Calibration Methods for ^{192}Ir High Dose Rate Brachytherapy Sources

■ **Chirapha Tannanonta, M.S**
Department of Radiology, Ramathibodi Hospital

■ **Sukanya Rutchantuek, M.S**
Department of Radiology, Ramathibodi Hospital

■ **Tasanee Layangkul, M.S**
Department of Radiology, Ramathibodi Hospital

ABSTRACT

The calibration of ^{192}Ir high dose rate source is needed to verify the value certified by the manufacturer before clinical use. Three calibration techniques, in air, in cylindrical phantom and well type chamber were performed to calibrate twelve sources of the ^{192}Ir during March 1999 to August 2003. It was found that almost kerma rates obtained from all calibration systems were less than the manufacturer's by a maximum of 2.35 % except only one measured by in cylindrical phantom method for source number 10 which was 0.38% more. The mean discrepancies were -1.43% $\pm$ 0.63 in the range of -0.46% to -2.35% for in air, -0.84 % $\pm$ 0.67 in the range of 0.38% to - 2.19% for in phantom, and -1.26% $\pm$ 0.42 in the range of -0.73% to -2.07% for well type chamber. The results of all calibration systems agreed within 1.46%. It is not only more reproducibility and simpler set up, but also less time-consuming to use well type chamber for source calibration comparing with the other two techniques. For the institute where only the Farmer chamber is available, the measurements in phantom are easier and quicker to set up than using in air measurement technique.

INTRODUCTION

High dose rate (HDR) brachytherapy using an ^{192}Ir source with the activity of about 10 Ci (3.7 x 10^{11}Bq) is a common treatment modality. Independent verification of the source strength provided by the manufacturer is needed before starting clinical use [1-3]. The reference air kerma rate (the kerma rate to air, in air, at a reference distance of 1 m, corrected for air attenuation and scattering expressed in mGy. h^{-1} at 1 m or μGy. h^{-1} at 1 m) is the recommended quantity for the specification of the gamma sources[4].

The protocols for calibration of the source with well type ionization chambers, in air and in phantom by using ionization chambers have been established [2,3]. For in air measurement with Farmer type chambers, a source to chamber distance (SCD) of 10-40 cm is recommended by the IAEA [3]. To minimize the scatter from the holder, a calibration jig of low density plastic holding the chamber and the source in precise position during the calibration is used [2, 3, 5, 6]. The source calibration in a solid phantom (cylindrical or plate) has been reported by many authors [5, 7, 8] and is preferred due to improved reproducibility in set up.

The main purpose of the experiment reported here was to compare the calibration of HDR ^{192}Ir brachytherapy sources using the three systems accessible in our institute, in air, in cylindrical phantom and using a well type chamber and to compare our results with those given on the source certificate provided by the manufacturer. A difference from the manufacturer' s certificate value within $\pm$ 5% is required by our institute.

MATERIALS AND METHODS

For the calibration of the HDR ^{192}Ir brachytherapy sources in air and in cylindrical phantom, 0.6 cm^3 Farmer chamber (Type 30001; PTW, Freiburg, Germany) was used. The well type chamber used in this study is the SDS (Type No-077.094, Veenendaal, the Netherlands). The UNIDOS electrometer (Type 10002; PTW, Freiburg, Germany) was used for all measurements.

1. Interpolative calibration of cavity chamber

The Farmer chamber system is calibrated in exposure calibration factor (N_x) at the secondary Standard Dosimetry Laboratory (SSDL) of Thailand for 250 kVp x rays(HVL 3.01 mmCu, 137 keV$_{eff}$) and ^{60}Co energy (1250 keV) with the buildup cap used for both energies.

The exposure calibration factor for ^{192}Ir energy at 380 keV [9, 10] of 5.460 x 10^9 R.C^{-1} was determined by interpolation between these two energies. The ^{137}Cs γ beam, as used by the other investigators [11, 12] is not available in our country. The air kerma calibration factor (N_K) was calculated by [13]:

$$N_K = N_X \frac{W}{e} \frac{1}{1-g} \tag{1}$$

Where

$\frac{W}{e}$ is the mean energy expended in air per ion pair formed and per electron charge (=33.97 J. C^{-1} for dry air) [13],

g is the fraction of energy of secondary charged particles that is lost to bremsstralung, the value of 0.001 was used in this study [14].

The N_K value of 4.790 x 10^7 Gy.C^{-1} for ^{192}Ir energy calculated by Eq.(1) was used for the measurement in air and in phantom.

2. Calibration of ^{192}Ir sources

Between March 1999 to August 2003, twelve sources of ^{192}Ir for microSelectron HDR unit were calibrated by using the three systems as described above. The outer source dimensions are 10.9 mm diameter and 4.5 mm length and the active source dimensions are 0.6 mm diameter and 3.5 mm length.

Every measurement was made with the source position of the maximum sensitivity for each technique. To investigate the influence of wall scattering on the calibration for every technique, the measurements were made at various distances of the chamber center to the wall with the distance above the floor being fixed at 1000 mm.

For all systems, an externally triggered electrometer was used and the charge was collected during an interval after the source had stopped moving [13] to exclude the transit effects. The interval time of 600 seconds with + 400 V for in air and in phantom measurements and 180 seconds with +300 V for the well type chamber were operated. Because of long measurement time, the leakage current for every calibration was also checked and it was found to be very much less than 0.1% of the ionization reading. At least five readings in nC and nA were performed in every calibration for the Farmer type and well type chambers respectively. The average value was then corrected for the recombination losses [15] and for the ambient temperature and pressure [13].

2.1. Calibration in air

The Nucletron source calibration jig (Nucletron, Veenendaal, The Netherlands) was used to hold the ionization chamber and source during the calibration in air. It has two metal tubes (430 mm long) with thin PMMA rods of 50 mm long in the middle for holding the source at the distance of 100 mm from the center of the chamber with buildup cap.

The reference air kerma rate (K_R) at 1 m was determined by using the equation [3] :

$$K_R = N_K \cdot (M_u/t) \cdot k_{air} \cdot k_{scatt} \cdot k_n \cdot (d/d_{ref})^2 \quad (2)$$

Where

M_u is the measured charge collected during the time t and corrected for ambient temperature and pressure, and recombination,

k_{air} is the correction for attenuation in air of the primary photons (The value of 1.001 for 100 mm source chamber distance from Table XI of Ref. [3] was used in our study),

k_{scatt} is the correction for scattered radiation from the wall, floor, measurement set-up, air etc., (since other authors [6, 11] reported the values of 0.9987 and 0.997 which is very close to 1.0 and the investigation method is very complex, the value of 1.0 was used in the study),

k_n is the non-uniformity correction (The value 1.0111 was calculated using Eq. (14) in Ref.[3]),

d is the measurement distance, the value of 100 mm was used in for our study, and

d_{ref} is the reference distance of 1 m

2.2 Calibration in phantom

The polymethyl methracrylate (PMMA) cylindrical phantom type 9193(PTW, Freiburg, Germany) with a diameter of 200 mm and a height of 120 mm was used for this technique. The phantom was placed on a tripot (CULLMANN, Langenzenn, Germany) at a distance of about 1100 mm above the floor. By using this phantom, the distance between the source and the reference point of the detector is 8 cm. The reference air kerma rate (K_R) at the distance of 1 m was computed by using the equation[16] :

$$K_R = N_K \cdot (M_u/t) \cdot k_{a \rightarrow p} \cdot k_{zp} \cdot \left(\frac{d}{d_{ref}}\right)^2 \quad (3)$$

Where the definitions of (M_u/t) and $(d/d_{ref})^2$ are the same as in Eq.(2) and

$k_{a \rightarrow p}$ is the perturbation factor for the transit from air to acrylic glass for cylindrical compact chamber with PMMA walls and inner graphite for which the approximation value of 1.0 was used here[16],

k_{zp} is the geometry factor accounting for the presence of the absorbing and scattering cylindrical phantom instead of air surrounding, the value of 1.187 reported by Krieger [14] was used in our calibration.

2.3 Calibration by well type chamber

The reference air kerma rate (K_R) for the well type chamber was determined by the following formula[3] :

$$K_R = N_{K_R} \cdot (M_u/t) \quad (4)$$

Where

N_{K_R} is the reference air kerma rate calibration factor for the well type chamber; the value of 9.251 x 10^7 cGy. $m^2.h^{-1}.A^{-1}$ from the manufacturer's certificate was used (At that time, the well type chamber for comparison measurement of ^{192}Ir source was not available in our country),

(M_u/t) is the same as in Eqs. (2) and (3).

RESULTS

The influence of the lateral wall scattering on the measurements for every calibration system is shown in Fig.1. The minimum distance of the chamber center to the lateral wall with 500 mm for in air calibrations; 700 mm for cylindrical phantom and 300 mm for well type chamber measurements were needed to keep the scattering contribution below 0.1% of the reading for 1000 mm distance.

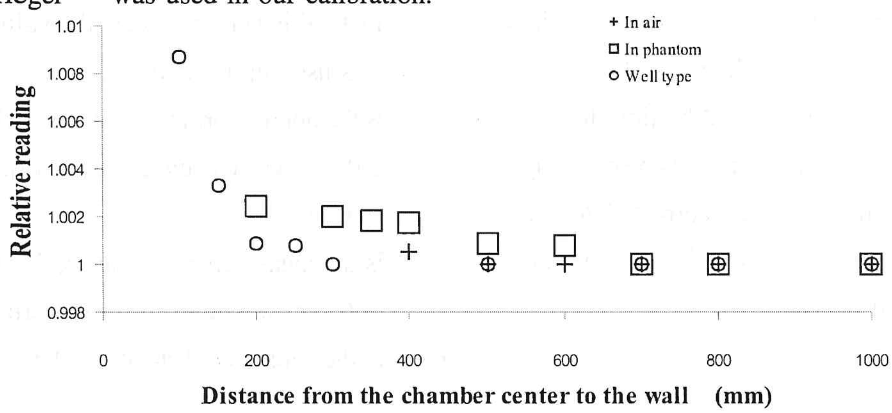

Fig.1. *The influence of wall scattering on the measurements for the three systems used in the study.*

Calibration Technique	Source Number												Ave.	SD
	1	2	3	4	5	6	7	8	9	10	11	12		
In air	-1.98	-1.80	**-2.35**	-0.96	-2.31	-1.54	-1.50	-0.88	-1.63	-0.61	-0.46	-1.09	1.43	0.63
In phantom	**-2.19**	-1.40	-1.08	-1.12	-1.43	-1.12	-0.84	-0.79	-1.09	0.38	-0.11	-0.31	-0.91	0.57
Well type chamber	-0.73	-1.06	-1.51	-1.27	-1.36	-1.51	**-1.78**	-0.79	-2.07	-0.74	-1.30	-1.05	-1.26	0.42
% max. diff. of each tech.	**1.46**	1.40	1.27	0.31	0.95	0.42	0.94	0.09	0.98	1.12	1.19	0.78	0.91	0.43

Remark : The bold typed value = maximum percent difference of each system.

Table I. *Percent difference of the air kerma rate of twelve ^{192}Ir sources measured by the three techniques compared with the manufacturer's values. The last row shows the percent of maximum different value for each source.*

Table I shows the comparison of the air kerma rate for all calibration systems with the manufacture's values for twelve ^{192}Ir sources. The value of every calibration technique was less with the maximum difference of 2.35% for in air calibration except one of the source number 10 measured by in cylindrical phantom technique which was more with 0.38%. (The ^{192}Ir half - life of 74.02 days as specified by the planning system was used for decay calculations). The mean discrepancies were −1.43% ± 0.63 in the range of −0.46% to −2.35% for in air, −0.84% ± 0.67 in the range of 0.38% to −2.19% for in phantom, and −1.26% ± 0.42 in the range of −0.73% to −2.07% for well type chamber. The results of all calibration systems were in agreement to within 1.46 % with the mean value of 0.91% ± 0.43 as shown in the last row of Table I.

DISCUSSION AND CONCLUSION

All calibration Techniques used in the study show very comparable results with the maximum discrepancy of 1.46% with the first source and are in agreement with the values reported by the manufacture with the maximum difference of −2.35% for in air measurement. For the measurement in phantom, the reading was not corrected for attenuation of the stainless steel applicator used in the calibration. Baltas et al.[8] report 1.7% correction for the wall thickness 0.56 mm of stainless steel applicator. If correction for the attenuation of calibration applicator is used in our measurements, the results should be closer to the manufacturers' values. Venselaar et al. [6] reported the higher maximum difference of −6.8% from the certificate for in air measurement that may be due to no correction for non-uniformity (non-collimated geometry) recommended by the IAEA [3].

From the study of the influence of wall scattering on the measurements (Fig.1), the well type chamber is less affected by the scattering from the wall compared with the other two systems.

Our data illustrate that all systems are appropriate for routine calibration in HDR brachytherapy sources but we prefer to use the well type chamber because of its higher reproducibility, simpler setup and reduced measurement time. For the institute that only the Farmer chamber is available, the measurement in phantom is easier and rapid to setup and also more reproducible than in the air geometry.

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