1%</td>
<td>1.0%</td>
</tr>
<tr>
<td>74</td>
<td>30</td>
<td>06-19-1986</td>
<td>2,007</td>
<td>0.5%</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

1.3 Operational quantities for beta radiation fields

For external beta radiation field the interesting operational quantities are: directional dose equivalent \(H'(0.07;\alpha)\) and the personal dose equivalent \(H_p(0.07)\). The \(H'(0.07;\alpha)\) under calibration conditions, is defined as [7]:
\[ H'(0,07; \alpha) = h'_D (0,07; E, \alpha) \cdot D_R \]  

(2)

where

\[ h'_D (0,07; E, \alpha) \] is the conversion coefficient for the slab phantom in dependence on the angle of incidence for commercial beta sources, with \( E \) denoting the (mean) energy of the reference radiation and \( \alpha \) the (mean) angle of beta particle incidence under calibration conditions \([7]\); \( D_R \) is the personal absorbed dose \( D_p(0,07) \) in a slab phantom made of ICRU tissue with an orientation of the phantom for which the normal to the phantom surface coincides which the (mean) direction of incident radiation \([8]\). The slab phantom is approximated with sufficient accuracy by the inherent slab of the standard instrument (extrapolation chamber) used for the measurement of the beta radiation field by the absorbed dose to equivalent tissue \( D \); therefore,

\[ D_R = D_p(0,07) = D_t(0,07) = \bar{S}_{t,a} \cdot T(0,07) \cdot D_{air}(0) \]  

(3)

here

\[ \bar{S}_{t,a} \] is the ratio of the average mass collision stopping power for tissue an air average over the spectral beta particle density;

\[ T(0,07) \] is the tissue transmission factor for a depth of 0,07 mm.

The \( H_p(0,07) \) is given by:

\[ H_p(0,07) = h_{p,D}(0,07; E, \alpha) \cdot D_R \]  

(4)

Note that \( h'_D = h_{p,D}(0,07; E, \alpha) \) \([7]\).

It is convenient to observe, that American Standards for radiation protection uses different names and definitions for the \( H_p \), for example, in our case for external beta radiation fields the \( H_p(0,07) \) is called Shallow dose equivalent \( H_S(0.07) \) or individual dose equivalent superficial \([9]\):

2. Characterization of the Mexican national standard

2.1 Measurement and control charts for \( \mathbf{S}_{air}(0) \)

2.1.1 Measurement of \( \mathbf{S}_{air}(0) \)

In the Table II are summarized the results of the measurements for the absorbed dose rate at SSDL-ININ \([\mathbf{S}_{air}(0)]_{ININ}\) and their percentage comparisons \( \Delta\% \) respect the PTB values \([\mathbf{S}_{air}(0)]_{PTB}\), where these latter obtained from the calibration certificates for BSS Nr 86, therefore:

\[ \Delta\% = \left( \frac{[\mathbf{S}_{air}(0)]_{ININ} - [\mathbf{S}_{air}(0)]_{PTB}}{[\mathbf{S}_{air}(0)]_{PTB}} \right) \cdot 100 \]  

(5)

Also in Table II are shown the expanded uncertainties \( U \) for \( \mathbf{S}_{air}(0) \), which are determined in agreement with the BIPM recommendations, in particular the effective freedom degrees \( v_{eff} \) \([11]\).

2.1.2 Control charts of \( \mathbf{S}_{air}(0) \)
Three sets of control charts CCH were constructed with the technique of Shewhart [12], for the variable I/L obtained from the ExC’s. These variables were determined in the period since 1988 to 2003 for the \(^{90}\)Sr/\(^{90}\)Y sources of 1850 MBq and 74 MBq of the BSS Serial No. 86. The first two sets of CCH’s allowed the identification of two assignable causes of variation: which one was due to the change of scattering and attenuation of the radiation inside the EC, such change because the lower atmospheric pressure \(P\) with respect to \(P_0 = 101.3\) kPa on which the measurements were made; and the other one, due to the lack of reproducibility of the source position [13].

Once corrected these causes, the third set of CCH’s was constructed which corresponds to a state of statistical control process, validated with the normality tests of Shapiro-Wilks. Finally, the true mathematical models were obtained for EC’s, validated with hypothesis tests for the significance of the models and hypothesis tests for lack of fit of the models [13].

Table II. Values of \(\hat{\mathcal{F}}_{w}(0)\) measured for \(^{90}\)Sr/\(^{90}\)Y BSS Nr 86 at SSDL-ININ since 1988 to 2003 [10].

<table>
<thead>
<tr>
<th>MBq</th>
<th>DSD cm</th>
<th>Date</th>
<th>(\mu Gy s^{-1})</th>
<th>(K=2)</th>
<th>(v_{eff})</th>
<th>(\Delta)%</th>
</tr>
</thead>
<tbody>
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<td>1850</td>
<td>11</td>
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<td>534,57</td>
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<td>3,3</td>
<td>1,39</td>
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<td></td>
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<td>536,94</td>
<td>5,28</td>
<td>13,1</td>
<td>1,84</td>
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<tr>
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<td></td>
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<td>4,90</td>
<td>12,4</td>
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<td>3,39</td>
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<td>08-09-1999</td>
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<td>5,26</td>
<td>13,8</td>
<td>-0,15</td>
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<td>04-06-2000</td>
<td>524,68</td>
<td>4,87</td>
<td>12,0</td>
<td>-0,49</td>
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<td>12,3</td>
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<td>7,02</td>
<td>10,0</td>
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<td>5,48</td>
<td>13,5</td>
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<td>5,73</td>
<td>13,4</td>
<td>4,85</td>
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<td>5,76</td>
<td>13,3</td>
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<td>12,8</td>
<td>1,81</td>
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<td>30</td>
<td>02-09-1988</td>
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<td>9,18</td>
<td>7,2</td>
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<td>1,573</td>
<td>5,14</td>
<td>12,5</td>
<td>-9,54</td>
</tr>
</tbody>
</table>

* normalized to the first date of each DSD.

2.2 Simulation for \(\hat{\mathcal{F}}_{w}(0)\)

The \(\hat{\mathcal{F}}_{w}(0)\) were simulated for the \(^{90}\)Sr/\(^{90}\)Y BSS Nr 86 and PTW EC model 30-360. It was employed the Penelope Monte Carlo algorithm [14]; the main results obtained are [15]:

(a) The \(kab=1.026\) with \(U(k=1)=3.28\%\) for the activity source of 1850 MBq, to DSD= 11 cm and the atmospheric pressure at Salazar 71,0 kPa. In this case the value determined by simulation is consistent with the values calculated by means of the technique of the NIST, which differences between both values are inside the experimental uncertainties. Physically
the correction factor indicate that the primary and dispersed radiation do not suffer an attenuation process before to arrive to the CE, rather they suffer an increment due to the dispersion processes in the air, [5];

(b) The nominal value for this model of CE window thickness 2.6 mg/cm is incorrect [16], being more probable the value of 0.75 mg/cm;

(c) The nominal values for construction of 1850 MBq source do not coincide with that we had used for simulate the $\vec{E}_{\text{air}}(0)$, see Table II. The position of the radioactive material was assumed to a depth $=100 \mu m$, which is different to the nominal depth of 150 $\mu m$ [16].

3. Calibration services for beta particles at SSDL-ININ-Mexico

3.1 National standard and BSS Nr. 86

3.1.1 Medical calibration services

The main service is the calibration for $\text{Sr}/\text{Y}$ flat ophthalmic applicators in function of $\vec{E}_{\text{air}}(0)$, with the EC; the SSDL had developed own procedures to considers the employ of quadratic regression models to fit the ExC. These regression models are validated with the lack of fit and normality tests for the residuals, with this protocol it is meet a better accuracy about to 15% respect to linear models [4].

Table III. Results for the MC simulation of $\vec{E}_{\text{air}}(0)$, $\text{Sr}/\text{Y}$, 1850 MBq BSS Nr 86 [15].

<table>
<thead>
<tr>
<th>DSD cm</th>
<th>N</th>
<th>T</th>
<th>$\bar{E}$, eV</th>
<th>$\sigma$, eV</th>
<th>$\mu$Gy s$^{-1}$</th>
<th>U%</th>
<th>$\Lambda$%</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>1.48722E+06</td>
<td>5.16180E+05</td>
<td>0.8228</td>
<td>0.019</td>
<td>567.92</td>
<td>2.35</td>
<td>0.38</td>
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<tr>
<td>30</td>
<td>1.45315E+06</td>
<td>5.16179E+05</td>
<td>0.0753</td>
<td>0.050</td>
<td>51.98</td>
<td>7.08</td>
<td>-30.7</td>
</tr>
<tr>
<td>50</td>
<td>9.31443E+05</td>
<td>5.16190E+05</td>
<td>0.0401</td>
<td>0.012</td>
<td>27.66</td>
<td>30.7</td>
<td>-31.8</td>
</tr>
</tbody>
</table>

here N is the number of primary particles simulated; T is the time of simulation, $\bar{E}$ is the mean energy deposited, $\sigma$ is the standard deviation of $\bar{E}$.  

3.1.2 Radiological protection services

The calibration services for radiological protection that involved reference beta radiation fields are:

(a) Construction of calibration curves in $Hp(0,07)$ or $H'(0,07)$ for TLD personal dosimeters;
(b) Tests of performance for personal dosimetry, category V, according the reference [9], for Laguna Verde Nuclear Power Plant;
(c) Calibration of: Geiger Muller GM, scintillator, photodiode [18], proportional detectors in terms of $H'(0,07;\alpha)$;
(d) Calibration in $\vec{E}_{\text{air}}(0)$ for external fields from beta sources;

3.2 Calibration of contamination superficial monitors

One of the problems related to the evaluation of surface contamination, it is calibrate the instruments in the appropriate quantities, the ISO 7503-1 establishes for alpha and beta emitters, that the monitor calibration should be in terms of $\varepsilon_{\alpha}$, which is defined as [19],

$$\varepsilon_{\alpha} = \frac{n - n_{B}}{q_{2\pi}} = \frac{n - n_{B}}{E_{SC} \cdot W} \tag{6}$$

where

n is the measured total count rate from the reference source plus background;
\( n_B \) is the background count rate;
\( q_{2\pi} \) is the surface emission rate of the reference source below the sensitive window area \( W \) of the probe;
\( E_{SC} \) is the surface emission rate per unit area.

For this propose the SSDL has a set of 29 reference sources, class 1 and 2, with traceability to primary laboratory LMRI, (France). The principal aspects in experience gained during the operation of Alpha-Beta calibration room for the calibration of surface contamination monitors are:

(a) Frequently, the users do not known the modern bibliography for evaluation of surface contamination, for this reason the SSDL-ININ advised into the Mexican republic to: users, regulatory agencies, experts in radiological protection, with the purpose to harmonize the different regulations for this kind of applications.

(b) To development calibration procedures coherent to ISO standards and International System of Units, and Basic Safety Standards [20];

(c) For the calibration of all GM detectors (except for end-window cylindrical detector), it is convenient to take as reference the \( \varepsilon_i \) value for 14C, which is set in our laboratory about to 10 %, with this value the \( ^{90}\text{Sr}/^{90}\text{Y} \) \( \varepsilon_i \) is 30%;

(d) The \( U (k=3) \leq 15\% \) for the \( \varepsilon_i \), in otherwise the instrument is rejected;

(e) It has been developed special procedures for calibration of beta particles and noble gases monitors, for the isotopes production plant and Triga Mark III nuclear reactor at Nuclear Centre of Mexico.

4. Conclusions

4.1 Results of measurements at SSDL-ININ

(a) For the atmospheric conditions at SSDL-ININ is necessary apply the correction factor indicated by the NIST [5];

(b) From the CCH is inferred that exists a lack in the reproducibility of the distance detector to radiation source;

(c) The \( \mathbf{H}_{\text{air}} (0) \) by MC simulation to valid the values obtained by measurements for 1850 MBq to \( DSD=11 \) cm, inside the order of experimental uncertainties. However, the others values of \( \mathbf{H}_{\text{air}} (0) \) are not satisfactory;

(d) It is very probable that the nominal value for this model of CE window thickness 2.6 mg/cm is incorrect being more accurate the value of 0.75 mg/cm;

(e) The nominal values for construction of 1850 MBq source do not coincide with that we had used for simulate the \( \mathbf{H}_{\text{air}} (0) \), see Table II. The position of the radioactive material was assumed to a depth \( =100 \) \( \mu \)m, which is different to the nominal depth of 150 \( \mu \)m;

(f) For the calibration of the flat ophthalmic applicators in function of \( \mathbf{H}_{\text{air}} (0) \), with the EC; the SSDL had developed own procedures that to considers quadratic regression models to fit the ExC. These regression models are validated with the lack of fit and normality test for the residuals, with this protocol is meet a better accuracy about to 15% respect to linear models.

(g) The SSDL-ININ has been calibrated radiological protection instruments in terms of \( H'(0.07;\alpha) \) rather than in older radiological quantities;

(h) For contamination monitors, the SSDL-ININ development calibration procedures coherent to ISO standards and International System of Units, and Basic Safety Standards;

4.2 Future activities

(a) The SSDL-ININ has to make intercomparisons in these and another’s dosimetric quantities with others metrological laboratories, concretely by the system Interamerican of Metrology (SIM);

(b) It is convenient that the SSDL update their BSS Type 1 for other called BSS type 2;

(c) Finally, the \( \mathbf{H}_{\text{air}} (0) \) process of measurement for low energy beta radiation from \( ^{147}\text{Pm} \) represents a defiance that the SSDL has to solve.
5. Bibliography

7. Soares C., National Institute of Science and Technology, Gaithersburg, personal communication, 2002.