Characterisation of Radioactive Contaminated Waste: Alpha-Induced Air-Fluorescence Detection Under Daylight Conditions

GAMAGE K.A.A. [1*] and CROMPTON A.J.[2]

[1] James Watt School of Engineering, University of Glasgow, Glasgow G12 8QQ, UK

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

*corresponding author:
e-mail: kelum.gamage@glasgow.ac.uk

Abstract Short travel of alpha particles in environments complicated the detection and characterisation of alpha-emitting contamination in mixed radiation fields in nuclear decommissioning sites. As a result, detection of alpha-induced radioluminescence became popular in nuclear decommissioning applications. The detection has to be done under dark conditions or special lighting conditions, in order to prevent interference of alpha-induced radioluminescence with background light. However, stand-off detection even under daylight condition, can be achieved by detecting alpha-induced radioluminescence in the ultraviolet C wavelength range (180-280 nm). We have demonstrated the use of an UVTRON flame sensor, which is solar-blind (developed by Hamamatsu), detecting photons in the ultraviolet C wavelength range. Ultraviolet C radioluminescence from a Po-210 sample was detected in normal lighting conditions using the UVTRON, with very low background counts found in all environments. As the Ultraviolet C radioluminescence signal is small, gas flows of Ar, Xe, Ne, N2, Kr and P-10 were directed over the Po-210 sample to enhance radioluminescence with positive effect. In one instance Xe doubled the count in relation to an air atmosphere.

Keywords: alpha-induced radioluminescence, UVTRON flame sensor, ultraviolet C, nuclear decommissionig

1. Introduction

The ability to detect alpha emissions from nuclear materials is important in nuclear operations, nuclear decommissioning and nuclear security applications. Due to their relatively large particle size and positive charge, alpha particles travel only a short distance after emission from nuclear materials, typically around 50 mm through air depending on their energy. Therefore detectors which require direct contact with alpha particles need to be in close proximity to any surface or object to determine if alpha contamination is present, at a distance of less than the mean free path of the alpha particles. This causes a number of issues as documented by other researchers [1 – 3]. As objects to be monitored may be in a mixed radiation environment, personnel carrying out detection activities may require PPE and may have limited time in which they can operate safely. Large structures or complex geometries take significant time to monitor in such close proximity. A stand-off detector, where a significant distance between the detector and surface can be achieved, can reduce the time taken for monitoring whilst distancing the operator from the radioactive environment.

As an alpha particle travels it ionises the air, transferring energy to the atoms and molecules in its path, mostly due to its positive charge. These excited atoms may emit a photon to return to a stable state and these photons have a mean free path in the order of kilometres [4, 5]. So in theory they could be detected from a significant distance, much further than direct alpha particle interaction detectors could achieve.

Although there have been experiments and several prototype detectors which have utilised this effect for stand-off alpha detection [1, 6-10], there are significant problems with this approach. The main issue is the interference of light, natural or from lighting equipment, which is typically present in much greater intensity compared with the signal from alpha-induced fluorescence. Although operating in dark or special lighting conditions alleviates this problem somewhat, it is not possible in the field where a variety of environments provide a variety of lighting conditions with which any viable detector must be able to cope. The variability of lighting levels over short time periods, especially from natural light sources, means that subtracting the background is not yet a viable option, and filtering causes an unwanted attenuation of the signal as well as removing background light. Ivanov et al had some success in using a solar-blind CCD camera [11] which could image UV fluorescence in daylight.

The work presented in this paper has focused on a detector which is less affected by natural and artificial light, the UVTron by Hamamatsu. This detector is designed to detect UVC emissions from flames for use in fire detection systems and to have a negligible background count in normal indoor lighting.

Experiments were carried out to determine if the UVTron was able to detect the UVC fluorescence photons generated by an alpha source, and the effect of different gas atmospheres on this detection.

2. Materials and Methods

Experiments were carried out at the National Physical Laboratory in Teddington, Middlesex. The set up for the experiments was as follows (see Figure 1).

In order to verify that the signal being received by the detector was indeed air fluorescence and not due to other emissions from the source, an optical black out cloth, a piece of paper or a sheet of fused silica were placed between the source and detector. With the optical cloth or the paper the observed cps immediately reduced to zero, returning to its former value when removed. The sheet of fused silica resulted in a negligible drop in counts per second. As the signal was transmitted through the fused silica window, but not through the paper or blackout cloth, verification was made that the detector was detecting UVC photons from the alpha source and not X/γ/β radiation.

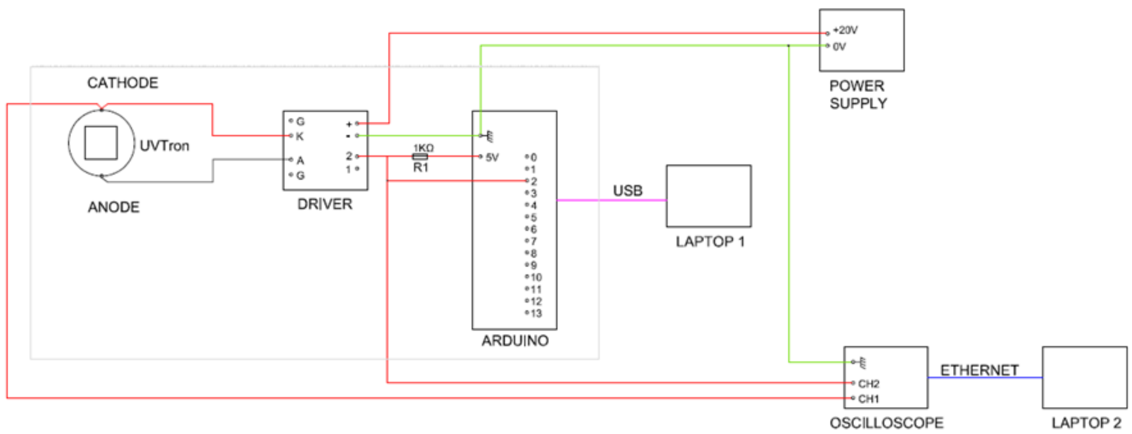

Figure 1. Schematic of equipment setup

A Po-210 source of 6.95 MBq was placed in close proximity to the UVTron detector (Hamamatsu, R9533, R1753-01 and R259), with an approximate separation of 20 mm between the source and detector. Po-210 decays through alpha emission only, with a very low X/γ emission intensity, eliminating the possibility of other radiations generating a response from the UVTron, either through direct interaction or secondary effects.

Experiments were run with the source inside a gas flow box with a window of 2 mm thick synthetic fused silica (Spectrosil©) which is specifically designed for deep UV (UVC) applications as it allows UVC to pass with little attenuation (<10%). During testing, the gases were flowed over the source using a small flexible pipe of 1 mm bore diameter.

The lab in which the experiments were carried out had no windows and conventional strip lighting. This lighting remained on for the duration of all experiments. The background count rate was found to be $2.224 \times 10^{-3} \pm 7.034 \times 10^{-4}$ counts per second. This was less than 1% of the count rate of all other experiments.

UVTron detectors utilise the photoelectric effect and gas multiplication to generate an output pulse when a photon is incident on the photocathode. The UVTrons used in this research have a Ni cathode which is insensitive to photons with a wavelength of greater than 260 nm. This makes them effectively solar blind (see Figure 2).

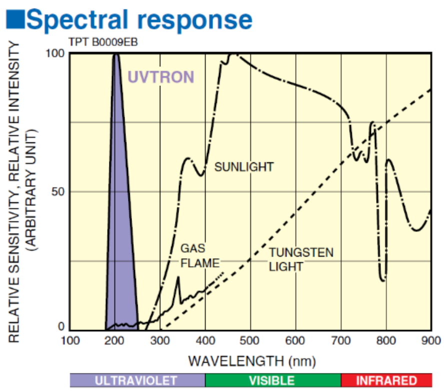

Figure 2. Spectral response of UVTron in comparison to sunlight, tungsten light and gas flame [12]

3. Results and Discussion

With the equipment and source as detailed above over a period of approximately 16 hours (60,871 s), 19,978 pulses were counted, giving an average of 0.3280 counts per second.

Five different gas environments were compared to air. These were selected following research into gases which were both likely to ionise at suitable energies and to emit photons of the required wavelength. The results are shown in Table 1.

Table 1: Variation in average cps by gas – in comparison to air

	Air	Nitrogen	Xenon	P10	Neon	Krypton
Gas flow rate (ml/min)	-	65	50	60	40	55
Average cps	3.28E-01	3.40E-01	5.00E-01	4.34E-01	4.13E-01	4.05E-01
uncertainty	±2.32E-03	±9.35E-03	±1.09E-02	±9.25E-03	±1.05E-02	±1.07E-02
% increase from air	-	3.61%	52.47%	32.21%	25.87%	23.26%

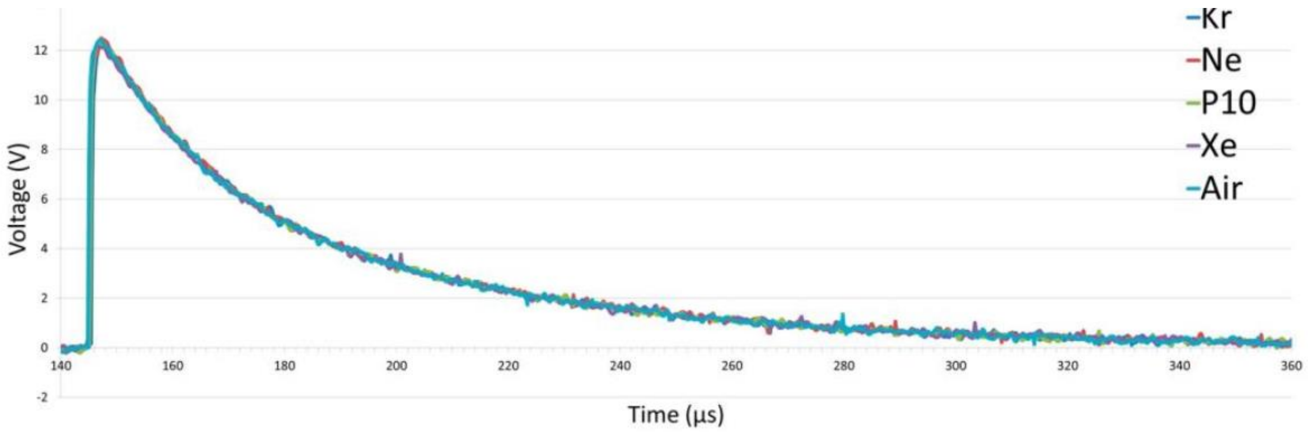

Figure 3. Pulse shape comparison of different gas atmospheres

There was an increase in the average cps for all gases compared to the air atmosphere. Xenon provided the greatest effect, with a 52% increase in the average cps compared to air. This new finding is most significant as it may provide a way to enhance fluorescence detection in the UVC wavelength range.

Nitrogen showed only a small increase (as shown in table 1, i.e. 3.61%), which could be accounted for within the uncertainty and therefore may not be an actual observed increase. As this is the primary constituent of air and is known to enhance fluorescence in the 300-400 nm wavelength range [1, 2, 5, 6, 8, 9] this result was unexpected.

For each of the experiments carried out with the ^{210}Po source, the pulse shape of the output from the UVTrons showed no distinguishable difference. Figure 3 shows a comparison of the shapes of a single pulse from each of the gas experiments. From this, it can be seen that it is not possible to differentiate one gas from the other in terms of the pulse shape.

4. Conclusion

Research presented this work has shows it is possible to use a UVC flame sensor to detect alpha radiation through radioluminescence, and therefore an approach which uses the UVC portion of the radioluminescence spectrum may be successful in the development of a stand-off alpha detector, which would overcome many of the difficulties affecting traditional alpha detection methods.

Acknowledgements

The authors would like to acknowledge the support of Dr Steven Bell (National Physical Laboratory, UK), Mr Alex Jenkins (Sellafield Ltd., UK) and Dr Divyesh Trivedi (National Nuclear Laboratory, UK).

References

1. Baschenko, S.M., *Remote optical detection of alpha particle sources*. Journal of Radiological Protection, 2004. 24(1): p. 75-82.
2. Ihantola, S., et al., *Fluorescence-assisted gamma spectrometry for surface contamination analysis*. IEEE Transactions on Nuclear Science, 2013. 60(1): p. 305-309.
3. Morishita, Y., et al., *Development of a Si-PM based alpha camera for plutonium detection in nuclear fuel facilities*. Nuclear Instruments and Methods in Physics Research, Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2014. 747: p. 81-86.
4. Waldenmeir, T., *Spectral resolved measurement of the nitrogen fluorescence yield in air induced by electrons*. Astroparticle Physics, 2008. 29: p 205 – 222.
5. Thompson, C.I., Barritt, E.E., Shenton-Taylor, C. *Predicting the air fluorescence yield of radioactive sources*. Radiation Measurement, 2016. 88: p 48 – 54.

6. Hannuksela, V., J. Toivonen, and H. Tivonen. *Optical remote detection of alpha radiation*, in Third European IRPA Congress. 2010. Helsinki, Finland.
7. Sand, J., et al., *Remote optical detection of alpha radiation*, in Symposium on International Safeguards. 2010: Vienna, Austria.
8. Lamadie, F., et al., *Remote alpha imaging in nuclear installations: new results and prospects.* IEEE Transactions on Nuclear Science, 2005. 52(6): p. 3035 - 3039.
9. Sand, J., et al., *Imaging of alpha emitters in a field environment*. Nuclear Instruments and Methods in Physics Research A, 2015. 782: p. 13-19.
10. Mahe, C. *Characterization and Visualization Technologies in DD&R - Alpha Imaging*, in Practical workshop on characterization and visualization technologies in DD&R. 2011. Marcoule, France: IAEA.
11. Ivanov, O.P., et al., *Development of method for detection of alpha contamination with using UV-camera "DayCor" by OFIL*, in Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC). 2011, IEEE: Valencia. p. 2192 - 2194.
12. Hamamatsu. *Flame Sensor UVTron*. 2010. Available from: http://www.hamamatsu.com/resources/pdf/etd/UVtron_TPT1021E.pdf