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A PRELIMINARY STUDY OF RADIATION QUALITY CORRECTION FACTOR (k_Q) DETERMINATION FOR WELL-TYPE IONIZATION CHAMBER

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ABSTRACT

This paper deals with the determination of the radiation quality correction factor (k_Q) well-type ionization chamber for the measurement of Co-60 brachytherapy. The measurement of the brachytherapy source has been done in the hospital brachytherapy facilities. The measurement of air Kerma has been done using three different ionization chambers 0.6 cm³, 30 cm³, 80 cm³, which have calibration factor traceability for Co-60 and one well-type ionization chamber which calibrated for Ir-192. The determination of the radiation quality correction factor (k_Q) was determined based on the results of the air Kerma ratio between measurements using ionization chambers, which have traceability to Co-60 and Ir-192 sources. The results of the measurement of the reference air Kerma rate (R_{AKR}) obtained from the three chambers were 21.36, 19.87, 19.34 mGy.m².h⁻¹, while the results of measurements with ionization chambers get a value of 19.01 mGy.m².h⁻¹. The k_{QCal} results from 0.6 cm³ ionization chamber get a value of 1.07. The k_{QCal} value was compared with the value of Andreas Schuller's et al. k_{Qreff} of 1.05 and get a deviation of 2.2%. Implementation of the booth k_Q value on the results of the R_{AKR} from the HDR1000Plus well-type ionization chamber in the measurement of brachytherapy in two different facilities gets a maximal deviation 1.7% with dose value from Treatment Planning System (TPS). The deviation was in the acceptable range of $\pm 5\%$. Based on this, the use of radiation quality correction factor (k_Q) value can be implemented as one method if it

does not have the traceability factor calibration of the Co-60 brachytherapy source.

Keywords: brachytherapy, radiation quality correction factor (k_Q), ionization chamber, well-type

INTRODUCTION

Brachytherapy is one of the modalities of radiation therapy in addition to external radiotherapy. The advantage of brachytherapy compared to external radiotherapy is the ability to deliver the right dose to the target, whereas the drawbacks can only be used for tumor cases that are located (for example, cervix and prostate) and relatively small [1]. Therapeutic modalities using brachytherapy are divided into two, namely, the high dose rate (HDR) modality and the low dose rate (LDR). However, for a low dose rate, brachytherapy is no longer used in Indonesia.

Initially, the radiation source used for brachytherapy was Ra-226. As artificial sources were discovered, the use of radium was replaced by Co-60, Cs-137, and Ir-192 [2]. Until now, the source of brachytherapy radiation that is often used by hospitals is Ir-192 and Co-60 [3]. The source of the Ir-192 brachytherapy has a half-life of 74 days with an average energy of 350 keV, while Co-60 has a half-life of 5.27 years with an average energy of 1250 keV.

In Indonesia, as of December 2019, eleven hospitals had brachytherapy with a source of Ir-192 and three hospitals had brachytherapy with a source of Co-60. The brachytherapy dosimetry equipment must be calibrated once a year by applicable regulations. This calibration activity is also part of the quality assurance activities of the brachytherapy because the dosimeter will be used to measure the brachytherapy radiation source [4,5].

Institutions that have brachytherapy with an Ir-192 source usually replace the radionuclide source with an interval of about 3 months. The new source is accompanied by a manufacturing certificate or measurement results by the vendor with an uncertainty of $\pm 5\%$ [6,7]. As for brachytherapy with a Co-60 source, it can usually replace the radionuclide source at intervals of one and a half times of the half-life source (5-7 years).

Related to the problem of replacing Ir-192 sources with a short amount of time, for some institutions, this is a crucial problem because it relates to the availability of funds for the procurement of sources, as well as licensing and transportation of Ir-192 sources [3]. Delays in licensing and clearance services at the customs services within a few days have a significant impact on the decay of the Ir-192 source activity, which then affects clinical irradiation because the source half-life is relatively short. In contrast to brachytherapy with a Co-60 source which, if there is a delay of some time, does not have a significant impact on the activity of the source.

The International Atomic Energy Agency (IAEA) has published protocols that describe in detail the calibration equipment, measurement techniques, stability checking, and recalibration intervals [8]. There were several methods in measuring the source of brachytherapy according to IAEA protocol, namely measurement in the air (free in-air measurement) and using a well-

type ionization chamber. Measurement in the air has the disadvantage of contributing to scattering in a large room, thus making the uncertainty of the measurement also large [9]. Unlike direct measurements in the air, well-type ionization chambers were specifically designed to measure the source of brachytherapy and open to the atmosphere. Well-type chambers were more recommended in measuring the source of the brachytherapy in terms of air Kerma strength (AKS) [10-12].

At present, the availability of calibration services for Ir-192 brachytherapy sources at the Primary Standard Dosimetry Laboratory (PSDL) level was available at several National Metrology Institute (NMI's) [13,14], but for Co-60 source brachytherapy only available at German NMI, Physikalisch-Technische Bundesanstalt (PTB) [15].

Andreas Schüller, et al. [15], in his research, investigated a value of the radiation quality correction factor (k_Q) that can be used for measurement of Co-60 source brachytherapy using a well-type ionization chamber which has a calibration factor at the Ir-192 source. In that study, 35 well-type ionization chambers with two different types were used, which were tested for measurements at the source of the Ir-192 and Co-60 brachytherapy.

On the other hand, the reference paper [15] used the ionization chamber volume 1000 cm^3 to measure the reference air Kerma rate from the PTB's brachytherapy primary standard source. Not only using the 1000 cm^3 ionization chamber, but the other reference also used the other volume of the ionization chamber, i.e., 0.6 cm^3 and well-type chamber with volume 245 cm^3 or 116 cm^3 [8]. For the reason of Co-60 brachytherapy measurement, the ionization chamber will be suitable because, generally, the chamber has the traceability calibration factor for Co-60.

This paper describes the determination of the radiation quality correction factor (k_Q) for the Co-60 brachytherapy source using an HDR 1000Plus well-type ionization chamber. Verification of the measurement results of a well-type ionization chamber was done by comparing the measurements with a 0.6 cm^3 , 30 cm^3 , and 800 cm^3 ionization chamber using a free in-air measurement method. Implementation of the results of the k_Q value was carried out on two measurements of Co-60 brachytherapy source using a 1000Plus HDR well-type ionization chamber compared to the TPS value in different brachytherapy facilities. The use of four different ionization chamber volumes has a purpose of ensuring that the measurement is in a good agreement. Besides, the 0.6 cm^3 , 30 cm^3 , and 800 cm^3 ionization chamber have the traceability of the Co-60 calibration factor.

METHOD

By documents published by the International Atomic Energy Agency (IAEA), namely IAEA TEC-DOC 1274: Calibration of photon and beta ray sources used in brachytherapy, there were several methods to calibrate dosimeters used in the measurement of brachytherapy sources.

The strength of the brachytherapy radiation source was determined by the amount of the reference air Kerma rate (R_{AKR}). R_{AKR} is the rate of air Kerma in the air at a distance of 1 meter (d_{ref}) corrected by attenuation and scattering [16]. Besides RAKR, another recommendation concerning the strength of the brachytherapy radiation source is in the amount of water kerma

strength (s_K) i.e the rate of air kerma in the air at a distance d from the radiation source is corrected by attenuation and scattering and multiplied by the square of the distance (d^2) [17].

FREE-IN-AIR MEASUREMENT METHOD

Based on IAEA TEC-DOC 1274 R_{AKR} measurements for brachytherapy were carried out at a distance of 1 meter. The determination of the R_{AKR} using an ionization chamber can be calculated using the equation below.

$$K_R = N_K \cdot (MU/t) \cdot k_{air} \cdot k_{scatt} \cdot k_n \cdot (d/d_{ref}) \quad (1)$$

Here the parameter description of EQUATION (1), K_R is the air Kerma rate, N_K is the air Kerma calibration factor, MU/t is the charge reading per time (60 seconds), k_{air} is the attenuation correction factor of the beam in the air, k_{scatt} is a factor scattering correction, k_n is the non-uniformity correction factor, d is the measurement point distance to the ionization chamber and d_{ref} is the measurement reference distance (1 meter).

N_K was obtained from the chamber calibration results against the standard reference chamber. The attenuation correction factor in the air (k_{air}), scattering correction factor (k_{scatt}), and the beam uniformity correction factor (k_n) were obtained from the calculation results.

The parameter k_n is obtained from the calculation using the equation below [8].

$$A_{pn}(d) = A_{pn}^{KR}(d) + \omega A'_{pn}(d) \quad (2)$$

Here the description of the parameters used in EQUATION (2), $A_{pn}(d)$ is a calculation parameter for anisotropic electron fluence between the air cavity and the degree of anisotropy given by radiation energy and material dependency factor (ω). The parameter value ω can be seen in Table VI IAEA TEC-DOC 1274. The parameters $A_{pn}^{KR}(d)$ and $A'_{pn}(d)$ were form function factors of cylindrical ionization chambers, $\sigma=R_c/L_c$, and distance factor $\alpha=R_c/d$. R_c is the internal radius of the chamber, and L_c is the dimension of half of the internal length of the ionization chamber, while (d) is the measurement distance. Based on the information on the radius and width of the chamber, conformity can be found in Table VII and Table VIII of IAEA TEC-DOC 1274. K_n parameter obtained after $A_{pn}(d)$ get from EQUATION (3).

$$K_n = 1/A_{pn}(d) \quad (3)$$

Some publications [18-20] state that to calculate k_{scatt} can use the 7 distance method published by Goestch et al. [21]. The 7 distance method uses an ionization chamber to measure the charge reading at several distances. The purpose of this method was to evaluate the scattering that occurs at each charge reading at each measurement point. The method was still used and developed for the measurement of brachytherapy sources.

Liyun Chang, et al. [22] developed a method to measuring scattering in a room with empirical modeling. This method verified to the results of the research Selvam, et al. [27] regarding the modeling of scattering in a room using Monte Carlo software. The results did not show a significant difference, which was 0.3%. Here the empirical equation from the Liyun Chang publication:

$$S_c \approx -[c \times \exp(-e \cdot h) + f \times \exp(-g \cdot h)] \times d + c' \times \exp(-e' \cdot h) + f' \quad (4)$$

Here the description of the constant used in EQUATION (4), $c = 0.01946$, $e = 1.472$, $f = 0.0006998$, $g = 0.02036$, $c' = 0.278$, $e' = 1.56$, $f' = 1.005$, and $a = -[c \times \exp(-e \cdot h) + f \times \exp(-g \cdot h)]$, $b = c \times \exp(-e \cdot h) + f$, d (cm) = source to chamber distance and h (m) = $(x \times y \times z)^{1/3}$.

MEASUREMENT USING WELL-TYPE IONIZATION CHAMBERS

The principle of measurement with this method was that the charge reading collected by the well-type ionization chamber was corrected and multiplied by the chamber calibration factor. The value of the chamber calibration factor used was traced to the University of Wisconsin Accredited Dosimetry Calibration Laboratory traced to the National Institute of Standards and Technology (NIST). Here the equation for calculating air Kerma rate using an ionization chamber.

$$R_{AKR} = M_{std} \cdot N_{AKRstd} \cdot K_{PT} \quad (5)$$

Here the description of the parameters in EQUATION (5), R_{AKR} is the air kerma rate, which in the brachytherapy modality is called air Kerma strength, M_{std} is the reading of a standard well type chamber (nC), N_{AKRSTD} is the value of the calibration factor of a standard well-type ionizing chamber ($\text{Gy m}^2 \text{ h}^{-1} \text{ A}^{-1}$), K_{PT} is a correction factor for temperature and room air pressure.

Measurement of charged particles by ionization chambers is influenced by external factors namely temperature and pressure [23]. The correction factors for temperature and room air pressure were calculated using the formula [8]:

$$K_{PT} = \frac{273,15 + T}{273,15 + T_0} \times \frac{P_0}{P} \quad (6)$$

Here the description of the parameters in EQUATION (6), K_{PT} is the correction factor for temperature and room air pressure, T is the measured temperature ($^{\circ}\text{C}$), T_0 is the reference temperature (20°C), P is the measured pressure (kPa), P_0 is the reference pressure (kPa).

MATERIALS

The radiation source used in this research was the Co-60 brachytherapy Saginova afterloading machine from the manufacturer Eckert & Zeigler BEBIG GmbH. This machine was equipped with 25 channels for loading the brachytherapy source. For Co-60 source brachytherapy seed from the Saginova machine has dimensions of 3.5 mm x 1.0 mm, while for seed source Ir-192 has dimensions of 3.5 mm x 0.9 mm.

There were several ionization chambers used in this study. Ionization chambers 0.6 cm^3 , 30 cm^3 , 800 cm^3 and well-type ionization chambers. The 0.6 cm^3 ionization chamber used was the PTW chamber TW30013 serial number 6367 made by the German PTW manufacturer Freiburg. The 30 cm^3 ionization chamber was also used from the German Freiburg PTW manufacturer with a type 23361 cylindrical stem chamber. For ionizing chambers with a volume of 800 cm^3 was used an ionization chamber from the manufacturer of Standard Imaging, USA, with Exradin A6 type. These three chambers have traceability factor

calibration to the Co-60 source. The use of ionization chamber volume 800 cm^3 was based on the reference [15], which used the LS-01 volume 1000 cm^3 for measurement of the brachytherapy source.

The well-type ionization chamber used was the HDR1000Plus well-type ionization chamber from the manufacturer of Standard Imaging, USA. This well-type ionization chamber has a traceability factor calibration to the source Ir-192. This well-type ionization chamber was calibrated in terms of air Kerma strength (AKS) at the University of Wisconsin Accredited Dosimetry Calibration Laboratory traced to the National Institute of Standards and Technology (NIST) with a calibration factor $N_{AKR} = 4.690 \times 10^5 \text{ Gy m}^2 \text{ h}^{-1} \text{ A}^{-1}$. This chamber has an active volume of 245 cm^3 , with air cavities open to the atmosphere. Measurement of temperature and pressure correction factors (k_{PT}) was needed to correct the charge reading by this chamber.

The electrometer used to read the charge reading from the ionization chamber was the PTW Unidos Webline electrometer.

EXPERIMENTAL SETUP

Measurement of air Kerma using an ionization chamber was done using a custom jig for positioning of the ionization chamber. A custom jig image can be seen in FIGURE 1 below.

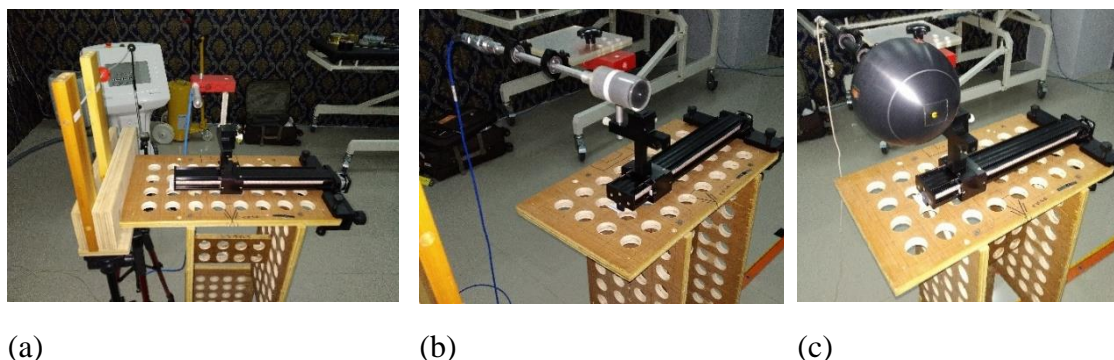


FIGURE 1. Custom Jig for positioning the ionization chambers (a) volume 0.6 cm^3 (b) volume 30 cm^3 (c) volume 800 cm^3 .

After the chamber was positioned parallel to the source of the brachytherapy, a scanning step was performed to determine the maximum response position of the reading of each ionization chamber. At the maximum point of the response, the measurement of air Kerma was carried out with five repetitions of data.

Measurement using a well-type ionization chamber was done by setting the chamber positioning on a wooden table. It is with a minimum distance of 1 meter from the floor and the wall. It aims to reduce the effect of scattering [12]. The placement of the well-type ionization chamber can be seen in FIGURE 2 below.



(a)

(b)

FIGURE 2. The positioning of well-type ionization chamber on wooden table.

Same with before, the first step was scanning the maximum response at a depth of the well-type ionization chamber [11]. Scans were performed in a well-type ionization chamber at each step according to the brachytherapy machine. After getting the maximum response position, measurements were taken at that position with five repetitions. Temperature and pressure conditions in the room were also calculated as a correction of temperature and pressure (*k_{PT}*).

RESULT AND DISCUSSION

The results of measuring the maximum response of the 0.6 cm³ ionization detector and the well-type ionization detector can be seen in FIGURE 3. Based on these measurements, the maximum response of the 0.6 cm³ ionization detector at step 85, while for the well-type ionization detector at step 54. Then, the measurement was done in this step for each chamber, respectively.

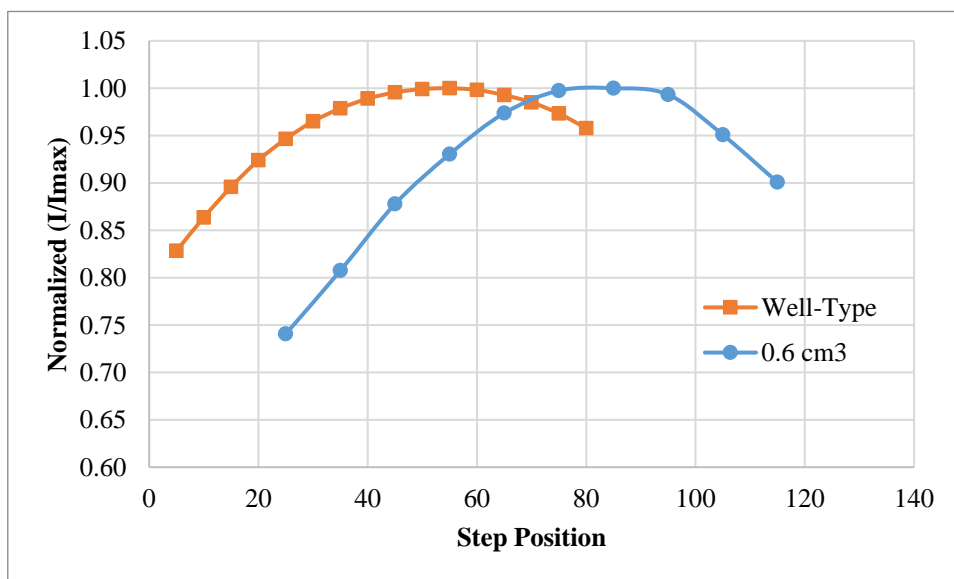


FIGURE 3. Maximum Response Graph for ionization chamber 0.6 cm³ dan well-type.

Based on FIGURE 3, the results of the normalization of responses obtained from the two chambers appear to be different. This was due to differences in the detector volume and the nominal response of each ionization chamber. Besides, the measurement of the response by the 0.6 cm³ ionization chamber was carried out in the air using a custom jig whose reading results have not been corrected for radiation scattering. Different from the well-type ionization chamber, which has been designed in such a way as to measure the source of the brachytherapy.

The results of measurements of air Kerma using several ionization chambers can be seen in TABLE 1, while the results of measurements with a well-type ionization chamber can be seen in TABLE 2. Scattering correction factor (k_{scatt}) values, attenuation correction factors (k_{air}), and correction factors non-uniformity (k_n) was also presented in TABLE 1.

TABLE 1. The result of measurement R_{AKR} with three different ionization chambers

Chamber	$M_{corr} \cdot d^2$ (nC.m ² .h ⁻¹)	N_k (mGy/nC)	k_{scatt}	k_{air}	k_n	R_{AKR} (mGy.m ² .h ⁻¹)
0.6 cm ³	0.426	49.76	0.998	1.000	1.009	21.36
30 cm ³	22.83	0.907	0.938	1.000	1.023	19.87
800 cm ³	557.8	0.037	0.938	1.000	0.999	19.34

In measuring the R_{AKR} of the brachytherapy source, the important thing to consider was the scattering correction factor in the measurement. As explained earlier, this research used an approach method for calculating scattering correction factors using analytical methods from Liyun Chang et al. [22]. The room area of the brachytherapy installation used was 5.5 m x 4.5 m x 2.3 m. The value was entered into EQUATION (1), then the k_{scatt} value was 0.988 for 0.6 cm³ chamber, 0.938 for 30 cm³ chamber, and 800 cm³ chamber.

The AKS rate based on the Treatment Planning System (TPS) calculation on the measurement day obtained a value of 21.01 mGy.m².h⁻¹. This value was obtained from the decay of the dose rate reference value given by the vendor during the brachytherapy afterloading machine installation.

It was known that value of the R_{AKR} in TABLE 1 has a deviation that varies with the value of the R_{AKR} from the TPS. The deviations were obtained 1.7%, -5.4%, and -8.0% for the 0.6 cm³, 30 cm³ and 800 cm³ ionization chamber, respectively. The acquisition of the R_{AKR} was measured by a well-type ionization chamber in TABLE 2 gets a deviation of -5.3% of the value of the R_{AKR} from the TPS.

The result of R_{AKR} measured by ionization chambers 30 cm³ and 800 cm³ obtained a deviation which was quite significant to the value of the R_{AKR} from TPS, while for the deviation result 0.6 cm³ ionization chamber to the value of R_{AKR} from TPS was 1.7%, which was still within the acceptable range of $\pm 5\%$.

TABLE 2. The result of measurement RAKR using a well-type ionization chamber

Chamber	M_{raw} (nC/min)	k_{PT}	M_{corr} (nC/min)	$N_{AKR Ir-192}$ (10 ⁵ Gy.m ² .h ⁻¹ .A ⁻¹)	R_{AKR} (mGy.m ² .h ⁻¹)
HDR1000 Plus/A152152	2554	0.997	2547	4.690	19.91

The radiation quality correction factor (k_Q) was calculated from the ratio between the R_{AKR} of the ionization detector having traceability of the Co-60 source calibration factor and the R_{AKR} value of the detector having traceability of the Ir-192 source calibration factor. Based on the R_{AKR} data from TABLE 1, the R_{AKR} values of 0.6 cm³ ionization chamber that were still within the acceptable range. Then these values were compared with the R_{AKR} values of the well-type ionization detector (TABLE 2). We obtained the result of the comparison of 1.07. Henceforth, the calculated value of the radiation quality correction factor is called k_{Qcal} .

Andreas Schüller, et al. [15] in their research obtained the k_Q value for a well-type ionization detector with the PTW brand Tx33004 was 1.19. While for the HDR 1000Plus ionization detector the k_Q value was 1.05. The value of k_Q 1.05 was only used for well-type ionization detectors with HDR 1000 Plus type made from Standard Imaging USA. Henceforth, the value of the radiation quality correction factor from the reference is called k_{Qref} . If the k_{Qcal} value of 1.07 was compared to the k_{Qref} value of 1.05, then there was a 2.2% deviation.

The implementation of the radiation quality correction factor (k_Q) was done by multiplying the R_{AKR} obtained by the HDR1000Plus/A152152 well-type ionization detector can be seen in TABLE 3. The implementation of the k_Q value was carried out on the measurement of Co-60 brachytherapy R_{AKR} in two different brachytherapy facilities.

TABLE 3. The result of implementation k_{Qref} and k_{Qcal}

Facilities	Parameter	k_Q	R_{AKR} by HDR1000	Result of R_{AKR}	TPS	Deviation
RS-A	k_{Qref}	1.05	19.91	20.90	21.01	-0.5%
	k_{Qcal}	1.07	19.91	21.36		1.7%
RS-B	k_{Qref}	1.05	16.64	17.47	17.74	-1.5%
	k_{Qcal}	1.07	16.64	17.85		0.6%

Based on TABLE 3, it was known that the results of the k_{Qcal} implementation results obtained a maximum deviation of 1.7%. According to reference [15] in the use of k_Q for determining the R_{AKR} of the Co-60 brachytherapy source, it has an uncertain uncertainty of 3%. Based on these results, the use of k_Q for measurement of Co-60 brachytherapy source with ionization chambers traced to the calibration factor of the Ir-192 brachytherapy source can be implemented. In addition, the R_{AKR} reference value provided by the vendor has an expanded uncertainty (U_{EXP}) of 5%. So with a maximum deviation of 1.7% was still in the acceptable range.

The measurement was held at RS-A and RS-B, which were they have the same facilities as Co-60 brachytherapy. Although the brachytherapy afterloading machine came from the same manufacture, the source activity and the dose rate will not same for the day measurement. Also, the geometry of the facilities (bunker). It will impact the performance of the measurement. So it became an excellent facility to take the measurement for research purposes.

It was one of the breakthroughs to facilitate the calibration service provider laboratory to calibrate the dosimeter and Co-60 brachytherapy source afterloading machine if they do not yet have a dosimeter whose calibration factor was traced to Co-60 source. However, the authors recommend continuing to calibrate directly to the laboratory that provides traceability for Cobalt 60 brachytherapy source, especially for well-type ionization chamber.

Further study about determination of the radiation quality correction factor (k_Q) for Co-60 brachytherapy is needed in terms of software calculation and experimental for many sampel of brachytherapy well-type ionization chamber.

CONCLUSION

Based on the results of the calculation of the radiation quality correction factor (k_Q), the k_Q value of 1.07 was obtained. This value was obtained from the ratio of the charge reading from the ionization chamber to the charge reading of the well-type ionization detector. The 0.6, 30, and 800 cm³ ionization chamber used have traceability to Co-60 sources, while well-type chamber ionization detectors have traceability to Ir-192 sources. The use of k_Q value as a correction for measurements using a well-type ionization chamber gets a good match to the R_{AKR} value resulting from the TPS calculation. Among the three of the ionization chamber were used, the deviation obtained was in a good agreement was 2.2%.

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