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Performance Assessment of Semiconductor Detector Used in Diagnostics and Interventional Radiology at the Nigerian Secondary Standard Dosimetry Laboratory

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Abstract

Radiation doses to patients in diagnostics and interventional radiology need to be optimized to comply with the principles of radiation protection in medical practice. This involves using specific detectors with respective diagnostic beams to carry out quality control/quality assurance tests needed to optimize patient doses in the hospital. Semiconductor detectors are used in dosimetry to verify the equipment performance and dose to patients. This work aims to assess the performance, energy dependence, and response of five commercially available semiconductor detectors in RQR, RQR-M, RQA, and RQT at Secondary Standard Dosimetry for clinical applications. The diagnostic beams were generated using Exradin A4 reference ion chamber and PTW electrometer. The ambient temperature and pressure were noted for KTP correction. The detectors designed for RQR showed good performance in RQT beams and vice versa. The detectors designed for RQR-M displayed high energy dependency in other diagnostic beams. The type of diagnostic beam quality determines the response of semiconductor detectors. Therefore, a detector should be calibrated according to the beam qualities to be measured.

Keywords

Semiconductor Detectors, Optimization of Protection, Calibration, Patient Dose, Diagnostic Radiology

1. Introduction

Dosimetry is important in diagnostics and interventional radiology for the verification of equipment performance and the optimization of patient dose [1]-[3]. Ionization chambers and semiconductor dosimeters are used in diagnostic and interventional radiology for dosimetry and quality control (QA) [4] [5]. Semiconductor detectors are now widely used for dosimetry because they are sensitive to radiation, rigid, and do not require temperature and pressure correction, making them suitable for field application [6]. The dosimeter must be calibrated with standard radiation quality of well-defined properties to ensure the accuracy of the measurement. The International Atomic Energy Agency (IAEA) Technical Report Series (TRS) 457 outlines the specific standards and procedures for calibrating dosimeters at the Secondary Standard Dosimetry Laboratory (SSDL) [2]. The standard radiation qualities for diagnostics and interventional radiology, which are characterized by their tube voltage and Half Value Layers (HVLs), are the RQR, RQT, RQA, and RQM [2]. The Nigerian Secondary Standard Dosimetry Laboratory (SSDL), domiciled in the National Institute of Radiation Protection and Research (NIRPR), is responsible for the calibration of dosimeters in Nigeria. The standard of the SSDL is traceable to IAEA Laboratories in Seibersdorf. The Nigerian SSDL calibrates different detectors for diagnostics and interventional radiology using the established radiation qualities from TRS 457. Although there is substantial research on the performance of semiconductor detectors in diagnostic radiology, much of it is from developed regions with advanced healthcare systems [7]. Have established the importance of continuous performance monitoring of these detectors [8]. Further underscore the importance of detector accuracy, noting that inaccuracies can lead to misdiagnoses and affect patient outcomes [1]. Also concluded that the dosimeters evaluated exhibit varying degrees of performance, with some demonstrating high accuracy and reliability in measuring radiation doses in interventional radiology settings. However, there is a notable absence of studies that explore the performance of these detectors in developing countries, particularly in Africa, where factors such as extreme environmental conditions, resource limitations, and varied equipment usage may uniquely impact detector performance. This work aims to investigate the performance of semiconductor detectors used in diagnostics and interventional radiology across different diagnostic radiology radiation qualities at the SSDL in Nigeria. It also includes assessing these detectors in radiological beams for which they were not originally designed or calibrated, providing crucial data that could lead to improved diagnostic accuracy and patient safety in similar settings across the continent.

2. Material and Method

2.1. Hopewell X-Ray Machine

This work used a Hopewell X-ray machine to generate different radiation reference beam qualities. The machine is a dosimetry-grade X-ray machine with a Comet Tube head, generator, and controller. The machine specification includes inherent filtration of 1 mm Be, tungsten target material, emergent angles of 40˚ and 15˚ for tube head and from shield respectively, 225 kV maximum tube voltage, and double focus.

2.2. Exradin A4 Ion Chamber and PTW Electrometer

Standard imaging's Exradin A4 spherical ion chamber, 300 cc was used as the reference dosimeter for establishing the radiation quality beams and dose rate generations. The Exradin A4 was calibrated at the IAEA laboratory in Vienna. PTW UNIDOS electrometer was also used in conjunction with the Exradin A4.

2.3. Semiconductor Dosimeter

Five semiconductor devices were investigated for their response in RQR, RQR-M, RQA, and RQT beams. Some of the devices have more than one detector, while some operate in various selectable modes. The indication and ranges of Dose, HVL, and Tube Voltage of the detectors are shown in Table 1.

Table 1. Semiconductor detectors and their properties.

S/N	Measuring Assembly	Detector/Mode	Indication			Range		
			Dose	HVL	Tube Voltage	Dose (mGy)	HVL (mm Al)	Tube Voltage (kVp)
1	PTW CONNY II (Two modes)	70/100	x	-	-	2E−3 to 9.99E3	-	70 - 100
2		30	x	-	-	5E−3 to 9.99E3	-	30
3	PTW DIADOSE E (Two External Detectors)	40 - 150	x	-	-	1E−4 to 5E6	-	40 - 150
4		25 - 45	x	-	-	1.5E−4 to 13E6	-	25 - 45
5	PTW DIAVOLT UNIVERSAL (Three Modes)	RAD/FLU	x	-	x	5.0E−2 to 5.0E4	-	40 - 150
6		CT	x	-	x	5.0E−2 to 5.0E4	-	40 - 150
7		MAM	x		x	5.0E−2 to 5.0E4	-	22 - 40
8	PIRANHA 657 (With one external detector and one internal detector)	Internal Detector	x	x	x	1.3E−3 to 1.5E3	0.72 - 13	35 - 160
9		DOSE PROBE	x	-	-	1E−7 to 1.5E6	-	-
10	RAYSAFE X2 (External detectors)	RF	x	x	x	1E−3 to 9.99E6	1 - 14	40 - 150
11		MAM	x	x	x	1E−3 to 9.99E6	1 - 14	20 - 50

2.4. X-Ray Beam Qualities

RQR, RQR-M, RQA, and RQT beam qualities were generated using the procedure in IAEA TRS 457 with reference Exradin A4 dosimeter. The added filtration and HVL of the generated RQR, RQA, RQR-M, and RQT are shown in Table 2 and Table 3. The generated beam qualities are within the allowable limit standards prescribed in TRS 457.

Table 2. Added filtration and HVL of RQR and RQA beam qualities.

RQR				RQA			
Beam quality	kV	Added filtration (mmAl)	First HVL (mmAl)	Beam quality	kV	Added filtration (mmAl)	First HVL (mmAl)
RQR 2	40	2.25	1.41	RQA 2	40	7	2.22
RQR 3	50	2.4	1.82	RQA 3	50	12.2	3.85
RQR 4	60	2.4	2.16	RQA 4	60	18.2	5.3
RQR 5	70	2.65	2.65	RQA 5	70	24.4	6.9
RQR 6	80	2.7	3	RQA 6	80	27	8.1
RQR 7	90	2.85	3.4	RQA 7	90	32	9.3
RQR 8	100	3.3	4	RQA 8	100	37	10.3
RQR 9	120	3.6	5	RQA 9	120	40	11.5
RQR10	150	4.2	6.4	RQA 10	150	49.2	13.5

Table 3. Properties of RQM and RQT beam qualities.

RQM Beam Quality				RQT Beam Qualities			
Beam quality	kV	Added filtration (mmAl)	First HVL (mmAl)	Beam quality	kV	Added filtration (mmAl + Cu)	First HVL (mmAl)
RQM 25	25	0.55	0.325	RQT 8	100	3.3 + 0.18	7.1
RQM 28	28	0.5	0.35	RQT 9	120	4.0 + 0.23	8.5
RQM 30	30	0.5	0.392	RQT10	150	4.2 + 0.28	10.35
RQM 35	35	0.52	0.445				

2.5. Dose Rate Generation for the Beam Qualities

The dose rates for different beams from RQR 2 to RQR 10 and RQA 2 to RQA 10 were generated using the Exradin A4 reference ionization chamber. Charges collected from the electrometer for each beam quality were recorded for 2.5, 5, 10, 12.5, and 15 mA selected current at a fixed source-detector distance (SDD) of 1 m. The charges were corrected for temperature and pressure using Equation (1) [2], and the dose rates were calculated using Equation (2) [2].

$$K_{TP} = \frac{\left(273.2 + T\right) \times P_{ref}}{\left(273.2 + T_{ref}\right) \times P} \tag{1}$$

where K_{TP} is the Temperature-Pressure correction factor, P_{ref} and T_{ref} are the Reference Pressure and Temperature respectively from the Exradin A4 calibration certificate, P and T are the Laboratory pressure and Temperature.

$$D_R\left(\text{mGy/s}\right) = N_k\left(\text{mGy/nC}\right) \times R_E\left(\text{nC/s}\right) \times K_{TP} \tag{2}$$

D_R is the dose rate at a particular mAs, N_k is the Reference calibration coefficient from the Exradin A4 calibration certificate and R_E is the Electrometer Reading.

2.6. Assessment of Semiconductor Detector

The responses of the semiconductors were calculated as the ratio of the dose value indicated by the semiconductor detectors to the reference value calculated from the Exradin A4 dose rate. The dose from the reference dosimeter and the response of the dosimeter was calculated using Equation (3) and Equation (4) [2] respectively.

$$D_{Ref} = D_R\left(\text{mGy/s}\right) \times t\left(\text{s}\right) \tag{3}$$

$$\text{Response} = \frac{D_I}{D_{Ref}} \tag{4}$$

where t is the exposure time in seconds, D_{Ref} is the reference dose while D_I is the dose indicated by the semiconductor device. The absolute response deviation in percentage was then obtained for the detectors for all the beams using Equation (5).

$$\text{Response deviation} = \left|100 \times \left(1 - \text{Response}\right)\right| \tag{5}$$

The energy responses of the detectors were also obtained by finding the quotient of the detector response at each energy beam and the detector response at the reference beam as stated in Equation (6) [2].

$$\text{Energy Response} = \frac{R_Q}{R_{ref}} \tag{6}$$

R_Q is the response of the detectors at a particular beam, and R_{ref} is the response of the reference beam. The reference beams are RQR 5 for the RQR beam, RQA 5 for the RQA beam, RQR-M 2 for the RQR-M beam, and RQT 9 for the RQT beam. The energy response of the detectors was plotted against the Half Value Layers of the beam qualities.

2.7. Uncertainty Measurement

The measurement uncertainty was evaluated for each detector in the four diagnostic beam qualities. The uncertainty assessment measurement procedure was based on IAEA TECDOC-1585 [9], and the major sources of uncertainty contributors are type A and type B uncertainties. Type A uncertainty is determined through the statistical analysis of a series of laboratory measurements. Type B uncertainty includes the transferred uncertainty from the calibration coefficients of the reference chamber, as well as long-term stability and detector positioning. The uncertainty in the calibration result is computed by combining the type A and type B uncertainty in the calibration result presented as a 95% confidence interval. In all cases, the expanded combined uncertainty (k = 2) ranges from 3% to 7% for all the dosimeter measurements in the SSDL.

3. Results

This study assessed five semiconductor devices across four diagnostic radiation beam qualities: RQR, RQA, RQR-M, and RQT. The PTW Diavolt Universal (MAM mode) did not respond to radiation in RQR, RQA, and RQT beams, while the PTW Diavolt Universal (CT mode) failed to respond in RQR 2, RQR 3, RQA 2, and RQA 3 and displayed KV over-range (KVO) in RQR 10, RQA 9, and RQA 10. The PTW Diavolt Universal (RAD/FLU mode) exhibited similar issues, not responding in RQR 2 and RQA 2 and displaying KVO in higher energy beams. The PTW Diavolt Universal (CT mode) and the Piranha Dose Probe did not respond to RQR-M beam qualities. The acceptable limit for energy dependency of semiconductor detectors is 5% [10].

Performance of the detectors in RQR Beams: The graph of energy dependency of the detectors in RQR beam qualities against the HVL is shown in Figure 1. The energy dependency of detectors in RQR beams was generally within the acceptable 5% limit except for certain deviations noted in the PTW CONNY II (30 kV), PTW DIADOSE E (24 - 45 kV), and RAYSAFE X2 MAM mography detectors. Specifically, the PTW DIADOSE E exhibited response deviations ranging from 62.77% to 74.97%, and PTW CONNY II (30 kV) indicating significant response at higher energy of 11.95% to18.61% at RQR8 to RQR 10 as shown in Table 4.

Table 4. Response deviation of detectors in RQR beam.

	Beam Energy	RQR2	RQR3	RQR4	RQR5	RQR6	RQR7	RQR8	RQR9	RQR10
Response Deviation (%)	PTW CONNY II^{a}	9.58	5.58	3.79	1.89	1.29	3.37	11.95	16.76	18.61
	PTW CONNY II^{b}	7.20	7.01	7.68	8.00	6.37	5.57	3.44	2.66	3.54
	PTW DIADOSE E^{c}	6.93	2.92	7.57	7.46	4.96	3.15	5.79	3.46	5.90
	PTW DIADOSE E^{d}	62.77	65.32	65.26	66.68	68.79	71.17	73.62	74.16	74.97
	PTW DIAVOLT^{e}			0.67	0.99	0.67	2.37	0.99	4.98	
	PTW DIAVOLT^{f}		2.27	4.45	6.11	3.59	6.39	4.49	7.30	
	PIRANHA 657	5.86	4.90	3.81	1.98	2.42	1.92	1.62	3.48	0.82
	PIRANHA 657^{g}	2.91	2.61	0.90	0.63	1.04	0.68	0.83	1.84	0.45
	RAYSAFE X2 RF	4.72	0.49	3.32	3.86	5.44	5.65	2.66	3.55	5.35
	RAYSAFE X2 MAM	3.09	0.08	1.07	0.94	2.09	5.39	6.05	9.75	7.02

^{a} = 30 kV, ^{b} = 70/100 kV, ^{c} = 40 - 150 kV, ^{d} = 25 - 45 kV, ^{e} = CT, ^{f} = RAD/FLU, ^{g} = Dose Probe.

3.1. Performance in RQA Beams

The energy dependence and response deviations for various detectors across RQA beam qualities in Figure 2 and Table 5 reveal that detectors like the PTW DIADOSE E 40 - 150 kV, PIRANHA 657, and RAYSAFE X2 RF consistently performed within acceptable energy dependencies threshold of 5% and response deviations under 10%. However, other detectors, such as the PTW DIADOSE E 25 - 45 kV, PTW CONNY II, and RAYSAFE X2 MAM, showed higher energy dependencies and greater variability in response, indicating less stability and accuracy across different RQA beam qualities.

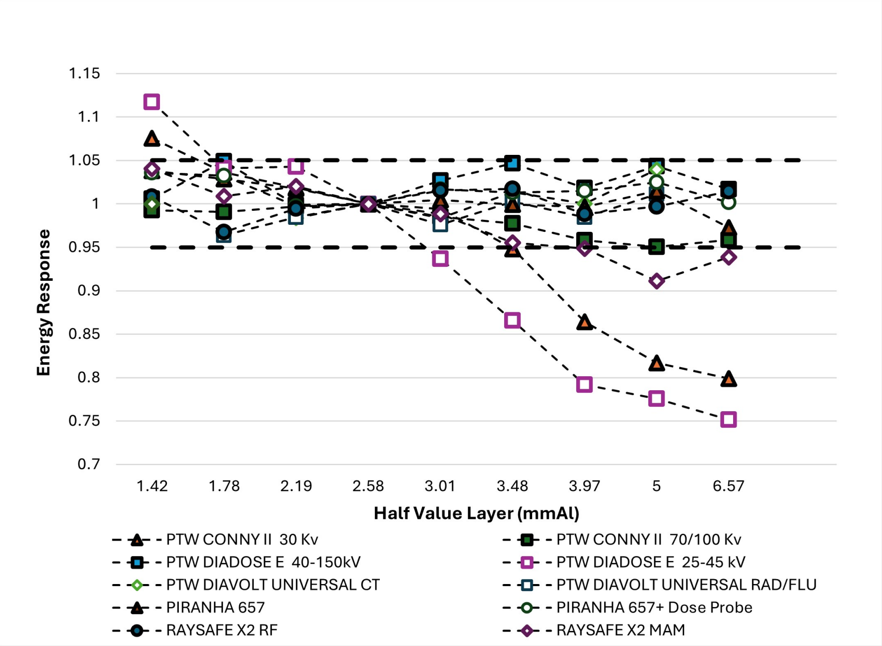

Figure 1. Energy response in RQR beam.

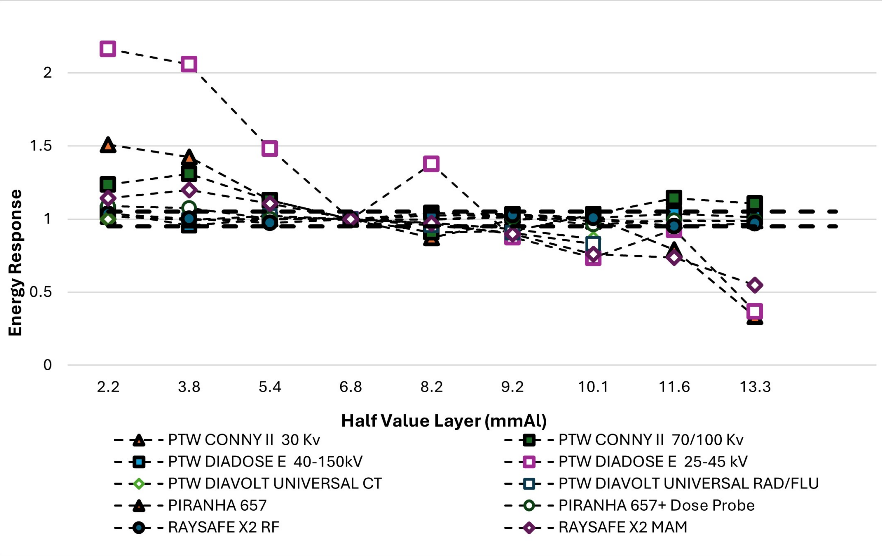

Figure 2. Energy response in RQA beam.

Table 5. Response deviation of detectors in RQA beam.

	Beam Energy	RQA2	RQA3	RQA4	RQA5	RQA6	RQA7	RQA8	RQA9	RQA10
Response Deviation (%)	PTW CONNY II[a]	15.97	9.60	13.12	23.08	32.92	23.34	22.26	39.16	74.35
	PTW CONNY II[b]	14.81	21.72	4.85	7.03	15.45	14.72	4.07	6.27	2.73
	PTW DIADOSE E[c]	2.40	6.57	2.39	2.20	1.74	0.95	1.38	1.14	0.93
	PTW DIADOSE E[d]	58.81	60.81	71.79	80.95	73.80	83.32	86.00	82.34	92.99
	PTW DIAVOLT[e]			15.84	14.31	11.28	6.29	1.45		
	PTW DIAVOLT[f]		20.20	23.58	20.91	15.65	9.60	0.21		

Continued

PIRANHA 657	2.15	4.55	3.77	3.99	4.46	1.60	5.58	5.40	5.22
PIRANHA 657[g]	5.48	4.04	2.93	3.19	3.71	2.02	6.81	4.09	4.54
RAYSAFE X2 RF	6.51	2.98	0.11	2.78	5.24	5.59	3.64	2.18	0.16
RAYSAFE X2 MAM	4.82	9.85	1.48	8.30	11.08	17.64	30.32	32.34	49.88

[a] = 30 kV, [b] = 70/100 kV, [c] = 40 - 150 kV, [d] = 25 - 45 kV, [e] = CT, [f] = RAD/FLU, [g] = Dose Probe.

3.2. Performance in RQR-M Beams

The energy dependence of PTW CONNY II 30 kV, PTW DIADOSE E 25 - 45 kV, PIRANHA 657, and RAYSAFE X2 MAM as presented in Figure 3, reveals reliable performance in RQR-M beams, all maintaining energy dependencies below 5%. In contrast, PTW DIADOSE E 40 - 150 kV shows higher variability, peaking at 16.31% for RQR-M 1, while PTW DIAVOLT UNIVERSAL MAM exceeds 5% in RQR-M 3 and RQR-M 4. Notably, PTW CONNY II 70/100 kV exhibits significant instability, with energy dependencies ranging from 49% to 221%. Response deviations as shown in Table 6 are below 10% for PTW CONNY II 30 kV, PTW DIADOSE E 25 - 45 kV, PTW DIAVOLT UNIVERSAL MAM, PIRANHA 657, and RAYSAFE X2 MAM, while RAYSAFE X2 RF show moderate deviations (10% - 30%), and PTW DIADOSE E 40 - 150 kV and PTW CONNY II 70/100 kV exceed 50%, indicating limited precision in RQR-M beams.

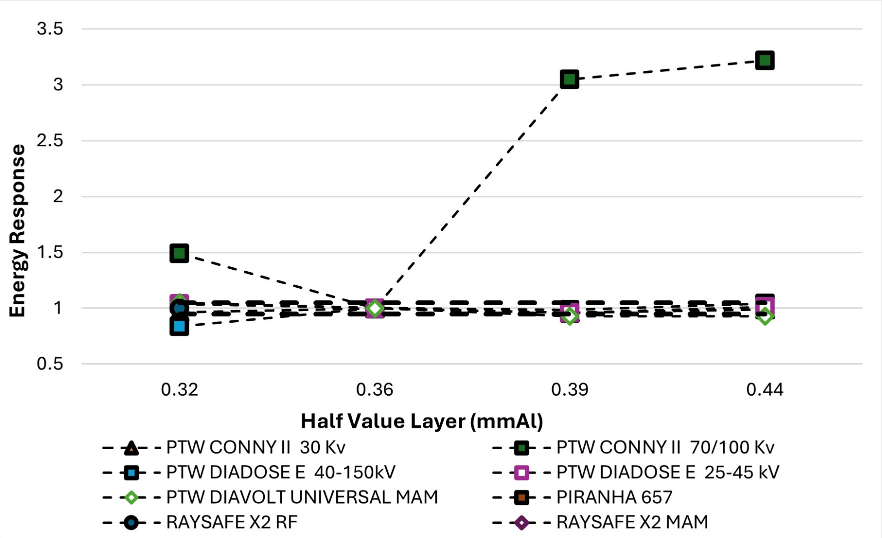

Figure 3. Energy response in RQR-M beam.

Performance in RQT beams

In RQT beams, the energy dependence analysis indicates that PTW DIADOSE E 40 - 150 kV, PTW DIAVOLT UNIVERSAL CT, PTW DIAVOLT UNIVERSAL RAD/FLU, PIRANHA 657, PIRANHA 657 dose probe, and RAYSAFE X2 RF maintain energy dependencies below 5% as presented in Figure 4. In contrast, PTW CONNY II 30 kV, PTW CONNY II 70/100 kV, PTW DIADOSE E 24 - 45 kV,

Table 6. Response deviation of detectors in RQR-M beam.

	Beam Energy	RQR-M1	RQR-M2	RQR-M3	RQR-M4
Response Deviation (%)	PTW CONNY II 30 kV	3.81	8.01	3.37	6.74
	PTW CONNY II 70/100 kV	58.77	72.34	15.65	11.03
	PTW DIADOSE E 40 - 150 kV	57.79	88.53	85.69	96.49
	PTW DIADOSE E 25 - 45 kV	2.34	1.48	5.53	0.49
	PTW DIAVOLT UNIVERSAL MAM	6.92	1.99	5.53	5.20
	PIRANHA 657	6.68	2.12	2.14	1.12
	RAYSAFE X2 RF	29.58	29.09	26.71	20.37
	RAYSAFE X2 MAM	3.98	1.43	2.00	2.74

and RAYSAFE X2 MAM exhibit energy dependencies exceeding 5%. In Table 7, response deviations of PTW DIADOSE E 40 - 150 kV, PTW DIAVOLT UNIVERSAL CT, PTW DIAVOLT UNIVERSAL RAD/FLU, PIRANHA 657, PIRANHA 657 dose probe, and RAYSAFE X2 RF are below 5%, while PTW CONNY II 30 kV, PTW CONNY II 70/100 kV, PTW DIADOSE E 25 - 45 kV, and RAYSAFE X2 MAM have deviations above 10% in RQT beams.

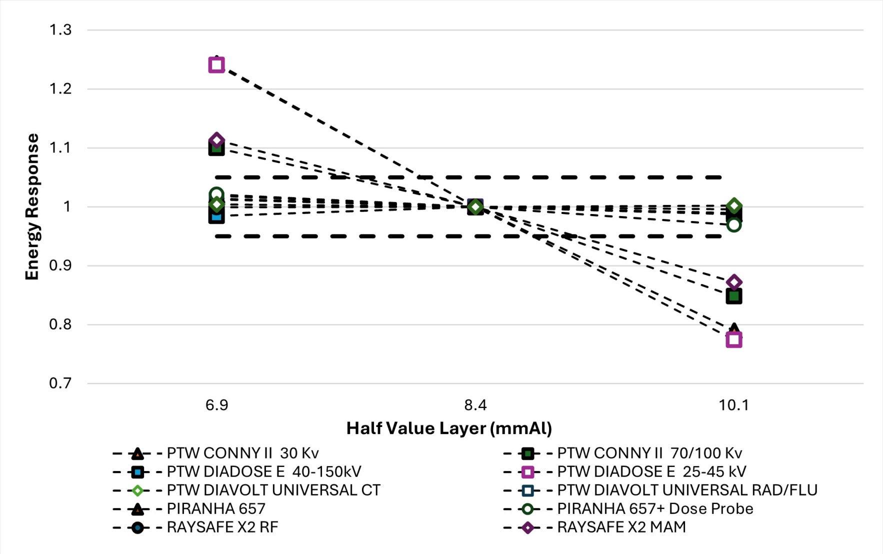

Figure 4. Energy response in RQT beam.

Table 7. Response deviation of detectors in RQT beam.

	Beam Energy	RQT8	RQT9	RQT10
Response Deviation (%)	PTW CONNY II 30 kV	24.84	39.55	52.27
	PTW CONNY II 70/100 kV	9.01	17.29	29.86
	PTW DIADOSE E 40 - 150 kV	3.57	2.05	3.13
	PTW DIADOSE E 25 - 45 kV	78.74	82.86	86.73

Continued

PTW DIAVOLT UNIVERSAL CT	4.09	2.70	
PTW DIAVOLT UNIVERSAL RAD/FLU	4.75	3.48	
PIRANHA 657	0.62	1.20	2.46
PIRANHA 657+ Dose Probe	1.12	0.94	4.03
RAYSAFE X2 RF	3.10	3.22	2.80
RAYSAFE X2 MAM	15.23	23.85	33.61

4. Discussion

The energy dependency and response of all the semiconductor detectors tested in this research vary for different beam qualities. As discussed below, the variation determines the semiconductor suitability for the different beam qualities.

PTW Diavolt Universal

MAM mode

The PTW Diavolt Universal MAM's complete lack of response suggests that this detector is highly specialized and not versatile across the broad range of diagnostic radiology beams. It may have an internal threshold that was not met by the tested beams, or it could be optimized for a very narrow range of energy levels typical of mammography, which often requires lower-energy X-rays. This lack of response implies that PTW Diavolt Universal in Mammo mode is not suitable for general diagnostic radiology.

CT mode

The PTW Diavolt Universal CT detector showed a clear limitation in its energy range, failing to respond to lower-energy beams (RQR2, RQR3, RQA2, and RQA3) and exhibiting KV over-range (KVO) errors at higher energies (RQR 10, RQA 9, RQA 10). This behavior suggests that the detector is designed for a specific range of energies typical of CT imaging. The KVO errors indicate that the detector's design may not accommodate the full spectrum of energies encountered in a broader diagnostic setting, making it unsuitable for use outside of CT-specific applications.

RAD/FLU Mode

The PTW Diavolt Universal RAD/FLU detector exhibited similar limitations to the CT variant, with no response in lower-energy beams (RQR 2, RQA 2) and over-range errors in higher-energy beams (RQR 10, RQA 9, RQA 10). This suggests that the RAD/FLU detector is designed for moderate energy levels typical of general radiography and fluoroscopy, where mid-range X-rays are used.

PTW CONNY II

30 kV mode

The PTW CONNY II 30 kV detector showed significant variability in energy dependency, with deviations exceeding 5%, especially in higher-energy RQR beams, RQA and RQT. Response deviations also surpassed 10% in these beam conditions, indicating that the detector may not be well-suited for diagnostic beam outside of mammography beam. The high variability suggests that the detector is sensitive to changes in beam quality, which could lead to inaccuracies if used in a broader diagnostic context without proper calibration. This detector seems optimized in mammography beams where it can provide stable and accurate measurements, necessitating the need to adhere to manufacturer specifications when deploying it in clinical environments.

70/100 kV mode

This detector demonstrated stable performance in RQR beams, maintaining energy dependencies within 5%. However, it showed significant variability in RQA, RQT, and RQR-M beams, with response deviations often exceeding 10%. This variability suggests that while the detector performs reliably in mid-range energy levels typical of general radiography, it struggles with the broader spectrum of energies encountered in other diagnostic radiology procedures.

PTW DIADOSE E

40 - 150 kV probe

The PTW DIADOSE E 40 - 150 kV detector performed well across RQR, RQA, and RQT beams, maintaining energy dependencies below 5% and response deviations under 10%, suggesting that the detector is suitable for the energies for which it is designed. However, in RQR-M beams, the detector exhibited significant response deviations, ranging from 57.79% to 96.49%. This indicates that while the detector is versatile across standard diagnostic beam qualities, it is not desirable in RQR-M beams.

25 - 45 kV probe

This detector showed strong performance in RQR-M beams, with energy dependencies below 5% and response deviations under 10%. However, it exhibited significant energy dependencies and wider response deviations exceeding 10% in higher-energy beams, indicating that the detector is highly specialized for mammography beams.

PIRANHA

PIRANHA 657

The PIRANHA 657 detector demonstrated robust performance across all tested beam qualities, consistently maintaining energy dependencies below 5% and response deviations under 10%. This indicates a high degree of versatility and reliability, making the PIRANHA 657 suitable for a wide range of diagnostic radiology applications. Its consistent performance suggests that it is capable of providing accurate measurements across various diagnostic radiology applications.

PIRANHA 657 with Dose Probe model

The PIRANHA 657 Dose Probe variant also exhibited strong performance across all beam qualities, with energy dependencies within 5% and response deviations below 10%. However, there is more than 5% energy dependency in RQA 2 and RQA 3.

RAYSAFE X2

RAYSAFE X2 RF

The RAYSAFE X2 RF detector demonstrated generally good performance across most beam qualities, maintaining energy dependencies below the 5% threshold for RQR, RQA, and RQT beams. This indicates that the detector is suitable for the typical energy levels encountered in radiography. However, mammography beams, such as those simulated by RQR-M beams, the RAYSAFE X2 RF exhibited significant response deviations, sometimes exceeding 10%. This variability implies that while the detector is effective for conventional radiographic and fluoroscopic applications, it may not be as reliable in mammography beams.

RAYSAFE X2 MAM

The RAYSAFE X2 MAM detector is designed specifically for mammography. The detector performed reliably in RQR-M beams, maintaining energy dependencies below 5%, which is critical for the accurate measurement of low-energy radiation typical in mammography. However, when used outside its specialized application, such as in RQR beams, the RAYSAFE X2 MAM exhibited significant energy dependencies exceeding 5% and response deviations above 10%, indicating that the detector's calibration is highly tuned to the lower energies used in mammographic imaging.

5. Conclusion

The comprehensive evaluation of twelve semiconductor detectors across various diagnostic radiation beam qualities (RQR, RQA, RQR-M, and RQT) provided critical insights into their performance, energy dependency, and response deviations, crucial for determining their suitability in specific clinical applications. Detectors like the PTW Diavolt Universal RF, MAM and CT were highly specialized, showing limitations in versatility, particularly failing to respond to certain beams or exhibiting over-range errors at higher energies. This indicates their use should be confined to specific applications like RF, mammography or CT. Conversely, the PIRANHA 657 and its dose probe variant displayed robust, reliable performance across all tested beam qualities, maintaining low energy dependencies and response deviations, making them versatile for a broad spectrum of radiological applications. The PTW CONNY II and DIADOSE E detectors performed well in their optimized energy ranges but struggled outside their designed beam conditions, indicating a need for careful application. The RAYSAFE X2 detectors generally performed well but showed significant deviations in some beam qualities outside their designed beam. This demonstrates that while some semiconductor detectors are versatile and reliable across multiple diagnostic applications, others are highly specialized and require careful selection and understanding of the detector operation for optimal performance. Knowledge of the specific strengths and limitations of each detector is essential for enhancing diagnostic accuracy, optimizing radiation protection, and ensuring patient safety in radiological practices.

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Conflicts of Interest

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

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