Detecting Alpha-induced Radioluminescence in the UVC Wavelength Range Using a UVTron Flame Sensor, and the Effect of a Gas Flow on Detection Rates as Compared to an Air Atmosphere.

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***Abstract*–Alpha-induced radioluminescence provides a potential avenue for the detection of alpha-emitting materials from a distance far greater than the travel of alpha-particles themselves. This work details experiments carried out into the detection of this radioluminescence in the ultraviolet C wavelength range (180-280 nm) using an off-the-shelf flame sensor, the UVTron (Hamamatsu, Japan). There is less interference from natural and artificial background lighting in the ultraviolet C wavelength range than at other ultraviolet wavelengths. A UVTron flame sensor (R9533, Hamamatsu, Japan), which is sensitive only in the ultraviolet C wavelength range, was used to detect the presence of a 6.95 MBq ^{210}Po source at a distance of approximately 20 mm. The signal (0.3280 counts per second) was over 147 times that of the background, which was very low (2.224×10^{-3} counts per second) under the general laboratory/commercial lighting conditions. The limit of detection, where the signal can be distinguished from background, can be calculated to be approximately 240 mm under these conditions, assuming a standard $1/r^2$, which is much greater than the alpha particle travel. Gas was flowed over the alpha sample to determine if this would enhance the radioluminescence and hence the detection by the UVTron. Gases of Ar, Xe, Ne, N_2, Kr and P10 were tested, all of which increased the signal detected by the UVTron sensor. The greatest increase was found to be in a flow of Xe, which greater than doubled the counts per second of the detector in one instance. The ability of the UVTron to detect the radioluminescence from alpha-emitting materials and the enhancement which may be possible using a flow of gas, indicate the potential of the UVTron sensor for inclusion in an alpha-emitting materials detection system which could be operated at a distance in the field, for example for nuclear decommissioning characterisation purposes or nuclear security applications.**

I. Introduction

THE detection of alpha-emitting materials, deposited either through contamination, anticipated nuclear operations, or potential security threats, is essential in nuclear decommissioning, nuclear power generation and nuclear security operations. Many of the radionuclides resulting from nuclear operations, e.g. uranium, plutonium, americium, are primarily alpha emitters and therefore the detection of emitted alpha particles is essential in detection and characterisation of equipment and plant. However, the short travel of alpha particles in air makes their detection time consuming and hazardous. The difficulties in alpha detection has also resulted in slow progress to develop new technologies to overcome these issues, with gamma, beta and neutron detection having more advanced and mature technologies.

The short travel of alpha particles, around 50 mm depending on energy, means detectors and therefore their operators require close proximity to contaminated surfaces to allow the direct interaction of the alpha particles with the detector probe. In areas with complex geometry or where a large surface area requires scanning, it can be time consuming to maintain a 1 cm distance between the detector probe and the surface as is required with traditional alpha detectors. To speed up the detection process by allowing automated scanning of large areas, and to remove personnel from contaminated areas, which may include a hazardous mixed radiation environment, a stand-off alpha detector has long been sought. Although desirable, there are significant difficulties in achieving such technology. However, the use of radioluminescence in the ultraviolet C (UVC) wavelength range may provide a solution.

II. Background

To design a stand-off alpha detector, is it essential to understand what mechanism could be used. As alpha particles travel they transfer energy to the surrounding atmosphere, ionising gases and causing the emission of radioluminescence photons. These travel in the order of km, much greater than the travel of the alpha particles themselves. Hence, these have been investigated for their potential in a stand-off alpha detection system. The main radioluminescence comes from the nitrogen, which comprises just over 78% of air. This radioluminescence

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is mainly in the 300 – 400 nm wavelength range, ultraviolet A (UVA) and ultraviolet B (UVB). When trying to detect this radioluminescence, however, there is a great deal of interference from natural and artificial lighting. Fig. 1 shows the overlap between the radioluminescence spectrum of alpha particles in air and the spectrum of daylight.

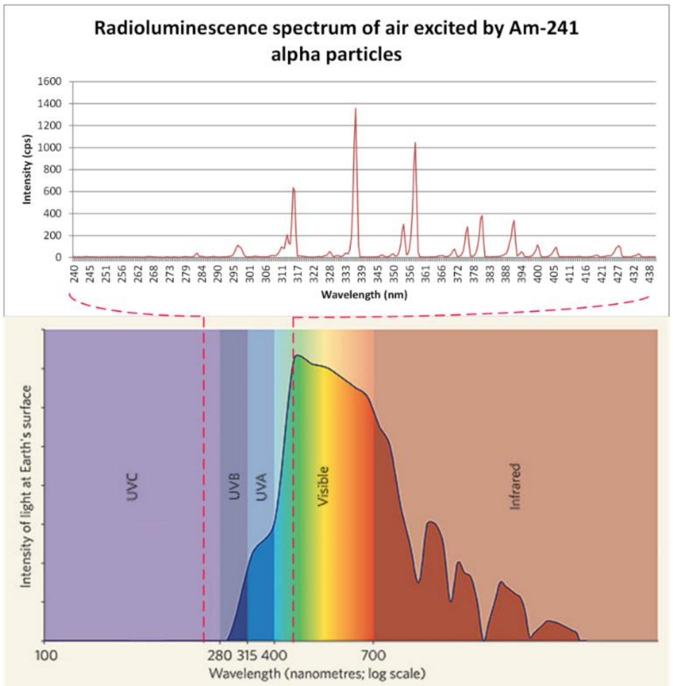

Fig. 1. Showing the overlap between the radioluminescence from ^{214}Am alpha particles [1] and the wavelength of light at the earth's surface [2]

It can be seen from Fig. 1. that there is overlap between the alpha-induced radioluminescence and light from the sun in the UVA and UVB wavelength ranges. This has led to the development of stand-off detectors which use filtering or background subtraction methods, and which also require operation in darkness or special lighting conditions [3 - 5].

However, there is a small amount of radioluminescence in the UVC wavelength range, 180 -280 nm. As UVC light from the sun is blocked by the earth's atmosphere there is not the background interference from natural light, as can be seen from Fig. 1. Artificial lights also do not emit UVC, due to it being a waste of energy and potentially harmful to the human eye. Although there has been previous work on the viability of the UVC approach due to the small signal size [6], there are many implementation scenarios for a stand-off alpha detector and therefore it is worth further exploration from a practical standpoint with empirical research to supplement the purely theoretical.

III. MATERIALS AND METHODS

Experiments to determine the ability of a flame sensor to detect radioluminescence photons from an alpha source and the effect of a gas flow on this detection were carried out at the National Nuclear Laboratory, Teddington, Middlesex, UK.

The UVTron R9533 (Hamamatsu) is a flame sensor which is sensitive to photons in the 185-260 nm wavelength range, as given off by flames and corona discharge. Using the photoelectric effect, when a photon in this wavelength range is incident on the Ni cathode an electron is emitted. Using the gas multiplication effect, this electron is accelerated through a high voltage field, generating more electrons and causing a current at the anode, which is outputted as a pulse. This is detected by the driver circuit (C10807, Hamamatsu) and a 5 V square wave is emitted. In these experiments an Arduino Uno was used to count the pulses from the driver circuit. This was relayed to a laptop where the number of counts for each second was recorded. The total number of counts for each experiment was divided by the duration (in seconds) of each experiment, and an average count per second (cps) was determined.

A 6.95 MBq ^{210}Po sealed source was placed inside a black Perspex box of dimensions 260 x 234 x 230 mm. The UVTron was placed at approximately 20 mm from the source. A fused silica window allowed the UVC photons generated by the source's alpha emissions to reach the UVTron cathode. The fused silica window had a transmittance of greater than 90% in this wavelength range [7]. It also prevented the alpha particles impacting directly on the UVTron.

A small gas pipe of 1 mm diameter was positioned inside the Perspex box order that a flow of gas could be directed over the surface of the source. The set up can be seen in Fig. 2.

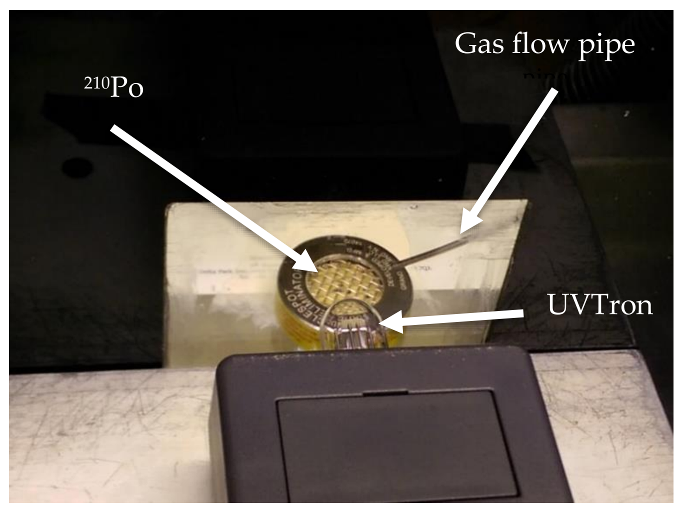

Fig. 2. Showing the UVTron protruding from the grey box which houses the electronics, and the ^{210}Po source (the yellow and silver disk) inside the Perspex box, behind the fused silica window. The gas flow pipe can be seen angling down from the top right of the fused silica window.

IV. RESULTS

A background count was taken prior to placement of the source, with the ordinary laboratory lighting turned on. This was strip (fluorescent) lighting. The count was taken over 75 min and gave an average cps of $2.224 \times 10^{-2} \pm 0.7034 \times 10^{-3}$. This equates to 10 pulses in the 75 min count, which is very low in comparison to other light detecting equipment, e.g. photomultiplier tubes.

The ^{210}Po source was placed inside the Perspex box at approximately 20 mm from the UVTron sensor. Under the same laboratory lighting conditions, the count increased to 0.3280 cps, which is significantly above the background count. A second layer of fused silica was inserted between the source and detector to ensure that UVC photons were the cause of the count. The count dropped by approximately the same margin as the attenuation of the silica glass as specified by the manufacturer. A sheet of paper between the source and sensor blocked the signal completely.

Gas was then flowed across the surface of the ^{210}Po to determine the effect of this on the count. Table 1 lists the gases, their flow rates and the average increase in signal in comparison to air over up to three repetitions of the experiment.

TABLE I. GAS FLOW INFORMATION AND RESULTS

Gas	Purity	Flow Rates ($1^{st}/2^{nd}/3^{rd}$ run) (ml/min)	Signal Increase Compared to Air (%)
Nitrogen	N5.0	65/65/65	9.09
Xenon	N5.0	50/65/65	82.50
Neon	CP grade	60/-/65	38.69
Krypton	N5.0	55/65/65	36.08
P10	± 5%	40/-/65	32.55
Argon	N5.0	-/-/65	30.27

Each of the gases caused an increase in the count, with Xenon causing the highest increase (see Fig. 3.). Each of the counts was compared to a baseline count taken in air at the commencement at each set of gas flow measurements. This allowed a determination of the increase in signal achieved in relation to air for each experiment.

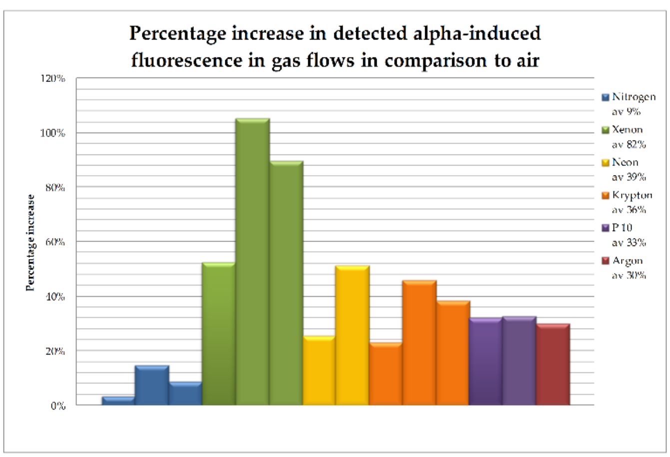

Fig. 3. Showing the percentage increase in the alpha-induced radioluminescence signal when different gases were flowed over the source.

This increase in the signal is likely due to the replacement of O_2 from the area surrounding the source, which is known to quench radioluminescence in the UV range. The different gases also affect the distance travelled by an alpha particle. Xenon for example reduces the travel to 25.2 mm [8], meaning that the alpha energy is deposited in a smaller area and this may enhance the radioluminescence in the area closest to the source. It has been shown that the area of most radioluminescence is with 10 mm of the source [3]. This may also be the reason why a flow of gas, as can also be found with a purged atmosphere, can increase the signal, and why over the duration of the experiment where the Perspex box would have been filling with the gas, the count did not increase over time.

V. CONCLUSIONS

The results show that under normal indoor lighting conditions it is possible to detect UVC radioluminescence using the UVTron.

The background is low under normal lighting conditions. Using Hurtgen et al's equation [9], with a confidence level of 95.45% (as advised by ISO, 1993), the limit of detection was determined using the equation;

$$at\ L_{d,}\ s_{net} = 2.86 + 4.78\sqrt{(b + 1.36)} \qquad (1)$$

where L_d is the limit of detection, s_{net} is the net signal (gross signal minus background), b is the background. This gives a limit of detection of 17.4 counts per hour, which is low in comparison to the counts measured in air and in the different gas flows.

Assuming a $1/_{r^2}$ drop off in signal value as would be expected with an isotropic emission of alpha particles and photons, the limit of detection would be approximately 240 mm between the ^{210}Po source and UVTron detector, before the signal would reach background levels. Alternatively, at the same distance, approx. 20 mm separation, the minimum detectable activity level would be approximately 47 kBq (±15 kBq). The sensitivity of any detection system using the UVTron would depend on the distance separation and the activity level. However, 240 mm is well beyond the travel of alpha particles, and the activity level found in some areas where such a detector could be used in the field are in the GBq range. This therefore is a positive indication that this sensor could be part of a field operational detector system for certain deployment scenarios.

The results of the gas flow experiments show that if this can be introduced, the small UVC signal from alpha emissions could be enhanced. It is not unusual in the nuclear industry for alternative atmospheres to be used for some routine operations, and there is already some infrastructure for the supply of gas to areas of interest.

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