



## **Analysis of Collimation Field Size Accuracy and Beam Perpendicularity Test in the Apelem Camargue X-Ray Machine**

**Yusron Adi Utomo<sup>1\*</sup>, Imam Suyudi<sup>1</sup>, Heni Fa'riatul Aeni<sup>1</sup>, Ade Pitriyani<sup>1</sup>**

*<sup>1</sup>Sekolah Tinggi Ilmu Kesehatan Cirebon, Indonesia*

*\*Corresponding Email: [yusronadiutomo@gmail.com](mailto:yusronadiutomo@gmail.com)*

### **Abstract**

The Quality Control program is a program that deals with supervision, maintenance, and technical maintenance techniques. Quality control activities for X-ray equipment consist of testing the collimation tube. The purpose of this study was to determine the test results of the suitability of the collimation field area and the straightness of the light beam on the Camargue Apelem brand X-ray aircraft in the Integrated Emergency Room of the RSD Gunung Jati Kota Cirebon. This type of research is descriptive quantitative with an observational approach. The subject of the study was the Apelem Camargue brand X-ray aircraft in the Integrated Emergency Room of Gunung Jati Hospital, Cirebon City. Tools and methods of data collection are observation, measurement, and documentation. The test results for the deviation of the collimation field area obtained at FFD 100 cm, 120 cm, and 130 cm each for 0,9%; 0,9% and 1%. As for the deviation of the straightness of the light beam, the result is 0° in all FFDs. Based on the test results, it can be said that both still meet the acceptance limit standards according to PERBA BAPETEN No.2 of 2018. Periodic testing of X-ray equipment must be carried out by the radiology installation itself, to ensure that every parameter of the X-ray equipment is tested for accuracy, linearity, and stability of its function in accordance with the specifications of the equipment and if there are deviations, appropriate repairs can be made immediately.

**Keywords:** Collimation, light beam, quality control, x-ray.

### **1. Introduction**

Quality Assurance (QA) is a fundamental management program implemented in healthcare services to ensure the safety, effectiveness, and consistency of medical procedures (Sarkar, 2025) through systematic data collection and continuous performance evaluation. In diagnostic radiology, QA plays a crucial role in evaluating healthcare performance (Shalom et al., 2024) and maintaining image quality while minimizing unnecessary radiation exposure to patients (Nocum, Robinson, & Reed, 2021). An effective QA program encompasses various components, including patient selection and scheduling, technical management, departmental policies and procedures, operational efficiency, educational services, and timely and accurate image interpretation. Central to the QA framework is the control of human and

technical factors that may contribute to variations in diagnostic quality and patient safety (Papp, 2018).

Within the QA framework, Quality Control (QC) represents a technical subset that focuses on monitoring, testing, and maintaining radiological equipment to ensure optimal performance. QC activities in radiology installations generally include acceptance testing, routine performance evaluations, and corrective testing (Gray et al., 2008). Acceptance tests are conducted when an X-ray unit is first installed to establish baseline performance values (Lin et al., 2022). Routine performance evaluations are performed periodically to detect any deviations in equipment performance over time, while corrective tests are carried out when malfunctions or performance degradation are suspected to identify the root causes and ensure appropriate repairs are undertaken (Papp, 2018). These procedures are essential to ensure that diagnostic X-ray systems operate within regulatory and manufacturer-specified tolerances.

One of the most critical parameters evaluated in QC testing of diagnostic X-ray equipment is the accuracy of X-ray beam collimation. Proper collimation directly affects patient radiation dose, image quality, and radiation protection for both patients and operators. Inaccurate collimation may lead to unnecessary irradiation of surrounding tissues, increased scattered radiation, and suboptimal diagnostic images. According to the Indonesian Nuclear Energy Regulatory Agency (BAPETEN) Regulation No. 2 of 2018 concerning conformity testing of diagnostic and interventional radiology X-ray equipment, collimation accuracy is identified as a mandatory component of conformity testing due to its direct impact on patient safety and operational feasibility of X-ray units ( Regulation of the Nuclear Energy Regulatory Agency of the Republic of Indonesia Number 2 of 2018 Concerning Conformity Testing of Diagnostic and Interventional Radiology X-Ray Equipment, 2018).

Furthermore, the Indonesian Ministry of Health Decree No. 1250 of 2009 on Quality Control Guidelines for X-ray equipment emphasizes that collimator testing should be routinely performed using standardized methods, such as the scollimator test tool (Maharani et al., 2025; Rosidah, Jamil, & Suraningsih, 2024). This method is widely recognized as one of the most accurate techniques for evaluating the congruence between the light field and the radiation field. The regulation specifies that collimator conformity testing should be conducted at least once a month or after equipment maintenance, with allowable collimation deviation limits set at 2% of the Focus-to-Film Distance (FFD) (Saputra & Bisra, 2021; Decision of the Minister of Health of the Republic of Indonesia No. 1250/MENKES/SK/XII/2009 concerning Guidelines for the Quality Control of Radiodiagnostic Equipment, 2009). Compliance

with these standards is essential to ensure diagnostic reliability and radiation safety in clinical practice.

Despite the availability of regulatory guidelines, deviations in collimation accuracy and beam perpendicularity are still reported in clinical settings, particularly in high-workload emergency radiology units. Preliminary observations conducted during clinical field practice at the Emergency Radiology Unit of RSD Gunung Jati Hospital, Cirebon, revealed inconsistencies in thoracic radiographic images. Specifically, chest radiographs obtained using a collimation field size of  $35 \times 43$  cm demonstrated partial truncation of the left thoracic region, despite symmetrical patient positioning. This finding suggests potential inaccuracies in collimation field size alignment or beam perpendicularity, which may compromise diagnostic accuracy and increase unnecessary radiation exposure.

Previous studies have primarily focused on general QC implementation or compliance assessments of diagnostic X-ray equipment (Nkuba & Nyanda, 2017; Nurcahyo & Asri Indah Aryani, 2023; Tuchyna, Wilkinson, & Jacob, 2002); however, limited research has specifically addressed the combined evaluation of collimation field size accuracy and beam perpendicularity in emergency radiology settings using specific X-ray machine models. This gap highlights the need for focused, equipment-specific investigations to ensure that routinely used radiographic systems meet conformity standards under real clinical conditions.

Therefore, this study aims to analyze the accuracy of collimation field size and beam perpendicularity of the Apelem Camargue X-ray machine used in the Integrated Emergency Department of RSD Gunung Jati Hospital, Cirebon. The findings of this research are expected to contribute to improving quality control practices, enhancing patient radiation safety, and providing practical evidence to support routine conformity testing of diagnostic X-ray equipment in emergency healthcare settings.

## 2. Method

This study employed a quantitative descriptive research design with an observational approach to evaluate the accuracy of collimation field size and beam perpendicularity of a diagnostic X-ray machine. The object of the study was an Apelem Camargue X-ray unit installed in the Integrated Emergency Department of RSD Gunung Jati Hospital, Cirebon. Primary data were obtained directly from equipment performance measurements, without involving patient-related data, ensuring that the study focused exclusively on conformity testing of the radiographic system.

Data collection was conducted through direct observation, measurement, and documentation using standardized quality control instruments, namely a collimator test tool and a beam alignment test tool. Measurements were performed at three different Focus-to-Film Distances (FFD), namely 100 cm, 120 cm, and 130 cm, to represent common clinical imaging conditions. For each FFD variation, the tests were repeated three times to improve measurement reliability and minimize random error. Radiographic exposures were carried out following standard operating procedures to obtain clear and interpretable test images.

The collected data were analyzed quantitatively by calculating the deviation between the light field and radiation field as well as the beam perpendicularity deviation indicated on the test tools. The deviation values were expressed as a percentage of the corresponding FFD and averaged across repeated measurements. The results were then compared with the tolerance limits specified in BAPETEN Regulation No. 2 of 2018 concerning Conformity Testing of Diagnostic and Interventional Radiology X-ray Equipment, which stipulates a maximum allowable collimation deviation of 2% of the FFD, to determine the conformity status of the X-ray machine.

### 3. Results and Discussion

#### 3.1 Collimation Field Size Conformity Test

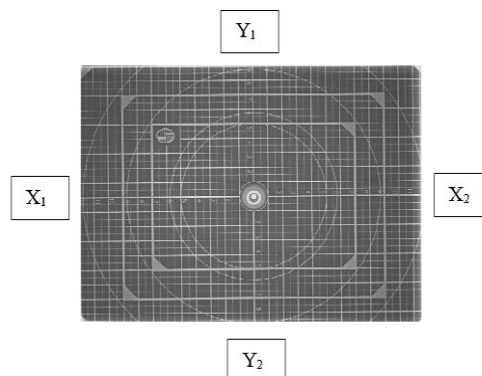


Figure 1. Radiographic image of the first conformity test (FFD 100 cm)

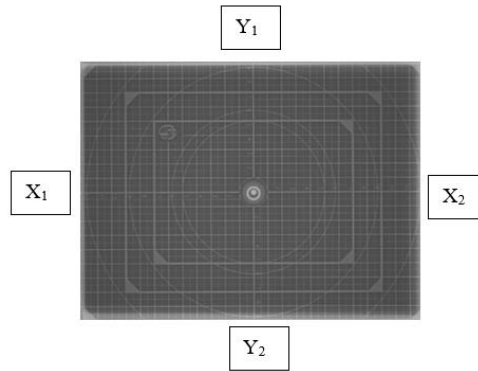
Table 1. Measurement results of the first conformity test

Axis	Light collimation field	X-ray field	Measurement deviation
X1	12 cm	11.9 cm	+0.1 cm
X2	12 cm	11.5 cm	+0.5 cm
Y1	9 cm	9.0 cm	0 cm
Y2	9 cm	8.7 cm	+0.3 cm

Note: a negative (-) value indicates inward deviation, whereas a positive (+) value indicates outward deviation.

Based on the data presented in Table 1, the initial configuration of the light collimation field was set at 12 cm along the X1 axis and 12 cm along the X2 axis, as

well as 9 cm along both the Y1 and Y2 axes, in accordance with the predetermined field size parameters. However, following X-ray exposure and subsequent image evaluation, the measured dimensions of the resulting radiation field demonstrated discrepancies when compared with the preset light field dimensions across nearly all measured axes, except for the Y1 axis, which remained consistent with the initial setting. To quantitatively assess these discrepancies, deviations for each axis were calculated by determining the difference between the radiation field measurements and the corresponding light collimation field values. In this context, negative deviation values indicate an inward displacement of the radiation field relative to the light collimation field, whereas positive deviation values represent an outward expansion beyond the predefined light field boundaries, thereby providing a systematic basis for evaluating the accuracy and alignment of the collimation system.



**Figure 2. Radiographic results of the second test (FFD 120 cm)**

**Table 2. Measurement results of the second test**

Axis	Light field collimation	X-ray field	Measured deviation
X1	12 cm	12.1 cm	-0.1 cm
X2	12 cm	11.7 cm	+0.3 cm
Y1	9 cm	9.0 cm	0.0 cm
Y2	9 cm	8.5 cm	+0.5 cm

Note: A negative (-) value indicates an inward deviation, while a positive (+) value indicates an outward deviation.

Based on Table 2, the light field collimation openings were set to 12 cm on the X1 axis, 12 cm on the X2 axis, 9 cm on the Y1 axis, and 9 cm on the Y2 axis. Following X-ray exposure, discrepancies between the light field and the radiation field were observed on all axes except the Y1 axis. The deviation for each axis was subsequently calculated, where negative values indicate inward displacement of the X-ray field relative to the light field, whereas positive values indicate outward displacement.

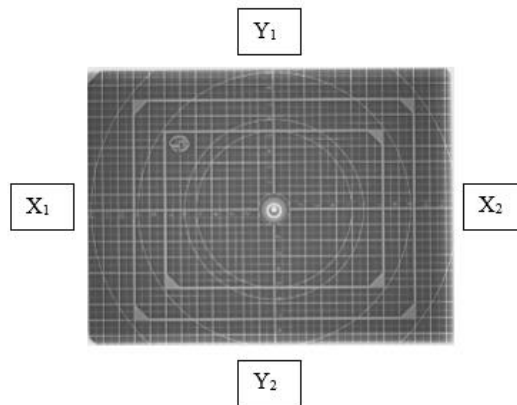


Figure 3. Radiographic image of the third test result (FFD 130 cm)

Table 3. Measurement Results of The Third Test

Axis	Light collimation field	X-ray field	Measurement difference
X1	12 cm	12.1 cm	-0.1 cm
X2	12 cm	11.5 cm	+0.5 cm
Y1	9 cm	9.0 cm	0.0 cm
Y2	9 cm	8.6 cm	+0.4 cm

Note: (-) indicates inward deviation, (+) indicates outward deviation.

Based on Table 3, the light collimation field was set to 12 cm on the X1 axis, 12 cm on the X2 axis, 9 cm on the Y1 axis, and 9 cm on the Y2 axis. After exposure, discrepancies were observed on all axes except the Y1 axis. Subsequently, the deviation for each axis was calculated. A negative (-) value indicates an inward displacement of the X-ray field relative to the light field, whereas a positive (+) value indicates an outward displacement.

Table 4. Conformity test results of collimation field size

FFD (cm)	$\Delta X$	$\Delta Y$	$\Delta X + \Delta Y$	Tolerance limit ( $\leq 3\%$ of FFD) (cm)
100	0.6	0.3	0.9	Yes
120	0.4	0.5	0.9	Yes
130	0.6	0.4	1.0	Yes

Based on the data presented in Table 4, the evaluation of collimation field size accuracy in the Apelem Camargue X-ray machine installed at the Integrated Emergency Department of RSD Gunung Jati Hospital, Cirebon, demonstrates that the measured deviations at all examined Focus-to-Film Distance (FFD) variations consistently remained within the tolerance thresholds established by BAPETEN Regulation No. 2 of 2018. The quantitative analysis indicates that the extent of deviation between the light field and the radiation field did not exceed 3% of the respective FFD in any of the testing conditions, thereby satisfying the regulatory acceptance criteria for conformity testing. These findings confirm that the collimation system maintains adequate alignment performance across different imaging

distances, ensuring compliance with national quality control standards and supporting the safe and effective clinical operation of the X-ray equipment.

### 3.2 Collimator Light Beam Perpendicularity Test

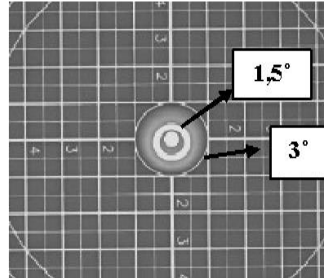


Figure 4. First test result

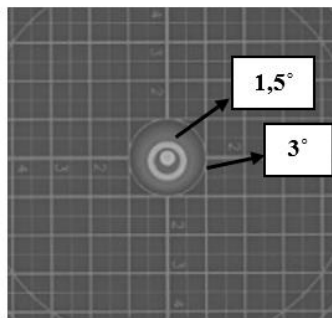


Figure 5. Second test result

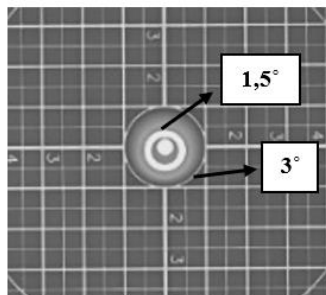


Figure 6. Third test result

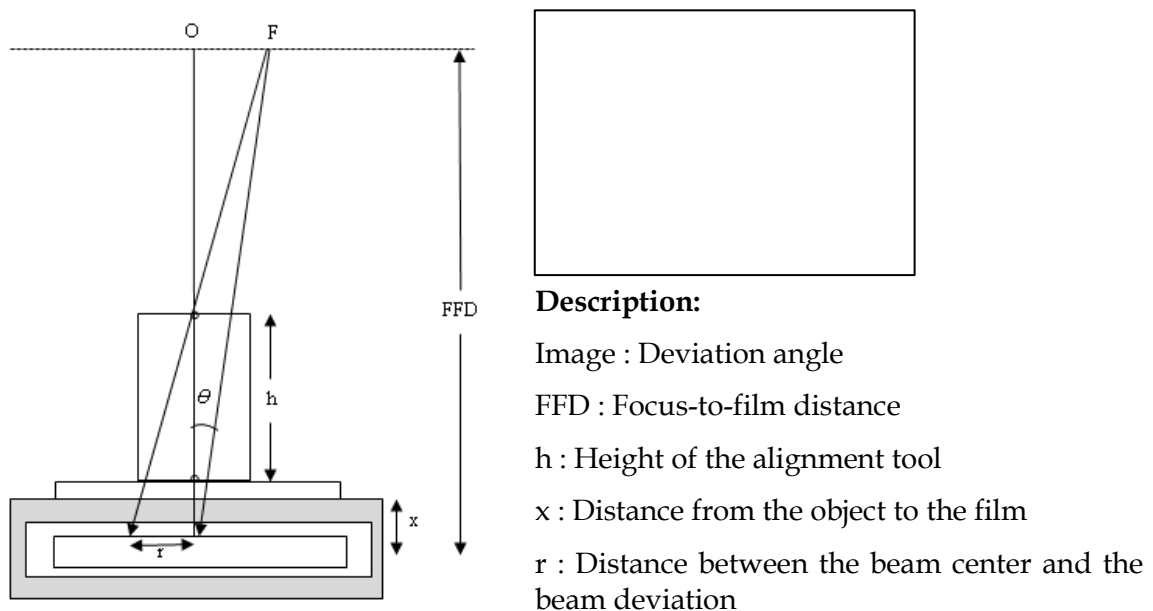
Following the completion of the beam perpendicularity tests, the results illustrated in Figures 4, 5, and 6 demonstrate that the central light beam consistently remained within the inner reference circle, indicating that the angular deviation did not exceed the permissible tolerance threshold of  $1.5^\circ$ . The assessment of beam perpendicularity was conducted through careful observation of the displacement of the steel ball marker relative to the concentric reference circles on the beam alignment test tool. The absence of marker displacement beyond the first reference circle confirms that the X-ray beam axis maintained a perpendicular orientation with respect to the image receptor surface. This finding signifies that the alignment between the collimation light field and the actual X-ray beam was geometrically accurate, thereby minimizing the potential for

image distortion, magnification errors, and diagnostic inaccuracies associated with beam misalignment.



**Figure 7. Standard limit for light beam deviation**

To determine the magnitude of the angular deviation, the following formula was applied:



**Figure 8. Illustration of the calculation of the magnitude of deflection deviation (4).**

After performing the measurements and calculations, the angular deviation of the X-ray light beam was obtained as follows:

**Table 5. Results of Collimator Light Beam Angular Deviation Calculation**

FFD (cm)	Angular Deviation	Acceptance Limit $\leq 3^\circ$
100	0°	Yes
120	0°	Yes
130	0°	Yes

Based on the results presented in Table 5, it can be concluded that the collimator of the Apelem Camargue X-ray machine installed in the Integrated Emergency Department of RSD Gunung Jati Hospital, Cirebon, shows no deviation in the direction of the light beam. The measurements indicate an angular deviation of 0° at all evaluated focus-to-film distances (FFD), confirming that the beam perpendicularity fully complies with the established acceptance criteria.

### 3.3 Discussion

According to BAPETEN Regulation No. 2 of 2018 concerning conformity testing of diagnostic and interventional radiology X-ray equipment, collimation is a mandatory test component and one of the primary parameters in conformity assessment, as it directly affects patient radiation dose and determines the operational suitability of X-ray equipment for clinical use (Peraturan Badan Pengawas Tenaga Nuklir Republik Indonesia No.2 Tahun 2018 Tentang Uji Kesesuaian Pesawat Sinar-X Radiologi Diagnostik dan Intervensional)

Furthermore, the Indonesian Ministry of Health Decree No. 1250 of 2009 states that collimator conformity testing should ideally be performed monthly and at least once every six months, or after any repair or maintenance of the X-ray tube housing and collimator. The frequency of testing may be increased depending on the workload and intensity of X-ray equipment utilization (Decision of the Minister of Health of the Republic of Indonesia No. 1250/MENKES/SK/XII/2009 concerning Guidelines for the Quality Control of Radiodiagnostic Equipment).

The conformity tests for collimation field size accuracy and beam perpendicularity were conducted using a collimator test tool and a beam alignment test tool, both of which are standardized and officially recommended instruments. This testing method is considered superior to alternative techniques due to its higher accuracy and reliability in evaluating the congruence between the light field and the X-ray beam.

Based on the measurement and calculation results obtained from the collimation system testing, the discussion is presented as follows.

#### 3.3.1 Discussion on Collimation Field Size Accuracy Test Results

Following the conformity testing of the collimation field size on the Apelem Camargue X-ray machine installed in the Integrated Emergency Department of RSD Gunung Jati Hospital, Cirebon, measurable deviations were identified. At a Focus-to-Film Distance (FFD) of 100 cm, deviations along the x-axis were 0.6 cm (0.6% of FFD) and along the y-axis were 0.3 cm (0.3% of FFD), both of which were within the acceptable tolerance limit ( $\leq 2\%$  of FFD). At an FFD of 120 cm, deviations were 0.4 cm (0.4%) on the x-axis and 0.5 cm (0.5%) on the y-axis. Similarly, at an FFD of 130 cm, deviations of 0.6 cm (0.6%) were observed on both the x- and y-axes, remaining within the allowable tolerance range.

The combined deviation values ( $\Delta X + \Delta Y \leq 3\%$  of FFD) were 0.9% at an FFD of 100 cm, 0.9% at 120 cm, and 1.0% at 130 cm. These results indicate that the observed collimation deviations remain within the acceptable conformity limits stipulated by BAPETEN Regulation No. 2 of 2018, confirming that the collimation performance of the tested X-ray machine meets regulatory standards.

Previous research conducted by Mardikaningrum (2019) reported collimation deviations of 1.0% on the x-axis and 0.7% on the y-axis for mobile X-ray units at an FFD of 100 cm, while stationary X-ray units demonstrated deviations of 1.1% on the x-axis and 0.4% on the y-axis at the same distance. Another study by Andi Pasinringi (2012) demonstrated deviations of 1.81% on the x-axis and 2.83% on the y-axis at an FFD of 120 cm.

Variations in collimation deviation values across studies may be attributed to differences in equipment type, operational age, workload intensity, and testing methodology. Older X-ray machines with higher cumulative workloads are more susceptible to mechanical wear, increasing the likelihood of collimation inaccuracies. Moreover, the paper clip method is known to produce less accurate and less consistent results compared to standardized collimator test tools.

In accordance with the Indonesian Ministry of Health Decree No. 1250 of 2009 on Quality Control Guidelines for Radiodiagnostic Equipment, collimator testing using a collimator test tool is recognized as the most accurate and reliable method compared to other techniques (Decision of the Minister of Health of the Republic of Indonesia No. 1250/MENKES/SK/XII/2009 concerning Guidelines for the Quality Control of Radiodiagnostic Equipment).

Inaccurate collimation field size alignment with the X-ray beam can significantly affect radiographic image quality by preventing optimal visualization of the region of interest, potentially necessitating repeat examinations. Such repeat exposures increase the radiation dose received by patients, underscoring the importance of maintaining accurate collimation field alignment at all times.

Misalignment between the visible light field and the actual X-ray field may result from improper angulation of the reflective mirror, which should ideally be positioned at a 45° angle. Additional issues may arise from improper handling during tube angulation adjustments, preventing the X-ray tube from returning to a true vertical position. These factors may cause the X-ray field to appear misaligned relative to the examination table (Carroll, 2011).

### **3.3.2 Discussion on Beam Perpendicularity Test Results**

Following the beam perpendicularity testing of the collimation light beam, observations and measurements revealed a deviation angle of 0° at FFD variations of 100 cm, 120 cm, and 130 cm. Additionally, the central light beam remained within the inner circle of the beam alignment test tool, indicating that the misalignment between the central beam and the X-ray beam direction was  $\leq 1.5^\circ$ . These findings confirm that the collimator of the Apelem Camargue X-ray machine installed in the Integrated Emergency Department of RSD Gunung Jati Hospital complies with the standards specified in BAPETEN Regulation No. 2 of 2018.

Consistent with these results, previous research by Mardikaningrum (2019) reported central beam deviations of  $\leq 1.5^\circ$  at an FFD of 100 cm, which also satisfied the regulatory tolerance limits established by BAPETEN. Variations in beam perpendicularity results among studies may arise from differences in equipment condition, operational age, and maintenance practices. Therefore, routine maintenance and proper handling of X-ray equipment are essential to ensure stable and reliable system performance.

Beam perpendicularity is a critical factor influencing partial resolution in radiographic imaging. Partial resolution refers to the ability of an imaging system to distinctly visualize two closely spaced small objects. Deviations in the accuracy of the X-ray beam central axis may result in image magnification and geometric distortion, which can compromise diagnostic accuracy and hinder appropriate clinical decision-making (Sari & Hartina, 2017).

#### 4. Conclusion

Based on the analysis of collimation field size accuracy and beam perpendicularity testing of the Apelem Camargue X-ray machine installed in the Integrated Emergency Department of RSD Gunung Jati Hospital, Cirebon, it can be concluded that the performance of the collimation system remains within the acceptable tolerance limits. The conformity tests conducted using a collimator test tool at Focus-to-Film Distance (FFD) variations of 100 cm, 120 cm, and 130 cm demonstrated that the collimation field size accuracy complies with the acceptance criteria specified in BAPETEN Regulation No. 2 of 2018. Furthermore, beam perpendicularity testing using a beam alignment test tool revealed no angular deviation ( $0^\circ$ ) across all FFD variations, confirming that the direction of the collimation light beam meets the applicable regulatory standards.

Routine quality control testing of diagnostic X-ray equipment should be independently conducted by radiology departments to ensure the accuracy, linearity, and functional stability of all system parameters in accordance with technical specifications and regulatory requirements. Regular implementation of these tests is essential for early detection of potential deviations, enabling timely corrective and maintenance actions, and for maintaining patient safety and the overall quality of radiological services.

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