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STABILITY TEST FOR NaI(TI) SCINTILLATION DETECTOR

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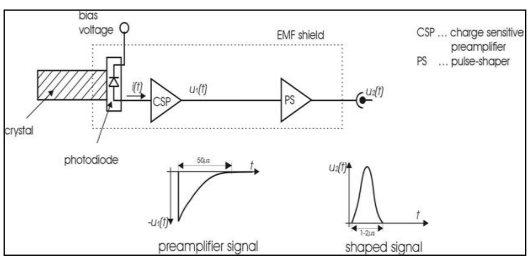
Graphical abstract



Abstract

The objective of this endeavor is to present a brief description of a stability test performed on a NaI(TI) scintillation detector to determine its most suitable operating voltage range. The Chi-square test is used to check the reliability of the data obtained. Some test results are included.

Keywords: Stability test, scintillation detector, gamma-ray tomography, gamma-ray transmission

1.0 INTRODUCTION

Quality control and quality assurance procedures on nuclear instruments are a very necessary requirement to ensure that the instruments in question are safe for use, in good working order to ensure proper behavior, and avoiding the possibility of getting false pulses due to noise, high voltage failures, interference pick-up and leaking. It is also a very important aspect to consider because in most cases, these instruments are related to critical processes that include radiological protection, industrial processes, human health and even national safety. Accurate representation and measurement of radiation parameters must be ensured, for example the accurate measurement of the number of radioactive events, counting times and in some cases accurate measurements of the radiation energy and occurring time of the nuclear events (Ramirez Amirez–Jimenez *et al*., 2007). Quality control tests are done at every various levels starting at the manufacturers of the instruments right up to the end users. There are several IEEE/ANSI standards that are in use as listed in the references [4-7]. The major quality control tests commonly conducted are count accuracy, clock accuracy, integral and differential non-linearity, count rate non-linearity and chi square test (R. Engels and H. Kaufmann, 2000)

A stability test is one of the quality control procedures for detectors that is conducted by end users. A stability test must be conducted before a scintillation detector can be used in order to obtain its most suitable operating voltage, at which point its readings are stable and dependable.

2.0 NAI(TI) SCINTILLATION DETECTOR

Scintillation is the ability of certain materials to display luminescence (light emission) when excited by ionizing radiation. This property enables us to use scintillation to detect ionizing radiation by measuring the light emitted. However, the resultant light from scintillation is very low and requires a fair bit of amplification to convert the few photons into a usable electronic signal. For this purpose we can use photomultipliers or semiconductors. Figure 1 shows the principal design of a scintillation detector with photoelectric conversion by a photodiode (Bieberle et al., 2000).

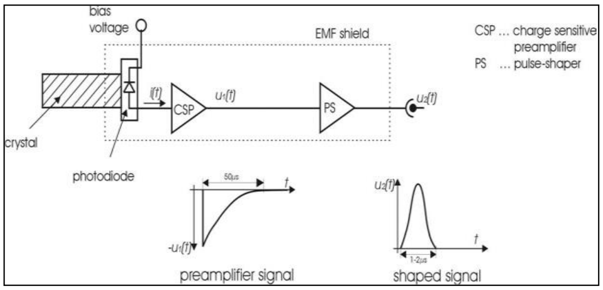


Figure 1 Principal setup for a scintillation detector with photodiode

Thallium doped Sodium Iodide NaI(Tl) is by far the most widely used scintillation material and has the highest light output. It is available in single crystal form or the more rugged polycrystalline form. NaI(Tl) is very hygroscopic and needs to be housed in an air-tight enclosure. When a charged particle strikes the scintillator, a flash of light is produced, which may or may not be in the visible region of the spectrum. Each charged particle produces a flash. If a flash is produced in a visible region, it can be observed through a microscope and counted - an impractical method. The association of a scintillator and photomultiplier with the counter circuits forms the basis of the scintillation counter apparatus. When a charged particle passes through the phosphor, some of the phosphor's atoms get excited and emit photons. The intensity of the light flash depends on the energy of the charged particles. NaI(Tl) crystal is used as a scintillator for the detection of gamma waves (Radiation Safety Manual, 2005).

The scintillation counter has a layer of phosphor cemented in one of the ends of the photomultiplier. Its inner surface is coated with a photo-emitter with less work potential. This photoelectric emitter is called as photocathode and is connected to the negative terminal of a high tension battery. A number of anodes called dynodes are arranged in the tube at increasing positive potential. When a charged particle or photon strikes the phosphor, a light flash is emitted. This light flash strikes the photocathode in the photomultiplier, releasing an electron. This electron accelerates towards the first dynode and hits it. Multiple secondary electrons are emitted, which accelerate towards the second dynode. More electrons are emitted and the chain continues, multiplying the effect of the first charged particle. By the time the electrons reach the last dynode, enough have been released to send a voltage pulse across the external resistors. This voltage pulse is amplified and recorded by the electronic counter (Radiation Safety Manual, 2005).

3.0 GAMMA-RAYS

Gamma-rays are attenuated when they travel through matter. The extent of this attenuation is dependent upon the density and composition of the matter, and the distance the rays travel in it. The attenuation of a narrow beam of mono-energetic photons penetrating a homogeneous material follows Lambert-Beer's exponential decay law:

$$I = I_o e^{-\mu x} \quad \text{................ (1)}$$

Where I_0 is the incident or initial intensity, x the thickness of the absorber; I the remaining beam intensity and μ is the linear attenuation coefficient. By selecting gamma-ray sources with correct emission energy it is possible to measure the thickness of material of constant attenuation coefficient, or the attenuation coefficient of material of constant thickness. Pulse mode read-out electronics or detectors are used to measure the intensity by detecting and counting individual gamma-ray photons transmitted through the process (Susiapan *et al*., 2009). In this experiment, since there is no obstacle between the source and detector, the factor that is kept constant throughout the experiment is the distance of travel between the detector and source to ensure the same rate of attenuation.

4.0 EXPERIMENTAL SETUP

The instruments required for the test to be conducted are the ratemeter (Ludlum 2200 scaler), blocks of lead for shielding, checksource (Cs-137), and 3 detectors (Named Detector A, B, D). Instruments required for the safety of the facility and the personnel are the Film badge, gloves and survey meter. Film badges or TLDs must be worn by all persons entering a site which houses radioactive materials. Gloves must be used when handling the lead blocks used for shielding to reduce risk of lead poisoning. A survey meter must be used to monitor the surrounding radiation and ensure it is at safe levels whenever a radiation source is in the vicinity or in use.

The ratemeter, checksource, detector and shielding are set up as shown in Figure 2. The ratemeter 'Threshold' dials is set to '1'. The ratemeter multiplier is set to 'x.1' and the numerical value set to '1' so that a reading is taken every 6 seconds i.e 0.1 x 1 min = 6 seconds. Setting the ratemeter 'HV Dial Setting' to 1.5 and pressing the 'count' button, the intensity count is noted. The ratemeter 'HV Dial Setting' is gradually increased by 0.01 and the intensity count noted down until it is approximately

5000 counts. The data is tabulated and an intensity vs HV dial setting graph is plotted. The most suitable HV dial setting is determined from the intensity vs HV dial setting graph.

Figure 2 Stability test setup

5.0 RESULTS

Intensity count measurement obtained using Detectors A, B and D is used to construct the graphs shown in Figure 3, Figure 4 and Figure 5.

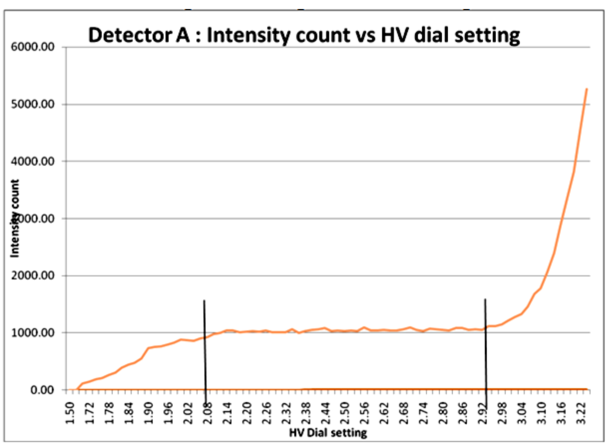


Figure 3 Intensity counts for Detector A vs HV dial setting

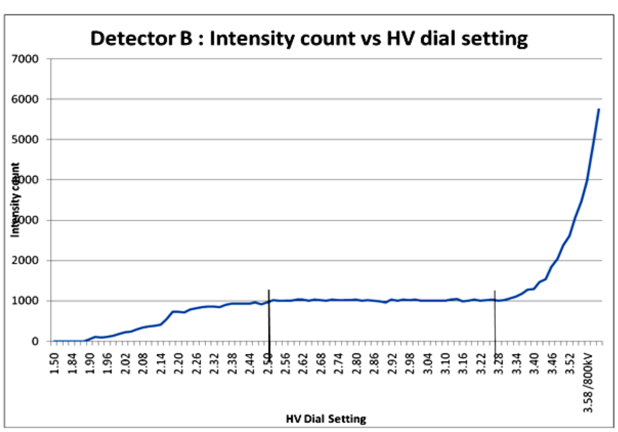


Figure 4 Intensity counts for Detector B vs HV dial setting

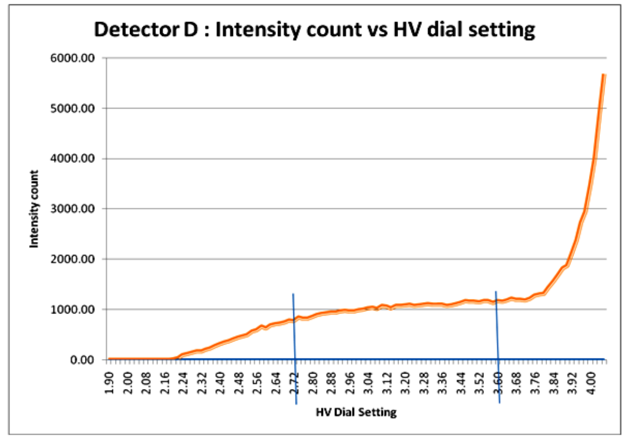


Figure 5 Intensity counts for Detector D vs HV dial setting

The optimum HV dial setting is approximately midway between the two vertical lines drawn on the graph. From the graphs, the most suitable HV settings for each detector are:

Detector A – 2.6
Detector B – 2.86
Detector D – 3.2

These HV dial setting values obtained experimentally for each respective detector is its most suitable operating voltage, at which point readings obtained are stable and dependable.

5.1 Chi Square Test Results

The Chi Square test, as shown in Table 1, is a type of QC test that gives an indication of the validity of the measurements made. It gives an indication of the proper operation of the counting system when applying random pulses from a radioactive source. As stated in IAEA-TECDOC-602 (1988), Chi Square test results should be within 3.325 and 16.919. Results within these stated boundaries indicate that there are no instabilities in HV, amplifiers (base line shift or gain stability), counters (time base variations) nor any electronic influence. The chi square test is only dependent on the statistic pattern coming from a radioactive source.

The Chi Square method is performed on the previously determined HV settings for each detector (Detector A – 2.6, Detector B – 2.86, Detector D – 3.2) and the results for the p-value are shown as follows. The chi square values obtained for each HV setting falls in the valid range.

Table 1 Chi square test

Detector	Ci	Ciaverage	Ci-Ciaverage	Square of (Ci-Caverage)	Sum of (Ci-Cav)2	Chi Square
Detector D	3758	3816.67	-58.67	3442.1689	33484.6667	8.773
	3965		148.33	22001.7889		
	3727		-89.67	8040.7089		
Detector B	1012	967.67	44.33	1965.1489	3428.6667	3.543
	930		-37.67	1419.0289		
	961		-6.67	44.4889		
Detector A	1044	1040	4	16	5226	5.025
	987		-53	2809		
	1089		49	2401		

6.0 CONCLUSION

A stability test must be conducted before a scintillation detector can be used in order to obtain its most suitable operating voltage, at which point its readings are stable and dependable. If the HV dial setting is set to a value that is too high above or too low below its stable range, the intensity counts obtained may not be accurate or even usable. A HV dial setting that gives an intensity count of more than 6000 may result in the detector being damaged hence the test is stopped once the intensity count logged is approximately 5000 counts.

References

[1] F.J. Ramirez-Jimenez, L. Mondragon-Contreras and P. Cruz-Estrada. 2007. QC Test on Radiation Detectors and The Associated Nuclear Counting Systems.

[2] André Bieberle, Eckhard Schleicher and Uwe Hampel. 2000. New Concepts for Gamma Tomography Detectors.

[3] R. Engels and H. Kaufmann. 2000. Quality Control Test For Nuclear Counting Systems.

[4] ANSI N42.14-1999, (Revision of ANSI N42.14-1991), American National Standard for Calibration and Use of Germanium Spectrometers for the Measurement of Gamma-Ray Emission Rates of Radio-nuclides.

[5] IEEE Std 300-1988 (R2006). (Revision of IEEE Std 300-1982), IEEE Standard Test Procedures for Semiconductor Charged-Particle Detectors.

[6] ANSI N42.25-1997. American National Standard Calibration and Usage of Alpha/Beta Proportional Counters.

[7] ANSI N42.31-2003. American National Standard for Measurement Procedures for Resolution and Efficiency of Wide-Band-gap Semiconductor Detectors of Ionizing Radiation.

[8] Radiation Safety Manual. 2005. Section 430, Contamination Monitoring, University of Manitoba rev. Jan 2010.

[9] INTERNATIONAL ATOMIC ENERGY AGENCY. 2000. Calibration of Radiation Protection Monitoring Instruments, Safety Report Series No. 16, IAEA, Vienna.

[10] Y. Susiapan, R. Rahim, J. Pusppanathan, R. Zain. 2009. Development of a Distillation Column Scanning Apparatus Using Gamma-Ray Tomography. The Second International Conference on Control, Instrumentation and Mechatronic Engineering (CIM 2009).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY. 1988. Quality Control of Nuclear Medicine Instruments. IAEA-TECDOC-602, IAEA, Vienna.