World Journal of Nuclear Science and Technology, 2025, 15(1), 30-44
https://www.scirp.org/journal/wjnst
ISSN Online: 2161-6809
ISSN Print: 2161-6795

Retrospective Assessment of Calibration Behaviour, Faulty Trends and Durability of Commonly Used Radiation Survey Meters in Nigeria

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How to cite this paper: Akerele, O.O., Oyeyemi, S.M., Agada, F.A., Obarhua, S.U., Alakiu, H.E., Ayuba, W.K., Olaniyi, D.O. and Ofoegbu, E.E. (2025) Retrospective Assessment of Calibration Behaviour, Faulty Trends and Durability of Commonly Used Radiation Survey Meters in Nigeria. *World Journal of Nuclear Science and Technology*, **15**, 30-44.
https://doi.org/10.4236/wjnst.2025.151003

Received: October 8, 2024
Accepted: January 6, 2025
Published: January 9, 2025

Abstract

Radiation detectors, such as survey meters, are essential for ensuring radiation safety in various sectors, including healthcare, industrial processing, emergency response, etc. However, regular calibration and proper maintenance of survey meters are important in order to ascertain their accuracy and reliability. This study provides a comprehensive retrospective assessment of the calibration behaviour, durability, and fault trends of 160 survey meters, spanning ten different models. They were calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) in Nigeria over a decade (2012-2023) using an X-Ray Beam Irradiator Model X80-225K and Cs-137 irradiator (OB6) with a PTW reference spherical chamber traceable to the IAEA SSDL in Seibersdorf, Austria. The calibration stability of each model was evaluated, revealing that models like Instrument A and Instrument B demonstrated high reliability with calibration factors close to the ideal value of 1, while models like Instrument C exhibited higher variability, suggesting less consistent performance for dose rate monitoring. Fault analysis showed that the most common issues were related to the battery compartment, indicating a need for improved handling practices. Correlation analysis reveals no statistically significant correlation between calibration factor and age of survey meter across the analysed models. The study concludes that regular calibration, proper handling, and user training are crucial for maintaining the accuracy and longevity of radiation detectors.

Keywords

Radiation Detectors, Survey Meters, Calibration Stability, Fault Trends, Radiation Safety, Maintenance Strategies, Handling Practices

1. Introduction

Radiation detectors are essential for measuring radiation by converting it into electrical signals or pulses, facilitating quantitative analysis [1]. Common types of survey meters used for personal and environmental radiation monitoring include ionization chambers, Geiger-Müller (GM) counters, and scintillation counters [2]-[5]. Modern digital survey meters utilize GM detectors filled with gas to detect gamma, X-ray, and beta radiation. These meters work on the principle that radiation ionizes the gas within the detector tube, creating ions proportional to the radiation's intensity [6] [7]. Portable, handheld, battery-operated radiation detectors are commonly used for area monitoring, contamination detection, and radiation safety. They help localize radioactive sources and prevent illicit trafficking, which is widely utilized by emergency responders, law enforcement, firefighters, and healthcare professionals. However, survey meters differ in energy dependency, stability, durability, and task suitability, making it challenging for users to choose the most appropriate devices, balancing durability, maintenance, and accuracy.

To ensure reliability, radiation monitoring instruments must be calibrated under standardized conditions before initial use and periodically thereafter [8] [9]. Calibration is the process of determining a device's response in relation to actual radiation levels under controlled conditions [8]. Studies such as [10] have highlighted the need for calibration by revealing significant variations in readings among different survey meter models when measuring natural background radiation. [11] identified sensitivity declines in Geiger-Müller survey meters after prolonged use, underscoring the importance of regular calibration for maintaining accuracy.

In Nigeria, the National Institute of Radiation Protection and Research (NIRPR), a technical arm of the Nigerian Nuclear Regulatory Authority (NNRA), operates the Secondary Standard Dosimetry Laboratory (SSDL). The SSDL is responsible for maintaining and disseminating radiation standards through the calibration of radiation detectors. The Nigeria Basic Ionizing Regulations (NiBIRR), 2003 [9], requires all users of ionizing radiation to calibrate their detectors annually. Therefore, each year, the SSDL calibrates numerous radiation survey meters of different models and makers used across healthcare, emergency services, research, industrial processing, border control, etc. Ensuring these devices perform according to specifications is challenging due to substantial repair, maintenance, and calibration needs.

There is a critical need to understand the performance, reliability, repair and maintenance needs of radiation detectors, which are vital for radiation safety, emergency response, and regulatory compliance across various sectors in Nigeria.

This is because there is no adequate data on the faulty trends and calibration behavior of these detectors over a period. This research retrospectively assesses the fault trends and calibration behaviour of commonly used radiation detectors in Nigeria, focusing on the performance of survey meters over a decade in relation to their age. The findings will provide critical empirical data that can enhance calibration techniques, maintenance protocols, and equipment reliability. The identification of faulty trends in survey meters will provide valuable information for manufacturers and consumers. The results can assist regulatory bodies and organizations in optimizing investments by providing explicit recommendations for choosing models that balance cost-effectiveness with long-term reliability, thereby minimizing the risk of inaccurate radiation measurements and ensuring adherence to safety standards. The result may also establish the basis for future improvements in radiation detector design and durability, particularly important in resource-constrained environments where environmental and operational factors may impact equipment lifespan, thus aiding both national and international efforts to enhance radiation monitoring and safety.

2. Materials and Method

2.1. Equipment and Beam Qualities Used for Calibration

2.1.1. Equipment

X-Ray unit used for calibration was a Hopewell X-Ray Beam Irradiator Model X80-225 kV, equipped with a Comet tube-head, high-voltage generators, a control panel, an electronic power supply, a water cooler, cables, and hoses for operation, an inherent filtration of 1 mm Be, tungsten target material, emergent angles of 40˚ and 15˚ respectively for tube head and from shield respectively, 225 kV maximum tube voltage, and double focus.

The second irradiator was Cs-137 irradiator of type OB 6, manufactured by STS Technology with an initial activity (November 1996) of 740 Gbq.

The reference instrument utilized was the spherical chamber type 32,002, which is employed for radiation protection measurements with traceability to the International Atomic Energy Agency (IAEA) Secondary Standard Dosimetry Laboratory (SSDL) in Seibersdorf, Austria. The measuring energy range for this reference instrument spans from 25 keV to 50 MeV, and it is used in conjunction with the PTW Unidos electrometer at the SSDL to ensure precise radiation measurements.

2.1.2. Beam Qualities and Beam Specifications

The beam qualities utilized for calibration conform to the ISO Narrow beam spectrum defined in ISO 4037:2019 and the Cs-137 beam established at the SSDL for radiation protection calibration. The properties of the ISO narrow beam qualities are outlined in Table 1. The SSDL's beam profile indicates a homogeneously flat X-ray beam with uniform irradiation, maintaining a variation of less than 3%. Environmental conditions, such as temperature and air pressure, are critical factors influencing calibration accuracy; hence, corrections are applied using the temperature-pressure correction factor (K_{TP}), calculated as follows:

$$K_{TP} = \frac{(373.2 + T) * P_0}{(273.2 + T_0) * P} \quad (1)$$

where T is the temperature in the measuring volume (˚C), P is the air pressure at the measuring point (mmHg), T_0 is the reference temperature (20˚C), and P_0 is the reference air pressure (101,325 kPa).

Table 1. ISO narrow beam qualities.

BEAM	kV	11ST HVL	2ND HVL	HOMOGENEITY
N40	**40**	0.083	0.092	0.902174
N60	**60**	0.25	0.26	0.961538
N80	**80**	0.58	0.62	0.935484
N100	**99.5**	1.12	1.16	0.965517
N120	**120**	1.72	1.78	0.966292
N150	**150**	2.42	2.48	0.975806
N200	**196**	4.02	4.15	0.968675

2.2. Calibration Procedure

The calibration process involves positioning the reference standard ionization chamber at a specified distance from the radiation source within the radiation beam, ensuring that the effective point of measurement of the ionization chamber is aligned precisely at the centre of the beam. The electrometer reading in coulombs (nC) is noted, which are subsequently corrected for deviations in temperature and pressure using the K_{TP} correction factor described above. The corrected electrometer reading (R) is then used to calculate the Air Kerma (K_a) at the desired point as follows:

$$K_a = \left(\frac{R * K_{TP} * N_K}{t} \right) * H^*(10) \quad (2)$$

where R = corrected electrometer reading (nC), N_K = chamber calibration coefficient (μGy/nC) K_{TP} = Corrected Temperature Pressure Condition, t = (time) Minute and K_a = μGy/min.

The conversion coefficients $H^*(d)$ to convert air Kerma free in air to the operational quantities $H^*(10)$ for different x-ray energies are as given in ISO 4037 (2019).

2.3. Calibration (Substitution Method)

For a radiation field in which the dose equivalent quantity H of the field at the point of test is known using a reference instrument, the instrument under calibration is placed at this same point by substitution. The measured value of the instrument under calibration is given as MI and the calibration factor of the instrument under calibration NI is obtained by

$$NI = H/MI \quad (3)$$

where NI is the calibration factor of the instrument under calibration (under reference conditions); MI is the measured value of the instrument under calibration, corrected for reference conditions and H is the conventional true value of the dose equivalent quantity measured using reference instrument.

2.4. Uncertainties of Measurements

Uncertainties of measurement are expressed as relative standard uncertainties, and the evaluation of these uncertainties is classified into type A and type B. In most cases, the SSDL of NIRPR usually rejects calibration results with measurement deviation greater than 20% from the true value for radiation protection purposes, except the owner can prove to be knowledgeable enough and make appropriate consideration of the calibration factor during field use. The first step towards uncertainty estimation was the definition of all variables involved in the calibration, and then the uncertainties for each one were evaluated. The evaluation was made following the procedures described by the European Co-operation for Accreditation (EA 1999) [12], IAEA 2008 [13]. The components of the uncertainties identified in the process of calibration were Air Kerma rate determination (true value); Repeatability of the instrument reading; Resolution on the instrument; Positioning of the instrument during calibration; Temperature and pressure etc. The overall uncertainty is expressed as the quadratic sum of the individual uncertainties of each one of its components.

2.5. Assessment of Calibration Factors and Stability of Survey Meters

The calibration factors of 160 survey meters, spanning ten different models, calibrated at the SSDL were retrospectively analyzed over ten years (2012 to 2022). Technical specifications of the survey meters used for the research are given in Table 2. Each model had between 12 to 20 survey meters analyzed, totaling 115 digital and 45 analogue meters. The stability of the calibration factors was assessed using the percentage stability formula in Equation (4):

$$\text{Percentage Stability} = \frac{\text{HCF} - \text{LCF}}{\text{true value}} * 100 \quad (4)$$

where:

Highest calibration factor (HCF) is the highest of the calibration factor obtained within the 10-year period.

Lowest calibration factor (LCF) is the lowest of the calibration factor obtained within the 10-year period.

2.6. Correlation of Calibration Factors with Age

To assess the correlation between the age of survey meters and their calibration factors, three meters from each model were selected. The trend of the average calibration factor for each model was evaluated over ten years, and statistical analysis such as correlation coefficient and p-value were conducted to determine the correlation between age and calibration factor variability.

Table 2. Technical specifications.

	Radiation Type	Energy Range	Dose Rate Range	Alarm	Operating Temperature	Humidity	Weight	Dimensions	Detector	Manufacturer
Instrument D	Gamma	50 keV - 1.3 MeV	0.05 µSv/h - 100 mSv/h	Yes	−20˚C to +50˚C	20% to 90%	160 g	9.6 × 3.1 × 6.1 cm		Thermo Scientific
Instrument A	Gamma, X-rays, Beta radiation with an external probe	50 keV - 1.3 MeV	0.01 µSv/h - 10 Sv/h		−30˚C to +55˚C			(92 × 199 × 44) mm		Mirion Technologies
Instrument B	Gamma, X-rays	50 keV - 3 MeV	0.01 µSv/h - 10 Sv/h	Audible, visual	−30˚C to +55˚C		610 g	(92 × 199 × 44) mm	GM tube	Mirion Technologies
Instrument E	Alpha, Beta, Gamma, X-ray		0.01 µSv/h to 100 mSv/h	Audible, vibration, visual	−25˚C to +60˚C		0.17 kg	(10 × 6.7 × 3.3) cm	GM tube	Mirion Technologies
Instrument F	Gamma, X-rays	50 keV - 3 MeV	0.05 µSv/h - 99.99 mSv/h	freely adjustable	−25˚C to +55˚C		570 g	88 × 185 × 42 mm	GM tube	Mirion Technologies
Instrument C	Gamma	60 keV to 1.3 MeV	0.01 µSv/h to 250 µSv/h	Yes	−20˚C to +50˚C	20% to 90%	160 g	(110 × 67 × 62) mm	NaI(Tl)	Thermo Scientific
Instrument G	Gamma	17 keV - 1.3 MeV	0 - 2 mS/h	LED, sound, vibrator			300 g	(13 × 7 × 13) cm	Pancake GM tube	Thermo Scientific
Instrument H	Gamma, X-rays	50-2000 keV	0 - 10,000 µSv/h 0 - 1000 µSv/h 0 - 100 µSv/h 0 - 10 µSv/h	Audible, visual	−20˚C to +50˚C		1.73 kg	(11.18 × 19.69 × 15.88) cm	GM tube	
Instrument I	Gamma, X-rays	80 - 2000 keV	0 - 10,000 µSv/h 0 - 1000 µSv/h 0 - 100 µSv/h	Audible, visual	−20˚C to +50˚C	Non-condescending 95%	1.73 kg	(11.18 × 19.69 × 15.88) cm	GM tube	
Instrument J	Alpha, Beta, Gamma	Dependent on detector	Dependent on detector		−20˚C to +50˚C	Non-condescending 95%		(16.5 × 8.9 × 21.6) cm	GM, Scintillation	

2.7. Assessment of Fault Trends and Durability

The fault trends of survey meters were evaluated by examining all the faulty survey meters brought to the SSDL for repair or calibration without considering the manufacturer or model. Fault types and their potential causes were identified and recorded for 2021 to 2023.

Durability was assessed by tracking the initial number of each model of survey brought for calibration in 2012 noting the serial numbers and comparing the initial number of survey meters with those available for calibration in 2022, typically the number of survey meter per model in this test ranges from 8 to 12 per model. Follow-up phone calls and client facility inspections were conducted to ascertain the status of survey meters not received for calibration. The assessment provided insights into the durability and maintenance requirements of various models.

3. Results

3.1. Long-Term Stability

Results of the evaluation of the long-term stability, which is indicative of how stable measurements with the meter are over time, are presented in Table 3 and Figure 1 for the various models of Survey meters used.

Table 3. Stability of survey meters.

	Highest CF	Lowest CF	Average % Stability	Std of % Stability	Range of % Stability	Max % Stability	Min % Stability
Instrument D	1.2	0.89	9.11	4.25	14	15	1
Instrument A	1.03	0.92	7.11	2.7	6	9	3
Instrument B	1.03	0.91	5.7	2.2	6	9	3
Instrument G	1.06	0.89	5.44	3.78	11	12	1
Instrument H	1.07	0.9	4.21	3.36	11	12	1
Instrument I	1.04	0.94	4.38	1.61	5	6	1
Instrument J	1.07	0.95	3.72	2.27	7	8	1
Instrument F	1.05	0.81	5.46	4.24	16	17	1
Instrument C	1.32	0.94	26.44	6.83	18	38	20
Instrument E	1.06	0.81	11.73	4.9	14	18	4

The stability analysis of 10 different models of radiation survey meter provides valuable insights into their response to calibration. Meters, such as Instrument A (highest CF: 1.03, lowest CF: 0.92), Instrument B (highest CF: 1.03, lowest CF: 0.91), Instrument G (highest CF: 1.06, lowest CF: 0.89), Instrument H (highest CF: 1.07, lowest CF: 0.90), and Instrument I (highest CF: 1.04, lowest CF: 0.95), indicated calibration factors (CFs) closest to the ideal value of 1. These models also exhibit relatively low average % stability values, with Instrument I showing the lowest average % stability (4.56) and a standard deviation of 1.70, indicating

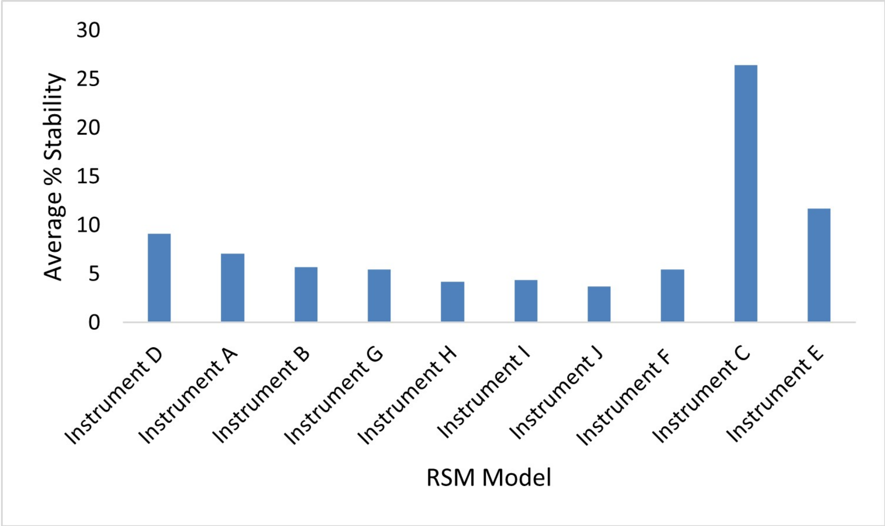

Figure 1. Average % stability of different survey meters.

high reliability and consistency. Similarly, Instrument H has an average % stability of 4.40 with a standard deviation of 3.68, while Instrument G shows an average % stability of 5.44 and a standard deviation of 3.78. The narrow range of % stability in these models (e.g., Instrument I: 4.38, Instrument H: 4.21) further underscores their stable performance under varying conditions and Instrument D (highest CF: 1.20, lowest CF: 0.89) showing average % stability of 9.11.

Conversely, models with higher CFs, such as Instrument C (highest CF: 1.32, lowest CF: 0.94) tend to have higher average % stability value (26.44) larger variability (standard deviations of 6.83. Their performance is less consistent in the standard radiation beams, as indicated by the wider range of % stability (e.g., Instrument C: 18).

3.2. Durability of Radiation Survey Meters

Table 4 presents the durability of 10 different models of radiation meters (RSMs) initially calibrated in 2012/2013 and their functional status in 2021/2022. The Instrument A model shows the highest durability, with 87.5% of the devices still in use after 10 years, followed by the Instrument E at 76.92%. The Instrument C and Instrument B models show moderate durability, with 60% and 50% still in use, respectively. The Instrument D has 38.46% of the meters still functional, while both Instrument H and Instrument I models have 22.22% still in use. The Instrument F and Instrument J models demonstrate lower durability with 15.38% and 14.28% still in use, respectively, while the Instrument G model showed the lowest durability, with only 10% of the devices remaining functional after 10 years. Figure 2 shows the percentage durability of the survey meters over a period of 10 years.

3.3. Fault Trend of Commonly Used Radiation Detectors

The common fault trend for radiation detectors from 2021 to 2023 shows varying numbers of survey meters received, calibrated, and found faulty each year. In

Table 4. Durability of 10 different models of survey meters.

RSM	RSM Calibrated 2012/1013	RSM still in use 2021/2022	% Still in Use 2021/2022
Instrument G	10	1	10
Instrument J	14	2	14.28
Instrument F	13	2	15.38
Instrument H	18	4	22.22
Instrument I	18	4	22.22
Instrument D	13	5	38.46
Instrument B	10	5	50.00
Instrument C	10	6	60.00
Instrument E	26	20	76.92
Instrument A	8	7	87.5

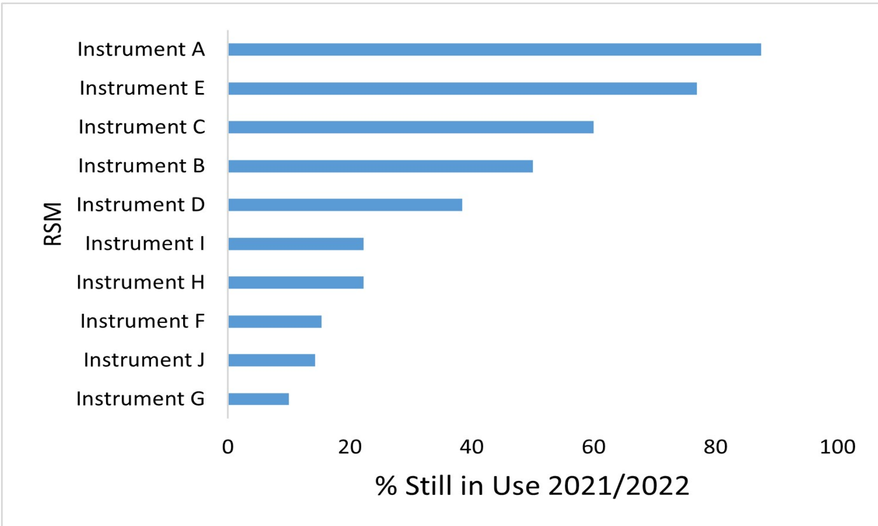

Figure 2. Percentage durability of radiation survey meters over 10 years.

2021, 656 meters were received, 604 were calibrated, and 52 were faulty. In 2022, 613 meters were received, 546 were calibrated, and 57 were faulty, indicating a slight increase in faults. By 2023, 690 meters were received, 651 were calibrated, and 39 were faulty, showing a decrease in faults compared to the previous years. The analysis of the common faults in survey meters from 2021 to 2023 highlights that "Battery Compartment" faults are the most frequent, with a total of 36 instances over the three years, indicating recurring issues related to power supply and battery connection. "Abnormal Response" faults are also prevalent, totaling 31 instances, suggesting consistent issues with device calibration or detector sensitivity. "No Response to Power Botten" faults, totaling 17 cases, bad detector with 14, cases bad screen with 12 cases and "Faulty Board," with 10 cases. Other faults, such as "Bad Potentiometer and Sticky Needle" and "Faulty Board", although less frequent, point to specific failures in key components. Figure 3 shows the total common in the survey meters from 2021 to 2023.

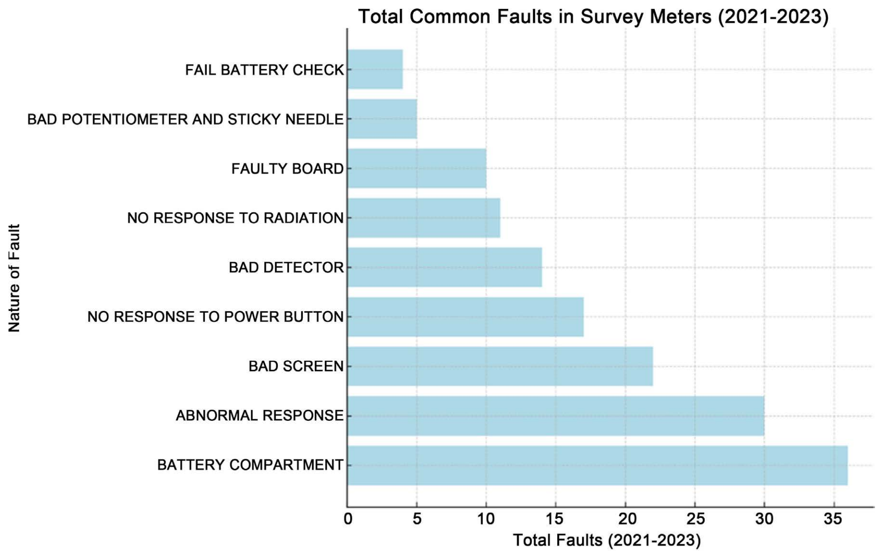

Figure 3. Total common faults in survey meters.

3.4. Correlation of Calibration Factors with Age

Table 5. Correlation coefficient and P value of the different models of survey meters.

SURVEY METER MODEL	Correlation Coefficient	P-Value
Instrument D	−0.29	0.388
Instrument E	0.40	0.219
Instrument G	0.55	0.100
Instrument C	−0.23	0.502
Instrument B	0.03	0.937
Instrument F	0.02	0.953
Instrument A	−0.23	0.524
Instrument J	−0.16	0.648
Instrument H	0.37	0.265
Instrument I	0.57	0.065

Table 5 reveals a correlation analysis of calibration factors among 10 survey meter models. The result indicates that Instrument G and E exhibit moderate positive correlation coefficients of 0.55 and 0.40, accompanied by P-values of 0.10 and 0.22, respectively. Instrument D and C show weak negative correlations of −0.29 and −0.23, respectively, with P-values of 0.39 and 0.50. Furthermore, Instrument B demonstrates a minimal correlation of 0.03, accompanied by a P-value of 0.94. In all models analysed, none of the observed correlations achieved statistical significance at the 0.05 level, suggesting that there is no significant relationship between the calibration factor and age for the devices studied.

4. Discussion

The evaluation of the long-term stability, durability, and fault trends of radiation survey meters (RSMs) presented in this study offers key insights into the performance, reliability, and degradation of commonly used devices over extended periods.

The stability study of the ten RSM models (Table 3) reveals performance variations contingent upon the calibration factor (CF) and the percentage stability over time. Devices with CFs near 1, such as Instrument A, Instrument B, Instrument G, Instrument H, and Instrument I, provide enhanced stability and reduced variability. This signifies that these meters exhibit more consistency in sustaining accurate readings over time, which is essential for guaranteeing dependable radiation protection measures. The Instrument I model exhibits a low average stability of 4.38% and a standard deviation of 1.61, indicating consistent performance with negligible departure from the calibration factor. Likewise, the Instrument H demonstrates a little superior stability percentage (4.21%) alongside a greater standard deviation (3.36), indicating its potential efficacy for long-term applications. It is noteworthy that the three analogue survey meters tested—Ludlum, Instrument H, and Instrument I—exhibited low average percentage stability of 3.72, 4.38, and 4.21, respectively. This could also be attributable to the availability of manual adjustment via potentiometer, whereas most digital survey meters lack provisions for detector sensitivity adjustment. On the other hand, models with higher calibration factors, like the Instrument C (CF: 1.32), demonstrate larger fluctuations in their % stability (26.44%), and standard deviations (6.83), suggesting less reliable performance. The greater variability in these models can pose challenges for ensuring precision in radiation dose measurements, as shown in Figure 1. Instrument C has high sensitivity ability and this is the reason it is mostly used in scrap yards, border crossings, or other public locations that present a significant potential threat by anyone responsible for finding and localizing radiation sources.

The durability analysis in Table 4 and Figure 2 offers significant data regarding the operational condition of radiation survey meters following approximately ten years of utilization. The Instrument A model, with an 87.5% survival rate after a decade, seems to be the most durable, followed by the Instrument E at 76.92%. The elevated percentages indicate that these models are resilient and capable of enduring extended use in field circumstances, hence decreasing the necessity for frequent replacements and cutting operational expenses. In contrast, models such as Instrument G (10%) and Instrument J (14.28%) exhibit markedly reduced durability, suggesting that a substantial percentage of these devices fail to remain operational within a decade. This may be due to design constraints or the models' incapacity to sustain stability over time, as evidenced by the long-term stability analysis. Handling and environmental conditions are also possible reasons. The diminished longevity of these models necessitates more maintenance expenditures and more regular replacements, potentially burdening resources in radiation monitoring initiatives. The Instrument D and Instrument B models have intermediate durability, with ratings of 38.46% and 50%, respectively. This indicates that although their calibration stability is satisfactory, issues like mechanical wear or component failure may adversely affect their longevity. Comprehending these failure processes can inform future design enhancements to prolong the durability of RSMs in operational condition. Defects such as "Battery Compartment" and "Abnormal Response" are the most prevalent issues in Nigeria, which shows that the durability of these survey meters may be affected by factors beyond the manufacturer's control, including handling, storage conditions, and usage patterns. This research does not intend to undermine any company; instead, it offers findings derived from data gathered in our laboratory in Nigeria from 2012 to 2023. The examination of durability and fault trends offers critical insights for decision-makers in radiation safety management, facilitating the identification of models that necessitate less maintenance and exhibit greater reliability, therefore informing investments in cost-efficient and trustworthy equipment.

The fault trend study (**Figure 3**) indicates that "Battery Compartment" faults are the predominant issue, with 36 occurrences documented from 2021 to 2023. This indicates that power supply problems are a persistent concern with survey meters, potentially affecting their functioning and reliability. This indicates that poor battery quality is being used for survey meters and the batteries are left inside the battery compartment during storage of the survey meters leading to the damage of the compartment. Therefore, training and the use of quality batteries are very important. "Abnormal Response" faults, totalling 31 occurrences, indicate sensitivity difficulties with the detector, leading to inappropriate detector functionality and response. The occurrence of "No Response to Power button" and "Faulty Board" faults underscores internal circuitry and power management as critical issues. It is advisable for certain manufacturers to establish maintenance workstations equipped with pertinent survey meter components in Nigeria to facilitate the repair of these meters exhibiting common defects.

The correlation analysis between the calibration factor and age for various survey meter models indicates that age does not significantly affect calibration stability. While certain models, including Instruments G, I and E, exhibit moderate positive correlation coefficients of 0.55, 0.57 and 0.40, respectively, their associated P-values of 0.10, 0.07 and 0.22 surpass the conventional significance threshold of $p < 0.05$, suggesting that these trends lack statistical robustness. Other models, including Instrument D, C, and B, demonstrate weak or negligible correlations (−0.29, −0.23, and 0.03) along with high P-values (0.39, 0.50, and 0.94), indicating a minimal association between calibration factor and aging. The findings suggest that the calibration factor for the majority of models is stable over time, with any observed variations likely attributable to random fluctuations rather than age. Thus, age may not serve as a dependable criterion for the recalibration, performance and accuracy of survey meters. The result underscores the importance of individual performance assessments over the age of instruments in ensuring measurement precision.

5. Conclusions

This study evaluates the long-term stability, durability, and failure trends of commonly used radiation survey meters (RSMs) in Nigeria, highlighting significant performance differences among models. Instruments A and I exhibited calibration factors close to the ideal value with minimal variability, indicating superior stability essential for accurate and reliable radiation measurements. These stable models necessitated moderate maintenance over time, highlighting the balance between performance and upkeep. Instruments C and G demonstrated high sensitivity and effectiveness across various radiation types; however, they exhibited significant calibration variability and were susceptible to frequent malfunctions, especially in battery and sensitivity components, which raises concerns regarding their long-term reliability. Instrument E offers a practical balance between stability and durability, exhibiting moderate failure rates; however, it may fall short of the precision requirements for highly controlled radiation environments. Conversely, models such as Instrument J, despite being less stable and durable, provide cost benefits and simplicity, rendering them appropriate for applications with less stringent requirements. The findings of the study indicate trade-offs among calibration stability, reliability, and cost-efficiency, underscoring the significance of model selection in relation to application requirements and maintenance considerations. Calibration stability exhibited no statistically significant correlation with device age, suggesting that age-based recalibration schedules may be unwarranted. Therefore, individualized calibration protocols for each device model are recommended to maintain accuracy.

The study's limitations include a relatively small sample size of 160 survey meters across ten models, potentially impacting the generalizability of the findings. Furthermore, environmental and operational variables that could affect calibration and fault trends were not systematically regulated. Future research should expand the sample diversity to encompass a wider range of models and manufacturers, as well as integrate controlled environmental testing (e.g., temperature, humidity, usage frequency) to evaluate the external influences on calibration stability with greater precision. A component-level fault analysis enhances the understanding of specific design and environmental factors affecting reliability. Additionally, tracking cumulative radiation exposure may reveal nuanced calibration effects associated with dose accumulation. Establishing regional maintenance centers and implementing targeted user training may mitigate recurring faults and extend device lifespans. These insights provide critical information for optimizing the selection, maintenance, and calibration of RSMs, thereby enhancing the reliability and accuracy of radiation safety management across diverse operational contexts worldwide.

Acknowledgements

We appreciate the International Atomic Energy Agency's (IAEA) assistance under the Coordinated Research Project J02014 (CRP J02014), which made a substantial financial contribution to this study. This support has enhanced our research efforts by offering financial assistance, essential resources, and expert guidance. We extend our gratitude to the team at the Secondary Standard Dosimetry Laboratory, Nigeria, for their expertise and dedication, which were essential to the successful execution of this research. Their commitment and collaboration were crucial for achieving the outcomes outlined in this study.

Author Contribution

Conceptualization: Akerele, O.O. Methodology: Agada, F.A. Formal analysis: Obarhua, S.U. Funding acquisition: Oyeyemi, S.M. Project administration: Alakiu, H.E. Visualization: Ayuba, K.W. Writing—original draft: Olaniyi, D.O. Writing—review and editing: Ofoegbu, E.E. Approval of final manuscript: all authors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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Appendix A: Key to Survey Meter Model

Table Name: Survey meter model

Radeye G10: Instrument D

RDS 120: Instrument A

RDS 200: Instrument B

Radeye B20: Instrument G

NDS 2500: Instrument H

ND 2000: Instrument I

Ludlum 3A: Instrument J

RDS 110: Instrument F

Radeye PRD: Instrument C

RDS 31: Instrument E