p ISSN 1907-0322
e ISSN 2527-6433

Dosimetry Characteristic of Co-60 Calibration Source in SSDL Jakarta Facility After Source Replacement

Karakteristik Dosimetri Sumber Kalibrasi Co-60 di Fasilitas SSDL Jakarta Pasca Penggantian Sumber

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ABSTRACT

Secondary Standard Dosimetry Laboratory (SSDL) Jakarta's main task is to maintain the traceability of ionizing radiation units in Indonesia. One of their public services is calibration for nuclear instruments for therapy, consisting of dosimeter calibration and radiotherapy machine output. In the early of 2020, the dosimeter's calibration facilities have been out of date. The replacement of the Co-60 machine was done with a new one. However, the Co-60 machine re-used the Co-60 machine from Hospital radioactive nuclear waste. This paper discusses the dosimetric characteristic of the reusable Co-60 machine as a calibrator machine. Measurement data consisted of timer error, beam center and profile, dose rate in air Kerma and absorbed dose rate to water, and decaying stability. The reference used for measurement was IAEA Publication TRS No. 469. All measurement was taken by standard ionization chamber. The timer error result shows -2.52 seconds delayed after switching on the machine. The air Kerma rate was obtained at 230.15 µGy/min, meanwhile for absorbed dose rate to water was obtained 211.08 mGy/min. The source activity was monitored at 51.4 TBq on Dec 07, 2020. The decays of activity and dose rate were lies in the acceptable range. It should be lies on the 20 – 40 TBq for activity, meanwhile for dose rate should more than 100 mGy/min at 1 m distance. The stability was covered up in terms of dose rate and maintained in one percent deviation limit. Based on the result, this reusable Co-60 machine is ready to use as a calibrator source in gamma-ray facilities**.**

Keywords: Co-60 machine, calibration, SSDL, metrology, ionizing radiation

ABSTRAK

Tugas utama Laboratorium Dosimetri Standar Sekunder (SSDL) Jakarta adalah untuk menjaga ketertelusuran kalibrasi dari besaran radiasi pengion di Indonesia. Salah satu layanan publik yang disediakan adalah kalibrasi alat instrumen nuklir untuk terapi, terdiri dari kalibrasi dosimeter dan luaran radioterapi. Pada awal tahun 2020, fasilitas kalibrasi dosimeter harus diperbaharui. Pergantian sumber Co-60 telah dilakukan dengan menggunaan sumber baru. Tetapi, sumber baru tersebut merupakan sumber Co-60 hasil pemakaian kembali dari sumber bekas yang berasal dari limbah rumah sakit. Makalah ini mendiskusikan parameter dosimetri dari pemakaian kembali sumber Co-60 sebagai pesawat kalibrator. Pengukuran data terdiri dari pengukuran kesalahan pewaktu, profil berkas radiasi, laju dosis radiasi pada besaran Kerma udara, dan dosis serap air, dan stabilitas peluruhan. Referensi yang digunakan adalah publikasi IAEA TRS No. 469. Semua pengukuran dilakukan dengan menggunakan detektor ionisasi standar. Hasil kesalahan pewaktu menunjukkan adanya penundaan waktu selama -2.52 detik setelah tombol mesin dinyalakan. Laju Kerma udara didapatkan sebesar 230,15 µGy/menit, sedangkan untuk laju dosis serap air didapatkan 211,08 mGy/menit. Aktifitas sumber didapatkan sebesar 51,4 TBq pada 07 Desember 2020. Hasil peluruhan aktifitas dan laju dosis masih dalam rentang yang diterima. Aktifitas harus pada 20 -40 TBq, sedangkan untuk laju dosis harus melebihi 100 mGy/menit pada jarak 1 meter pengukuran. Stabilitas pengukuran dilakukan pada peluruhan laju dosis, dan dijaga pada deviasi satu persen. Berdasarkan hasil tersebut, pemakaian kembali mesin Co-60 telah siap untuk digunakan sebagai mesin kalibrator pada fasilitas sinar gamma.

Kata Kunci: Mesin Co-60, kalibrasi, SSDL, metrologi, radiasi pengion

Jurnal Ilmiah Aplikasi Isotop dan Radiasi
A Scientific Journal for The Applications of Isotopes and Radiation
Vol. 17 No. 2
p ISSN 1907-0322
e ISSN 2527-6433

INTRODUCTION

The Secondary Standard Dosimetry Laboratory (SSDL) Jakarta was established in June 1984 by acknowledging International Atomic Energy Agency (IAEA) as the world organization that organizes the SSDL network. The main task of SSDL is to maintain the traceability for ionizing radiation units to the Primary Standard Dosimetry Laboratory (PSDL). In a few references, the SSDL dramatically impacts the dosimetry's quality assurance, especially radiation therapy[1], [2]. Another task is to give users the calibration service, including the calibration service for radiation protection and therapy. The therapy level dosimeter must have a traceability calibration factor to ensure accurate measurement [3], [4]. At the end of 2018, the amount of calibration service in SSDL Jakarta was about ±5000 units and ±34 units for radiation protection and calibration output therapy.

The calibration source used for the therapy level was Co-60, and for protection level was Cs-137. The SSDL Jakarta used the calibration source installed in 2009 with activity 233,636 TBq on Jun 01, 1999. It was the first time for SSDL Jakarta to use the reusable Co-60 radioactive from the radiotherapy facilities to calibration facilities. By early 2020, the SSDL Jakarta has been replaced the calibration source.

IAEA holds an audit dose activity for SSDL. This activity aims to ensure the quality of each SSDL for giving service. Figure 1 shows the Audit Postal Dose results by IAEA for the SSDL Jakarta during 2010 - 2019. It is proved that the performance of the reusable Co-60 as a calibration source was good for delivered dose for calibration purpose.

The new calibration source was reusable Co-60 radioactive after considered radioactive waste from radiotherapy facilities. This source's activity was 348 TBq on May 24, 2006 [5]. The Co-60 machine was modified as the calibration facilities requirements, for example machine dimension, collimators, and operation control.

The SSDL Jakarta has more than 44 radiotherapy centers as user clients in Indonesia. It will become an important role to ensure the quality because the detector therapy is used for quality assurance in radiotherapy facilities to give the patient an accurate dose [8].

Figure 1. The results of Audit Postal Dose by IAEA from 2010 – 2019 [6], [7].

The calibration facilities should follow the guidelines given by the International Atomic Energy Agency (IAEA) on Technical Report Series (TRS) number 469, which explains the reference condition of dosimeter calibration for external beam radiotherapy. This study discusses the measurement's analysis to fulfill the IAEA TRS No. 469 guidelines. The specific topic was for the preparation of Co-60 gamma-ray calibration facilities. There are few requirements following that guidelines, (i) leakage and stray radiation, (ii) determination of beam center and field size, (iii) output variations due to source movement (iv) timing uncertainty (v) long term stability of output rate. The measurement result will be provided as the dosimetric characterization of SSDL Jakarta calibration facilities.

BASIC THEORY

Cobalt-60 machine as calibration source

Co-60 is a radioactive with a half-life of around 5.27 years. For radiotherapy purpose, the Co-60 radioactive was installed in the machine with the activity of about 5000 – 10,000 Ci or 185 – 370 TBq. The replacement should be done in terms of decay times periods to maintain the quality of radiotherapy. So, if the Co-60 decays to be half of the activity (2500 Ci), it can still be used as a calibration source because it fulfills the requirements of TRS 469, which is 20 TBq or 540 Ci. This reusable radioactive can save a large of funding for providing the radioactive and maintain the nuclear radioactive waste from the Hospital instead of sending it back to the manufacturers across the sea.

The last replacement of the Co-60 calibration source had been carried out in 2009. When it was installed in the SSDL Jakarta

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e ISSN 2527-6433

calibration facilities, the Co-60 activity lies around the value of 62.62 TBq on Jun 01, 2009. On Jun 01, 2019, the source activity lay around the value of 16.81 TBq. It was out of requirement from the IAEA TRS 469 recommendation, which is the source calibration should have the minimum activity of the order of 20 TBq.

Based on the half-life calculation, the Alcyon machine has been decayed up to 4 times from 1999 to 2019. The decay's stability could be monitor either using the decay's of activity or dose rate. Figure 2 shows a linear graph for the dose rate of Co-60 source from the period 2016 – 2020. As a reference value on Jan 07, 2016, the dose rate was 0.126 Gy/minute, and it decayed up to 0.072 Gy/minute on Mar 13, 2020. This dose rate was out of requirements, not less than 0.1 Gy/minute at a 1 m distance.

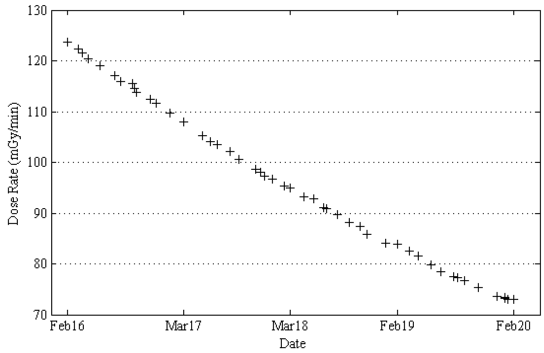

Figure 2. The decays of Co-60 source plot from periods of 2016 – 2020.

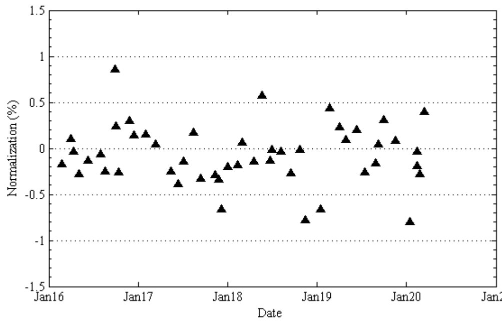

Figure 3. Co-60 source stability from periods of 2016 – 2020.

Based on the IAEA TRS 483 recommendation, the output machine calibrator's stability should be monitored. The value of measured decay's stability was normalized to the decay's value by calculating each day's measurements. Figure 3 shows the normalization value of Co-60 machine stabilization from 2016 to 2020. The output machines were maintained below 1% deviation.

Replacement of Co-60 calibration source

The reusable radioactive Co-60 was taken from Ulin Hospital, Kalimantan, Indonesia. The Co-60 machine has been modified as a simple as possible to use as a calibration source. Figure 4.a shows the original shape and the modified Co-60 machine for calibration purposes.

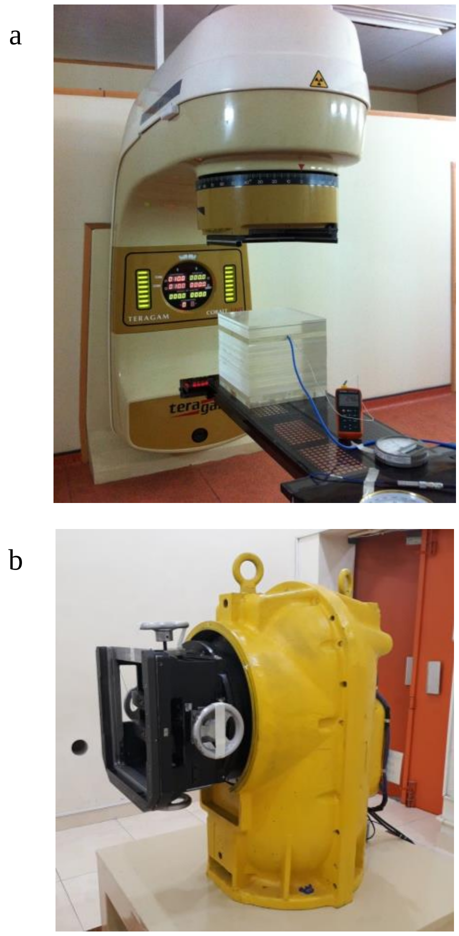

Figure 3. (a) Original shape of Teragam Co-60 machine in the Hospital[5] (b) Modified as Co-60 Calibration Source.

The collimator is set up using lead (Pb) block material. The collimator for calibration at the therapy level is different from the calibration level at radiation protection. The machine uses a panoramic source type in the protection level, no need to add a collimator for the beam.

MATERIALS AND METHODS

Materials

The secondary standard ionization chamber used was the Farmer chamber NE 2571/2693 calibrated in the SSDL IAEA traced to Primary Laboratory BIPM, France March 2018. The

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chamber was calibrated in terms of absorbed dose to water ($N_{D,\ W}$), air Kerma (N_K), and X-ray for radiotherapy. This chamber was maintained as the highest standard in calibration facilities, so for the daily work purpose, the other chamber should be used as the working standard.

The absorbed dose rate measurements to water and air Kerma were done using the NE 2571/2693 volume 0.6 cm^3 Farmer chamber. For the relative measurements, i.e., beam profile, the measurement was done using PTW Semiflex chamber TW31010/7865 volume 0.125 cm^3. Those ionization chambers were connected to the PTW Unidos Webline Elektrometer T10022/268.

Table 1. Specification of Ionization Chamber

SN	Volume (cm^3)	Voltage	Calibration Factor	
			$N_{D,W}$ mGy/nC	N_K μGy/nC
NE 2571/2693	0.69	250	45.14	50.06
TW31010/ 7865	0.125	400	290.8	-

The measurements in terms of absorbed dose rate to water were done using the 1D water phantom manufactured by IBA, Germany. This water phantom has an inner dimension of 35 cm x 39 cm x 36.2 cm. The maximum distance for scanning is 30 cm; it is more than enough to cover the reference field size of 10 cm x 10 cm. The PC Electrometers was set-up as one unit with the 1D water phantom as the control unit for auto-measurements.

METHODS

Timer error measurement

Measurement of the Co-60 machine's timer error is needed because the machine uses a Co-60 source where the operation of the source uses the pattern of movement of the radiation source from one point to another. The measurements were done using the timer's machine instead of the timer's electrometer. Calculation of timer errors can be done using the following equation[13]:

$$\tau = \frac{M_B.\mathrm{t}_A - M_A.\mathrm{t}_B}{\mathrm{n}.\mathrm{t}_A - M_B} \tag{1}$$

Which M_A is integrated reading in a time (t_A), M_B is integrated reading in n short irradiation of a time (tB/n), t_A and t_B is measurement time for 60 seconds, and n is a number for repeating the reading, can be $2 \geq n \leq 5$. For this study, the n used was four, so the M_B should be integrated reading in 15 seconds and repeated four times.

Determination of beam center and field size

The determination of beam center and field size was done using a small ionization chamber, PTW 31010 Semiflex chamber. The ionization chamber relative response measurements were set up in the reference calibration distance (100 cm) for the horizontal and vertical axis. Each axis's field size was determined as the distance between the two 50% points. The beam center was determined by pointing a line between the four 50% points. Those beam profile data also give a measure of the beam uniformity data.

Output variation due to source movement

This parameter should be checked because the Co-60 machine was controlled by the source's movement from storage (beam-off) to the irradiation position (beam-on). Due to source movement to one point of irradiation position, it can introduce a variation of the output rate of more than 0.1%.

Two measurements will represent the results for the checking purpose variations in source position. The first measurement was a series of at least ten measurements of the Co-60 output rate with the source continuously exposed (beam-on position) and data taken by the electrometer timer. The second measurement was a series measurement with the source returned to its storage position between measurements. All of the measurements were taken after the source is fully open and stop before the beam is switched off. For the results conclusions, the data were taken from those two measurements should be calculated and compared.

Air kerma rate measurement

The air Kerma rate measurement can be calculated using the following equation.

$$K_U = M.N_K.k_{pt}.k_{(2019)} \tag{2}$$

Which K_U is air Kerma (μGy/minute), M is corrected reading (nC/minute), N_K is calibration factor (μGy/nC), K_{pt} is pressure and temperature correction factor, and $k_{(2019)}$

p ISSN 1907-0322
e ISSN 2527-6433

is the correction for calibration factor which traced to the SSDL IAEA before 2019.

Absorbed dose rate measurement

IAEA Technical Report Series (TRS) publication No. 398 was used as a reference for determining the absorbed dose to water. The equation can be seen below:

$$D_W = M.N_{D,W}.k_s.k_{pol}.k_{pt}.k_{(2019)} \qquad (3)$$

Which $D_{W,\ Q}$ is absorbed dose to water (mGy/minute), M is corrected reading (nC/minute), $N_{D,\ W}$ is calibration factor (mGy/nC), k_s is ion recombination correction factor, K_{pol} is ion polarity correction factor, K_{pt} is pressure and temperature correction factor and $k_{(2019)}$ is the correction for calibration factor which traced to the SSDL IAEA before 2019. The $k_{(2019)}$ values for therapy level in terms absorbed dose rate to water is 0.9990 with uncertainty 1.0 (k=2); for therapy level in terms of air Kerma rate is 0.9918 with uncertainty 0.8 (k=2).

Decays and stability of Co-60 source

One of the methods to identify the performance stability from Co-60 is using the routine consistency check after the Co-60 output rate. Technically, the stability of the machine can be determined using the measurements of output rate compared against the calculation of Co-60 decays. The decays of the Co-60 can be calculated using the regular decays equation with a half-life of Co-60 5.27 years. The decays equation shows in Equation 4.

$$A = A^0 e^{-\lambda t} \qquad (4)$$

A is the current source activity, A0 is the source activity, and e-λt is the exponential values of decays constant per unit.

$$Stability(\%) = \frac{X_{measurement} - X_{decays}}{X_{decays}} x100\% \qquad (5)$$

The reference value is the value of the decay for the stability calculation. The stability of the Co-60 source is maintained in the range of ±1% deviation.

RESULTS AND DISCUSSION

Timer error measurement

The results of timer error measurement shown in Table 2. The results of 60 seconds and 15 seconds measurements were 4.581 nC/minute and 0.995 nC/minute, respectively. Timer error was calculated using Equation 1.0, and get the results -2.52 seconds. The minus sign for the results has meant that the beam of Co-60 starts after 2.52 s the buttons push on.

Table 2. Timer error measurements

M_1 Reading (nC/60 s)	M_2 Reading (nC/15 s)
4.851	0.995
	0.995
	0.995
	0.995
M_1 = 4.851	ΣM_2 = 0.995

Beam centre and beam profile measurements

Figure 5 shows the measurement results of relative response for beam profile of Co-60 machines.

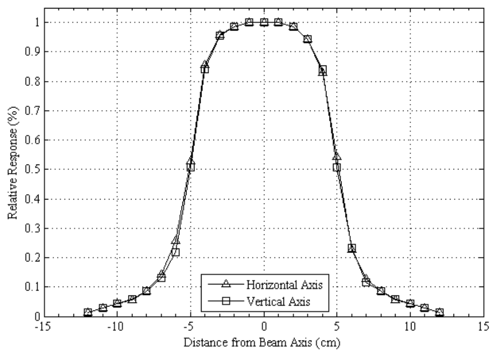

Figure 2. Horizontal and vertical profile

The beam profile was measured for the horizontal and vertical axis for calibration purposes. The field size set up was 10 x 10 cm^2. Both lines' symmetry obtained -0.93% and 1.14% for horizontal and vertical, respectively. The value was still in the acceptable range of 3% deviation symmetry. The beam center was defined by the reference value to normalize the relative response. Based on the measurement results, the center of the beam located at zero points.

Output variation due to source movement

Output variation measurements were done using an electrometer timer (for the first measurement) and a machine timer (for the second measurement). The average readings were 3.883 nC and 3.839 for the first and second measurements. The standard deviation was obtained for the first measurement was 0.0007, meanwhile for the second measurement was

p ISSN 1907-0322
e ISSN 2527-6433

0.013. There was a difference between the results more than a factor of two. It should be introduced to random effect measurements due to source positioning.

Air kerma rate and absorbed dose rate measurements

The air Kerma rate measurement has been done using an ionization chamber with a building cap. The air Kerma rate was 230.15 µGy/min at a distance of 1 m. There was a -0.3% deviation between the measurement result and the value of the air Kerma rate decay. In contrast, the measurement of absorbed dose rate to water obtained 211.08 mGy/min at the source to surface distance (SSD) 100 cm and depth 5 cm. The deviation between measurement and decay value was -0.8%. Both measurements were lie in the acceptable range for the stability of output rate.

Decays and stability of Co-60 source

The decays of the Co-60 output rate were obtained at the excellent agreement. The stabilization of the output rate was also maintained at under 1%. However, some data shows the stabilization percentage differs up to 0.4 % maximum by comparing to the reference value.

Application on calibration dosimeter

Forty-four dosimeters were calibrated using this reusable Co-60 machine in 2020. The dosimeters consist of a reference standard detector class (0.6 cm^3 and 0.35 cm^3 ionization chamber) and scanning detectors (0.125 cm^3 and 0.13 cm^3 ionization chamber). The calibration results are appropriate. It shows a deviation of below ±1% compared to the previous calibration factor.

Compared to previous calibration results, the data package shows that each detector calibration factor is tracked from 2017 to 2020. The data is the same detector and is tracked to previous years. Twenty-three units were traced from 2017, and 21 units were traced from 2018. This is shown in Figure 7. The four-year comparison shows good agreement within the 1% limit.Figure 6 shows a few calibration results using the Co-60 machine in 2020 after replacement.

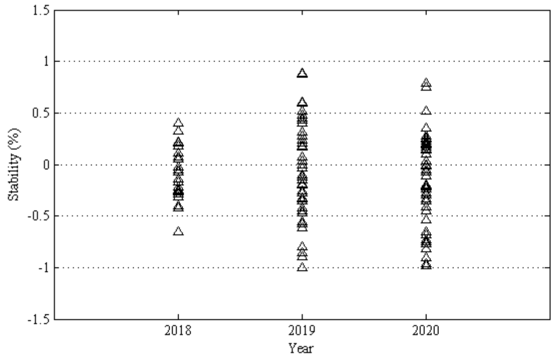

Figure 3. Comparison of calibration results stability at periods of 2017 – 2020

Uncertainty

In the uncertainty estimation of the calibration dosimeter, the Co-60 machine is one of the components which influence the measurement. The uncertainty from the reusable Co-60 machine was the source position and timer error. For the calibration purpose, the uncertainty of source position should be added as a component in calculating uncertainty estimation. Meanwhile, the timer error uncertainty is negligible for calibration purposes. However, the error timer uncertainty should be added if dose irradiation (for example, for audit dose purpose or calibration film). The uncertainty of source position was categorized as type A uncertainty because it was from series of measurements within 20 data of output source. The source position uncertainty value was 0.02 % with 68% confidence level and coverage factor by 1 (k = 1).

DISCUSSION

Based on the decay calculation, this reusable source's activity was monitored at 51.4 TBq on Dec 07, 2020. It fulfills the calibration source requirements, which stated should have activity between 20 TBq – 40 TBq.

The calibration facilities for the therapy level need the collimator to set up the field size by 10 cm x 10 cm. In the machine's original shape, the collimator is operated by a motor and controlled using the software. In contrast, the collimator has been modified to manual control by using a mechanic gear. It because the central part of electricity has been out of reoperation again. It will not be a problem since the collimator's primary purpose is to provide the field size in a specific size.

p ISSN 1907-0322
e ISSN 2527-6433

This machine controlled the source using movement from storage (beam-off position) to irradiation condition (beam-on position) instead of applying a beam shutter. The use of source movement introduced a few factors that should be evaluated. For this study, the timer error and output variation due to source movement had been calculated. The timer error measurement results show there are delays of up to three seconds between the start and irradiation beam-on. For the delivery dose purpose, the irradiation must be corrected with timer error or would give the inaccurate delivery dose. Based on the reference [14], the correction of timer error will give an impact to reduce the uncertainty up to a factor of 7.5. In contrast, the timer error can be negligible for the calibration purpose because the calibration methods do not need a specific dose.

The two measurement method's standard deviation shows half of its value difference based on output variation measurements. It is unlikely due to random measurement error, but the irradiation mode's source position can be the main reason. The age of the machines has been more than 14-years old of operation. Using the source movement method since early installation, it is normal if there is some lack of irradiation source position. By the results of standard deviation comparison, it can be concluded that the difference between one minute of the electrometer and machine timer should be corrected. The correction can be added to the uncertainty calculation.

The beam center and beam profile were determined by relative response measurements in reference condition of field size. The field size was analyzed just for size 10 cm x 10 cm. Currently, the protocol for calibration of therapy level is still provided in the reference field size. It is also for the calibration of small field detectors. The beam profile's symmetry was obtained in the acceptable range (± 3 %). It also provides that the collimator's modification has successfully given the excellent shape of field size.

The dose rate of air Kerma and absorbed dose to water were essential parameters to analyze. IAEA recommended a recommendation for the minimum dose rate, which was 100 mGy/minute. The air Kerma rate and absorbed dose rate to water were obtained value by 230. 15 µGy/min and 211.08 mGy/min, respectively. These measurements were conducted on December 7th, 2020. The dose rate of the Co-60 machine will influence the detector response. There is a detector which has characteristic on dose rate dependence. In normal circumstances, these Co-60 machines should be replaced after one time of decays because the dose rate would be half of its value. By decays calculation, at the early of January 2026, the dose rate would be around 118.0 µGy/min and 107.3 mGy/min for air Kerma and absorbed dose to water, respectively.

Many parameters should check for the quality assurance of the Co-60 machine used for patient treatment [15],[16]. However, for the gamma-ray calibration facilities, the stability check for decays of dose rate and output rate was a good quality assurance option. The stability should be maintained within the limit of 1%. If there is an overestimation of stability results, it should be re-check for the equipment of measurements and the Co-60 machine. The possibility of the measurement device can be an error due to broken. In the previous experience of stability check on Co-60 machines, there was an overestimation of over 1% of output rate. The main reason was the change in the machine's position, and it moved from the origin position since installed in the laboratory. On the other hand, a reference stated that the maximum deviation between the output could be tolerance up to 2% [17].

Figure 8 shows the results of comparison within four years of calibration results. The comparison's primary purpose was to provide that the calibration results using the new reusable Co-60 machines still get a good agreement within an acceptable range, likely the previous year using the old calibrator machine. However, in Figure 8, the trends of deviation values in 2019 and 2020 were more extensive than in 2018. In 2018, the deviation values were spread between -0.66% and 0.40%. In contrast, in 2019, the values lie between 0.88% and -1.00%, and for the years of 2020, the values lie between 0.79% and -0.99%.

A few possible factors can be caused: the dose rate of Co-60 has been lower and the use of the correction factor from IAEA (k_{2019}). The use of k_{2019} makes a difference up to 1%. IAEA's recommendation for the dose rate was a minimum of 100 mGy/minutes. In the calibration of reference class dosimeter, i.e., farmer chamber of a 0.6 cm3, plane-parallel chamber of 0.35 cm3, the calibration results usually are still under a 0.5% deviation. The reference class ionization

p ISSN 1907-0322
e ISSN 2527-6433

chamber has a large volume due to maximum performance to read the ionization.

Those parameters have been evaluated due to standardization of characterization gamma-ray facilities after source replacement. In the future, the development of the SSDL Jakarta would reach in the radiation therapy verification [1],[18] and establish a new method of calibration in the small field dosimetry. The small field dosimetry still has many problems to solve [19]. On the other hand, the use of reusable Co-60 machines was giving a great benefit to the country because it can save much funding rather than provide a new source.

CONCLUSION

The possibility to use a reusable Co-machine after from radiotherapy facilities is now available. For the country which is considered as middle-low economic income, this option has a great benefit. However, the maintenance in quality assurance should be done frequently, daily, or weekly to ensure the quality of Co-60. The laboratory should participate in the intercomparison simultaneously to ensure the quality in terms of yearly and under the supervisor of higher laboratory level (PSDL).

ACKNOWLEDGEMENT

The author acknowledges the management and the Secondary Standard Dosimetry Laboratory staff as a part of the Center of Radiation Safety Technology and Metrology for the support due to this paper project.

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p ISSN 1907-0322
e ISSN 2527-6433