Influence of the Irradiation Systems on Beta-ray Calibration for Dosemeters
—Characteristics of the Beta-ray Irradiation Systems at the Facility of Radiation Standards (FRS) in JAEA—

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(Received on April 22, 2016)
(Accepted on June 16, 2016)

With regard to the calibration of dosemeters in the 90Sr/90Y reference field, the influence of the difference of beta-ray irradiation systems on the calibration results has been investigated. Two different types of beta-ray irradiation systems installed at the Facility of Radiation Standards (FRS) in the Japan Atomic Energy Agency (JAEA) were chosen for the comparison. The 90Sr/90Y sources of each system showed different depth-dose profiles reflecting different energy spectra due to their source structure. The difference in depth-dose curves implied the calibration results would be affected in the case of a thick dosemeter. In order to confirm the influence of the difference of depth-dose curves, optically stimulated luminescence ring type dosemeters were irradiated with both systems. The results showed the calibration factors were slightly different as predicted from the depth-dose curves.

KEY WORDS: beta reference radiation field, beta dosimetry, beta-ray absorbed dose, depth-dose curve, calibration factor, optically stimulated luminescence, calibration.

1 INTRODUCTION

External exposure from beta-ray often makes a significant contribution in the assessment of the skin dose. To assess the skin dose to radiation workers, the area monitoring in terms of H(0.07) and the personal monitoring in terms of Hp(0.07) have been carried out. For properly implementing the reliable monitoring, an appropriate calibration must be required for survey meters and personal dosemeters in beta reference radiation fields.

A beta reference radiation field is produced by a beta-ray irradiation system that is composed of sealed beta radiation sources, calibration table, source stand and beam-flattening filters if required. The calibration factor of a dosemeter should be independent of a beta-ray irradiation system if calibrated with the same radionuclide. However, due to the strong scattering and absorption properties of beta-rays in materials, the characteristic of the beta-ray irradiation system such as the structure of the source, the beam-flattening filter and the layer of air between the source and dosemeters might be attributed to variations in a depth dose profile and beta spectrum. These differences in the beta-ray irradiation systems might lead to different calibration factors obtained from the beta-ray radiation sources with the same radionuclide.

Two different types of beta-ray irradiation systems have been installed and served as beta reference radiation fields at the Facility of Radiation Standards (FRS) in the Japan Atomic Energy Agency (JAEA). One is so-called the Beta Secondary Standard type 2 (BSS2),1) which is commercially available and commonly used worldwide as a de facto standard in beta calibration. The BSS2 was newly installed in 2010 at the JAEA-FRS. The other system, hereinafter called the JAEA Beta-ray irradiation System (JBS) in this paper, has quite different types of the beta-ray radiation sources from those for the BSS2. The JBS has been used for more than two decades for beta calibration at the JAEA-FRS. It has been concerned that the dependency of the irradiation system on the calibration results would results in not only affecting on the dose assessment but also making it difficult for us to compare a dosemeter response obtained by the JBS field with a literature data obtained by the BSS2 field.

In our previous study,2) the direct comparisons of depth dose profile for beta reference radiation fields produced by both beta-ray irradiation systems were carried out. A series of investigation showed as follows: 1) Differences were observed in the depth-dose curves, 2) These implied the calibration results of a dosemeter would be affected.

The aim of this study is to evaluate the dependency of the irradiation system on calibration factors in practice. It is also important to show that this difference can be explained from
the depth-dose curves and structure of the dosemeter in order to estimate the difference easily in advance. In this paper, calibrations for Optically Stimulated Luminescence Ring type Dosemeters (OSLDRDs) were performed in the \(^{90}\text{Sr/}^{90}\text{Y}\) beta-ray reference fields for each system as a model case. The difference of obtained calibration factors was then compared to the estimated one from the depth-dose curves. Calculations were also made for these fields to discuss the relationships between their depth-dose curves and their structural properties in detail. This will provide the useful information for the influence of the beta-ray irradiation systems on the calibration for dosemeters.

II MATERIALS AND METHODS

1. Two beta-ray irradiation systems at the FRS

Two different types of beta-ray irradiation systems at the FRS, the JBS and the BSS2, are employed. The BSS2 manufactured by Eckert & Ziegler comprises three kinds of beta-ray radiation sources, i.e. \(^{147}\text{Pm}, \quad ^{85}\text{Kr}\) and \(^{90}\text{Sr/}^{90}\text{Y}\) beam-flattening filters, the source stand, and the control unit. The JBS is composed of an alignment apparatus, the precise scale and beta-ray radiation sources, i.e. \(^{147}\text{Pm}, \quad ^{204}\text{Tl}\) and \(^{90}\text{Sr/}^{90}\text{Y}\) manufactured by the former Amersham Corporation. The JBS source has a larger active area of 4.2 cm in diameter and a thinner source window with 50 \(\mu\)m silver whereas the BSS2 source has a smaller but thicker active area (0.6 cm in diameter and 0.4 mm thickness) and a thicker source window with 100 \(\mu\)m stainless steel.

2. Beta reference radiation fields

The standard beta reference radiation fields produced by \(^{90}\text{Sr/}^{90}\text{Y}\) sources with 30 cm calibration distance of both systems were chosen for this comparison. These BSS2 fields with calibration certificate provided by Physikalisch Technische Bundesanstalt (PTB) fully satisfy the requirements for ISO 6980 series. The JBS fields using higher activity sources without beam-flattening filter can provide higher dose rate. Detailed specifications for these beta reference radiation fields used in this paper are given in Table 1.

3. Depth-dose curves

Since the energy fluence of beta-ray can change as betarays penetrate the medium, beta-ray dose in the medium significantly depends on a depth. Although the absorbed dose at the depth of 0.07 mm (= 7 mg/cm\(^2\)) in the ICRU tissue is the reference value for calibration, it is not easy for a practical personal dosemeter to measure the absorbed dose at the exact depth directly but to measure the averaged dose over the sensitive layer with a certain thickness at a different depth. Thus, the dose distribution in depth provides an important information when considering the response of a dosemeter. The depth-dose for \(^{90}\text{Sr/}^{90}\text{Y}\) field is defined in this paper as follows:

\[
\tau_{s}(d) = \frac{D_{s}(d)}{D_{s}\left(7 \text{ mg/cm}^2\right)}
\]

where, \(\tau_{s}(d)\): the depth-dose, \(D_{s}(d)\): the absorbed dose in slab made of ICRU tissue at a depth of \(d\).

Subscription \(s\) represents either Sr, Y or Sr + Y, which means \(^{90}\text{Sr}\) contribution, \(^{90}\text{Y}\) contribution or both \(^{90}\text{Sr}\) and \(^{90}\text{Y}\) contribution is considered, respectively. Superscription “sys” represents either the JBS or the BSS2 irradiation system. It should be noted that \(\tau_{s}(d)\) is normalised by the total absorbed dose in ICRU tissue at the depth of \(d = 7 \text{ mg/cm}^2\) which is the basic physical quantity in beta dosimetry and is directly related to \(H(0.07)\) or \(H(0.07')\).

In order to determine \(D_{s}\left(7 \text{ mg/cm}^2\right)\), the measurements using the extrapolation chamber with a 6.85 cm/cm\(^2\) entrance window were carried out as described in the previous study in detail. This method directly provides absorbed dose in ICRU tissue at the depth of \(d = 7 \text{ mg/cm}^2\) for any irradiation systems. \(D_{s}\left(7 \text{ mg/cm}^2\right)\) with associated uncertainties used in this paper are given in Table 1. The uncertainties were obtained by propagating together individual uncertainty components such as the extrapolated ionization current, the correction factors and the W value.

The averaged absorbed dose, \(A_{\text{ave}}\), over a sensitive volume of a tissue-equivalent dosemeter irradiated with these fields can be estimated using this \(\tau_{s}\). For a dosemeter with \(u\) mg/cm\(^2\) thickness of a sensitive volume covered with a tissue-equivalent filter with \(d\) mg/cm\(^2\) thickness, the \(A_{\text{ave}}\) can be obtained by the following equation,

\[
A_{\text{ave}} = D_{s}\left(7 \text{ mg/cm}^2\right)\int_{s}^{d} \tau_{s} \left(\text{mg/cm}^2\right) d\mu
\]

For a dosemeter composed of low-Z materials, the same

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**Table 1** Specifications for the standard \(^{90}\text{Sr/}^{90}\text{Y}\) fields at the FRS.

<table>
<thead>
<tr>
<th>System</th>
<th>JBS</th>
<th>BSS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal activity</td>
<td>740 MBq</td>
<td>460 MBq</td>
</tr>
<tr>
<td>Diameter and thickness of active area</td>
<td>4.2 cm (\Phi); 0.2 mm</td>
<td>0.6 cm (\Phi); 0.4 mm</td>
</tr>
<tr>
<td>Source window</td>
<td>50 (\mu)m silver</td>
<td>100 (\mu)m stainless steel</td>
</tr>
<tr>
<td>Beam flattening filter</td>
<td>None</td>
<td>PET filter</td>
</tr>
<tr>
<td>Calibration distance</td>
<td>30 cm</td>
<td>30 cm</td>
</tr>
<tr>
<td>(D_{s}\left(7 \text{ mg/cm}^2\right)) (mGy/h)(^{k})</td>
<td>79.4 (\pm) 0.9(^{k})</td>
<td>34.5 (\pm) 0.7(^{k})</td>
</tr>
</tbody>
</table>

\(^{k}\) These values were obtained directly from the measurements using extrapolation chamber.

\(^{k}\) As of 13th November 2013 and the associated uncertainties are given for \(k = 1\).
equation can be applied by replacing the values \( u \) and \( d' \) with their tissue-equivalent ones which is obtained by multiplying the scaling factor relative to the tissue given in ISO 6980-2.\(^4\)

4. Calculations

The Monte Carlo calculations were made using the Monte Carlo code EGS\(^5\)\(^6\) to obtain the depth-dose curves. Photons and electrons were both tracked down to their kinetic energies of 10 keV. Beta spectra of \(^{90}\)Sr and \(^{90}\)Y were taken from the ICRP Publication 107.\(^7\) In the calculations, the geometries of the sources which consist of an active source area, a source window, backing materials and a stainless-steel source holder were modelled as precisely as possible, according to the available data from the manufacturer, adjusted so as to reproduce the experimental data.\(^2\)\(^7\) All the regions concerned were filled with dry air (120 cm in diameter \( \times \) 100 cm) for these calculations. For the calculations of the depth-dose, the ICRU tissue slab phantom (30 cm \( \times \) 30 cm \( \times \) 15 cm in depth) was placed perpendicular to the central axis of the irradiation systems at the point of test. At the 31 different depths of \( d \) mm (\( d = 0 – 9 \) mm) in this phantom, 30 mm in diameter \( \times \) 5.0 \( \mu \)m cylindrical regions on the central axis of the irradiation systems were employed to score the deposit energies from which \( D_{vs}(d) \) were calculated as an averaged absorbed dose over each cylindrical region. A geometrical model for the BSS2 system used in the calculation is shown in the Fig. 1 (a) as an example.

In the calculations of the beta fluence spectra, electrons generated isotropically in the active source area according to the initial energy distribution of beta particles from \(^{90}\)Sr and \(^{90}\)Y, which is called (1) initial \(^{90}\)Sr\(^{90}\)Y spectrum in this paper, traveled through (2) the active source area, (3) the source region including the source window and (4) all the structure of the system including 30 cm air layer. A circular plane was placed (2)–(3) on the source window, or (4) at the point of test as shown in the Fig. 1 (b). The areas of these planes, \( S \), were 13.85 cm\(^2\) (4.2 cm in diameter) for JBS field and 7.07 cm\(^2\) (3.0 cm in diameter) for BSS2 field. The electrons crossing this plane were scored in 45 keV energy bins and weighted by \( 1/(S \cos \theta) \), where \( \theta \) is the angle between the direction of the electron and the central axis of the source, in order to determine the fluence.

5. Calibration of dosemeters

OSLRDs were employed for calibrations in \(^{90}\)Sr\(^{90}\)Y beta-ray reference fields by both beta-ray irradiation systems in this study. The reason why the OSLRD was chosen is that the OSLRD previously developed by ourselves has simple and well-known structure. This is also because the OSLRD has been practically used for the extremity monitoring at the Nuclear Science Research Institute (NSRI) of JAEA. The OSLRD contains two nanoDotTM dosemeters (Landauer, Inc) separated with metal filters between them. Metal filters which are the combination of aluminum and copper can fully stop incident beta-ray so that the nanoDotTM under metal filters can only detect penetrating photons. The sensitive material used in the nanoDotTM is aluminum oxide with carbon doping (Al\(_2\)O\(_3\); C). The sensitive layer has approximately 0.2 mm in thickness and 7 mm in diameter binding with thin polyester films (7 mg/cm\(^2\)) on either side for a total thickness of 0.3 mm. All the components are housed in a light-tight plastic casing. The thickness of the plastic casing is assumed to be 37 mg/cm\(^2\).\(^8\)

Six OSLRDs on the ISO rod phantom (19 mm in diameter made of polymethyl methacrylate (PMMA)) were irradiated with each system as shown in Fig. 2. Although all the OSLRDs were positioned within 5.5 cm from the central axis of the irradiation systems, no significant differences for the readings of the dosemeters were observed regardless of their positions.

The delivered personal dose equivalents \( H_p(0.07) \) at the point of test, denoted by \( H \), were evaluated using following equation as analogously given by P. Ambrosi et al.\(^{11}\)

\[
H = D_{\beta, Y}^{sys}(7 \text{ mg/cm}^2) \times e^{\frac{t}{t_{\frac{1}{2}}}} \times c_{abs} \times h_{0.07} \times T \quad (3)
\]

Where,

\( D_{\beta, Y}^{sys}(7 \text{ mg/cm}^2) \): the absorbed dose rate in ICRU tissue at a depth of 7 mg/cm\(^2\) given in Table 1.

\( t \): the date when the irradiation was carried out.

\( t_{\frac{1}{2}} \): the half-life value for \(^{90}\)Sr\(^{90}\)Y, i.e. (10,523 ± 35) days.
abs: the correction factor for variation of air density between the source and the point of test from reference condition. 

\( k_p \): the conversion coefficient from \( D_{\text{Sr}, \gamma} \) to \( H_p(0.07) \) (=1; since the angle of radiation incidence is 0° and quality factor for beta particles is unity).

\( T \): the irradiation time.

The irradiated dosemeters were processed using a microStar OSL reader (Landauer, Inc) by reading light output signals from the nanoDots\textsuperscript{TM}. Personal dose equivalents \( H_p(0.07) \), denoted by \( R_p \), were evaluated from the averaged readings of the six OSLRDs by following equation.

\[
R_p = C(M_1 - M_2)
\] (4)

Where,

\( M_1 \) and \( M_2 \): averaged readings of six nanoDots\textsuperscript{TM} over metal filters and under metal filters, respectively (counts).

\( C \): the conversion factor from counts to dose (mSv/counts), which was determined by the reading counts of the nanoDots\textsuperscript{TM} to an exposure of 5 mSv with the JBS\textsuperscript{90Sr/90Y} source at the distance of 50 cm with respect to \( H_p(0.07) \).

Calibration factor, \( k \), is defined as a ratio between the delivered personal dose equivalent at the point of test and the estimated dose from the dosemeter readings as follows.

\[
k = \frac{H}{R_p}
\] (5)

### III RESULTS AND DISCUSSIONS

1. **Calibration factors for the OSLRD between systems**

In order to determine calibration factors of the OSLRD, the delivered dose and the dosemeter readings were evaluated with associated uncertainties (Table 2). Uncertainties for the delivered dose were estimated according to the equation (3) including uncertainty components related to \( D_{\text{Sr}, \gamma} \) (7 mg/cm\(^2\)), the irradiation time, the ambient conditions and the calibration distance. Standard deviations for the readings of irradiated six OSLRDs were evaluated as the standard uncertainties for the dosemeter readings. Since no significant difference depending on the irradiation positions among six dosemeters was observed and the signals from the control dosemeters to monitor background did not significantly increase, any correction and uncertainty related to the uniformity of the radiation field and background radiation were not taken into account. Calibration factors for the OSLRD were found to be 1.06 ± 0.03 for the JBS field and 1.00 ± 0.03 for the BSS2 field. This indicates that the dosemeter responses were different by 6% even though the same dosemeters irradiated with the same quantity, \( H_p(0.07) \).

2. **Difference in depth-dose curves between systems**

If a dosemeter measures the absorbed dose in the ICRU tissue at the depth of 7 mg/cm\(^2\) directly, the dosemeter response should be the same regardless of the beta-ray irradiation systems used. However, the observed difference indicates that it measured the dose at a different depth. It is useful to obtain depth-dose information in order to explain this.

<table>
<thead>
<tr>
<th>System</th>
<th>JBS</th>
<th>BSS2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calibration factor (( k ))</td>
<td>1.06 ± 0.03 (2.8%)</td>
<td>1.00 ± 0.03 (3.4%)</td>
</tr>
<tr>
<td>Delivered dose (( H )) (mSv)</td>
<td>2.98 ± 0.03 (1.3%)</td>
<td>2.99 ± 0.06 (2.0%)</td>
</tr>
<tr>
<td>Dosemeter reading (( R_p )) (mSv)</td>
<td>2.82 ± 0.07 (2.6%)</td>
<td>3.00 ± 0.08 (2.7%)</td>
</tr>
</tbody>
</table>

* The associated uncertainties are given for \( k = 1 \). The values in brackets are estimated relative standard uncertainties.
Fig. 3 Calculated depth-dose curves for $^{90}$Sr/$^{90}$Y fields produced by both beta-ray irradiation systems. The ones from the experiments in the previous study were also shown for reference. $\tau_{Sr+Y}(d)$ was normalised at $d = 7$ mg/cm$^2$ according to the equation (1). Arrow indicates the range of the integration to calculate the ratio of calibration factors for OSLRD.

difference.

Figure 3 shows the calculated depth-dose curves for both $^{90}$Sr/$^{90}$Y fields with experimental data from the previous studies using the extrapolation chamber with various thickness of filters.$^{2,3}$ Over the range from 15 mg/cm$^2$ to 250 mg/cm$^2$, where the important region for a practical $H_f(0.07)$ dosemeter, the JBS field showed lower build-up profile. In order to reveal what kinds of characteristics of systems cause this difference, depth-doses and fluence spectra due to the beta-rays emitted from $^{90}$Sr and $^{90}$Y for each source were calculated as a first step. Variations of the fluence spectra affected by the structure of systems were then evaluated by calculations.

It was assumed that $^{90}$Y ($E_{max} = 2.28$ MeV) in the beta reference source was in fully equilibrium with $^{90}$Sr ($E_{max} = 0.546$ MeV). It would be consistent, taking into consideration of time elapsed from the fabrication of sources. Calculated $^{90}$Sr fraction of the depth-dose curves for both irradiation fields, $\tau_{Sr+Y}(d)$, were shown in Fig. 4 (a). A significant contribution can be seen for the JBS field whereas the dose from the $^{90}$Sr component can be negligible for the BSS2 field. The value of $\tau_{Sr+Y}(7$ mg/cm$^2$), $^{90}$Sr contribution to $D_{Sr+Y}(7$ mg/cm$^2$) was found to be 7.8%. $\tau_{Sr+Y}(d)$ decreased sharply with the increase in $d$, resulting in no contribution over 100 mg/cm$^2$. In contrast, no significant $^{90}$Sr contribution was observed for the BSS2 field even in a shallow region, which means the dose at the point of test for the BSS2 field comes from the $^{90}$Y component of the source regardless of the evaluation depth. Figure 4 (b) shows the calculated $^{90}$Y fraction of the depth-dose curves for the JBS field, $\tau_{Y}(d)$. Since $\tau_{Y}(d)$ is equal to $\tau_{Sr+Y}(d) - \tau_{Sr}(d)$ according to the equation (1), $\tau_{Y}(d)$ at shallow depth $d$ is relatively lower. In order to compare the shapes between $\tau_{Y}(d)$ and $\tau_{Sr+Y}(d)$ (which is almost equal to $\tau_{Sr+Y}(d)$) shown in Fig. 3, $\tau_{Y}(d)$ was normalised at 7 mg/cm$^2$ multiplying 1.079 ($= 1/\tau_{Y}^{max}(7$ mg/cm$^2$)). These two curves show similar profiles each other except for a slight discrepancy over a 300 mg/cm$^2$ region. This discrepancy was due to the high energy region above 2 MeV in the fluence spectra described later.

Figure 5 shows the variation of beta-fluence spectra taking into account a part of the source structure for both systems. $^{90}$Sr components were observed in both spectra transmitted through only active source areas ($\tau_{Sr+Y}(d)$) and through both active source area and source window ($\tau_{Sr+Y}(d)$) are also shown for reference. $\tau_{Sr+Y}(d) \times 1.079$ has almost identical shape to the one for $\tau_{Sr+Y}(d)$ except for the 300 mg/cm$^2$ region.

$\tau_{Y}^{BSS2}(d)$ shown in Fig. 3, $\tau_{Y}(d)$ was normalised at 7 mg/cm$^2$ multiplying 1.079 ($= 1/\tau_{Y}^{max}(7$ mg/cm$^2$)). These two curves show similar profiles each other except for a slight discrepancy over a 300 mg/cm$^2$ region. This discrepancy was due to the high energy region above 2 MeV in the fluence spectra described later.

(a) $^{90}$Sr fraction of the calculated depth-dose curves, $\tau_{Sr+Y}(d)$, for both field. (b) $^{90}$Y fraction of the calculated depth-dose curve for the JBS field, $\tau_{Y}^{BSS2}(d)$, $\tau_{Sr+Y}^{BSS2}(d)$ and $\tau_{Sr+Y}^{BSS2}(d) \times 1.079$ ($= 1/\tau_{Y}^{max}(7$ mg/cm$^2$)) are also shown for reference. $\tau_{Sr+Y}^{BSS2}(d) \times 1.079$ has almost identical shape to the one for $\tau_{Sr+Y}^{BSS2}(d)$ except for the 300 mg/cm$^2$ region.
Thus, beta-rays emitted from 90Sr source used in the BSS2 almost totally absorbed in the thicker active area and source window. This leads to the differences in depth-dose curves.

3. Calibration factors estimated from depth-dose curves

The tissue-equivalent thickness of the cover over the sensitive volume for the nanoDot™ was determined to be 42 mg/cm², assuming that the scaling factors of polystyrene (representative of the plastic cover) and the polyethylene terephthalate (representative of the polyester layer) to tissue were 0.952 and 0.933, respectively.4 Also, the tissue-equivalent thickness of the cover over the sensitive volume for the nanoDot™ was 72 mg/cm² using the scaling factor of Al₂O₃ (0.908).4) Also, the tissue-equivalent thickness of the sensitive volume for the nanoDot™ was 72 mg/cm² using the scaling factor of Al₂O₃ (0.908).4) The equivalent tissue thickness of the nanoDot™ was found to be 114 mg/cm² in total. The difference of the calibration factors between two fields was then assumed from the equation (2) as follows:

\[
\frac{114 \text{ mg/cm}^2}{42 \text{ mg/cm}^2} = 1.06.
\]

The range of the integration was also indicated in the depth-dose curves in Fig. 3, where the discrepancy was observed. As a result, small difference, 6%, was expected from the depth-dose curves in the calibration of OSLRD, which is consistent of the experimental result.

IV CONCLUSIONS

Throughout the whole investigation, it was found that the difference in depth-dose curves for both 90Sr/90Y fields mainly caused by 90Sr component which deposits its energy on shallow depth of ICRU tissue. Beta-rays emitted from 90Sr of the JBS source could reach to the point of test whereas those of the BSS2 source could not. This was because the active layer and source window for the BSS2 source had enough thickness to absorb the low energy beta-rays from 90Sr.

In the previous paper,2) the absorbed dose rates in ICRU tissue at the depth of 7 mg/cm² for both 90Sr/90Y fields were directly determined by the measurements using the extrapolation chamber. However, a dosemeter used for the routine monitoring such as the OSLRD generally measures dose at the different depth due to the difficulties in measurement at 7 mg/cm², which result in a different response depending on the irradiation systems. In this paper, we showed the difference in the calibration of OSLRD with a common 90Sr/90Y field as a typical case. The calibration factor of OSLRDs irradiated with the JBS 90Sr/90Y fields was 6% higher than that irradiated with the BSS2 90Sr/90Y fields. The difference agreed with expected one from the depth-
dose curves. This suggests that the calibration results could depend on the beta-ray irradiation systems especially when calibrating a thick dosemeter using beta-ray irradiation system with different source structure. In that case, depth-dose curves provide useful information about their differences. However, this difference would be acceptable in most cases of calibrations for personal dosemeters composed of low-Z materials using $^{90}\text{Sr}^{90}\text{Y}$ source. That is why the difference is estimated to be about 10% at maximum from the difference of the depth-dose curves which is comparative with their uncertainties of calibration factors. In addition, some of the whole body type dosemeters have a few elements under filters with different thickness to assess $H_p(0.07)$ more precisely. This might reduce the difference among beta-ray irradiation systems.

ACKNOWLEDGEMENTS

The authors express their gratitude to Mr. M. YOSHIZAWA, Mr. T. OHISHI and Mr. T. SUZUKI in JAEA, for his continuous encouragement and many valuable comments. The authors also would like to thank all the members at the FRS, especially Dr. S. NISHINO, Mr. K. KAWAI and Mr. K. UMINO, for their support.

REFERENCES


7) J. BRUNZENDORF; Depth-dose curves of the beta reference fields $^{147}\text{Pm}$, $^{85}\text{Kr}$ and $^{90}\text{Sr}^{90}\text{Y}$ produced by the beta secondary standard BSS2, Radiat. Prot. Dosim., 151 (2), 211–217 (2012).


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