Jurnal Ilmu Fisika
Vol. 16, No. 1, March 2024, pp. 46–54
ISSN: 1979-4657 (Print); 2614-7386 (Online)
https://doi.org/ 10.25077/jif.16.1.46-54.2024

Jurnal Ilmu Fisika
Open Access

Quality Control Analysis of Linear Accelerator Radiotherapy Device in the Department of Radiotherapy at Pasar Minggu District Hospital

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Article Info

Article History:

Received March 02, 2023
Revised October 01, 2023
Accepted October 12, 2023
Published online November 11, 2023

Keywords:

Linear Accelerator
Quality Control
Radiotherapy
Pasar Minggu District Hospital

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ABSTRACT

Radiation accidents pose a significant risk, often stemming from inadequate calibration of radiation output, procedural lapses, and faults in radiation monitoring systems. Addressing these risks is pivotal, particularly in radiotherapy, where the precise functioning of linear accelerator (Linac) devices is crucial. This study delves into the quality control procedures applied to the Linac radiotherapy device within the Department of Radiotherapy at Pasar Minggu District Hospital. Drawing upon the renowned reference standards set by the AAPM Task Group 142 and BAPETEN Regulation No. K2N.2/MT-08, this research, conducted in November 2022, rigorously evaluated the mechanical, dosimetry, and safety aspects of the Linac device. The examination encompassed critical elements, including gantry angles, optical distance indicators, laser precision, collimator angles, light field size, and photon and electron beam outputs. Safety features such as door interlocks, audiovisual indicators, and radiation alert systems were scrutinized. The analysis reveals a reassuring finding: the Linac device at Pasar Minggu District Hospital adheres commendably to tolerance limits specified by reference standards across all measured parameters, indicating robust performance in mechanics, dosimetry, and safety. This meticulous quality control regimen has proven highly effective in ensuring the device's operational integrity and safety, affirming its reliability for precise radiotherapy treatments.

1. INTRODUCTION

Radiotherapy is a radiation therapy used to treat malignant and some benign tumors (Shirzadfar & Khanahmadi, 2018; Torres Royo et al., 2020). Radiotherapy can be used for curative and palliative treatment.(Fitriatuzzakiyyah et al., 2017; Gianfaldoni et al., 2017; Hariyanto & Munandar, 2020; Smith & Smith, 2014) Radiotherapy must prioritize quality services with interdisciplinary integration. Rapid development is in line with science and technology, occupational health and safety, including radiation safety aspects for patients, staff, and the environment (Fiorino et al., 2020).

The first medical use of the linear accelerator (Linac) was in 1953 at Hammersmith's Hospital in London (Dyk et al., 2020). The Linac is most commonly used in cancer radiation therapy, where it

delivers precise doses of radiation to tumors and cancer cells. Linac accelerate electron in a linear motion to produce a beam of electrons or photons. The electron beams are used to irradiate tumors that are on the surface while the photon beams are used to irradiate tumors far below the surface (Asrisal et al., 2015; Dian et al., 2018; Winarno et al., 2021). Complete radiotherapy equipment is very useful and provides hope for survival for cancer patients.

According to the International Atomic Energy Agency (IAEA) and BAPETEN, radiation accidents generally result from poorly managed radiation use (Wurdiyanto & Trijoko, 2004). Failure to strictly enforce the relevant rules and regulations can lead to severe accidents. Radiation facilities must prioritize quality assurance programmes to uphold safety and excellence. The Radiotherapy Department relies on stringent quality control measures to facilitate the radiotherapy service process. In addition, it serves as a benchmark for evaluating quality improvement initiatives, ensuring the precision and accuracy of results. This commitment to quality control in radiotherapy encompasses all procedures necessary to safeguard patient health, adhere to established safety protocols and standards, and strive for continuous quality improvement of services (Abdel-Wahab et al., 2017).

Conducting daily checks on the Linac radiotherapy device is imperative for quality control, ensuring the stability of predefined parameters, preventing any potential impact on patient dosage. Monthly assessments focus on parameters with minor variations, given their subtle changes over a month (Djuita et al., 2011). Simultaneously, annual quality control involves a comprehensive device test, comparing a year's worth of dose measurements to assess the device's consistency. Emphasizing the significance of meticulous record-keeping, the recording of all daily, monthly, and yearly quality control activities is essential for thorough documentation and proper management (Suharmono et al., 2020).

The Radiotherapy Department implements regular and permanent quality control accordance with established procedures. The Linac radiotherapy device's quality assurance program encompasses three components: dosimetry, mechanical, and radiation safety aspects. These components undergo periodic assessments, including daily, monthly, and yearly checks. Daily quality control for the Linac radiotherapy device is performed 30 minutes prior clinical execution, aligning with the commencement of each day's clinical service. Monthly quality control is conducted outside clinical service hours, within a range of 28-30 calendar days. Annual quality control for Linac devices performed outside clinical service hours. Records of quality control implementation are meticulously kept for future reference.

The Linac radiotherapy device's comprehensive quality assurance program consists of three key test parameters: dosimetry, mechanical, and radiation safety aspects. The mechanical aspect of quality control involves inspecting engines and functions on radiotherapy devices, specifically evaluating geometric accuracy. In the dosimetric aspect, the aim is to assess the Linac radiotherapy plane's condition to ensure that the emitted beam aligns with the patient's needs (Dian et al., 2018). Dose measurement on radiotherapy shall be carried out appropriately and according to standards. Dose measurements on radiotherapy are conducted meticulously and in adherence to standards, with dose calculations following the Technical Report Series (TRS) 398 protocol issued by the IAEA in 2000 (Ataalla et al., 2021). Safety aspects undergo quality control to verify the proper functioning of safety equipment, emphasizing the overall commitment to ensuring a secure environment.

American Association of Physicists in Medicine (AAPM) Task Group 142 provides important guidance on the quality control of Linac radiotherapy devices, which was developed based on parameters from the previous AAPM task group 40 report. These quality control parameters have been fine-tuned to accommodate advances in techniques such as Intensity Modulated Radiotherapy (IMRT) and Stereotactic Radio Surgery (SRS). Robust management systems and quality assurance programmes are essential to ensure the achievement of high standards. Indonesia's own 2018 BAPETEN Guidelines for Cobalt-60 and Linac radiotherapy equipment serve as an important reference for Radiotherapy Departments, especially for medical physicists, facilitating effective quality control measures to ensure optimal functioning of radiotherapy equipment and minimising the risk of errors in both organisational and service activities.

Indonesia already has legal protection for radiotherapy services as in the Regulation of the leader of BAPETEN number 3 of 2013 concerning radiation safety in the use of radiotherapy. Additionally, in

the Decree of Ka. Bapeten no. 21/Ka. BAPETEN/XII-02 concerning the quality assurance program in the Department of Radiotherapy, safety aspects regarding the use and utilization of radiotherapy devices are addressed. To guarantee the accuracy of the radiation dose administered, a series of tests based on AAPM TG 142 guidelines and BAPETEN Technical Guidelines No.K2N.2/MT-08 concerning Radiotherapy Equipment Quality Control Guidelines for Cobalt-60 and Linac are essential (Maulana & Mukhlisin, 2017). Given this context, a study is warranted to analyze the quality control of the Linac radiotherapy device applied in the Department of Radiotherapy at Pasar Minggu District Hospital.

2. METHOD

2.1 Materials

Various tools and materials employed in this study included the Varian Trilogy linac radiotherapy device, identified by the serial number 6258 and manufactured by an American company. This device is equipped with photon beam energies of 6 MV and 10 MV, as well as electron beam energies of 6 MeV, 9 MeV, 12 MeV, 15 MeV, 18 MeV, and 22 MeV. Additionally, various auxiliary tools such as the Linac consul control, lasers, millimeter blocks, water pass, front pointer assembly with optical distance indicators, radiation indicator lights, audiovisual monitors (including Closed Circuit Television - CCTV - and intercom), water phantoms, ion chambers, water tanks, thermometers, barometers, and electrometers were utilized in the study.

2.2 Instrumentation

The instruments of this study are worksheets, documentation results, and interview sheets. Worksheets served as a tool for systematically recording observations made throughout the study. Documentation results comprised photographic records capturing the tools and materials utilized in the research. Additionally, interview sheets were administered to proficient individuals, including one radiotherapist and one medical physicist with a minimum of three years of experience in the Department of Radiotherapy at Pasar Minggu District Hospital.

2.3 Research Procedure

The research method used is descriptive qualitative by outlining the process of implementing daily and monthly quality control. The research was conducted at the Department of Radiotherapy at Pasar Minggu Hospital.in November 2022. Observations were made through testing of mechanical aspects (Gantry angle, Optical Distance Indicator, Laser, Collimator angle, and Light Field Size) the dosimetric aspect (photon and electron beam output), and the safety aspect (door interlock, audiovisual and radiation indicator light).

2.3.1 Procedure for Implementing Quality Control of Linac by Mechanical Aspect

The gantry angle test is conducted to assess the precision of degree measurement during gantry rotation. This examination is performed at angles of 90º, 180º, 270º and 0º, using waterpass for verification, as illustrated in Figure 1(a) Simultaneously, the Optical Distance Indicator (ODI) test, depicted in Figure 1(b), aims to confirm the alignment between the radiation source and the target (set at 100 cm). The procedure involves setting the gantry angle at 0º, installing the front pointer assy tool and optical distance indicator. The display on the monitor indicates the compatibility of distances, ensuring accurate and consistent measurements.

Figure 2(a) illustrates the Laser testing procedure, aimed at assessing the compatibility of laser markers from different directions. Utilizing a millimeter block as a tool, this test ensures the alignment of the laser with the linac head's crosshair. The examination involves positioning the gantry at angles of 270º, 180º, and 90º to verify the accuracy of the laser markers.

Laser testing as in Figure 2 (a) is used to determine the suitability of laser markers from different directions. The test used a tool (millimeter block) to check the suitability of the laser whether it was squeezed or not with the line on the linac head (crosshair) and was carried out by positioning the gantry with angles of 270º, 180º and 90º. This includes testing mechanical aspects such as laser localization, which ensures the precision and accuracy of the laser's center position (isocenter) (Djuita et al., 2011).

Figure 1 The process of testing the quality control of mechanical aspects in the Department of Radiotherapy at Pasar Minggu District Hospital: Gantry angle testing process (a) and ODI testing process (b)**.**

Figure 2 The process of testing the quality control of mechanical in the Department of Radiotherapy at Pasar Minggu District Hospital: Laser testing (a), Collimator testing 45º C (b), Light Field Size testing 10x10 cm^2 (c).

Figure 2(b) displays the Collimator angle test, employed to ascertain the accuracy of the centration point's location during collimator rotation. Using a millimeter block, this test compares the collimator's suitability at angles of 45º and 90º, ensuring that changes in collimator angle do not impact the isocenter.

The Light Field Size testing, illustrated in Figure 2(c), is conducted to verify the accuracy of the irradiation field area. This involves setting the field size to 10x10 cm^2 and an additional 4x4 cm^2 for monthly quality control. Millimeter blocks are used to assess the suitability of the irradiation field area. A research article in the graduate bioscience journal at UNAIR describes the testing of the isocenter using millimeter block paper as a substitute for the target or radiation field area of 10 cm x 10 cm. The position of the patient table is adjusted vertically, horizontally, or longitudinally until the light field on the collimator aligns with the paper area (Suharmono et al., 2020).

2.3.2 Procedure for Implementing Quality Control of Linac by Dosimetry Aspect

Testing the output of both photon and electron beams serves to ensure their alignment with the required specifications. Daily photon beam output testing, depicted in Figure 3(a), involves using EPID with a 0º gantry at a field size of 10x10 cm^2. This test is conducted using 6 MV and 10 MV photon beam energy, with a dose rate of 600 and 200 MU (Djuita et al., 2011). The results are then analyzed to ensure conformity with the reference base of the tool. It's worth noting that daily electron beam output testing is omitted due to the infrequent use of electron therapies.

Monthly absolute electron and photon beam testing was carried out using detector IBA FC 65-G ionization chamber on water phantom with a 100 cm Source to Surface Distance (SSD). Measurements were made using a field size of 10 x10 cm^2 , covering photon energies of 6 MV and 10 MV, and electron energies of 6 MeV and 9 MeV. The tests of photon and electron beam output are shown in Figure 3(b).

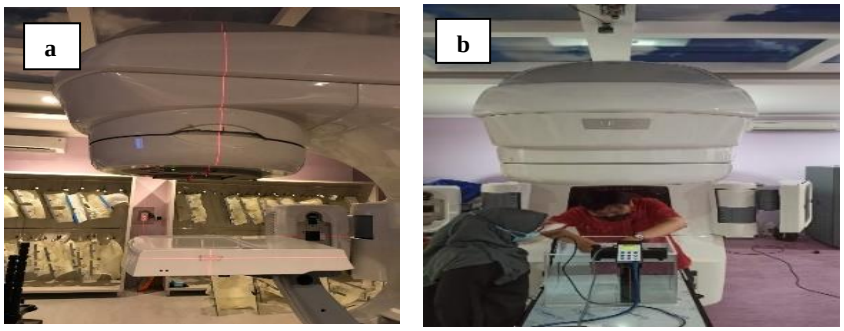

Figure 3 The process of testing output photon and electron beam in the Department of Radiotherapy at Pasar Minggu District Hospital: test uses EPID (a), and absolute output photon and electron beam testing (b).

2.3.3 Procedure for Implementing Quality Control of Linac by Safety Aspect

Door interlock testing is carried out to ensure that radiation does not escape when the irradiation door is still open. Door interlock testing is done indirectly with irradiation monitoring. Radiation indicator light testing is done to ensure that the light is on when irradiation is carried out. Audiovisual testing is used to determine whether monitoring equipment as patient monitoring is functioning properly. Audio visual testing is done by checking the function of the intercom and CCTV equipment**.**

Table 1 Results in daily quality control checks on the Linac radiotherapy device

Aspect	Test Parameters	Daily Measurement Results *		Tolerance		Result	
		Average	SD	AAPM 142	BAPE TEN	Suit able	Unsuit able
Mechanical	Gantry Angle 90° (°)	90.1°	0.01	-	-		
	Gantry Angle 180° (°)	180.1°	0.01	-	-		
	Gantry Angle 270° (°)	270.1°	0.01	-	-		
	Gantry Angle 0° (°)	0.1°	0.01	-	-		
	ODI (mm^2)	100% True		2	1-2	√	
	Laser Gantry 270° (mm^2)	0.61	0.10	2	1-2	√	
	Laser Gantry 180° (mm^2)	0.93	0.10	2	1-2	√	
	Laser Gantry 90° (mm^2)	0.68	0.10	2	1-2	√	
	Light field size (mm^2)	0.78	0.09	-	-		
	Collimator Angle 45° (mm^2)	45.1 °	0.01	1.5	1-2	√	
	Collimator Angle 90° (mm^2)	90.1 °	0.02	1.5	1-2	√	
Dosimetry	Photon Beam Output 6 MV (%)	95.5 True 4.5 False		3	2-3	√	
	Photon Beam Output 10 MV (%)	95.5 True 4.5 False		3	2-3	√	
	Electron Beam Output (%)			3	2-3		√
Safety	Door interlock	100% Function		Function	Function	√	
	Radiation Indicator Light	100% Function		Function	Function	√	
	Audio visual (Intercom, CCTV)	100% Function		Function	Function	√	

* Direct observations and secondary data for a month (November 1, 2022, to November 30, 2022)

3. RESULT AND DISCUSSION

Following the quality control tests conducted on the Linac radiotherapy device at the Department of Radiotherapy, Pasar Minggu District Hospital, the results were analyzed based on AAPM TG 142 guidelines and BAPETEN 2018 technical guidelines. Table 1 presents the outcomes of the daily radiotherapy device analysis over 22 days, utilizing SPSS for data processing. In the assessment of

mechanical aspects, gantry angle testing was performed at rotation angles of 90°, 180°, 270°, and 0°, revealing average measurements of 90.1°, 180.1°, 270.1°, and 0.1°, respectively, with a standard deviation of 0.01.

Table **2.** Results monthly quality control checks on Linac radiotherapy device.

Aspect	Test Parameters	Monthly Measurement Results *		Tolerance		Result	
		Average	SD	AAPM 142	BAPETEN	Suitable	Unsuitable
Mechanical	Gantry Angle 90° (°)	90.1	0.03	1	< 1	√	
	Gantry Angle 180° (°)	180.1	0.05	1	< 1	√	
	Gantry Angle 270° (°)	270.2	0.05	1	< 1	√	
	Gantry Angle 0° (°)	0.1	0.03	1	< 1	√	
	ODI (mm^2)	100% True		1	-	√	
	Laser Gantry 270° (mm^2)	0.8	0.14	±1	1-2	√	
	Laser Gantry 180° (mm^2)	0.4	0.24	±1	1-2	√	
	Laser Gantry 90° (mm^2)	0.6	0.47	±1	1-2	√	
	Light field size 10x10 cm^2 (mm^2)	0.5	0.29	2	1-2	√	
	Light field size 4x 4 cm^2 (mm^2)	0.3	0.24	2	1-2	√	
	Collimator Angle 45° (°)	45.2	0.05	1	< 1	√	
	Collimator Angle 90° (°)	90.1	0.04	1	< 1	√	
Dosimetry	Photon Output (absolute) 6MV (%)	0.6	0.27	2	± 1- 2	√	
	Photon Output (absolute) 10 MV (%)	0.4	0.15	2	± 1- 2	√	
	Electron Output (absolute) 6 MeV (%)	1.6	0.14	2	± 1- 2	√	
	Electron Output (absolute) 9 MeV (%)	1.8	0.34	2	± 1- 2	√	
Safety	Door interlock	100% Function		Function	-	√	
	Radiation Indicator Light	100% Function		Function	-	√	
	Audiovisual (Intercom, CCTV)	100% Function		Function	-	√	

* Direct observations and secondary data for 4 months (May, June, September, and November 2022)

The results of the irradiation field size accuracy evaluation showed an average measurement of 0.78 mm^2 for a 10x10 cm^2 field, with a standard deviation of 0.09. Similar research has been conducted by Mochtar Riady Comprehensive Cancer Center (MRCCC) Hospital in 2011, with an average irradiation field size error of 0.5 mm^2 for a 10x10 cm^2 field, with a standard deviation of 0.2 mm^2 (Djuita et al., 2011). Another study conducted by the University of Indonesia Hospital (RSUI) in 2016 obtained an average irradiation field size error of 0.6 mm^2 for a 10x10 cm^2 field, with a standard deviation of 0.1 mm^2.

In general, these results show that the accuracy of the irradiation field size of Linac radiotherapy devices in these three hospitals is relatively good. Both the gantry angle and field size tests did not have the tolerance limits specified in AAPM TG 142 and BAPETEN Technical Guideline 2018. Despite having no tolerance limit values, these tests play an important role in the quality control of Linac radiotherapy devices on a daily basis, ensuring the suitability of the gantry and irradiation field area and preventing significant shifting during patient irradiation.

In the Optical Distance Indicator (ODI) test, precise results (no shift) were obtained, with 100% accuracy at a distance of 100 cm. Laser tests performed at gantry angles of 270°, 180°, and 90°, yielded average measurements of 0.61 mm^2, 0.93 mm^2, and 0.68 mm^2, with a standard deviation of 0.10 for each gantry. These results are within the range of tolerance limits specified in the reference standards of each guideline, ranging from 1-2 mm^2.

The collimator rotation tests, which were performed at angles of 45° and 90°, commonly used angles, showed average measurements of 45.1° and 90.1°, with standard deviations of 0.01 and 0.02, respectively. The tolerance limit in each guideline's reference standard for collimator rotation is 1-2 mm^2. Therefore, the quality control of each test parameter for the daily Linac radiotherapy device is still below the tolerance limits outlined in AAPM guideline TG 142 and BAPETEN Technical Guideline 2018.

On the dosimetry aspect, the daily photon beam output parameters, as shown in Table 1 for the 6 MV and 10 MV energy levels, remained within the tolerance standards (2-3%). The frequency distribution shows an accuracy rate of 95.5% and an error rate of 4.5%, the latter attributed to a measurement reading omission, specifically on 7 November 2022. These incidents resulted in EPID problems or errors. However, the EPID was repaired by the vendor and tested the following day, and showed restored functionality. The daily electron beam output is not tested regularly due to infrequent electron irradiation actions. Instead, electron beam testing is performed monthly and whenever there is a radiation plan involving the use of electrons. In terms of safety, the results of the quality control analysis of the daily Linac radiotherapy devices confirmed that all devices were functioning properly.

In general, the results of the daily quality control inspection of Linac radiotherapy equipment at Pasar Minggu Hospital show good results. All parameters meet the tolerance limits set in the AAPM TG 142 guidelines and BAPETEN Technical Guidelines 2018. This shows that the hospital has a good and consistent quality control programme to ensure the safety and quality of radiotherapy services.

Table 2 presents the results of the monthly Linac radiotherapy device quality control analysis, focusing on the mechanical aspects. The gantry angle parameters were tested at angles of 90°, 180°, 270°, and 0°, which showed average measurements of 90.1°, 180.1°, 270.2°, and 0.1°, with standard deviations of 0.03, 0.05, 0.05, and 0.03, respectively. The tolerance limit for gantry angle accuracy in each reference standard is set at <1°.

Regarding the Optical Distance Indicator (ODI) parameter, the monthly radiotherapy device showed 100% correct results, indicating no movement, at an SSD distance of 100 cm. Laser testing for quality control of monthly Linac radiotherapy devices was performed at gantry angles of 270°, 180° and 90°. The average monthly measurements for each gantry were 0.8 mm2, 0.4 mm^2, and 0.6 mm^2, with standard deviations of 0.14, 0.24, and 0.47. The tolerance limit for laser accuracy on each reference standard was ±1-2 mm^2.

Testing the accuracy of the irradiance field size resulted in an average measurement of 0.5 mm^2 for an irradiance field size of 10x10 cm^2, with a standard deviation of 0.29. Additionally, for an irradiance field size of 4x4 cm^2, the average measurement was 0.3 mm^2, with a standard deviation of 0.24. The tolerance limit for field size accuracy for each reference standard was set at 1-2 mm^2.

The collimator rotation tests, conducted at 45° and 90° angles, showed average measurements of 45.2° and 90.1°, with standard deviations of 0.05 and 0.04. The tolerance limits for the accuracy of the collimator rotation at 45° and 90° angles within each reference standard were set at 1-2 mm^2. Therefore, the results show that in the mechanical aspects which include the gantry angle test, ODI, laser, collimator rotation, and field size accuracy, the quality control of the monthly Linac radiotherapy device is appropriate and does not exceed the tolerance limits outlined in both the AAPM TG 142 guidelines and the BAPETEN Technical Guidelines 2018.

In the dosimetric aspect of monthly Linac radiotherapy device quality control, focusing on the monthly photon beam output parameters as detailed in Table 2, the average measurement for the 6 MV energy photon beam output was 0.6% with a standard deviation of 0.27. Similarly, the average output for the 10 MV energy photon beam is 0.4% with a standard deviation of 0.15. For the electron beam output at 6 MeV energy, the average measurement result was 1.6% with a standard deviation of 0.14. Meanwhile, for the electron beam at 9 MeV energy, the average measurement result is 1.8% with a standard deviation of 0.34. The measurement results of photon output and electron beam are below the tolerance standard (±1-2%).

Overall, the results of the monthly Linac radiotherapy device quality control for photon and electron beam output are satisfactory. Both photon beam output parameters are within the tolerance standard, while the electron beam output parameters are slightly above the tolerance standard. However, it is important to note that the standard deviation for both electron beam output parameters is relatively high, which suggests that there is some variability in the measurements.

In terms of safety, monthly quality control analysis of Linac radiotherapy devices, particularly door interlock parameters, audiovisual components (sound and CCTV), and radiation indicator lights, showed 100% functionality.

The implementation of quality control in the Radiotherapy Department is supervised by the Medical Physicist. Recording and documentation of quality control activities are computerised using Google spreadsheet, which is automatically stored in Google Drive owned by the Radiotherapy Department of Pasar Minggu Hospital. If there is a test parameter that exceeds the tolerance limit, it will be re-examined by other test implementers using alternative methods. In addition, a report is submitted to the Head of the Radiotherapy Department, to initiate system repairs by the hospital facility maintenance team or vendor. Any necessary adjustments are made by the vendor's technicians to align with acceptable tolerance values.

The research findings indicate that the mechanical aspect remains highly stable, with minimal changes in average output, well below the tolerance limits in the dosimetry aspect. The safety aspect demonstrated that all tests were functioning correctly. These results align with the standards outlined in AAPM Task Group 142.

4. CONCLUSION

The stringent quality control measures applied to the linear accelerator radiotherapy devices at Pasar Minggu Hospital's Radiotherapy Department ensure a consistent, high-caliber performance. The comprehensive approach encompasses meticulous mechanical, dosimetry, and occupational safety monitoring. The integrity of the Linac devices is assured through rigorous daily and monthly evaluations conducted by adept Medical Physicists adhering to tailored Standard Operating Procedures. These evaluations adhere to the standards delineated by the AAPM Task Group 142 and BAPETEN standard No.K2N.2/MT-08, ensuring the equipment meets and exceeds industry benchmarks.

ACKNOWLEDGEMENT

We would like to thank the Director and Lecturers of the Radiodiagnostic and Radiotherapy Department of Politekknik Kesehatan Kemenkes Jakarta II for their contributions during the research We are sincerely grateful to the Directors and staff of the District Hospital of Pasar Minggu Jakarta and Badan Pengusahaan Batam Hospital for their valuable contributions, facilities, assistance, and constructive suggestions during our research.

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