Calibration of ^{192}Ir HDR Brachytherapy Source in Air and in a Cylindrical Phantom

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ABSTRACT

Two ^{192}Ir HDR brachytherapy sources were calibrated with a Farmer ionization chamber in air method and in a PMMA cylindrical phantom. The calibration air method used ionization chamber with buildup cap, and 8 variation distances for center-to-center of the source to chamber. In the optimum distance the measured activity, especially for the high activity source, deviation was 0.3% from the activity provided by manufacturer. Calibration with a PMMA cylindrical phantom was less sensitive, and suitable for quick check method with accuracy less than 10%.

INTRODUCTION

For the treatment of cervical cancer, remote after loading HDR brachytherapy is commonly used in several hospitals in Indonesia. Most of the HDR brachytherapy unit uses ^{192}Ir as the radiation source. Since the half-life of ^{192}Ir is 73.83 days [1], therefore the source is frequently changed. Although the commercial supplier provides the source strength, it is unwise to rely solely on this value for dose calculations [2]. Each radiotherapy institution should calibrate the source to verify the source strength given by the manufacturer before using for clinical applications.

Using cavity chamber with buildup cap, or using calibration jig can perform calibration of sources in air. The calibration results indicate the source strength, which is expressed as reference air kerma rate (K_R) at 1 m. Since the measurements cannot be carried out directly at 1m, then the K_R value is calculated from the measurement results using the following equation [3]

$$K_R = N_K . (M_u/t). k_{air}. k_{scatt}. k_n. (d/d_{ref})^2 ....(1)$$

N_K is the air kerma calibration factor of the ionization chamber for ^{192}Ir source

M_u is the reading obtained in each measurement during the time t, and corrected for ambient temperature and pressure, recombination losses and transit effect during the source transfer.

k_{air} is the correction for attenuation in air of the primary photon between the source and the chamber.

k_{scatt} is the correction for scattered radiation from the walls, floor, measurement set-up, air, etc.

k_n is the non-uniformity correction.

d is the distance between the center of the source and the center of the ionization chamber.

d_{ref} is the reference distance of 1 m.

The N_K value was obtained by using the following equation [3]

$$N_K = (0.8\, A_{w,250\,KV} . N_{K,250KV} + 0.2\, A_{w,Co} . N_{K,Co})/A_{w,Ir} ....(3)$$

The value of $A_{w,250\,KV}$, $A_{w,Co}$, and $A_{w,Ir}$ for the Farmer chamber are 0.999, 0.988, and 0.989.

The k_{air} value from ^{192}Ir sources at difference distances is already tabulated in IAEA TECDOC 1079. The scatter correction factor k_{scatt} is a function of the true center-to-center source to chamber distances (d'). This d' is obtained from the d value and the offset value c which appears in the set-up distance.

$$d' = d + c ....(4)$$

The kerma rate at the true distance K(d') in each measurement is due to primary $K_p(d')$ and scattered beam K_s which is assumed constant. The $K_p(d')$ value varies following the inverse square relation with the distance, therefore $K_p(d')\,(d')^2$ was constant.

$$K_p(d')\,(d')^2 = [K(d') - K_s]\,(d + c)^2 \;.............(5)$$

In the above equation there are three unknown $K_p(d')$, K_s, and c , while K(d') and d are the measurement results. To have solution of this equation with three unknown, at least three data measurements are required. Finally, the k_{scatt} value can be obtained by using this equation

$$k_{scatt} = 1 - K_s / (N_K .\, M_u .\, k_n) \;....................(6)$$

The non-uniformity correction of the chamber (k_n) is due to the high divergence of the incident beam. The non-uniformity photon fluence over the wall chamber, affecting the electron fluence is also non-uniform in the air cavity of the chamber. The k_n value depends on the shape and dimension of the chamber, measurement distance and the source geometry, material in inner wall chamber, and energy radiation measured [3]. In this technical document, the k_n value for various distance (d) is available for the Farmer chamber with internal radius 3.15 mm and length 24.1mm.
Besides in air, calibration of brachytherapy source can also be done in the medium, such as in a PTW PMMA cylindrical phantom. In this measurement, correction for the present of absorbing and scattering cylindrical phantom instead of air is taken into account for calculating the K_R value. The following equation [4] is used to determine the K_R value from the measurement results.

$$K_R = 0.00760 \,.\, k_\lambda .\, N_K .\, (M_u/t) ....(7)$$

M_u/t is expressed in digits/hour
k_λ is correction factor for radiation quality deviating from ^{60}Co radiation, and for ^{192}Ir source the vaue of $k_\lambda \approx 1$.

The source activity is determined by using the following equation

$$A = K_R/\Gamma \;..................(8)$$

The air kerma rate constant Γ for ^{192}Ir is equal to 0.411 cGy $m^2\,Ci^{-1}\,h^{-1}$ [5]
In this report, it is presented the calibration results of the ^{192}Ir source of MicroSelectron HDR brachytherapy in air and in a PMMA cylindrical phantom. The source activity is calculated from the K_R value, and compared to the value provided by the manufacturer.

MATERIAL AND METHOD

Two ^{192}Ir sources from Nucletron Micro Selectron were used in this study. The source was in the form of a solid pellet, 1.1 mm in diameter and 5.0 mm in length. The active part was 0.6 mm in diameter and 3.5 mm in length, and encapsulated with stainless steel.
Activity provided by the supplier for the first source was 12 Ci at October 1, 2001, and the second source was 12.5 Ci at Januari 30, 2002. Calibration of these sources used Farmer dosimeter (2570) and NE 0.6 cm^3 Farmer ionization chamber (2571), and performed in air and in a cylindrical PMMA phantom. At the time of measurements in air, activity of the first source (A1) was 4.112 Ci (114 days decay time), and the second source (A2) was 9.000 Ci (35 days decay time). On the other hand, the activity at the time of measurements in cylindrical phantom, the value of A1 and A2 source were 4.155 Ci (113 days decay time) and 7.321 Ci (57 days decay time).
The method of calibration in air was accomplished following the IAEA TECDOC 1079. The ionization chamber was provided with the buildup cap for gamma radiation ^{60}Co. The source and the chamber were placed at the straight line by the help of a wooden scaled rule. The measurements were performed with the distance between the source and the chamber was 10, 14, 15, 16, 17, 20, 25, and 30 cm.
The PMMA cylindrical phantom has a diameter of 20 cm and a height of 12 cm. In the center there is a hole for placing the source, which is in the after loading applicator. For the measurements, there are 4 holes available for the chamber, on a circle with 8 cm in diameter and at 2 cm from the rim, at the position of 0^0, 90^0, 180^0, and 270^0.

RESULTS AND DISCUSSION

A. Calibration in air

The results at 8 distance measurements (M_u/t) for the A1 source and the A2 source are indicated in Table 1. Each result in this table is the average of three measurements. Several factors were required for obtaining the K_R value from the data in the Table 1. The calibration factor (N_K) was determined by using its calibration factor for ^{60}Co and 250 KV X-rays provided by National Atomic Energy Agency (BATAN) that have the value of 0.8393 and 0.8577 cGy/div. Using equation (3), the value of N_K was equal to 0.8608 cGy/div. The k_n value for the Farmer chamber and k_{air} from ^{192}Ir were obtained from the interpolation data provided by literature [3]. Finally, the k_{scatt} was calculated by using equation (5) and (6). Using equation (1), the source strength of the A1 and A2 source were estimated, and the results were shown in the Table 2. Using equation (8) the activity of the A1 and A2 source were calculated, and the results were indicated in Table 3.

Compare to the activity provided by manufacturer, the measurement results of A1 source at the distance of 14 and 17 cm showed the minimum deviation, while for the A2 source the optimum measurement distance was obtained at 14 and 16 cm. Especially for the calibration of A2 source, the 16 cm optimum distance was in a good agreement with that was suggested for the measurement using Farmer type chamber [3]. At this optimum distance the measurement result differed only 0.3 % with the activity given by manufacturer. But for the A1 source, it appeared that measurement result at the optimum distance (17 cm) was 3.2%, higher than 3% that was the limitation value for QA [2]. This found indicated that the accuracy of the measurement depended on the source activity.

Table 1. The measurement results of ^{192}Ir HDR source at various distances between the source and the chamber (d).

d (cm)	(M_u/t), Gy/h	
	A1 source	A2 source
10	2.042	4.444
14	0.972	2.194
15	0.840	1.800
16	0.720	1.680
17	0.660	1.470
20	0.462	1.050
25	0.282	0.630
30	0.180	0.458

Table 2. The reference kerma rate (K_R) of the ^{192}Ir HDR source measured in air

d (cm)	N_K. k_{air}. k_n. $(d/d_{ref})^2$x 10^{-2} (cGy/div)	A1 source			A2 source		
		M_u/t (Gy/h)	k_{scatt}	K_R (cGy m^2 h^{-1})	M_u/t (Gy/h)	k_{scatt}	K_R (cGy m^2 h^{-1})
10	0.8694	2.042	0.9967	1.775	4.444	0.9981	3.856
14	1.6990	0.972	0.9931	1.640	2.194	0.9961	3.713
15	1.9504	0.840	0.9920	1.625	1.800	0.9952	3.494
16	2.2190	0.720	0.9907	1.583	1.680	0.9948	3.709
17	2.5027	0.660	0.9898	1.636	1.470	0.9941	3.657
20	3.4639	0.462	0.9855	1.577	1.050	0.9917	3.607
25	5.4123	0.282	0.9762	1.490	0.630	0.9862	3.363
30	7.7937	0.180	0.9626	1.350	0.458	0.9810	3.508

Table 3. The activity of the ^{192}Ir HDR source measured in air and provided by manufacturer.

d (cm)	A1 source activity (Ci)			A2 source activity (Ci)		
	measured	manufacturer	Δ (%)	measured	manufacturer	Δ (%)
10	4.319	4.112	+ 5.0	9.382	9.000	+ 4.2
14	3.990	4.112	- 3.0	9.034	9.000	+ 0.3
15	3.954	4.112	- 3.8	8.501	9.000	- 5.5
16	3.852	4.112	- 6.3	9.024	9.000	- 0.3
17	3.981	4.112	- 3.2	8.895	9.000	- 1.2
20	3.837	4.112	- 6.7	8.776	9.000	- 2.5
25	3.625	4.112	- 11.8	8.182	9.000	- 9.1
30	3.285	4.112	- 20.1	8.535	9.000	- 5.2

B. Calibration in PMMA cylindrical phantom

The measurement results for the A1 and A2 source with the chamber at the four holes are shown in the Table 3. The reference kerma rate K_R is calculated using equation (7), with using the N_K value of 0.8608 cGy/div. The estimation of the activity of the A1 source and A2 source were indicated in Table 4.

Table 3. Reference kerma rate (K_R) of the ^{192}Ir HDR source measured in PMMA cylindrical phantom

Chamber position	A1 source		A2 source	
	M_u/t (Gy/h)	K_R (cGy m^2 h^{-1})	M_u/t (Gy/h)	K_R (cGy m^2 h^{-1})
0^0	2.398	1.58	4.212	2.76
90^0	2.378	1.56	4.152	2.72
180^0	2.340	1.53	4.200	2.74
270^0	2.328	1.52	4.272	2.79

Table 4. Activity of the ^{192}Ir HDR source measured in PMMA cylindrical phantom

Chamber position	A1 source activity (Ci)			A2 source activity (Ci)		
	measured	manufacturer	Δ (%)	measured	manufacturer	Δ (%)
0^0	3.849	4.155	7.4	6.715	7.321	8.3
90^0	3.785	4.155	8.9	6.618	7.321	9.6
180^0	3.723	4.155	10.4	6.667	7.321	8.9
270^0	3.698	4.155	11.0	6.788	7.321	7.3
Average	3.764		9.4	6.697		8.5

Calibration using the PMMA cylindrical phantom was less sensitive compare to calibration in air. The measurement results showed that the average activity of the A1 and A2 source was 9.4% and 8.5% lower than that given by the manufacturer. From the limitation QA point of view, these deviation values could not fulfill the requirement. However, this calibration method was more practice and took shorter time compare to the air calibration method. Therefore this method was helpful for quick check measurement with the accuracy less than 10%.

CONCLUSSION

The calibration of the ^{192}Ir HDR brachytherapy source in air was a good method for verifying the source activity before clinical application. In this calibration method, measurements at several distances center-to-center of the source to the chamber were required. The optimum distance was determined by measurement, although it was suggested at 16 cm. In this study the verification of the A1 and A2 source at the optimum distance was 3.2% and 0.3%. This found indicated that this air calibration method could not applied to low activity source.

The calibration using a PMMA cylindrical phantom was less sensitive compare to calibration method in air. This method was practice and suitable for quick check of the source activity with the accuracy within about 10%.

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