In–air calibration of an HDR $^{192}$Ir brachytherapy source using therapy ion chambers

ABSTRACT
The Gammamed Plus $^{192}$Ir high dose rate brachytherapy sources were calibrated using the therapy level ionization chambers (0.1 and 0.6 cc) and the well-type chamber. The aim of the present study was to assess the accuracy and suitability of use of the therapy level chambers for in-air calibration of brachytherapy sources in routine clinical practice. In a calibration procedure using therapy ion chambers, the air kerma was measured at several distances from the source in a specially designed jig. The room scatter correction factor was determined by superimposition method based on the inverse square law. Various other correction factors were applied on measured air kerma values at multiple distances and mean value was taken to determine the air kerma strength of the source. The results from four sources, the overall mean deviation between measured and quoted source strength by manufacturers was found –2.04% (N = 18) for well-type chamber. The mean deviation for the 0.6 cc chamber with buildup cap was found –1.48 % (N = 19) and without buildup cap was 0.11% (N = 22). The mean deviation for the 0.1 cc chamber was found –0.24% (N = 27). Result shows that probably the excess ionization in case of 0.6 cc therapy ion chamber without buildup cap was estimated about 2.74% and 1.99% at 10 and 20 cm from the source respectively. Scattered radiation measured by the 0.1 cc and 0.6 cc chamber at 10 cm measurement distance was about 1.1% and 0.33% of the primary radiation respectively. The study concludes that the results obtained with therapy level ionization chambers were extremely reproducible and in good agreement with the results of the well-type ionization chamber and source supplier quoted value. The calibration procedure with therapy ionization chambers is equally competent and suitable for routine calibration of the brachytherapy sources.

Key words: Brachytherapy, $^{192}$Ir source, Calibration, Ionization chamber, Multiple-distance

INTRODUCTION
A high dose rate $^{192}$Ir source is commonly used in brachytherapy by most of the radiotherapy centers. This source is commercially available and the manufacturer issues a calibration certificate of source strength with an overall uncertainty of ± 5%. A large uncertainty in the source strength quoted by the supplier requires an independent calibration by the users for clinical purpose. The short half–life$[^{[1]}]$ of $^{192}$Ir source compels the user to change the source at every interval of four to five months. Frequent calibrations of source at the time of source exchange and routine quality assurance of brachytherapy unit$[^{[2]}]$ require a use of established and recommended calibration procedures.

The recommended quantity for specifying the strength of brachytherapy sources is air kerma strength (AKS).$[^{[3,4]}]$ Air kerma strength is defined as the product of air kerma rate at a calibration distance, $d$, in the free space, $K(d)$, measured along the transverse bisector of the source, and the square of the distance, $d$. An uncertainty in the determination of AKS is estimated to be ± 5%.$[^{[4]}]$ However, a source calibration accuracy of ± 3% relative to existing air kerma strength standards seems to be reasonable.$[^{[2]}]$ There are two recommended methods for the calibration of $^{192}$Ir source, first by using re-entrant well-type ionization chamber$[^{[6,7]}]$ and second by in-air (or solid phantom) measurement using a Farmer-type ion chamber.$[^{[6,7,8]}]$ The well-type ionization chamber method is recommended for the clinical environment to achieve greater precision due to reproducible geometry. The well-type ionization chamber is a tertiary level instrument. The overall uncertainty in calibration of a $^{192}$Ir source using a well-type ionization chamber is then higher than the accredited calibration laboratory using thimble ionization chamber formalism, since it necessarily involves a calibration of another $^{192}$Ir source.$[^{[9]}]$ The difficulty with ionization chamber
is to obtain a direct calibration factor for $^{192}$Ir due to wide energy spectrum of photons emitted from $^{192}$Ir source.

The calibration factor of $^{192}$Ir gamma-ray beam was first derived from the average of the calibration factors for the 250 kV X-ray and the $^{60}$Co gamma-ray beam. This method was later modified by defining the air kerma calibration factor of $^{192}$Ir as the average of calibration factor for the 250 kV X-ray and the $^{137}$Cs gamma-ray beam. In above case, the calibration factors for all the energies were obtained with 0.321 g cm$^{-2}$ thick buildup cap. IAEA-TEDOC[11] and AAPM[2] recommends use of ion chamber with air kerma calibration factor $N_0$ obtained by weighted interpolation between 250 kV X-ray and $^{60}$Co or $^{137}$Cs energies. The energy response curve based on the photon spectrum of the $^{192}$Ir source was determined. Authors experimentally derived the wall correction factor for different ionization chambers to make a correction for attenuation and scattering through buildup cap for above three different beams.

Goetsch et al[6] and Stump et al[8] have used spherical ionization chamber of volume 3.6 cc. The German standard[13] has recommended the use of ionization chamber of volume of more than 1.0 cc for in-air calibration. The multiple-distance measurement method was adopted for in-air calibration to make a correction for an error in positioning of the chamber and scattered radiation. However, they concluded that this method is time consuming and unnecessary to use for routine source calibration. Therefore, it was advised that the results of in-air calibration should be used for deriving a calibration factor for an alternative, quicker technique using simpler instrument. The DGMP[14] recommends the use of specially calibrated solid-state phantom for higher reproducibility and accuracy in brachytherapy source calibration. This method resolved the problem due to positioning error and room scatter but also contributes an uncertainty since the calibration factor is derived from the measurement in a solid phantom with calibrated reference source. The ESTRO guidelines recommend to minimize the positioning uncertainty and scatter contribution using a calibration jig with source position at a distance of 10 cm from both sides of a centrally placed 0.6 cc Farmer-type chamber.[15]

In the present study, details of the calibration procedures with therapy level ionization chambers and the well-type chamber has been described. In-air calibration was performed by the multiple-distance method in specially designed jig. The aim of this study was to analyze the accuracy and the suitability of therapy level chambers for in-air-calibration of brachytherapy source for routine clinical practice.

**MATERIALS AND METHODS**

The calibrations of an HDR $^{192}$Ir sources were performed by in-air measurement using therapy ionization chambers (0.1 and 0.6 cc) and by using the well-type ionization chamber. Further, the 0.6 cc ionization chamber was used with and without buildup cap for the in-air measurement. Table (1) shows the details of technical specification of chambers used in the present study. Both the therapy ionization chambers (UNIDOS dosimeter from PTW–Freiburg, Germany) were calibrated for the absorbed dose to water calibration factor ($N_0$) from PTW Freiburg. The wall thickness of the 0.6 cc chamber was 0.054 g/cm$^2$ with a provision of buildup cap of thickness of 0.547 g/cm$^2$ for $^{60}$Co beam and for the 0.1 cc chamber was 0.12 g/cm$^2$ without any buildup cap. The well-type ionization chamber HDR–1000 from Standard Imaging Inc., Middleton, Wisconsin was used for the source calibration.

The GammaMed Plus HD $^{192}$Ir sources from MDS-Nordion Haan GmbH, Germany (Now Varian Medical System) were calibrated. The material composition and construction design of source consists of a cylindrical active iridium core (70% Ir and 30% Pt, $\rho = 21.76$ g/cm$^3$) of 0.6 mm diameter and 3.5 mm length. The active iridium is uniformly distributed in this core, which is encapsulated in a stainless steel wire. The active core is filtered in the extreme end by cylindrical piece of aluminum and 0.9 mm outer diameter of cap of stainless steel.

Two different basic methodologies used for the source calibration are described below.

**Well-type Ionization Chamber**

Many authors[5, 7, 16] have described the procedure of the source calibration in detail using the well-type chamber. In the case of well-type ionization chamber the air kerma rate

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**Table 1: Technical specification of ionization chambers.**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ionization Chamber</th>
<th>Well-type Chamber</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>PTW M-30001</td>
<td>PTW M-23322</td>
</tr>
<tr>
<td>1. Manufacturer</td>
<td>PTW– Freiburg</td>
<td>PTW–Freiburg</td>
</tr>
<tr>
<td>2. Volume (cm$^3$)</td>
<td>0.6</td>
<td>0.1</td>
</tr>
<tr>
<td>3. Dimension (cm) Length/diameter</td>
<td>2.3/6.1</td>
<td>1.2/3.5</td>
</tr>
<tr>
<td>4. Wall + Cap Material</td>
<td>PMMA, Graphite + PMMA</td>
<td>PMMA</td>
</tr>
<tr>
<td>5. Wall + Cap Thickness (g/cm$^3$)</td>
<td>0.054+0.547</td>
<td>0.12 (No cap)</td>
</tr>
<tr>
<td>6. Voltage (V)</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>7. Calibration factor</td>
<td>5.301E+07 Gy/C</td>
<td>3.597E+08 Gy/C</td>
</tr>
<tr>
<td>8. Reference point of measurement</td>
<td>1.5cm behind chamber tip</td>
<td>0.89cm behind chamber tip</td>
</tr>
<tr>
<td>9. Calibrated by</td>
<td>PTW, Freiburg</td>
<td>PTW, Freiburg</td>
</tr>
</tbody>
</table>
(\(K_{p}\)) of \(^{192}\text{Ir}\) source was determined from the following formula:
\[
(\mathcal{K}_p) = N_A K_p I_{\max} K_{\text{ion}} C
\]
Where:
- \(N_A\) is called air kerma strength calibration factor given in Gy m\(^{-2}\) h\(^{-1}\)A\(^{-1}\) and the value was supplied by the calibration laboratory. The calibration factor for the well chamber HDR-1000 was 4.591 x 10\(^{-6}\) Gy m\(^{-2}\) h\(^{-1}\)A\(^{-1}\) at one meter. \(K_p\) is the correction factor for the change in the temperature and air pressure from the reference calibration condition. \(I_{\max}\) is the maximum measured ionization current. \(C\) is the charge calibration factor of electrometer supplied by calibration laboratory.
- \(K_{\text{ion}}\) is the reciprocal of the ion collection efficiency factor \(A_{\text{ion}}\) calculated as follows:
\[
A_{\text{ion}} = \frac{4}{3} \cdot \frac{Q_1}{3Q_2}
\]
- \(Q_1\) and \(Q_2\) are the charge reading at voltage \(V\) (=300 volt) and \(V/2\) respectively.

**In-air Calibration**

This is an alternative established method for the calibration of the \(^{192}\text{Ir}\) brachytherapy source using therapy ionization chambers. The therapy ionization chambers are commonly available in the radiotherapy centers. The ionization chambers must have a recommended wall thickness (about 0.31 g/cm\(^2\)) to provide charge particle equilibrium for the \(^{192}\text{Ir}\) source emitting a photon spectrum in the energy range from 9-885 KeV. If the wall thickness of the chamber used in measurement differs from the recommended thickness, an appropriate correction should be applied for scattering and attenuation of photons. As per the new dosimetry protocols, both the chambers were calibrated in terms of the absorbed dose to water calibration factor \(N_w\) for \(^{60}\text{Co}\) beam from PTW, Freiburg. The DGMP recommendation\(^{[12,14]}\) was used to derive an air kerma rate of \(^{192}\text{Ir}\) source from the absorbed dose to water calibration factor.

The air kerma rate of an HDR \(^{192}\text{Ir}\) source is determined in terms of mGy m\(^2\) h\(^{-1}\) by using the following formula:
\[
(\mathcal{K}_a)_{\text{ir}} = \left( \frac{1}{1-g_a} \right) \left( \frac{\mu_{\text{en}}}{\rho} \right)_{\text{a-w}} N_w K_w A_w K_f \Delta
\]
where
- \(g_a\) is the fraction of energy of the secondary electrons, which is lost in bremsstrahlung.
- \(\left( \frac{\mu_{\text{en}}}{\rho} \right)_{\text{a-w}}\) is the ratio of mass energy absorption co-efficients for air and water. The spectrum-weighted value for \(^{192}\text{Ir}\) source is 0.899.
- \(N_w\) is the absorbed dose to water calibration factor of chambers.

\(K_w\) is the beam quality correction factor, which accounts for the differences in the energy spectrum of the reference photon beam (usually \(^{60}\text{Co}\)) for which chamber has been calibrated. The beam quality correction factor of both the chambers for \(^{192}\text{Ir}\) source (average energy = 390 keV) was determined by interpolation method. The energy response curves for both the chambers were provided by the supplier.

\(A_w\) is the correction factor for scattering and attenuation of wall thickness. The wall correction factor was determined using a formula \(A_w = 1 - \gamma t\), where \(\gamma\) is the attenuation and scattering fraction per wall thickness (cm\(^2\)/g) and taken 0.0277 and \(t\) is the total thickness (g/cm\(^2\)) of wall material\(^{[9]}\).

\[
K_s = (1/r_s)^2, \quad \text{Where } r_s \text{ is the reference distance of 1 meter. and } f \text{ is constant which is defined as }^{[6,8]}\]
\[
f = (M_s - M_f) (d + \Delta)^2 \tag{3}
\]
where \(M_s\) is the measured reading of air kerma in terms of charge (nA) at distance \(d\) (cm) from the source, which includes the air kerma from the primary radiation \(M_f\) and scattered radiation \(M_s\) i.e., \(M_s = M_f + M_s\). Scattered radiation was assumed to be constant over the range of measurement distance. In the above, expression \(\Delta\) is the offset error in measuring the initial nominal distance \(d\). The scattered radiation \(M_s\) was determined from the measured air kerma readings at several distances from the source. The superimposition method based on the inverse square was used to determine the scattered radiation. The methodology in details is described elsewhere (under publication).

Figure 1 shows the specially designed measurement jigs. The dimensions of jig were about 30 x 20 x 27 cm\(^3\) and made of non-scattering and low Z materials of acrylic plates and wooden frames. Both the chambers 0.1 and 0.6 cc can be placed at two different positions in the measurement jig. The chamber’s holder was mechanically fixed whereas the source applicator attached with holder was moved linearly along the track. The center of active volume of both the chambers was located at different heights from the base of the jig. A fine laser beam was projected over the jig to verify the sagittal, transverse and coronal cross-sections planes of the jig. There were two parallel aligned scale systems which help to determine the measurement distance and the vertical position of the applicator. The stainless needle was used as a source applicator. The inner and outer diameter of needle was 1.35 mm and 1.65 mm respectively and the needle can be placed at any mm scale pointer with an accuracy of about ± 0.01 cm.

A vertical scanning of the source along the applicator was
performed to draw the curve for the chamber response vs. source position. In vertical scanning, the source applicator to chamber distance was 1 cm and the source was moved to dwell positions along the applicator (1 mm and 2 mm stepping size for the 0.1 cc and 0.6 cc chambers respectively) and ionizations were measured successively. The source dwell position of the maximum chamber response was chosen from the curve for both the chambers. The selected dwell position was used for air kerma measurements. The air kerma were measured at multiple source - chamber distances. The distances between source and chamber vary in the range of 10 - 24 cm and 8 - 20 cm for the 0.6 cc and 0.1 cc chamber respectively. The air kerma were measured in charge mode for the period of 60 to 500 s that depends on the measurement distance, source activity and chamber’s sensitivity. Dosimeter timer was used for charge measurement to avoid any error due to the transit dose. The congruence test between dosimeter timer and treatment unit timer was performed by taking successive measurement of multiple exposures for different times. The temperature and air pressure was recorded during the measurement. The electrical leakage of dosimeter was measured.

The mean of the three readings measured at each distance was corrected for the temperature and pressure, air attenuation, leakage, finite source, chamber size and the attenuation due to the metallic applicator. The non-uniformity correction factor \( f \) was used for the correction of dose gradient inside the chamber’s volume. The measured air kerma at multiple-distances was used to determine the scattered radiation \( M_s \). The value \( M_s \) was used to determine the constant factor \( f \).

**Uncertainty Evaluation**

The uncertainty evaluation of measurements in the present study was performed as per the EA-4/02 1999 draft for expression of the uncertainty of measurement in calibration.\[^{[18]}\]

The quoted uncertainty of the instruments involved in this measurement and experimental results were used in the evaluation of the uncertainty. The sources of uncertainty in this measurement may arise from ionization chamber, electrometer, temperature and pressure, measured values,
The uncertainty of measurement associated with the input estimates is evaluated according to either a ‘Type A’ or a ‘Type B’ method of evaluation. The type A evaluation of standard uncertainty is the method of evaluating the uncertainty by the statistical analysis of a series of observations. The observation in this study was the measured readings at multiple distances from the source. Using Equation (3), the $f$ value for each measurement distance was determined using scatter radiation $M$ and an offset error $\Delta$. The standard deviation of $f$ values from several measurement distances for each occasion was calculated. The mean value of standard deviations from all the occasions was used as statistical type A value of uncertainty.

The Type B evaluation of standard uncertainty is the method of evaluating the uncertainty by means other than the statistical analysis and it is based on some other scientific knowledge. These include air density, leakage, stability of dosimeter and positioning error. These uncertainties were evaluated on the basis of previous measured data and manufacture’s specification. The uncertainty in measurement distance due to positioning of the source and chamber was evaluated. The accuracy in determining the positioning of the chamber center was about $\pm$ 0.2 mm from the actual scale. The inner diameter of the source applicator was 1.35 mm and the outer diameter of the source was 0.9 mm. This means that the source can be displace maximum of about $\pm$ 0.22 mm from the central axis of the applicator. The uncertainty in positioning of the applicator was $\pm$ 0.1 mm. The maximum overall uncertainty in the measurement distance may be taken as $\pm$ 0.52 mm. The uncertainty evaluation due to positional error was performed for reference distance 10 cm.

RESULTS AND DISCUSSION

The well-type chamber was placed at distance of more than one meter from the floor as well as from the walls to have minimum scatter contribution. The well-type chamber behavior and other various factors that influence the result have been determined experimentally. The result of the axial response of chamber vs. source stopping position of the well-type chamber is shown in Figure (2). The maximum response of chamber was obtained for source position at height of 51 cm.
mm (stepping position of 46 mm) from the bottom of chamber, with decrease in output by 0.1% was found by moving the source down by 4 mm. The ion collection efficiency of the well-type ionization chamber was about 99.96% with 300V applied. The results related to chamber parameters were in good agreement with the data provided by the manufacturer. The strength of the source using the well-type chamber was determined in terms of air kerma rate mGy hr\(^{-1}\) at one meter.

In the present study, the therapy ionization chamber of the 0.1 and 0.6 cc volumes were used for the source in-air calibration. In the case of 0.6 cc chamber following two options were considered:
• Chamber of wall thickness of 0.054 g/cm\(^2\) without any buildup cap
• Chamber of wall thickness of 0.601 g/cm\(^2\) including buildup.

The 0.1 cc chamber with wall thickness of 0.12 g/cm\(^2\) does not have any buildup cap. Figure 3 shows the chamber response vs. source dwell position for the 0.6 cc and 0.1 cc ionization chambers respectively. We observed steep fall in chambers response with the shift in source position. In the case of 0.1 cc chamber, shift in source position by 2 mm causes 4% decrease in chamber response. However for 0.6 cc chamber a decrease of 2.5% was observed for 3 mm shift. It was observed that FWHM of chamber response curve is directly proportional to the active length of the chamber.

The needle used as an applicator was made of stainless steel 1.4401 (equivalent to AISI/SAE 316, \(\rho = 8.0 \text{ g cm}^{-3}\)) with wall thickness of 0.15 mm. The inner and outer diameter of the applicator was 1.35 ± 0.02 mm and 1.65 ± 0.02 mm respectively. We assumed that stainless steel AISI/SAE 316 is equivalent to that of stainless steel ANSI 303/304 w.r.t. effective attenuation coefficient. The value of effective attenuation coefficient was taken as 0.030 ± 0.002 (ANSI 303/304) \(^[7]\). The calculated attenuation factor of wall material was 0.9955. Thus, the correction factor 1.00451 was applied for the applicator wall attenuation. The value of the chamber wall scatter and attenuation correction factor \(A_w\) was taken as 1.0172.

Figure 4 shows the contribution from scattered radiation (\(M_s\)) to the measured reading (\(M_d\)), and expressed in terms of percentage of primary radiation at various distance for the 0.1 and 0.6 cc chambers respectively. The scattered component at 10 cm measurement distance was 0.33% for 0.6 cc chamber and 1.1% for 0.1 cc chamber. The additional chamber holder used in the case of 0.1 cc chamber could be one of the major factor for increasing the scatter contribution to the measured air kerma.

The strength of an HDR \(^{192}\)Ir source was determined in terms of air kerma rate at one-meter distance. Table 2 shows the result of measured air kerma strength of Gammamed Plus an HDR \(^{192}\)Ir sources and expressed in terms of percentage difference from the specified source strength by the supplier. Total four numbers of sources were calibrated at 86 different occasions by different methods of the well-type chamber, 0.6 cc (with and without buildup cap) and 0.1 cc therapy ionization chambers.

Result shows that for the well-type chamber, the mean deviation in percentage for the four sources were found –2.04 ± 0.48, –2.32 ± 0.36, –1.99 ± 0.11 and –1.68 ± 0.22 respectively with an overall mean deviation of –2.04 ± 0.37 (N=18), where N represents the number of occasions of source calibration. Similarly for the 0.6 cc chamber with cap, the mean deviation for three sources were found –1.51 ± 0.46, –1.04 ± 0.29 and –1.97 ± 0.22 with an overall mean deviation of –1.48 ± 0.50 (N=19). In the case of
without buildup cap for 0.6 cc, the mean deviation for four sources were found 0.84 ± 0.30, 0.09 ± 0.64, –0.22 ± 0.17 and –0.49 ± 0.19 respectively with an overall mean deviation of 0.11 ± 0.62 (N=22). We also observed for the 0.1 cc chamber, the mean deviation for four sources as 0.23 ± 0.54, –0.35 ± 0.65, –0.74 ± 0.55 and 0.13 ± 0.38 respectively with an overall mean deviation of –0.24 ± 0.65 (N=27).

The uncertainty evaluation of measurements for the well-type chamber, 0.6 cc and 0.1 cc therapy ionization chambers is shown in Table (3). The uncertainties of components of measurement and overall combined uncertainty were expressed with a coverage factor, k = 1. The overall relative expanded uncertainty of the air kerma measurement was expressed with a coverage factor, k = 2 for 95% confidence limit. The well-type ionization chamber HDR-1000 was calibrated by ADCL at University of Wisconsin - Madison. As per the calibration report (1999), the uncertainty of calibration factor of well-type ionization chamber has been classified in three different values of 2%, 3%, and 5% based on the quality of the isotropic emission of photons from the source. Figure 5 shows the autoradiograph of Gammamed Plus 192Ir source on radiochromic film exposed with the source strength of 1000 Ci x second. The radiograph shows that the isodose distribution is not seem to be isotropic. Based on this radiograph, the uncertainty for well-type chamber was considered 2.5%; however in our knowledge, there is no any standard methodology for the classification of uncertainty. The overall expanded uncertainty in our measurement using well-type chamber was about 2.66%. The uncertainty in calibration factor quoted by the supplier for the 0.6 and 0.1 cc chambers was ± 2.2% at the coverage factor, K=2 for 95% confidence limit. The overall expanded uncertainty in our measurements for the 0.6 cc and 0.1 cc chambers were about 2.6% and 2.64% respectively.

The therapy level ionization chambers are commonly available in the radiotherapy centers. Our aim of present study was to evaluate the accuracy and feasibility for routine use of chambers for source calibration by in-air measurement. The results of source calibration in this study were in very good agreement with the experimental uncertainties. Figure 6 displays the flow chart of calibration standard of different chambers with uncertainty of calibration (coverage factor of k=2, level of confidence 95%) at different levels. The flow chart also represents the inter-comparison between the different calibration standards. The calibration factor \( N_{a,w} \) of 0.6 cc chamber obtained from RSL, BARC recently was 0.35% higher than the calibration factor given by PTW, Freiburg.

In the present study, it was observed in Table (2) that the 0.1 cc and 0.6 cc (without cap) chambers show positive response by 1.24% and 1.59% respectively than the response of 0.6 cc (with cap) chamber. These two chambers seem to have unique response as they were calibrated under similar condition at the same place. The minimum wall thickness recommended for measurement with iridium source is 0.321 g cm\(^{-2}\) for charge particle equilibrium. Ionization chamber with wall thickness of 0.601 g cm\(^{-2}\) (including buildup cap) is well enough to provide charged particle equilibrium (CPE) for the highest energy of secondary electrons present. The \( \gamma \) value used for the calculation of attenuation and scattering correction factor in the chamber wall was derived by experimental study by Marechal et al.\(^{[6]}\) having good agreement with the Monte Carlo derived value.

The response of the 0.6 cc chamber in absence of buildup cap (chamber wall thickness 0.054 g cm\(^{-2}\)) and in presence of buildup cap (total chamber wall thickness 0.601 g cm\(^{-2}\)) vs. source to chamber distance was studied experimentally. In case of with buildup cap, measured air kerma was corrected for the wall scatter and attenuation. The scatter and attenuation correction factor used was 1.0172. The ratio of ionization from without and with buildup cap of the 0.6 cc chamber was expressed as a function of the source to chamber distance and which is shown in Figure (7). The relative ionization gradually increases from 1.0181 at 25 cm to 1.0274 at 10 cm distance from the source. Further decrease in the measurement distance decreases the ratio of ionization. The variation in ratio of ionization with measurement distance could be due to the excess ionization from thin wall or excess attenuation from thick wall of the chamber even after the correction for attenuation. The Goetsch et al.\(^{[6]}\) estimated the excess ionization due to thin chamber wall was about 2.5% at 10 cm and 1.2% at 20 cm distance from the source. If the ionization of chamber with cap is taken as a reference which means that the higher response of the chamber with thin wall thickness is certainly due to the excess ionization. Even the ionization ratio of about 2.74% at 10

<table>
<thead>
<tr>
<th>Table 3: Uncertainty evaluation of measurements</th>
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<tbody>
<tr>
<td>Components</td>
</tr>
<tr>
<td>Positioning</td>
</tr>
<tr>
<td>Measurement</td>
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<tr>
<td>Temperature and pressure</td>
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<tr>
<td>Stability</td>
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<tr>
<td>Leakage</td>
</tr>
<tr>
<td>Charge measurement</td>
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<tr>
<td>Chamber calibration</td>
</tr>
<tr>
<td>Combined uncertainty (coverage factor n =1)</td>
</tr>
<tr>
<td>Expanded uncertainty (coverage factor n =2)</td>
</tr>
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</table>
cm and 1.99% at 20 cm distance assumed as due to the excess ionization. It was in agreement with the experimental study by Goetsch et al. Further explanation in this matter needs the theoretical study either by using Monte Carlo calculation or the experimental study.

The multiple-distance measurement seems to be very accurate and effective for the source calibration, while limiting the large uncertainty only up to calibration factor and wall thickness correction factor. The energy response curve of the chamber must be obtained from the vendor to determine the beam quality correction factor. The excess ionization due to thin wall thickness or attenuation from the wall can be estimated from the method and data published in the literatures. If once the scattered radiation for any particular measurement setup is determined then it remains unchanged afterward for the similar measurement set-up and only three-distance measurement is sufficient. The complete procedure of in-air measurement was very easier and simple, and it can be completed within twenty minutes using source of high activity. The measured readings can be fit in to the designed computer program to calculate the source strength directly. The simple designed measurement jig with an easier placement of the chamber and applicator holder is very much comfortable for the routine source calibration.

Our study shows that the source calibration with therapy ionization chamber were highly reproducible and in good agreement with well-type ionization chamber. If the proper procedure of the source calibration is adopted, then one can reliable on the air kerma rate of the brachy source measured by using therapy ionization chambers. Even the two therapy ionization chambers can be used for the cross check of source strength. As the therapy chambers are efficient to solve the purpose of source calibration then the purchase of additional expensive calibration instrument (well-type chamber) should be optional.

**CONCLUSION**

The source calibration using therapy ionization chambers of small volume show good agreement with quoted source strength and the well-type ionization chamber. User must obtained energy response curve of cylindrical ionization chamber including for equivalent energy of $^{192}$Ir source. The calibration procedure by using cylindrical chamber should adopt with multiple-distance measurement using simple designed jig. The appropriate buildup cap must be used with ionization chamber for charged particle equilibrium; in other case, correction should be made for attenuation of photon or excess ionization from wall of the chamber.

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