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Detection of alpha-induced radioluminescence in the Ultraviolet C range for nuclear decommissioning applications

Crompton A.J.[1] **, Gamage K.A.A.**[2]

[1] Department of Engineering, Lancaster University, Lancaster LA1 4YW, UK.

[2] School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK

*corresponding author: e-mail: a.crompton1@lancaster.ac.uk

Abstract

The close range of traditional alpha radiation detectors makes detection time-consuming and potentially hazardous. Alpha-induced radioluminescence in the ultraviolet C (UVC) wavelength range (180-280 nm) may be the mechanism through which stand-off detection can be achieved. The UVTRON (Hamamatsu) solar-blind flame sensor is sensitive to photons of wavelengths between 185 – 260 nm and has a low background count due to the absorption of natural UVC in the atmosphere. It has successfully detected a ^{210}Po source of 6.95 MBq from 20 mm distance, and flowing gases over the source, especially xenon, has shown the signal can be significantly increased. As a mature technology, which is small, robust, low-cost and easily available, the UVTRON would be ideal for inclusion in a scanning, stand-off, alpha detection system. It has been shown, however, to be sensitive to gamma and beta radiation and this would need to be taken into account in any system design. However, that this sensor can be used in normal lighting conditions makes it a potential candidate for stand-off alpha detection in field conditions, and results of distance, scanning and detection experiments support this.

Keywords: Alpha. radioluminescence, detection, decommissioning

1. Introduction

Alpha radiation is arguably the most challenging of the radiation types to detect, mainly due to the short travel of alpha particles in air, around 50 mm depending on energy. Yet many of the materials used for and produced through nuclear energy generation are primarily alpha emitters: including plutonium, uranium and americium. Therefore, the detection of alpha radiation is essential to operations such as the full characterisation of decommissioning sites, monitoring for health physic and contamination control. However, due to the difficulties posed by detection of alpha particles, developments in new detector technology in this area has lagged behind that of other types of radiation.

Alpha radiation is a form of ionising radiation where the emitted particles transfers their energy to the surrounding atmosphere as they travel, slowing the particles and limiting their distance of travel. Having a relatively large mass, atomically speaking, and being positively charged, alpha particle travel only a short distance in air, approximately 50 mm, compared to a few meters for beta electrons and many meters for gamma photons, depending on energy.

Traditional detectors require direct interaction with the alpha particle, which means that they must be operated within approximately 1 cm from the surface being scanned for alpha contamination [1]. It is usual in alpha detection to take swabs, have the isotopes chemically separated and then spectroscopy is carried out to determine the nature of the contamination, which can take a matter of weeks to complete and for results to be known.

Due to the issues with traditional alpha detection methods, a stand-off alpha detector has long been sought which will remove the operator from close proximity to the contamination and allow faster scanning of larger areas or complex surfaces. The process could be automated by the use of a scanning platform, freeing operators to work elsewhere.

2. Background

As alpha particles travel they ionise the gas around them, causing the emission of ultraviolet (UV) photons. These are mainly in the UVA and UVB wavelength range, with a small number of UVC photons. These photons travel much further than the initial alpha particles, providing an avenue for the possibility of developing a stand-off alpha detector.

Although the majority of the UV photons are in the UVA and UVB wavelength ranges there is a significant amount of natural and artificial light also within this wavelength range, requiring the use of filters and special optics to combat this background light. UVC is blocked by the ozone layer and is not produced by normal indoor lighting and though it is much less in terms of quantity, detection of radioluminescence in the UVC wavelength range does not suffer from the same background. Other gases have also been shown to emit radioluminescence in the UVC wavelength range, which could be used to enhance the signal.

3. Experimental Set-Up

The R9533 UVTRON (Hamamatsu, Japan) UVC sensor is solar blind (sensitive in the 180-260 nm wavelength range), rugged and easily available. It is available with an optimised electronic driving circuit which also processes the pulse from the UVTRON. It is designed to detect flames as part of a fire detection and warning system.

Output pulses from the driving circuit are counted by an Arduino Uno which relays this to the computer. An oscilloscope was used to monitor the direct pulses from the UVTRON and the driving circuit.

Initial experiments for distance and source location were carried out using a UVC emitting bulb in place of an alpha source. These were to determine the potential of the UVTRON for use in this application.

Following the initial experiments, further experiments were carried out. A 6.95 MBq ^{210}Po source was placed inside a black Perspex box with a fused silica window (<90% UVC transmission). The UVTRON was placed approximately 20 mm from the source, outside of the Perspex box.

A small diameter pipe was placed in close proximity to the source through which gases were flowed across the surface of the source.

Further experiments were carried out with the detector in close proximity to alpha, beta and gamma emitting sources to observe any effect from other radiation types.

4. Results

4.1 Background

A very low background count was found, with 10 pulses were recorded in 75 minutes, giving an average of 2.224 x 10^{-3} (± 0.7034 x 10^{-3}) counts per second (cps) in normal laboratory lighting.

4.2 Distance

Initial tests using a UVC bulb showed that the UVTRON was capable of detecting a UVC source from over 25 m distance (see Figure 1).

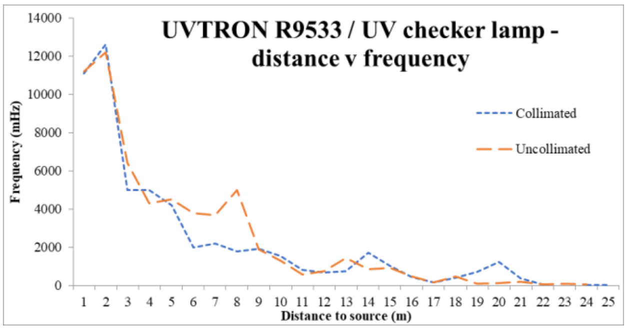

Figure 1: Frequency v distance between UVTRON and checker UVC lamp

4.3 Source location

Using a specially designed scanning platform a collimated UVTRON was able to determine the location of a source (see Figure 2).

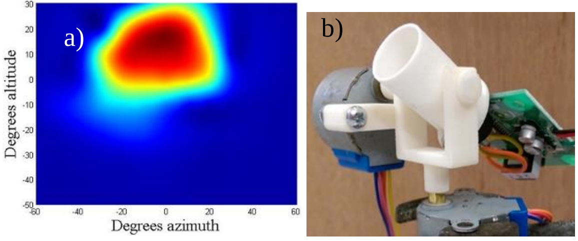

Figure 2: a) Source location and b) collimated UVTRON scanning platform

4.4 Air atmosphere and gas flow results

In an air atmosphere the count over 16 hours was 18,890 pulses, giving a cps of 0.3280. When gas was flowed over the source the count increased in all instances, with xenon more than doubling the count compared to an air atmosphere in one instance (see Table 1).

Table 1. Table of gas flow results

Gas	CPS (% incr)	CPS (% incr)	CPS (% incr)	Average % incr
N_2	0.34 (3.61)	0.4716 (14.86)	0.4898 (8.79)	(9.09)
Xe	0.5004 (52.47)	0.8431 (105.32)	0.8541 (89.71)	(82.5)
Ne	0.4131 (25.87)	-	0.6812 (51.51)	(38.69)
Kr	0.4045 (23.36)	0.6003 (46.21)	0.6247 (38.77)	(36.08)
P10	0.4339 (31.21)	-	0.5983 (32.9)	(32.55)
Ar	-	-	0.5865 (30.27)	(30.27)

4.5 Beta and gamma response

When exposed to ^{210}Pb, ^{241}Am, ^{36}Cl, ^{137}Cs, ^{152}Eu sources, the count recorded increased, showing that the UVTRON is susceptible to beta and gamma radiation. Table 2 shows a comparison of the response of the different sources.

Table 2. Table of beta and gamma exposure results – distance between source and sensor is 40 mm in all instances

Isotope	CPS per Bq
^{210}Pb	12.87 x 10^{-6}
^{241}Am	1.319 x 10^{-6}
^{36}Cl	7.6 x 10^{-6}
^{137}Cs	0.763 x 10^{-6}
^{152}Eu	3.231 x 10^{-6}

5. Conclusion and Discussion

In the search for a stand-off alpha detector the UVTRON has shown to be capable of detecting the UVC portion of alpha-induced radioluminescence in normal lighting conditions. It has a low background count which means it is not affected by natural and standard artificial lighting, making it ideal for use in field conditions. The affect of gamma and beta radiation on the count is a drawback to the use of this sensor in the field, where mixed radiation may be encountered.

It may also be possible in the field to flow gas over contaminated areas, which may be more easily achieved than a purged gas atmosphere, which would enhance the radioluminescence in the UVC wavelength range and therefore make detection easier.

Implementation methods to minimize the impact of other radiation on the sensor, the use of gas flows and the inclusion of specially designed optics are all avenues to be explored for a device ready to be deployed in the field.

References

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