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Note

Retrofitting an environmental monitor with a silicon photomultiplier sensor

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Abstract

We report on the retrofitting of a standard DP2 environmental radiation monitor replacing the photomultiplier tube with a silicon photomultiplier (SiPM). The use of a SiPM has several advantages for a hand-held radiation monitor, including convenient low-voltage operation and physical robustness. We report the detection efficiency and alpha/beta discrimination performance of the modified probe compared with an unmodified version.

Keywords: radiation monitoring, silicon photomultiplier, alpha beta discrimination

(Some figures may appear in colour only in the online journal)

1. Introduction

The routine handling of radiation sources represents a potential risk of contamination of the workplace and subsequent exposure of workers. The majority of the radiation monitoring equipment in use today in nuclear facilities, power stations, universities, and hospitals, etc, are based on the established technologies of a scintillating material coupled to a photomultiplier tube (PMT) [1]. The PMT is a well-characterised technology that has been proven in the field for many years. However, the PMT has undesirable properties, such as fragility, high



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cost, and the need to operate at high voltage. PMTs are also inherently sensitive to the presence of magnetic fields, which can be an operational issue in some applications. The recent availability of low-noise silicon photomultipliers (SiPM) provides an alternative sensor technology to the PMT with several operational advantages, namely the robustness of a solid-state device, a much lower operating voltage (~ 25 V compared with ~ 1 kV for a PMT), and a very small form factor. Additionally, SiPMs are generally insensitive to external magnetic fields.

In this note we present a study of the performance of the industry standard Thermo Scientific DP2 surface contamination probe [2] in which the existing PMT sensor was removed and replaced with a low-noise SiPM. We report the detection efficiency of the modified probes, and the effect that the change of optical sensor has on the alpha/beta discrimination properties. The main objective of this work was to study the performance of the retrofitted SiPM sensor as a direct replacement for the existing PMT, and to assess its performance using the existing analogue read-out electronics and multichannel analyser. Although the dual scintillator DP2 probe is capable of operating with pulse shape discrimination (PSD), due to the difference in decay time between the plastic and ZnS scintillators, this is not the normal mode of operation in the field. However, recent reports have described the operation of digital PSD for ZnS/BC400 scintillators coupled to a SiPM read-out [3].

2. Modification of the detector

The surface contamination monitor used in this work was the Thermo Scientific DP2 general purpose Dual Phosphor Probe. The operation and mechanical configuration of both the AP2 and DP2 models of the probe are similar; in the AP2 the detector contains a ZnS(Ag) scintillator which is sensitive to alpha particles. The model DP2 contains an additional polyvinyltoluene (PVT) plastic scintillator layer for added beta particle sensitivity.

The dismantled DP2 probe retrofitted with a SiPM is shown in figure 1, but the components are common between the two models. The probe has a large active surface area of 49cm^2 for detecting incident radiation. The outer surface of the scintillator is covered by a mylar window to shield the photosensor from ambient light while providing minimal attenuation to the highly ionising incident α particles. To support the mylar window a metal grill is used, which reduces the α particle transmission by up to 20%.

2.1. Scintillators

Both the AP2 and DP2 probes utilise a ZnS(Ag) scintillation layer, which is a commonly used material for the detection of α particles [4]. Its high scintillation efficiency makes it particularly suited for use in thin scintillation screens ($\sim 25\text{ mg cm}^{-2}$); however, the screen thickness is limited by the material's opacity to its own emission. The peak emission wavelength of the ZnS(Ag) scintillator is 450 nm.

In the DP2, the plastic support substrate is replaced by a layer of PVT plastic scintillator, type BC400, providing sensitivity to incident β radiation. The peak emission wavelength of the BC400 scintillator is slightly shorter than for the ZnS, at 423 nm. This thin layer of plastic scintillator also exhibits some sensitivity to gamma rays, although without full energy deposition. Conversely, the AP2 monitor, with the absence of the plastic scintillator layer, is only sensitive to α particles detected in the ZnS(Ag) scintillator.

In principle the layered construction of the DP2 in a phoswich-style configuration enables the separation of α or β signatures due to scintillation timing properties of ZnS(Ag) and BC400. The pulse from α events, which results from the inorganic scintillator, is relatively



Figure 1. Left: The opened DP2 probe with the scintillator removed. The PMT has been removed from inside the handle of the probe and replaced with a SiPM array. Right: The SiPM electronics and mounting ready for positioning inside the DP2 probe.

slow with a typical decay time of 110 ns, compared with the β pulses from the PVT with a typical decay time of 2.4 ns [5].

2.2. Silicon photomultiplier

The existing PMT used within each probe was the 29 mm diameter Electron Tubes 9924B, containing an enhanced green sensitive bialkali photocathode [6]. The active area of the optical window was 660 mm². The SiPM used in this work was a SensL J-series SiPM, model MicroFJ60035TSV 2 × 2 array [7]. This was selected as the largest widely available SiPM sensor array that could fit within the existing DP2 housing. The active area of the SiPM array was 12.46 mm × 12.46 mm, with an active area of 155 mm². The spectral quantum efficiency of the two sensors is shown in figure 2. The SiPM's peak maximum quantum efficiency was 38% (peaking at 420 nm), compared with 26% for the PMT (maximised in the range 390–400 nm). A passive read-out circuit (figure 3) was used with the SiPM sensor, containing an impedance matching load resistor that controlled the gain and the pulse decay time, and an RC circuit to filter high-frequency noise from the bias supply line [8].

The SiPM was suspended on a frame within the DP2 handle such that the face was in approximately the same position as that of the PMT window in the original probe. The SiPM and its associated circuit were supported by a 3D-printed mount, as shown in figure 1. The read-out circuit contained a passive RC filter network for the low-voltage bias supply, plus an impedance matching load resistor on the SiPM.

2.3. Data acquisition system and electronics

In normal use the AP2 or DP2 probe is powered and read-out is via an analogue scalar rate-meter; however, for this work an analogue pulse height spectroscopy system (figure 4) was used to allow inspection on the pulse height distributions. The output signal from the unmodified DP2 probe containing the PMT was amplified using an Ortec 142 preamplifier, with pulse

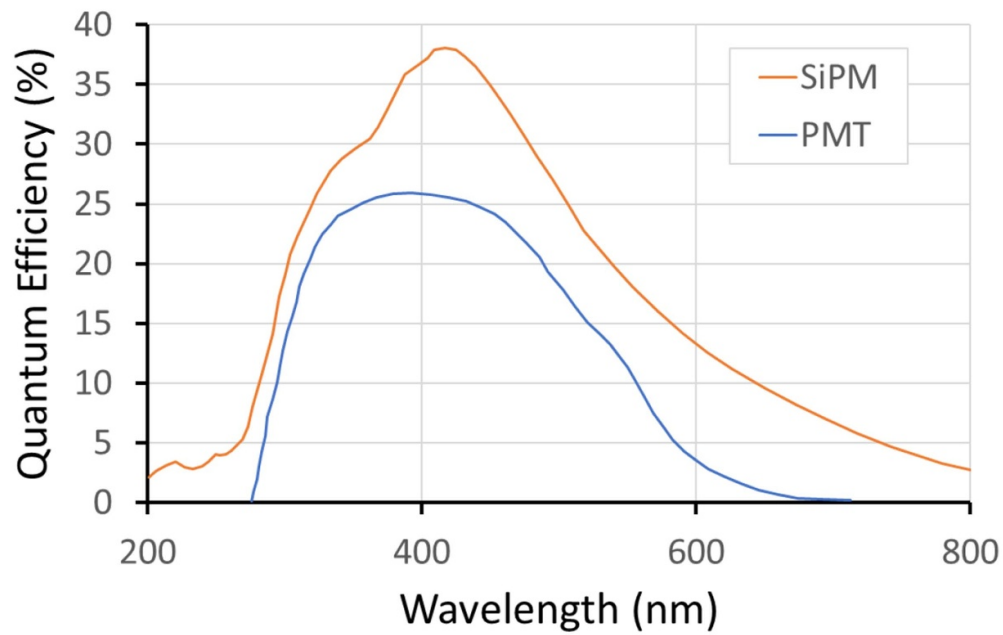


Figure 2. Quantum efficiency vs wavelength for the ET 9924B PMT [6] and the SensL J-series SiPM [7].

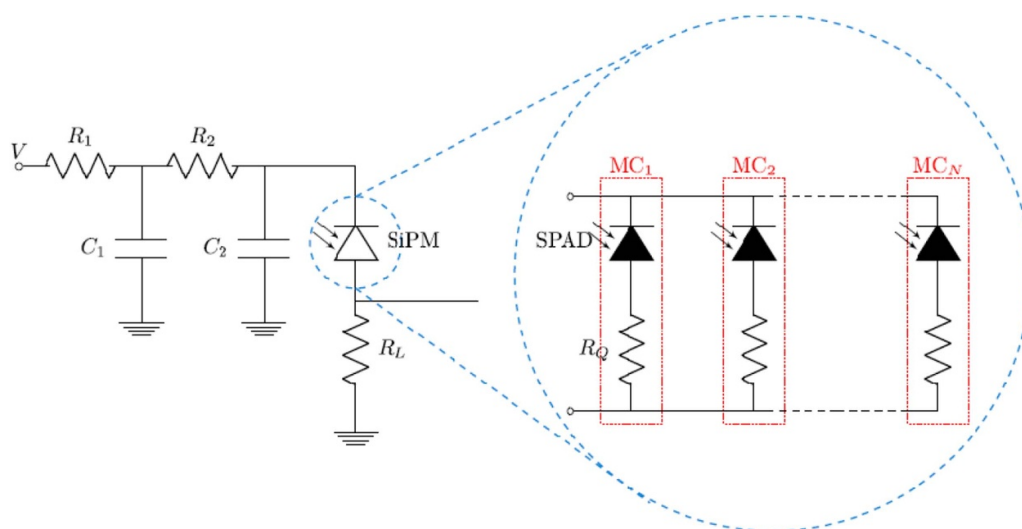


Figure 3. A schematic of the SiPM electrical connection [8], where R_L is the SiPM load resistor. R_1, R_2 and C_1, C_2 act as filters to remove high-frequency noise from the bias voltage.

shaping using a Canberra 2022 spectroscopy amplifier connected to a multi channel analyser (Ortec EasyMCA) [9]. The PMT high voltage was supplied using a Canberra 3102D power

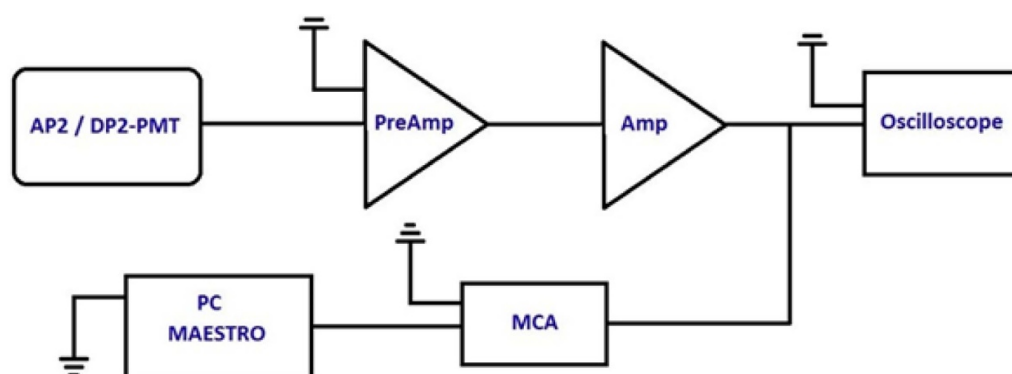


Figure 4. A schematic of the data acquisition system used for pulse height analysis using the PMT-based probe. For the SiPM-based probe the preamp is omitted.

Table 1. Optimum operating settings for the measurements.

Probe	Voltage (V)	Shaping Time (μ s)	Amp. Gain
DP2-PMT	840	0.5	30
DP2-SiPM	26.4	0.5	300

supply. For the probes containing SiPM sensors the same read-out chain was used, except that the preamplifier was omitted due to the larger signal amplitudes. A low voltage of approximately 27 V was supplied to the SiPM via an Ortec 710 Quad bias supply.

3. Experimental measurements

Pulse height spectra were acquired using two sources throughout this work: a ^{241}Am unsealed alpha source with an activity of 58.2 kBq, and a low-activity (3.4 kBq) $^{90}\text{Sr}/^{90}\text{Y}$ β particle source. The $^{90}\text{Sr}/^{90}\text{Y}$ source was a distributed source with a surface area of 10 cm $\times$ 15 cm, which avoided issues with edge effects [10]. The optimum operating settings for the measurements are given in table 1.

Due to the relatively long decay time of the ZnS(Ag) scintillator (0.2 μ s compared with 2.4 ns for the BC400) a shaping time of 0.5 μ s was used to minimise pulse height deficit from the longer pulses [5].

Typical α and β spectra are shown in figure 5(a) for the unmodified probe containing the PMT. In general the alpha signal pulse heights are greater than those from beta particles, due to the higher deposited energies. The dual probe uses this energy difference to distinguish between the two particle types through the use of dual energy windows. Figure 5(a) shows the two defined β and α energy windows, with the beta window extending from the lower level discriminator at channel 15 to channel 200, and the alpha window from channel 380 to the upper limit of the Multi Channel Analyser (MCA). It is important to optimise the position of the two energy windows, especially the separation between the two energy windows, in order to minimise the contamination of each energy window with events of the incorrect type.

The degree of cross-talk (either ^{241}Am signals within the β energy window, or $^{90}\text{Sr}/^{90}\text{Y}$ events in the α energy window) will be dependent on correct positioning of the energy windows, which is also related directly to the detector gain. A common method that is used to

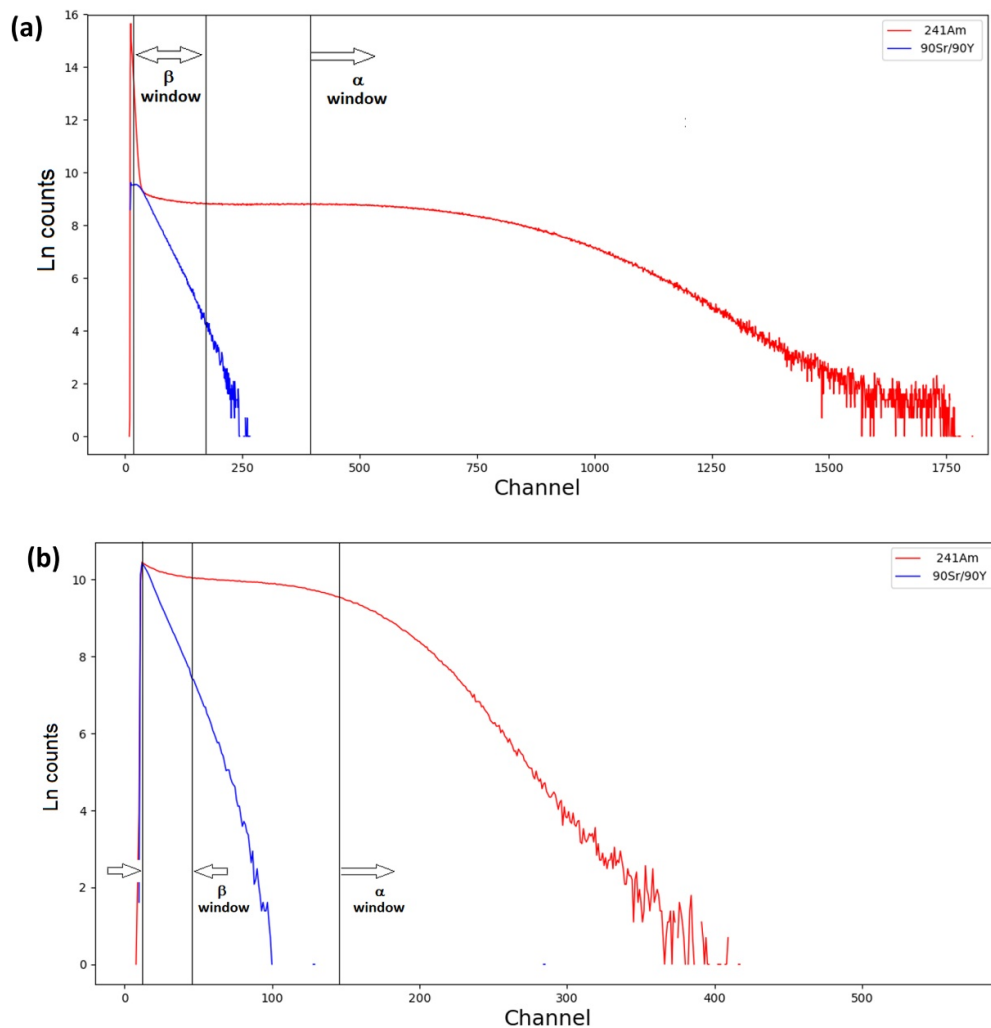


Figure 5. Pulse height spectra of α and β sources acquired in 100 s. (a) Spectra from the unmodified DP2 probe. The beta energy window covers channels 15–200, and the alpha energy window covers channels 380 upwards. (b) Spectra from the SiPM-based DP2 probe. The two energy windows cover reduced channel ranges compared with the PMT due to the lower gain of this detector.

optimise the gain of the probe and the alpha–beta separation is to increase the detector gain by varying the sensor supply voltage [11, 12]. This method can be applied for either the PMT or the SiPM sensors, since both devices have a sensitive gain dependence on the supply voltage. For the PMT the high voltage was varied in the range 700–1100 V. For the SiPM the supply voltage is much smaller: the voltage was varied in the range 25–27 V. This corresponds to varying the over-voltage over a 2 V range above the nominal 24.5 V SiPM threshold voltage. For energy windows with fixed channel numbers, figures 6 and 7 show how the ‘cross-talk signal’ varies as a function of sensor voltage for both the PMT and SiPM probes, when each source is used separately. In each case the minima in the data indicate the optimum operation

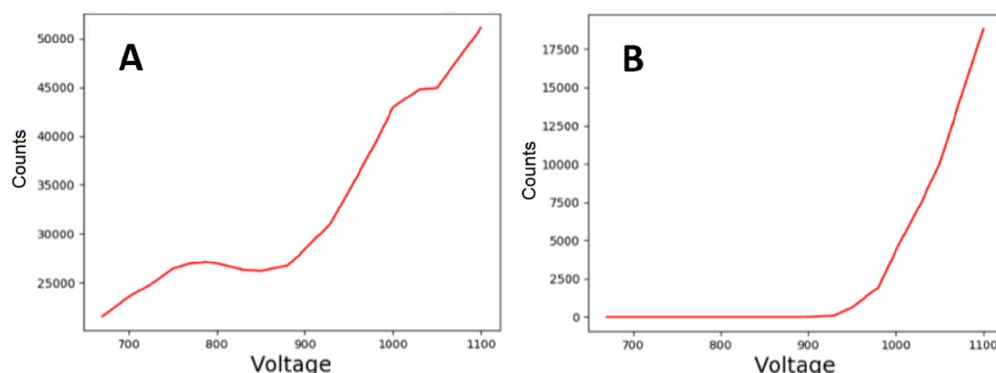


Figure 6. Pulse height response functions acquired using the PMT DP2: A—alpha counts in the beta energy window vs voltage. The dip of the curve determines the optimum operating voltage. B—beta counts in the alpha energy window.

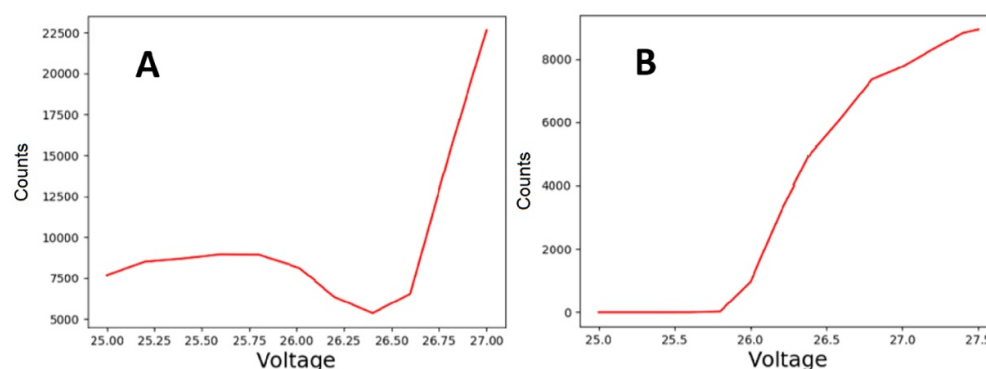


Figure 7. Pulse height response functions acquired using the SiPM DP2: A—alpha counts in the beta energy window vs voltage. The dip of the curve determines the optimum operating voltage. B—beta counts in the alpha energy window.

voltage in which the contamination of alpha events in the beta window (or vice-versa) is minimised. In these response functions the energy windows were chosen in order to obtain less than 1 count per second (cps) of alpha events in the beta window, and less than 0.02 cps of beta events in the alpha window.

In general the pulse height spectra from the two sources obtained using the SiPM probe are very similar to those of the PMT-based device. Figure 5(b) shows the pulse height spectrum obtained from the SiPM probe, which shows a very similar energy distribution for the two event types compared with the original device. The MCA lower-level discriminator excludes the SiPM noise pulses, which have a very low average pulse height. Based on the total number of events in each spectrum, the detection efficiency of the SiPM-based probe is approximately half that of the PMT device, which is less than the reduction in efficiency expected by the smaller active area of the SiPM sensor alone. However, there is a strong relative difference in pulse heights observed between the alpha and beta events. The overall gain of the DP2-SiPM to α particles, based on the channel position of the spectrum end point, is reduced by a factor

of approximately 4.3x compared with the gain of the DP2-PMT. In contrast the corresponding gain reduction of the DP2- SiPM β spectrum is only a factor of 2.5x compared with the DP2-PMT. This cannot be explained by the relative differences in optical quantum efficiency between the two sensors, and is most likely due to the different scintillator decay times. For the SiPM the longer decay time of the ZnS scintillator is convolved with the relatively slow response time of the SiPM (typically a 70 ns decay time into a 50 Ω load resistor) such that some signal amplitude may be lost through the use of a 0.5 μ s shaping time.

4. Conclusions

It has been shown that the retrofitted DP2 can achieve similar results to the unmodified version, with very similar energy spectra obtained from both devices. The compact and robust nature of the SiPM photodetector has several advantages for field instruments, such as contamination monitors, and the reduced power requirements of the SiPM offer a potential benefit over the traditional PMT. Further miniaturisation of the SiPM read-out circuitry and development of a portable digital DAQ system would enable the entire DP2-SiPM system to potentially provide a replacement for the traditional equipment.

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References

- [1] McElhaney S A, Ramsey J A, Bauer M L and Chiles M M 1990 A ruggedized ZnS(Ag)/epoxy alpha scintillation detector *Nucl. Instrum. Methods A* **299** 111–4
- [2] ThermoFisher DP2 Data Sheet <https://www.thermofisher.com/order/catalog/product/DP24A> (Accessed January 2020)
- [3] Griffiths J, Kleinesse S, Saunders D, Taylor R and Vacheret A 2018 Pulse shape discrimination and exploration of scintillation signals using convolutional neural networks arXiv:1807.06853
- [4] Mikhailik V B *et al* 2013 Investigation of luminescence and scintillation properties of a ZnS–Ag/⁶LiF scintillator in the 7–295 K temperature range *J. Lumin.* **134** 63–66
- [5] Knoll G F 2010 *Radiation Detection and Measurement* 4th Chapter 8 (New York: Wiley)
- [6] Electron Tubes 9924B PMT Data Sheet http://et-enterprises.com/images/data_sheets/9924B.pdf (Accessed January 2020)
- [7] SensL J-series SiPM Data Sheet <http://sensl.com/downloads/ds/DS-MicroJseries.pdf> (Accessed January 2020)
- [8] Hubbard M W J, Taggart M P and Sellin P J 2019 Exploration of Fourier based algorithms and detector designs for pulse shape *Nucl. Instrum. Methods A* **930** 64–73
- [9] Ortec <http://www.ortec-online.com/Products-Solutions/Applications-Software-MAESTRO.aspx> (Accessed January 2020)
- [10] ISO 7503-3:2016(en) *Measurement of radioactivity—Measurement and evaluation of surface contamination—Part 3: Apparatus calibration* (International Organisation for Standardization)
- [11] 2010 *Non-intelligent & Intelligent Scintillation Probs, Instruction Manual* (Reading: Thermo Fisher Scientific)
- [12] Pottinger M, Woods M and Keightley L 2001 *Measurement Good Practice Guide No. 29, the Examination, Testing and Calibration of Installed Radiation Protection Instruments* (Teddington: National Physical Laboratory)