Journal of Physics and Its Applications

Journal homepage : https://ejournal2.undip.ac.id/index.php/jpa/index

Verification of Co-60 Source in Brachytherapy Equipment Using TW33005 Well-Type Chamber

Junita Hemelia[1*], Pratiwi Sri Wardani[1], Sahara Hamas Intifadhah[2], Ahmad Zarkasi[3], and Devina Rayzy Perwitasari S.P[1]

[1]Medical Physics, Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Mulawarman, Samarinda, Indonesia
[2]Material Physics, Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Mulawarman, Samarinda, Indonesia
[3]Electronics and Instrumentation, Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Mulawarman, Samarinda, Indonesia

**Corresponding author: junitahemeliia@gmail.com*

ARTICLE INFO

Article history:
Received: 5 August 2024
Accepted: 19 November 2024
Available online: 30 November 2024

Keywords:
Accuracy
Brachytherapy
Stability
Well-Type Chamber

ABSTRACT

Accidents in brachytherapy have occurred and are documented by the IAEA. These incidents are attributed to various factors, such as inaccurate sources, lack of independent verification, and equipment failures due to inadequate calibration. Verifying radioactive sources is crucial for ensuring patient safety. Verification is conducted to confirm that the measured source activity is accurate and stable. Accuracy and stability of source activity are two essential parameters in verification. Source activity accuracy indicates how closely the measured source activity aligns with the reference source activity, while source activity stability reflects the well-type chamber's ability to produce consistent results over time. This study aimed to verify the Co-60 sources at Dr. Kanujoso Djatiwibowo General Hospital using a TW33005 well-type chamber and analyze the results against national and international standards. The results showed that the Co-60 source activity values remained accurate and stable over five months. The highest accuracy was observed in November 2023 (-2.011%), while the lowest was in October 2023 (-2.397%). The highest stability was recorded in September 2023 (-0.416%), and the lowest in October 2023 (-2.090%). In conclusion, the Co-60 sources at Dr. Kanujoso Djatiwibowo General Hospital met the accuracy standards set by ESTRO and BAPETEN of 3% to 5% and the stability standard set by the IAEA of ±3%. This indicates that the sources are safe for use in brachytherapy.

1. Introduction

The International Atomic Energy Agency (IAEA) states that radiotherapy or radiation therapy is one of the primary types of cancer treatment, which utilizes ionizing radiation to destroy cancer cells and limit cell growth. The ionizing radiation in question includes gamma radiation, such as Cobalt 60 (Co-60), Iridium 192 (Ir-192), Cesium 137 (Cs-137), as well as photon and electron radiation from Linear Accelerators (LINAC). Radiotherapy treatment is further divided into external beam radiation and brachytherapy [1]. In 1999, the International Atomic Energy Agency (IAEA) recorded 32 accidents in brachytherapy treatments, 7 of which were related to sources with incorrect strength, 6 cases were due to the lack of independent verification of source strength, and 4 were due to equipment failure caused by a lack of calibration. This highlights the importance of independent verification by medical physicists to ensure patient safety in the use of brachytherapy sources. One of the requirements for obtaining an operating permit is that the brachytherapy device sources must be verified before being used for patient therapy. The purpose of this source verification is to obtain the correct radiation dose [2].

Radiation is energy emitted from within an atom that can be in the form of particles or waves. Particle radiation is radiation that originates from particles such as alpha and beta particles. Electromagnetic wave radiation like gamma rays, X-rays, and others is radiation that has no mass or charge [3]. Gamma rays are electromagnetic radiation or photons that have the ability to penetrate matter. The penetration depth of gamma rays in a material depends on the photon energy and the type of material being penetrated. In the medical field, Co-60 is utilized as a source of gamma rays for radiation therapy due to its high penetration properties [4].

Co-60 and Ir-192 are radioisotopes recommended by the International Commission on Radiation Units (ICRU) 89 for High Dose Rate (HDR) brachytherapy due to Co-60's advantage of a long half-life of 5.27 years. Researchers have been increasingly studying the physical properties and dosimetric parameters of Co-60. However, the higher average energy of Co-60 at 1.25 MeV compared to Ir-192 at 0.38 MeV raises concerns regarding efficacy, increased toxic reactions, and radiation safety challenges. Although Ir-192 has a half-life of 74 days, aspects such as human resources, logistics, and costs make it less economical, especially for developing countries [5].

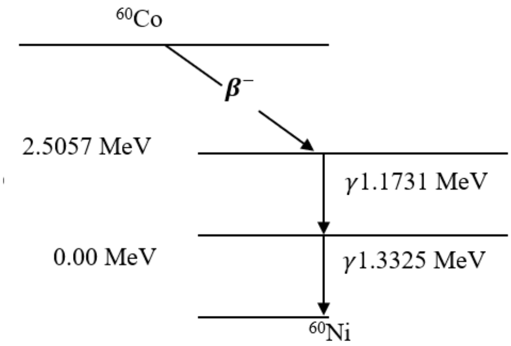

Fig. 1: The decay process of Co-60 emits two gamma rays with energies of 1.17 MeV and 1.33 MeV, respectively, transforming into Ni-60 accompanied by the emission of a beta particle with an energy of 0.31 MeV [6]

Well-type chambers are an ideal choice for calibrating brachytherapy sources. Their tube-like design allows for the accurate placement of radiation sources. This advantage makes them the perfect tool for measuring the radiation dose received by patients and calibrating Co-60 brachytherapy radiation sources. The calibration process involves placing the radiation source at a specific depth within the well-type chamber, aimed at producing a maximum response in the detector and determining the source activity [7].

Measurement of High Dose Rate (HDR) brachytherapy source strength is a crucial step to ensure the safety and efficacy of therapy. It is recommended to be performed by clinically qualified medical physicists and used as a reference input for the afterloader treatment console and Treatment Planning System (TPS). This is done to ensure the accuracy of source activity and consistency of measurements, and to comply with national or international practice codes. Specifically, measurement of the source strength of each HDR brachytherapy source is mandatory before clinical use. This is to ensure that patients receive the correct and safe radiation dose during therapy [8].

A researcher [9] once evaluated the accuracy of source activity from the radiation dose in HDR brachytherapy cancer patients at Nams BIR Hospital using a well-type chamber on Ir-192 sources. The results showed a deviation of -2.088% between the measured source strength and the source strength provided by the manufacturer. Then, other researchers [10] have measured measured the dose rate of a Co-60 HDR brachytherapy unit using a well-type chamber of their own design. The results showed that the well-type chamber was effective in measuring the dose rate with a deviation of 3-4% compared to the treatment planning system.

This study was conducted to verify the Co-60 source in a brachytherapy device using a TW33005 well-type chamber, by calculating the accuracy and stability of the Co-60 source activity measured using the well-type chamber through monthly QA for five months (August to December 2023), and analyzing the compliance of the verification results with national (BAPETEN) and international (IAEA & ESTRO) standards.

2. Materials and Method

This research is quantitative descriptive. The research data used is documentation of monthly QA results data (five months) which have been carried out on a brachytherapy device type TW33005 with a Co-60 source using a well-type chamber type TW33005. The equipment and materials that support the monthly QA implementation of the brachytherapy device at RSUD Dr. Kanujoso Djatiwibowo Balikpapan, thus producing the secondary data used, are the brachytherapy device, electrometer, and TW33005 type well-type chamber.

Fig. 2: Brachyhtherapy afterloading HDR

Fig. 3: Well-Type Chamber type TW33005

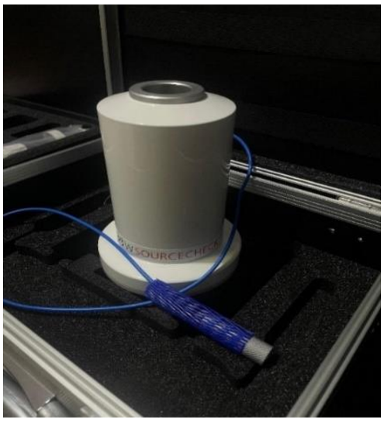

Fig. 4: Electrometer

Verification is a crucial step in ensuring the reliability and validity of test results. This process is conducted to reconfirm that the analytical methods or procedures used have met the requirements and produced valid data. The benefits of verification include assessing the quality, reliability, and consistency of results, as well as increasing confidence in measurement results and meeting standards [11]. The data analysis technique used is quantitative by calculating the accuracy and stability values of source activities based on the data that has been collected and then analyzed descriptively.

Accuracy is determined by comparing the source activity calculated by the medical physicist with the source activity stated by the supplier using a calibration standard traceable to national or international standards. The accuracy of the source activity is expressed as a percentage deviation from the actual activity and must be measured for all radionuclides to be used routinely [12]. Radioactive activity represents the number of decays that occur per second. The magnitude of activity does not depend on the type of radiation emitted or the energy of the radiation produced, but is only influenced by the number of atomic nuclei that decay per unit time [13].

$$\text{Accuracy} = \frac{A_t - A}{A} \times 100\% \tag{1}$$

Annotations:
A_t = Measured source activity ($\text{mGy} \times \text{m}^2/\text{h}$)
A = References source activity ($\text{mGy} \times \text{m}^2/\text{h}$) [14].

where, the measured activity can be calculated using the equation:

$$A_t = N_w \times \left(\frac{M_u}{t}\right) \times K(pT) \tag{2}$$

Annotations:
N_w = Calibration Factor ($\text{Gy} \times \text{m}^2/\text{ h A}$)
Mu/t = Measured electric current read on the electrometer (nA)
$K\ (pT)$ = Air density correction factor [15].

The activity of a nuclide can follow the equation:

$$A = A_0 e^{-kt} \tag{3}$$

Where is,

$$A_t = \frac{\ln\ 2}{T_{\frac{1}{2}}} \tag{4}$$

$\ln 2 = 0.693$

Annotations:
A_0 = Initial source activity
t = Decay time
$T_{\frac{1}{2}}$ = Half-life
λ = Decay constant [13].

Measurements using a well-type chamber are influenced by external factors such as temperature and pressure. The correction factors for room temperature and pressure are calculated using the following equation:

$$K(pT) = \frac{273.15 + T}{237.15 + T_0} \times \frac{P_0}{P} \tag{5}$$

Annotations:
$K(pT)$ = Air density correction factor
T = Air temperature (°C)
T_0 = Reference air temperature (°C)
P = Air pressure (Pa)
P_0 = Reference air pressure (Pa)
237.15 = Kelvin conversion value [16].

According to the Indonesian Nuclear Regulatory Agency (BAPETEN), brachytherapy mechanical tests include activity measurement/calibration, and this measurement ensures that the activity of the radioactive source used is within a tolerance of 5% of the reference value [17]. Meanwhile, the International organization, European Society for Radiotherapy and Oncology (ESTRO), states that accurate calibration measurements can be compared to certified source strength values with a deviation limit of 3% to 5% [18].

A reliable measuring instrument not only indicates the accuracy of the source activity but also stability when used to perform measurements under the same conditions. Stability (also called reproducibility) of a measuring instrument involves measurements taken on two occasions separated by different time intervals [19]. Stability is one of the important aspects of the reliability of a measuring instrument, indicating its ability to produce trustworthy results over time [20].

Stability can be assessed by performing repeated measurements on the same source [12]. To ensure the reliability of measurements, the well-type chamber must be verified periodically to calculate stability using the equation:

$$\text{Stability} = \frac{A_{t,i+1} - A_{t,i}}{A_{t,i}} \times 100\% \tag{6}$$

Annotations:
i = 1st month, 2nd, 3rd, ..., etc. [21]

In TECDOC 1274, the IAEA states that stability checks are usually performed by irradiating a well-type chamber, then comparing the output on the day of measurement to the output on the previous measurement to ensure that there are no significant changes. The results obtained from the measurement must first be corrected to the reference temperature and pressure, which are 20.0°C for temperature and 101.325 kPa for pressure. After correction, the reading should be within a range of ±3% to be considered stable [8]

3. Results and Discussion

In this study, Co-60 has a half-life of 5.27 years or 1925.2 days, which is required to decay to half of the initial source activity of 24.57. The reference source activity can be calculated using Equation 3, while the measured source activity can be calculated using Equation 2.

Table 1: Results of calculating the air density correction factor

Month	Temperature		Pressure		$K(pT)$
	T_o(K)	T(K)	P_o(Pa)	P(Pa)	
August	293.15	292.55	101.325	100,007	1,011
September		292.25		100,009	1,010
October		292.55		100,007	1,011
November		293.75		100,009	1,015
December		293.05		100,007	1,013

The deviation of the measured source activity value from the reference source activity is calculated in percentage to state the accuracy of the source using Equation 1. The accuracy results can be seen in Table 2.

Table 2: The results of calculating the accuracy of source activities (%)

Month	A_t (mGy × m²/h)	A (mGy × m²/h)	Accuracy (%)
August	21.708	22.175	-2.107
September	21.617	22.063	-2.021
October	21.166	21.685	-2.397
November	21.028	21.460	-2.011
December	20.775	21.230	-2.142

The radiation originating from Co-60 interacts with the material of the TW33005 well-type chamber through various processes, one of which is the ionization process that produces positive and negative ions. The change in conductivity due to ionization triggers the formation of an electric current. The magnitude of this electric current is the output of the TW33005 well-type chamber [7]. The generated signal is passed through a voltage regulated by an electrometer, in this case, a voltage of 400 V is applied. This 400 V voltage will convert the signal into a measurable form, representing the obtained information and producing data in the form of a measurable current output.

The accuracy of the source activity indicates how close the measured source activity is to the reference source activity, and can be calculated through the percentage deviation. Therefore, the smaller the deviation between the measured source activity and the reference source activity, the smaller the percentage accuracy of the source activity, and thus the more accurate the result. The accuracy of the source activity can be influenced by the time interval of the monthly QA, which affects the magnitude of the deviation of the source activity, as well as the ambient temperature and air pressure, which vary over time.

The highest source activity accuracy occurred in September at -2.021% with a difference of 0.446 and in November at -2.011% with a difference of 0.432. The lowest source activity accuracy occurred in October, where the measured source activity value had a difference of 0.520, equivalent to -2.397% of the reference source activity.

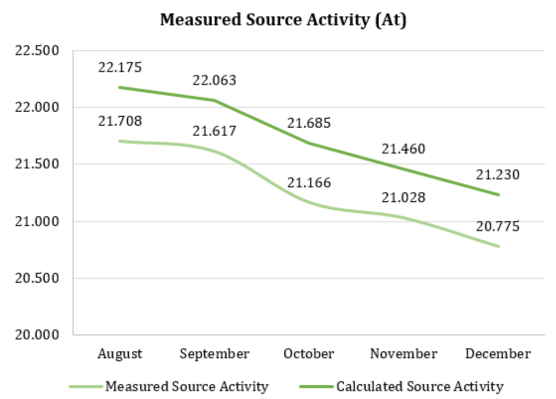

Fig. 5: Comparison of the decline in reference source activity with measured source activity over five months

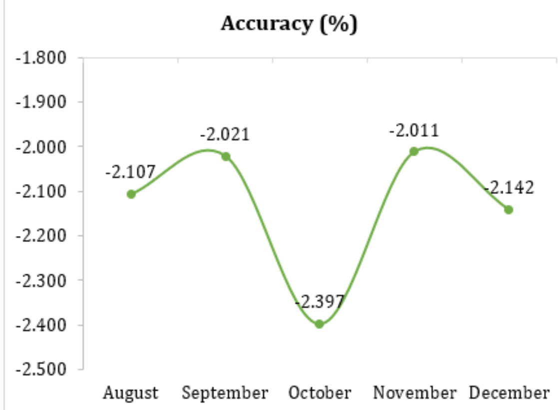

Fig. 6: Accuracy graph of source activity from well-type chamber response for five months

Comparing the measured source activity at the time of QA implementation with the previously measured source activity corrected for temperature and pressure is one of the objectives of verification, namely to ensure that the decay of Co-60 activity at that time shows stable results. Stability calculations can be performed using Equation 6, and the results can be seen in Table 3.

Table 3: Results of source activity stability calculations (%)

Month (i)	A_t (mGy × m²/h)	Stability (%)
August	21.708	
September	21.617	-0.416
October	21.166	-2.090
November	21.028	-0.648
December	20.775	-1.205

Stability indicates how stable the measured source activity is through repeated measurements on different days under the same measurement conditions. Considering the QA implementation range, the measurement in December occurred 30 days after November, which is an appropriate time interval. However, the smallest percentage indicates the most stable value over the five months. Therefore, Figure 4 shows the stability of the measured source activity over five months.

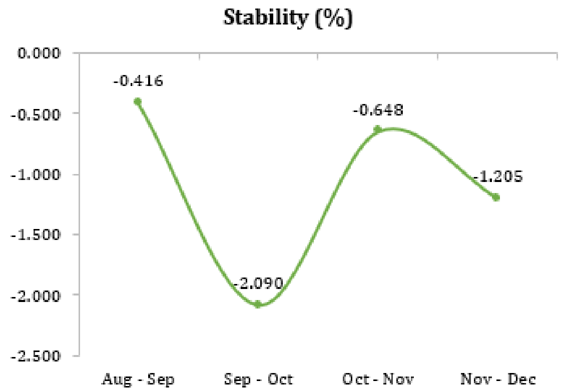

Fig. 7: Graph of source activity stability from well-type chamber response for five months

The comparison of the measured source activity values in August and September is 0.090 $mGy \times m^2/h$, which is equivalent to -0.416%. The comparison of the measured source activity value in September with October is 0.452 $mGy \times m^2/h$, which is equivalent to -2.090%. The comparison of activity values in October with November is 0.137 $mGy \times m^2/h$, which is equivalent to -0.648%. The comparison of the measured source activity value in November with December is 0.253 $mGy \times m^2/h$, which is equivalent to -1.201%.

4. Conclusions

Routine verification of the Co-60 source for brachytherapy devices was carried out during the last five months of 2023 using a well-type chamber. The resulting Co-60 source activity values were accurate and stable for five months. The verification results regarding the accuracy and stability of activity sources from August to December 2023 are considered accurate and stable because they are always within the 3% to 5% tolerance limit determined by ESTRO and BAPETEN, as well as their stability. tolerance limit of ±3% determined by the IAEA.

Acknowledgments

The authors of this research article would like to express their sincere gratitude to Nunung Choerus Sya'adah and the medical physics staff at RSUD Dr. Kanujoso Djatiwibowo Balikpapan for their contribution to the measurement of Co-60 source activity over the past five months of 2023.

References

[1] E. D. Martadiani, P. P. Y. S. Anandasari, & D. G. Maiswara, "Buku Panduan Belajar Dokter Muda: Radiologi" Penerbit Lontar Mediatama, Yogyakarta, (2020).

[2] I. Shobari, P. I. Masbatin, M. H. Amin, & Triyanto, "Perekayasaan Modul Kontrol Pemindai 1D Untuk Kalibrasi Perangkat Brakhiterapi" Prima, 17(2), 2–12, (2020).

[3] A. Zubaidah & Ruslan, "Nuclear Smart Book" Batan Press, Jakarta, (2016).

[4] Z. Abidin, "Nuclear and its Applications" BRIN Nuclear Polytechnic, Yogyakarta, (2022).

[5] A. Wen, X. Wang, B. Wang, C. Yan, J. Luo, P. Wang, & J. Li, "Comparative Analysis of 60Co and 192Ir Sources in High Dose Rate Brachytherapy for Cervical Cancer" Cancers, 14(19), 1–16, (2022).

[6] I. M. Sukarna, "Radiochemistry: Discovery of Radioactivity and Nuclear Stability" Open University, Jakarta, (2014).

[7] R. Fardela, R. Analia, A. Maulida, R. S. Ramda, F. Diyona, & D. Mardiansyah, "Verification of HDR Ir-192 Brachytherapy Source Using a Well Type Chamber Ionization Detector at Andalas University Hospital" Scientific Journal of Physics FMIPA Lambung Mangkurat University, 20(2), 2541–1713, (2023).

[8] IAEA, "IAEA-TECDOC-1274 Calibration of Photon and Beta Ray Sources Used in Brachytherapy" IAEA, Austria, (2002).

[9] K. P. Adhikari, A. Shah, B. Achraya, A. Karn, & S. Chapagain, "Acceptance Testing, Commissioning And Quality Assurance For A Nucletron 192Ir HDR Brachytherapy Afterloader At Nams, Bir Hospital" Scientific World, 12(12), 85-88, (2019).

[10] A. Rohmat, G. Maslebu, A. Setiawan, Muhtarom, & M. I. M. Arrozaqi, "Dose Rate Analysis of HDR Cobalt (Co-60) Afterloading Brachytherapy Unit Using Well Type Chamber Measurement Method" Journal of Xi'an University of Architecture & Technology, 12(3), 5354-5361, (2020).

[11] Riyanto, "Validation and Verification of test methods" Deepublish, Yogyakarta, (2016).

[12] D. L. Bailey, J. L. Humm, A. Todd-Pokropek, & A. V. Aswegen, "Nuclear medicine Physics: A Handbook for Teachers and Students" IAEA, Austria, (2014).

[13] M. Aziz, E. Hidayanto, & D. D. Lestari, "Determination of 60Co and 137Cs Activity in Unknown Samples Using an HPGe Detector" Youngster Physics Journal, 4(2), 189–196, (2015).

[14] D. T. Genç, L. Poyraz, B. Kovan, & C. Türkmen, "Quality control tests of dose calibrators used in nuclear medicine" Demiroğlu Bilim University Florence Nightingale Journal of Medicine, 5(1), 8–14, (2019).

[15] IAEA, "IAEA-TECDOC-1079 Calibration of Brachytherapy Source" IAEA, Austria, (1999).

[16] A. F. Firmansyah, O. A. Firmansyah, S. I. Sunaryati, & N. Rajagukguk, "Evaluation of Well-Type Chamber Calibration Factor for Measurement of Ir-192 Brachytherapy Source Over 10 Institutions" Jurnal Fisika dan Aplikasinya, 16(2), 95, (2020).

[17] BAPETEN, "Radiotherapy Licensing Handbook" BAPETEN, Jakarta, (2019).

[18] J. Venselaar, & J. Pérez-Calatayud, "A Practical Guide to Quality Control of Brachytherapy Equipment: ESTRO Booklet No. 8" ESTRO, Brussels, (2004).

[19] S. Polgar & S. A. Thomas, "Introduction to Research in the Health Sciences" Churchill Livingstone/Harcourt Publishers Ltd., London, (2000).

[20] S. M. Brookhart & A. J. Nitko, A. J, "Educational assessment of students" Pearson, London, (2018).

[21] C. M. Karaca, D. T. Genç, H. Kovan, M. Mulazımoğlu, & B. Demir, "Comparative Assesment of Dose Calibrators Used in Nuclear Medicine" Middle East Journal of Science, 6(2), 44–56, (2020).