Comparison of calibration procedures of iridium-192 sources used in high dose rate brachytherapy system

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Calibration of iridium-192 high dose rate (HDR) brachytherapy sources has been compared by using two independent systems. Two types of calibration systems, well-type chamber (SDS), and field dosimeter (0.6 cc graphite thimble) with nucletron calibration jig have been compared. A number of measurements have been performed to calibrate the six iridium-192 sources according to national/international protocol during the clinical half-life of the iridium-192 source. All influencing factors like room-scattering, positional errors and accuracy of source position etc. have been taken care of, because the accuracy of source position itself within the applicator can lead to an error of ±1.2% for the radial distance of 10 cm used in the calibration jig. Taking the 0.6 cc graphite thimble results as reference, percentage root mean square error (RMS) value of 0.33% for well-type chamber has been observed. It has been found that, both the calibration systems are equally good and can determine accurate and quick source calibration with careful measurements. Further, it should be mandatory to calibrate the source, prior to use of the source for the treatment of patients.

[Keywords: Iridium-192, Brachytherapy system, Calibration]

1 Introduction

High dose rate (HDR) remote after-loading brachytherapy device is becoming more common worldwide. The most common radionuclide used in these units is iridium-192 in the form of a small pellet. The most suitable half-life of iridium-192 source is 83.825 days¹ requiring relatively frequent source replacement to maintain short treatment times. The most common supplier of this source is Mallinckrodt Diagnostica in the Netherlands. The company’s calibration certificate provided with each new source states an overall uncertainty in activity of ±10%. Therefore, it is recommended that, each time, when a new HDR source be installed a source calibration in the hospital should be carried out²,³.

Historically, the strength of sealed radioactive sources has been specified, using a variety of physical quantities and units. Radium tubes and needles have traditionally been specified in terms of the actual mass of radium-226, which they contain. Whereas sources utilizing radium substitutes such as, cesium-137 and iridium-192 are usually specified in terms of equivalent mass of radium when the actual activity contained in the source remains in use for radiation protection and regulatory purposes.

Accordingly, the Task Group-41 (Ref. 4) and international guidelines recommended that these quantities are abandoned in favour of a single source strength specification quantity (air-kerma strength), which is applicable to all photon emitting brachytherapy sources. They defined the kerma rate to air-in-air at a reference distance of 1 metre⁵. This quantity is usually expressed in mGy/h at 1 m or cGy/h at 1 m.

The National Institute of Science and Technology (NIST) does not offer calibration of ionization chamber with the gamma-ray spectrum of iridium-192. Recommendations of the Radiation therapy committee Task Group No. 43(Ref. 6) has described a method to get the calibration factor for iridium-192 poly-energetic source, which interpolates between a calibration performed with cobalt-60 with build-up cap sufficient for 1.25 MeV gamma radiation and ortho-voltage X-ray calibration with no build-up cap.

International Commission of Radiation Units and Measurements (ICRU) recommendations⁶, which are also adopted by the American Association
of Physicists in Medicine (AAPM) as an interim standard were that, the calibration of HDR sources should be made using re-entrant ionization chambers (well-type chamber) that simplify, significantly, the calibration procedure.

The authors decided to compare the calibration for HDR iridium-192 brachytherapy sources using the well-type chamber calibration procedure and 0.6 cc graphite thimble procedure (Fig. 1) using calibration jig supplied by the firm.

<table>
<thead>
<tr>
<th>Source No.</th>
<th>Measurement date</th>
<th>Manufacturer's activity (a)</th>
<th>Measured activity SDS(b)</th>
<th>Ratio(a/b)</th>
<th>Measured by thimble chamber (b')</th>
<th>Ratio (a'/b')</th>
</tr>
</thead>
<tbody>
<tr>
<td>D35p-513</td>
<td>14-10-1998</td>
<td>33.013</td>
<td>32.258</td>
<td>1.023</td>
<td>32.127</td>
<td>1.027</td>
</tr>
<tr>
<td>D35R-018</td>
<td>17-06-1999</td>
<td>32.987</td>
<td>32.224</td>
<td>0.992</td>
<td>33.115</td>
<td>0.996</td>
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<tr>
<td>D35R-798</td>
<td>19-10-1999</td>
<td>40.793</td>
<td>40.325</td>
<td>1.012</td>
<td>41.102</td>
<td>0.992</td>
</tr>
<tr>
<td>D35S-778</td>
<td>03-04-2000</td>
<td>47.985</td>
<td>47.772</td>
<td>1.004</td>
<td>48.017</td>
<td>0.999</td>
</tr>
<tr>
<td>D35T-80</td>
<td>14-08-2000</td>
<td>33.012</td>
<td>32.45</td>
<td>1.017</td>
<td>32.670</td>
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<tr>
<td>D35T-638</td>
<td>12-12-2000</td>
<td>31.781</td>
<td>31.98</td>
<td>0.993</td>
<td>31.550</td>
<td>1.007</td>
</tr>
</tbody>
</table>

2 Experimental Details

Iridium-192 source for HDR brachytherapy — The iridium-192 source used in the HDR brachytherapy is usually in the form of stainless steel outer encapsulation of 1.1 mm diameter and 5.0 mm length and with active length 0.6 mm diameter and 3.5 mm length. It decays with 73.825 days' half-life to several excited states of Pt-192 and Os-192, which emits gamma-ray with a range of energies starting from 290 up to 608 keV. The average energy of the emitted photons from an un-encapsulated source is 370 keV. Mallinckrodt Diagnostic, of the Netherlands, supplied the Ir-192 sources for this study, which are mentioned in Table 1. Two calibration procedures, one using well-type chamber and the other using calibration jig, have been considered in this study.

2.1 Calibration procedure and ionization chamber

**Calibration jig** — One approach to iridium-192 source calibration is, the use of calibration jig and ionization chamber available in the external beam radiotherapy. The dose rate measurements for the iridium-192 source within the phantom are directly reference air kerma rate values. This jig is designed for in-air measurements, with an ionization chamber, placing the source at a distance of 10 cm, left and right, from the chamber. As a field instrument, Farmer 0.6 cc ionization chamber was used, with a graphite wall and its standard acrylic build-up cap. The inner diameter and the length are approximately 7 mm and 25 mm, respectively. This chamber, with UNIDOS electrometer, was calibrated for energies of cobalt-60, cesium-137 and 250 kV X-ray. With all their energies, the standard build-up cap was in situ during calibration. The source strength is expressed in terms of reference air kerma rate ($K_{air}$) in cGy/h at 1 m. The value of the $K_{air}$ of a source is derived from measurements using the following expression:

$$K_{air} = R_{air} \cdot N_b \cdot P_{air} \cdot K_b \cdot P_{b} \cdot P_{D} \cdot D^2/t \quad \ldots(1)$$

where
$K_{ref}$ is reference air kerma rate in free air at 1 m, in cGy/h;

$R_{av}$ is average reading of the electrometer;

$N_i$ is air kerma calibration factor of the chamber;

$P_t$ is correction for transit time;

$K_p$ is check reading during calibration of Sr-90;

$K_m$ is mean value of check reading at use of Sr-90;

$P_i$ is correction for the dose gradient across the chamber; and

$D$ is distance from source to chamber and $t$ is duration of each measurement.

$R_{av}$ is the average of all readings, corrected for the leakage current of the electrometer. The value of the $N_i$ factor of ionization chamber with build-up cup was derived. An interpolation procedure between the two energies was used as described.

The correction factor $P_i$ for the influence of the irradiation of the chamber during transport of the source through the catheter is typically dependent on the source chamber geometry and the duration of one measurement. In the present case, it is taken as unity, because the measurement was performed by the UNIDOS electrometer.

$P_m$ corrects the dose gradient that exists when a chamber of finite dimensions is used in a region of sharp dose gradient. In the field instrument with the calibration jig, a value of $P_m$ as 1.006 valid for the chamber with the stated dimensions at a distance of 10 cm from a source is used. This value is taken from the paper Dewerd & Thomadsen.

Fig. 1 - Measurement performed with 0.6 cc thimble chamber

Fig. 2 - Measurement performed with SDS well-type chamber

$P_i$ corrects the additional ionization that is produced in the detector, originated from radiation, scattered by the surrounding materials (jig, floor, and walls of the room). In the geometry of this paper, a value of 0.9975 is used which is determined by a method described earlier.
The distance \( D \) from source to chamber was 10 cm in the geometry of this paper. In order to obtain optimal stability of the geometry, a thin PMMA rod to the catheters is present in this jig (Fig. 2). In this way, the chamber being located in the mid-line greatly improved the reproducibility.

![Fig. 3 — Sensitivity curve for SDS well-type chamber. The ionization current is normalized for each curve at the maximum observed value.](image)

Y-axis: Relative ionization current
X-axis: Distance from chamber bottom (mm)

**Dosimeters** — The well-type chamber SDS (Nucletron B.V. VEENENDAAL, the Netherlands) (Fig. 2) and 0.6 cc ionization chamber (type M 2332, PTW, Freiburg, Germany) with calibration factors for air kerma calibration factor are used. A summary of the technical characteristics of both the ionization chamber is presented in Table 2. UNIDOS electrometers (PTW, Freiburg, Germany) used in both the ionization chambers (for SDS well-type and 0.6 cc graphite thimble).

**Well-type ionization chamber** — Using well-type chambers, the reference air kerma rate can be calculated generally using the following expression:

\[
K_a = N_i \cdot k_p \cdot I_{\text{max}} \cdot k_{\text{ion}} \tag{2}
\]

where

- \( N_i \) is the air kerma rate calibration factor;
- \( k_p \) is the correction factor for temperature and pressure;
- \( I_{\text{max}} \) is the maximum measured ionization current value with the well-type chamber. The manufacturer provides a typical axial response of the chamber ionization current with respect to the distance of the source from the bottom of the chamber; and
- \( k_{\text{ion}} \) is the reciprocal of the ion collection efficiency factor and calculated as follow:

\[
X_{\text{ion}} = \frac{3}{4} \times (Q_1/3Q_2) \tag{3}
\]

\( Q_1 \) and \( Q_2 \) are the charge readings at nominal (300 V) and half (150 V) potential.

**3 Results and Discussion**

The response of the well-type chamber and the dependence on the distance of the source from the bottom of the well was investigated. The results of our measurements are shown in the Fig. 3. However, the field instrument used was the secondary standard dosimeter. The calibration jig had the fixed geometry and measurements performed in the air. The shortest distance of the source and the thimble chamber was 10 cm fixed distance.

The over-all percentage RMS error for the source calibration result using the SDS well-type chamber, and the calibration jig with 0.6 cc graphite thimble is 0.32%. For analysis, the calibration jig with graphite thimble result is used as a reference chamber (secondary standard).

It was found that, the demonstrated method in the material studied is very accurate. Both the methods of calibration are equally good and suitable for the calibration of poly-energetic energy of iridium-192 clinical source. However, it is also noticed that, the manufacturer’s value is very close to measured value of the authors but, individual source calibration is mandatory prior to patient use.

**References**


9 Dewerd Larry A, & Thomadsen Bruce R, Source strength standards and calibration of HDR/PDR Source, Brachytherapy Physics, Chap 27, pp. 542-554.

