

Radiation Protection Intercomparison Activity for N-60 and N-80 X-ray Beam Qualities: Results from SNSU-BSN Indonesia

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ABSTRACT

The Ionizing Radiation Metrology Laboratory of Indonesia's National Metrology Institute participated in an international intercomparison of air kerma from the narrow-spectrum protection-level X-ray beam quality N-60 and N-80, as part of quality assurance efforts and preparation for expanding service scope. The measurements used X-ray beams based on the International Atomic Energy Agency (IAEA) Safety Report Series (SRS) No.16 for the N-60 and N-80 beam qualities, in accordance with ISO 4037, and under irradiation conditions specified by the intercomparison protocol from the Office of Atoms for Peace, Thailand (OAP). The air kerma rates measured from the experiments were used to determine the irradiation durations for the optically stimulated luminescence dosimeters (OSLDs). The results showed good agreement with the reference values. The mean air kerma deviated from the 2 mGy reference value by -0.63% for N-60 and -3.25% for N-80, both within the expanded measurement uncertainty of the laboratory (3.43% and 3.38% , $k = 1.96$). These results supported the laboratory's technical competence in radiation protection measurements and provided a basis for expanding its calibration service scope.

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1. INTRODUCTION

The utilization of ionizing radiation sources in Indonesia has been increasing, including in the health sector, with the sharpest growth rate occurring between 2004 and 2008 (Gondhowiardjo et al., 2008). As the number of healthcare facilities utilizing ionizing radiation sources continues to grow, the demand for calibrated protection dosimeters has also increased significantly (Firmansyah et al., 2021). Radiation protection aims to protect workers, patients, and the public from the hazards of ionizing radiation, where the quantities used are operational quantities, such as ambient or personal dose equivalent, related to biological risk (ICRP, 2007). The availability of reliable and accurate dosimeters traceable to the International System of Units (SI) is an absolute requirement to ensure that the principles of radiation protection, i.e., justification, optimization, and limitation, can be effectively implemented (ICRP, 2007). The calibration of protection dosimeters in terms of operational quantities involves the application of conversion coefficients and air kerma measurements, with conversion coefficient data provided in IAEA SRS-16 and ISO 4037:2019 (IAEA, 2000; ISO, 2019).

Within the scope of protection dosimetry, calibration can be performed using X-ray beams of Narrow-60 (N-60) and Narrow-80 (N-80) beam qualities, which represent medium-energy X-ray beams widely used for the calibration of survey meters and personal dosimeters (ISO, 2019; Bouzegzi et al., 2023). These beams are classified by effective energy: N-60 at approximately 47.9 keV and N-80 at approximately 65.2 keV (Le et al., 2023), with spectral characteristics including tube voltage, half-value layer (HVL), and effective energy determined for each beam in accordance with IAEA SRS-16 and ISO 4037:2019 (IAEA, 2000; ISO, 2019; Le et al., 2023). The establishment of such narrow-spectrum X-ray series at secondary standards dosimetry laboratories (SSDLs) has been documented in several countries as a key step in building regional calibration infrastructure (Dang et al., 2024).

The reliability of dosimeter measurement results is determined not only by instrument quality and calibration procedures, but also by the laboratory's ability to demonstrate and maintain the consistency and validity of its measurement methods (ISO, 2017). Interlaboratory comparison (ILC) is an established quality-assurance approach for evaluating the consistency of measurement results among participating laboratories and against a reference value (Iafrati et al., 2024). Such comparisons are particularly relevant to radiation protection dosimetry, where measurement performance depends on the dosimeter response, calibration traceability, beam quality, and irradiation conditions. International and regional intercomparison programmes, including those conducted under the IAEA, EURADOS, EURAMET (Živanović et al., 2023), COOMET (Saroka et al., 2023), and regional SSDL networks (Khoury et al., 2021), have demonstrated the role of such exercises in identifying deviations in dosimetric performance and supporting the harmonization of measurement practices (Mcwhan et al., 2023; Romero et al., 2023).

For X-ray dosimetry, the establishment and maintenance of appropriate reference measurement systems are also essential for ensuring reliable measurements across different beam qualities. The development of secondary standards for ambient dose equivalent $H^*(10)$ (Bairlein et al., 2020) and the evaluation of personal dosimeter response to operational quantities (Ekendahl et al., 2020) underpin the reliability of protection dosimetry systems. Calibration methods for ambient dose equivalent dosimeters have also been developed to ensure consistency between field and laboratory conditions (Gao et al., 2021). Relevant recommendations from the Swiss Society of Radiobiology and Medical Physics (SSRMP) specify reference dosimeter systems, dosimetry formalisms, and calibration conditions for low- and medium-energy X-ray beams, emphasizing the importance of using reference systems under beam qualities comparable to those for which they are calibrated (Aspradakis et al., 2023). International key comparisons, such as those for medium-energy X-rays in the Asia-Pacific region, further support the traceability and consistency of air kerma measurements across national metrology institutes (Chu et al., 2023). These considerations are directly relevant to radiation protection intercomparisons involving standardized X-ray beam qualities, where consistency of the irradiation field and reference dosimetry system is fundamental to meaningful comparison.

Against this background, the participation of the Ionizing Radiation Metrology Laboratory of SNSU-BSN, Indonesia, in an intercomparison using N-60 and N-80 X-ray reference qualities (IAEA, 2000; ISO, 2019) provides an evaluation of the laboratory's measurement performance within an internationally recognized quality-assurance framework. This study presents the intercomparison methodology and results for protection-level dosimetry at these two X-ray beam qualities, with particular emphasis on the agreement between the SNSU-BSN measurement results and the assigned reference values. The findings provide evidence of the laboratory's measurement capability and contribute to the ongoing harmonization and quality assurance of radiation protection dosimetry in Indonesia.

2. METHOD

The SNSU-BSN Ionizing Radiation Metrology Laboratory participated in a multilateral intercomparison organized by the Office of Atoms for Peace (OAP) in collaboration with the Thailand Institute of Nuclear Technology (TINT), covering air kerma measurements using N-60 and N-80 X-ray beam qualities with an assigned reference air kerma value of 2 mGy (OAP, 2022). The organizer sent

four optically stimulated luminescence dosimeters (OSLDs) for each beam quality (N-60 and N-80) along with additional OSLDs serving as control dosimeters to account for background dose accumulated during transit and storage.

2.1 Equipment and Facilities

The SNSU-BSN Ionizing Radiation Metrology Laboratory used an X-ray beam generated by a YXLON MG325 X-ray generator. The radiation qualities used were N-60, generated at 60 kVp with a 0.6 mm Cu filter, and N-80, generated at 80 kVp with a 2.0 mm Cu filter (IAEA, 2000). Air kerma determination was performed using a 600 cm³ thin-window ionization chamber, NE Technology NE2575, serial number 576, traceable to SI through the IAEA SSDL, with air kerma calibration coefficients (N_K) of 42.98 ± 0.52 $\mu\text{Gy/nC}$ for N-60 and 42.55 ± 0.52 $\mu\text{Gy/nC}$ for N-80 (expanded uncertainties, coverage factor $k = 2$). This detector was connected to a PTW Unidos Tango TW10052 electrometer, serial number 192335, as the dosimetry system. The measurement output (charge in nC) read by the electrometer was corrected for environmental factors (air pressure and temperature) using a Lutron MHB382SD thermo-hygro-barometer, serial number AM16255, traceable to SI through the SNSU-BSN laboratory.

2.2 Measurement Procedure

The air kerma measurements were performed in several stages: pre-irradiation preparation and irradiation of the OSLDs, in accordance with the OAP 2022 Air Kerma Intercomparison Technical Protocol (OAP, 2022). All measurements and irradiation of the OSLDs were done under standard test conditions of $20 \pm 1^\circ\text{C}$, 1010 ± 5 hPa, and relative humidity of $50 \pm 5\%$. Measurements were corrected to reference conditions according to IAEA SRS-16 (IAEA, 2000).

2.2.1 Pre-irradiation Preparation

One of the key preparatory steps was to determine the beam alignment and source-to-detector distance, together with the air kerma rate and the optimum irradiation configuration for the optically stimulated luminescence dosimeters (OSLDs), for the N-60 (≈ 48 keV) and N-80 (≈ 65 keV) beam qualities. Air kerma measurements were performed over one-minute intervals, timed with the X-ray generator controller, at source-to-detector distances of 1 m and 2 m and tube currents of 5 mA and 10 mA (Figure 1).

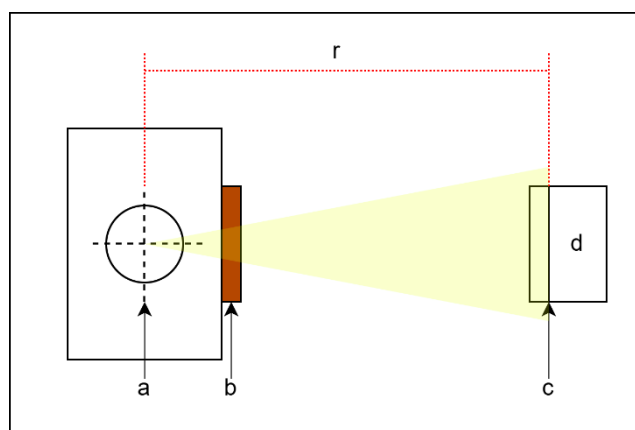


Figure 1. Side view of the air kerma rate measurement setup using the 600 cm³ detector. Label a indicates the X-ray tube reference point, label b indicates the Cu filter, label c indicates the detector reference point, label d indicates the NE2575 detector, and label r indicates the irradiation distance from the X-ray tube reference point to the detector reference point.

2.2.2 OSLDs Irradiation

Following the pre-irradiation preparation, the OSLDs were irradiated using the optimum configuration determined in Section 2.2.1, including beam alignment, source-to-detector distance, tube current, and irradiation time. During irradiation, the OSLDs were positioned at the established alignment

and distance, with the front face of all four OSLDs directed toward the X-ray beam (Figure 2). Beam alignment was carried out using laser systems (Figure 3a); the arrangement of the two laser systems is shown in Figure 4. The OSLDs were mounted on a cardboard holder equipped with adhesive tape to maintain stable positioning throughout the irradiation (Figure 3b), as suggested by the technical protocol of the intercomparison (OAP, 2022).

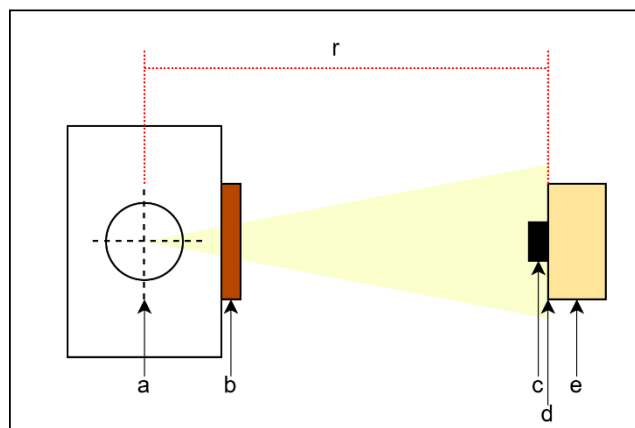


Figure 2. Side view of the OSLD irradiation setup. Label a indicates the X-ray tube reference point, label b indicates the Cu filter, label c indicates the OSLD, label d indicates the cardboard surface, label e indicates the cardboard backing, and label r indicates the irradiation distance from the X-ray tube reference point to the center point of the OSLD.

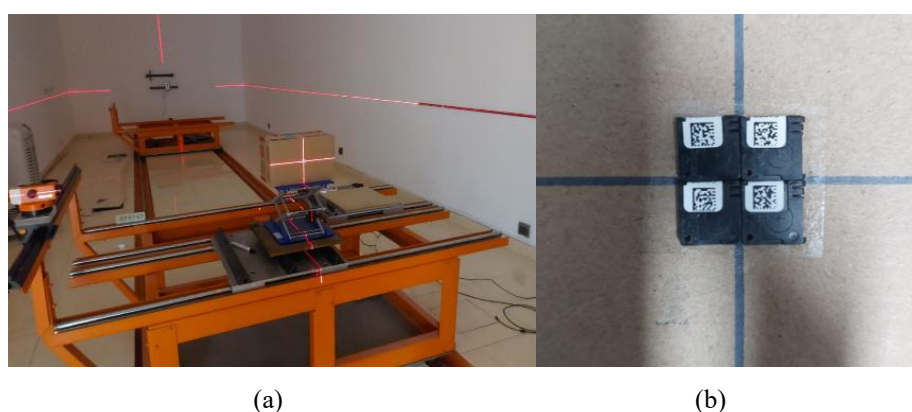


Figure 3. (a) OSLD irradiation setup showing beam alignment using a laser. (b) OSLD mounted on a cardboard holder using adhesive tape.

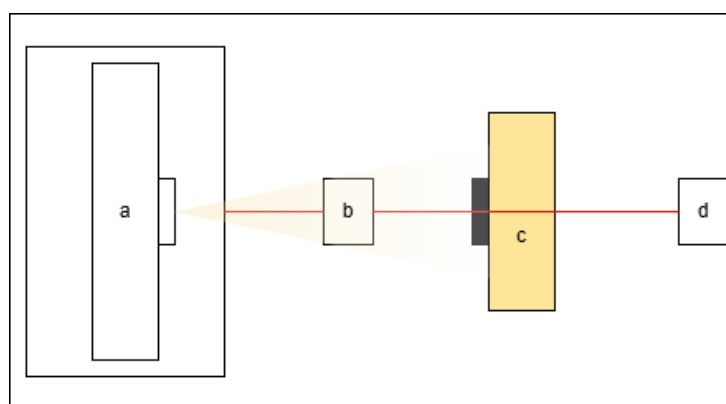


Figure 4. OSLD alignment setup using two laser systems. Label a indicates the X-ray tube, label b indicates the first laser system positioned between the X-ray tube and the OSLD and removed after alignment, label c indicates the OSLD with cardboard backing, and label d indicates the wall-mounted laser system.

2.3 Measurement Uncertainty Evaluation

The uncertainty of the air kerma delivered by the SNSU-BSN X-ray system was evaluated following the Guide to the Expression of Uncertainty in Measurement (JCGM, 2008). Type A components were evaluated statistically from repeated readings, and Type B components from calibration certificates, instrument specifications, and other available information. The standard uncertainties were combined by the root-sum-of-squares method to give the combined standard uncertainty. The expanded uncertainty was obtained by multiplying the combined standard uncertainty by a coverage factor of $k = 1.96$, corresponding to a coverage probability of approximately 95% for a normal distribution.

2.4 Evaluation of Measurement Results

The irradiated OSLDs were returned to the intercomparison organizer for dose readout. Upon receiving the reported readout results, the SNSU-BSN Ionizing Radiation Metrology Laboratory evaluated its performance from the deviation of the mean OSLD air kerma from the assigned value. Following the difference and percent-difference statistics in ISO 13528 (ISO, 2022), the deviation was calculated as:

$$D = \bar{x} - x_{ref} \quad (1)$$

$$D\% = \left(\frac{\bar{x} - x_{ref}}{x_{ref}} \right) \times 100\% \quad (2)$$

where D are absolute deviations in mGy, $D\%$ are relative (%) deviations, $\bar{x}$ is the mean air kerma, in mGy, obtained from the OSLD readouts, and x_{ref} is the assigned (reference) air kerma, in this case 2 mGy.

The assigned value was provided without an associated uncertainty. The deviation was therefore compared with the expanded uncertainty U (%) of the SNSU-BSN air kerma measurement, evaluated as described in Section 2.3. A result was rated consistent with the assigned value when $|D\%| \leq U$, as shown in Table 1.

Table 1 Deviations interpretation criteria

Deviation	Interpretation
$ D\% \leq U$	Consistent with the assigned value
$ D\% > U$	Further investigation required

Table 2 Air kerma rate measurement results at various irradiation configurations

Beam Quality	Current (mA)	Distance (m)	Air Kerma Rate (mGy/min)	Irradiation Time for 2 mGy (min)
N-60	5	1	0.665	3.01
		2	0.165	12.11
	10	1	1.327	1.51
		2	0.331	6.05
N-80	5	1	0.341	5.87
		2	0.086	23.26
	10	1	0.684	2.92
		2	0.173	11.56

3. RESULTS AND DISCUSSION

3.1 Determination of Irradiation Conditions

The irradiation configuration (tube current and source-to-detector distance) was selected based on the air kerma rate, the irradiation time, and the expected stability of the X-ray output. The combination of source-to-detector distance and tube current was optimized to achieve the target air kerma of 2 mGy. Tube current governed radiation intensity by controlling the number of X-ray photons

produced, while source-to-detector distance determined the air kerma rate at the measurement point through the inverse square law, with both parameters, together with irradiation time, determining the total delivered air kerma. The measured air kerma rates for N-60 (≈ 48 keV) and N-80 (≈ 65 keV) beam qualities at varying source-to-detector distances (1 m and 2 m) and tube currents (5 mA and 10 mA) are presented in Table 2.

Air kerma rate is directly proportional to tube current (mA) and inversely proportional to the square of the source-to-detector distance (m). Increasing the tube current increases the number of photons produced, resulting in a higher air kerma rate. However, this carries a risk of overshoot if irradiation time is not carefully controlled, especially in high air kerma rate situations. Conversely, increasing the distance from 1 m to 2 m reduces the air kerma rate, requiring a longer irradiation time to reach the target air kerma, as shown in Figure 5. Excessively long irradiation times introduce the risk of systematic error and bias, arising from output drift due to X-ray tube overheating or environmental fluctuations such as variations in supply voltage, room temperature, and humidity. A moderate air kerma rate with a controlled irradiation time allows for stable X-ray output and reduces the influence of short-term fluctuations from both the generator and detector response, which is expected to give better-controlled air kerma accumulation (Fukuda et al., 2015).

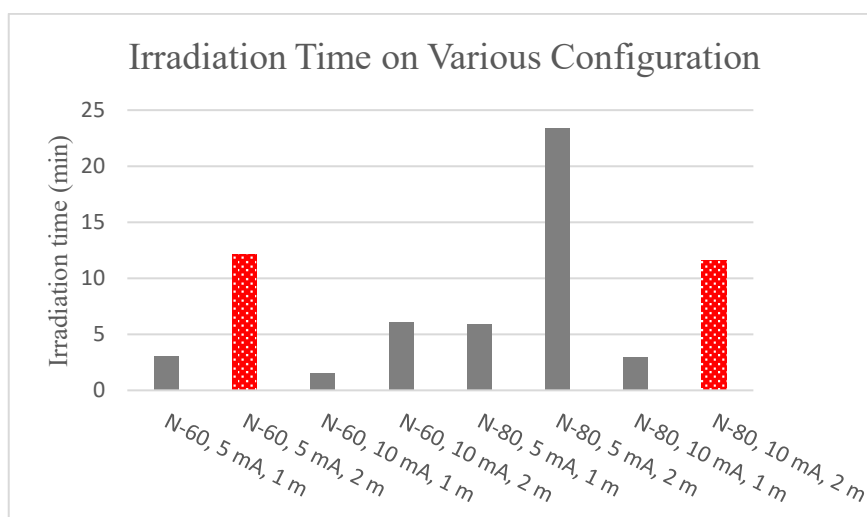


Figure 5. Irradiation time (minutes) required to deliver 2 mGy at various irradiation configurations for N-60 and N-80 X-ray beam qualities.

Based on these considerations, irradiation conditions of 5 mA at 2 m for the N-60 beam quality and 10 mA at 2 m for the N-80 beam quality were selected for the subsequent measurements. These conditions resulted in irradiation times of 12.11 min for N-60 and 11.56 min for N-80, respectively, allowing the target air kerma of 2 mGy to be reached within a practical irradiation period. The selected settings therefore provided a practical balance between irradiation time and the target air kerma.

The intercomparison OSLDs were irradiated under the conditions summarized in Table 3, with filter specifications in accordance with the requirements of IAEA SRS-16 and ISO 4037:2019 (IAEA, 2000; ISO, 2019).

Table 3 X-ray beam irradiation conditions for dosimeter irradiation

Parameter	N-60	N-80	Unit
Voltage	60	80	kVp
Current	5	10	mA
Distance	2	2	m
Time	12.11	11.56	min
Filter	0.6	2.0	mm Cu

3.2 Intercomparison Results

The four intercomparison OSLDs were irradiated with N-60 and N-80 X-ray beams under the established configuration. Air kerma readout was performed by the organizer, and the results for the SNSU-BSN Ionizing Radiation Metrology Laboratory are presented in Table 4 (OAP, 2022).

Table 4 OSLDs air kerma readings – SNSU-BSN Ionizing Radiation Metrology Laboratory

Beam Quality	OSLD Serial No.	Air Kerma Reading (mGy)	Mean Air Kerma (mGy)	Standard Deviation (mGy)
N-60	DB08104358P	1.95	1.988	0.056
	DB08615116T	1.96		
	DN08785003W	1.97		
	DB08725259E	2.07		
N-80	DN08386177K	1.92	1.935	0.052
	DN085729794	1.87		
	DB08314009U	1.96		
	DB08114803S	1.99		

The intercomparison results were evaluated against the assigned air kerma value using the absolute and percent deviations defined in Equations (1) and (2), and the results are presented in Table 5. The deviations were then compared with the expanded uncertainty of the SNSU-BSN air kerma measurement, which is derived later in Tables 6 and 7.

Table 5 Deviation evaluation of the SNSU-BSN Ionizing Radiation Metrology Laboratory results

Beam Quality	Air Kerma Reading (mGy)	Mean Air Kerma (mGy)	Reference Value (mGy)	Absolute deviation (mGy)	Relative deviation (%)	Expanded uncertainty, U (%)	Interpretation
N-60	1.95	1.988	2.00	-0.013	-0.63	3.43	Consistent
	1.96						
	1.97						
	2.07						
N-80	1.92	1.935	2.00	-0.065	-3.25	3.38	Consistent
	1.87						
	1.96						
	1.99						

The deviations were -0.013 mGy (-0.63%) for N-60 and -0.065 mGy (-3.25%) for N-80. The negative sign indicates that the mean OSLD air kerma (1.988 mGy and 1.935 mGy, respectively) was slightly below the 2 mGy assigned value. The deviations were calculated from the unrounded mean air kerma (1.9875 mGy for N-60 and 1.935 mGy for N-80). Under the criteria in Table 1, both results are consistent with the assigned value, since the absolute relative deviations are smaller than the absolute relative deviations are smaller than the corresponding expanded uncertainties of 3.43% (N-60) and 3.38% (N-80), as derived in Tables 6 and 7. This means they fall within the interval expected to contain approximately 95% of results from a normal distribution (Eurachem, 2022). The N-80 deviation is larger than that of N-60 and lies close to the expanded uncertainty, so its margin of agreement is small. This outcome is consistent with an Hp(10) dosimetry intercomparison conducted in Italy in 2023, which reported inter-laboratory differences that were not statistically significant and remained within acceptance limits (Iafrati et al., 2024). The result also carries broader relevance for regional metrological harmonization. The exercise was organized by OAP under a protocol consistent with the traceability framework of the IAEA/WHO Network of Secondary Standards Dosimetry Laboratories (SSDLs), which keeps the national dosimetry standards of Member States traceable to the SI (IAEA, 2025). Agreement with the externally assigned reference value, within the laboratory's expanded uncertainty, provides supporting evidence of the SNSU-BSN measurement capability for N-60 and N-80 X-ray beam

qualities. Although preliminary, this result, together with the laboratory's participation in an intercomparison organized within the IAEA/WHO SSDL traceability framework, is relevant to the Laboratory's ongoing development toward IAEA/WHO SSDL designation.

Table 6 Uncertainty evaluation for N-60 X-ray beam quality

Uncertainty Source	Type A (%)	Type B (%)
X-ray Generator System		
Stability	-	1.261
Timer error	-	0.933
Reference Dosimeter		
Calibration factor uncertainty	-	0.605
Drift	-	0.289
Dosimeter resolution	-	0.015
Ion recombination	-	0.000
Polarity	-	0.000
Repeatability	0.302	-
Thermometer	-	0.159
Barometer	-	0.015
Measurement reproducibility	-	0.062
Positioning	-	0.155
Quadratic Sum	0.302	1.722
Combined Uncertainty		1.748
Expanded Uncertainty		3.426
Coverage factor for expanded uncertainty is 1.96		

Table 7 Uncertainty evaluation for N-80 X-ray beam quality

Uncertainty Source	Type A (%)	Type B (%)
X-ray Generator System		
Stability	-	1.261
Timer error	-	0.933
Reference Dosimeter		
Calibration factor uncertainty	-	0.611
Drift	-	0.289
Dosimeter resolution	-	0.014
Ion recombination	-	0.000
Polarity	-	0.000
Repeatability	0.016	-
Thermometer	-	0.159
Barometer	-	0.015
Measurement reproducibility	-	0.062
Positioning	-	0.155
Quadratic Sum	0.016	1.724
Combined Uncertainty		1.724
Expanded Uncertainty		3.378
Coverage factor for expanded uncertainty is 1.96		

The reported air kerma values and their expanded uncertainties are shown in Figure 6. For N-60, the mean air kerma of 1.988 mGy with an expanded uncertainty of 3.426% ($k = 1.96$) gives an interval of approximately 1.919 to 2.056 mGy. For N-80, the mean of 1.935 mGy with an expanded uncertainty of 3.378% gives approximately 1.870 to 2.000 mGy. The 2 mGy assigned value lies within the interval for both beam qualities, although for N-80 it lies very close to the upper limit. Of the uncertainty components in Tables 6 and 7, ion recombination and polarity were both reported as 0.000%. At the reported precision, they did not contribute appreciably to the combined uncertainty under the measurement conditions applied.

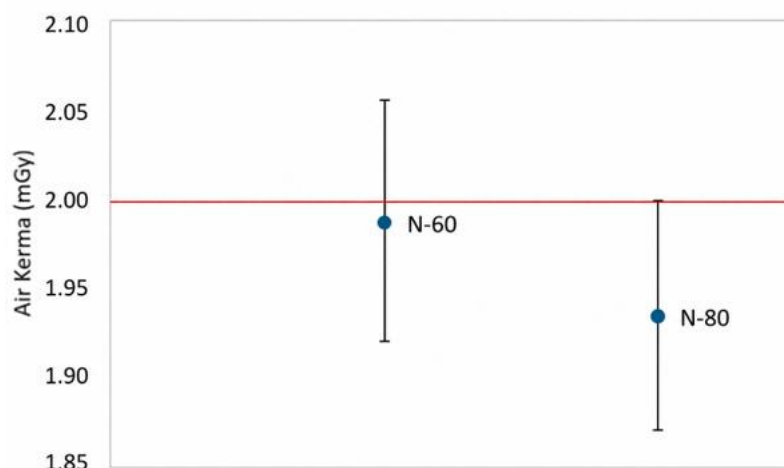


Figure 6. Intercomparison results of the SNSU-BSN Ionizing Radiation Metrology Laboratory. The red horizontal line represents air kerma readings of 2 mGy, error bar represents the expanded uncertainty at $k=1.96$.

In this exercise, the assigned air kerma value of 2 mGy was provided without an associated uncertainty. The performance of SNSU-BSN was therefore evaluated from the deviation of the mean air kerma from the assigned value, compared with the expanded uncertainty of the laboratory's own measurement (Table 1). The ζ -score and En number could not be determined because both require the uncertainty of the assigned value (ISO, 2022). Leaving out this uncertainty makes the criterion stricter, because including it would widen the range of acceptable deviations.

This limits the range of performance statistics that can be applied and the extent of direct comparison with exercises in which the uncertainty of the assigned value is available. The Italian Hp(10) intercomparison (Iafrati et al., 2024), for example, included uncertainty information, which allowed a more comprehensive evaluation of agreement between participating laboratories. The limitation reflects the information available for this exercise and not the SNSU-BSN measurement process, whose uncertainty was fully evaluated in Tables 6 and 7.

Where the uncertainty of the assigned value is available in future intercomparison exercises, ζ -score and En-based evaluation could be applied in line with ISO 13528:2022. This would complement the deviation-based assessment and make results easier to compare across regional and international intercomparisons.

4. CONCLUSION

This study evaluated the performance of the SNSU-BSN Ionizing Radiation Metrology Laboratory in an air kerma intercomparison using the N-60 and N-80 X-ray beam qualities, with an assigned value of 2 mGy. The mean OSLD air kerma deviated from the assigned value by -0.63% for N-60 and -3.25% for N-80, both smaller than the expanded uncertainties of the measurement system (3.43% and 3.38% , $k = 1.96$), so the objective of demonstrating agreement was achieved. These results provide evidence of the laboratory's technical competence in radiation protection dosimetry and support its preparation to extend its calibration service, although a single exercise covering two beam qualities is not sufficient on its own to confirm this. The assigned value was provided without an associated uncertainty, so the ζ -score and En number could not be determined, and the assessment considered only the uncertainty of the laboratory's own measurement. Future work should include further intercomparisons across additional beam qualities, ideally with the uncertainty of the assigned value available, together with improved X-ray output stability and timing control, which were the largest uncertainty contributors.

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AUTHOR CONTRIBUTIONS

Author Contributions: Conceptualization, O.A.F. and A.F.J.; methodology, Z.M.I., M.An., A.S. and M.Am.; validation, T.U. and A.F.J.; formal analysis, Z.M.I. and M.An.; investigation, Z.M.I., M.An., A.S., M.Am. and T.U.; resources, A.F.J. and O.A.F.; data curation, Z.M.I.; writing—original draft preparation, Z.M.I.; writing—review and editing, Z.M.I., O.A.F., A.F.J. and M.An.; visualization, Z.M.I.; supervision, O.A.F. and A.F.J.; project administration, O.A.F. and Z.M.I. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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