UVC Detection as a Potential for Alpha Particle Induced Air Fluorescence Localisation

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Abstract: As part of the decommissioning process, Plutonium-Contaminated Material (PCM) has to be identified, so it can be disposed of appropriately. Most conventional alpha detectors are only effective at relatively short range. This puts personnel in close proximity to the radiation exposure from this and other types of radiation. Alpha particles cause ionisation in air resulting in the emission of ultraviolet (UV) photons. These have a considerably longer mean free path than alpha particles, providing an avenue to detect alpha contamination from a distance. However, the intensity of this UV light is exceedingly small in comparison to natural daylight, making detection difficult in the field. Although the majority of emitted photons are in the 300 to 400 nm wavelength range, it may be possible to detect those in the UVC range (180 – 280 nm) as natural UVC is blocked by Earth's atmosphere. UVC detection is already used in the detection of fires and corona discharge. A group of such detectors have undergone a series of tests to determine their suitability for detecting UVC emissions from alpha particle induced air fluorescence. Results to date have shown that long range UVC detection and location is possible with these detectors.

Keywords: UVC detection, Alpha-induced air fluorescence, UVTron detector, Nuclear decommissioning, Plutonium-contaminated material

1. Introduction

Due to the limited range of alpha particles in air and the well documented difficulties this presents in the detection of alpha contamination in the field [1-3], a stand-off detection system using a secondary effect of alpha emission will provide benefits in terms of safety and cost savings to the nuclear industry. Alpha-induced air-fluorescence is such a secondary effect and is due to the ionisation of the air by the alpha particles. Research is underway to develop a detector system which will detect the fluorescence photons at a distance from the source.

Alpha particles ionise the air along their trajectory following emission during the radiation process. As they are positively charged they interact with the air molecules, transferring kinetic energy. This elevates the air atoms into an excited state. These then emit UV photons to return to their ground state. The exact mechanism for this has been described by other researchers [4, 5].

The main alpha-induced fluorescence intensity peaks in air are in the 300 to 400 nm wavelength range due to the excitation of nitrogen, the main constituent of atmospheric air. Therefore much of the work on detection has been centred in this range [1, 6-8]. This has led to several successful stand-off alpha detectors [1, 9, 10]. However, due to the interference of natural and man-made light in normal daytime conditions, these detectors require to be operated in darkness or under special lighting conditions. By using a solar blind CCD camera designed for the detection of corona discharge and arcing from high voltage power lines [11] Ivanov *et al* [12] were able to image alpha-induced air-fluorescence in daylight conditions. This use of the UVC wavelength range means detectors do not require darkness or special lighting conditions as sunlight in the UVC range is blocked by the atmosphere. Although the intensity of fluorescence in the UVC wavelength range is significantly smaller than in the 300 – 400 nm range, the lack of interference from daylight means that this could provide an avenue for detection in the field.

By specifically concentrating on detection in the UVC wavelength range, 180 – 280 nm, it is necessary to select equipment which result in a system which is sensitive only in this range, so called 'solar blind'. Due to the reduced intensity of fluorescence at this wavelength (95% is in the 300 – 400 nm wavelength range), the equipment must also be sufficiently sensitive to detect low intensity signals, and have low noise and a high signal noise ratio. It is also important that any optical elements have a high transmittance at the required wavelength to reduce attenuation of the signal.

The UVTron from Hamamatsu is such a solar blind detector and this paper presents initial tests with this detector, using UVC source lamp, to determine if it could be used for alpha-fluorescence detection.

2. UVTron Detector

2.1. Uses of UVTron

The detection of UVC light is one method used in the detection of flames in fire alarm systems or to detect corona discharge from high voltage power lines as UVC is emitted by both these phenomena. Commercial off-theshelf (COTS) equipment for this purpose is available from several suppliers, for example Hamamatsu, UViRCO and Ofil. These detect the presence of electromagnetic radiation in the UVC range (180 to 280 nm wavelength). They can therefore be used in daylight conditions as the atmosphere blocks natural UVC light from the sun. They are also designed to be used at a distance of several meters from the source of the UV light, depending on the application. As this proven technology is used to detect UVC for these phenomena, it may provide a route for detecting alpha induced fluorescence in daylight conditions.

The UVTron range of detectors has been selected for these experiments for several reasons. They are easily available and provide a number of options in terms of their sensitivity, wavelength range and other properties. They are available with pre-assembled drive circuits if required which have been optimised for these detectors. They can be used with a simple driving circuit allowing a bespoke circuit to be designed to test the response to variations in the circuit specification. The R9533 is vibration and shockproof making it more robust for possible future detectors. Due to the relatively low cost, these detectors could be used in an array to give a wider angle of view. This will reduce the scanning time of the detector system, whilst improving the ability to identify the location of the source. A UVC source lamp for checking the operation of these detectors is available, allowing set up to be carried out without the need to use an active alpha source, reducing potential experiment hazard. The aim of the experiments are to determine if the UVTron may be viable as a stand-off alpha detector by research into its response to a UVC emitting bulb under different condition.

2.2. Principle of Operation

The 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 1: Spectral Response of UVTron in comparison to sunlight, tungsten light and gas flame). Photons within the 180 – 260 nm range, when incident on the photocathode of the UVTron cause an electron to be emitted thought the photoelectric effect. An electric field generated by a voltage differential between the cathode and the anode causes this free electron to be accelerated through the gas contained within the UVTron. As the negatively charged electron passes through the gas it interacts with the gas molecules and transfers energy, causing ionisation and creating ion pairs. Noble gasses do not readily absorb free electrons, unlike oxygen which does and therefore quenches the process, and it is likely a noble gas, possibly argon or similar, is used in the UVTron to enhance the ionisation process. The created positive ions are attracted to the cathode, whilst the negative free electrons are attracted to the anode. As each free electron generates further free electrons there is an avalanche reaction which causes an exponential increase in the number of free electrons incident on the anode. This generates a signal which is interpreted by the driver circuit and a pulse is outputted by the driver circuit when this avalanche phenomenon occurs.

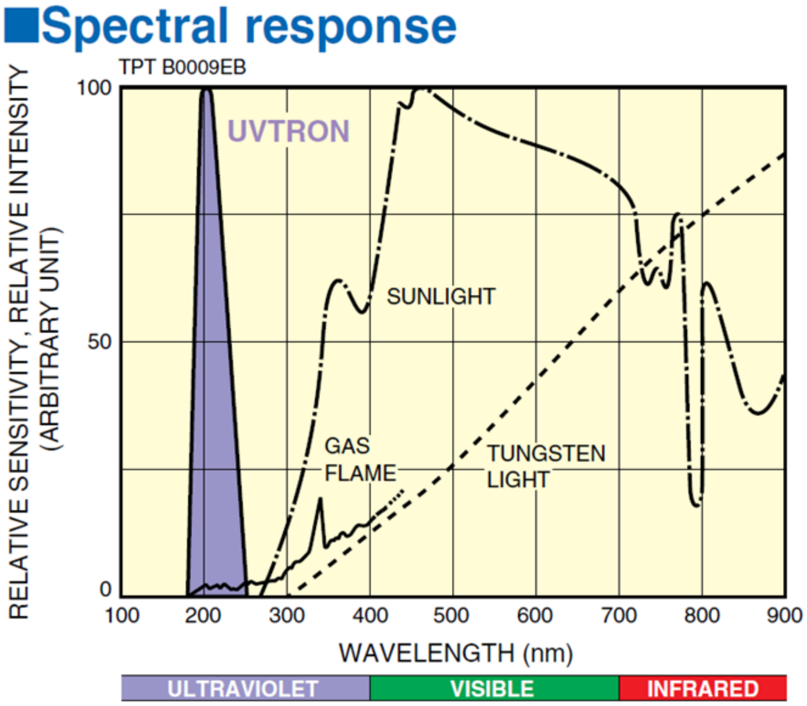


Figure 1. Spectral Response of UVTron in comparison to sunlight, tungsten light and gas flame [13].

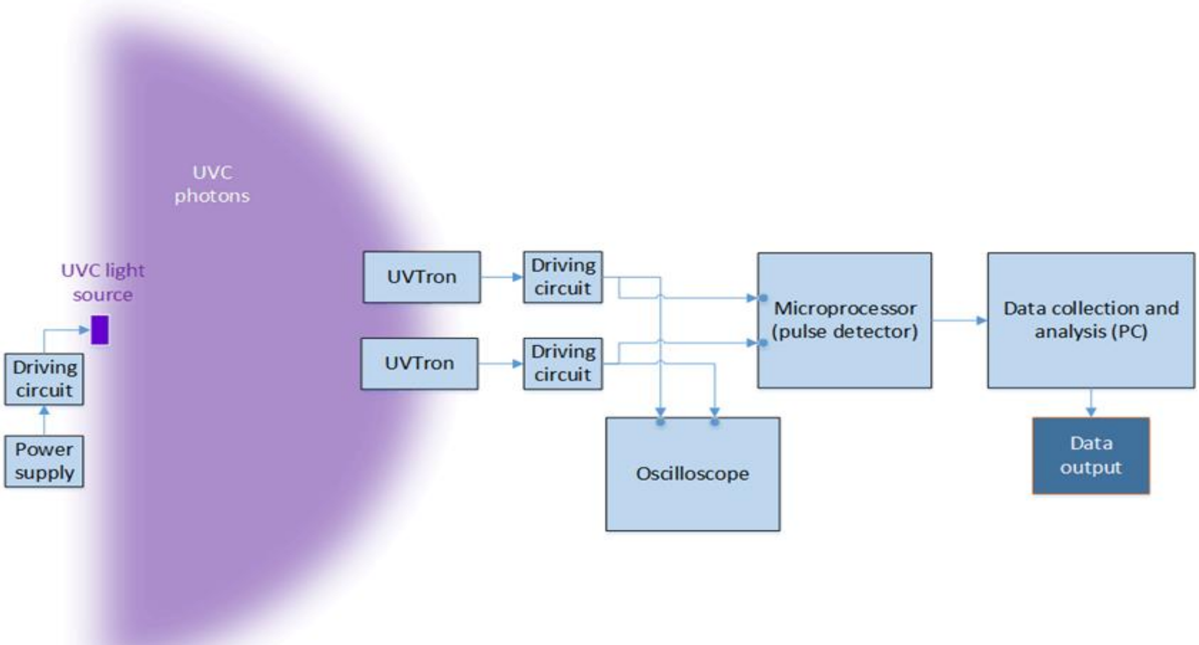
3. Experimental Method

The experimental system comprises of; one or two UVTron detectors with their associated driver circuits, UVC light source, an optional oscilloscope to confirm output, a microprocessor to detect and count the pulses (in this instance an Arduino Uno), and a PC to collect the count from the Arduino and to process the results. Schematic of the experimental set up is show in Figure 2. The UVTrons may be collimated. A second detector may be used to detect any variation in background lighting, electronic noise etc. which can be eliminated from the results. For example one of the UVTrons is collimated and mounted on a pan and tilt device for scanning, the other is not collimated and remains static to act as a control. The driver circuit provides the high voltage power supply and converts the output signal from the detector to a pulse. The UV light intensity input signal and output from UVTron and driver circuit are approximately proportional, with an increase in light intensity generating an increase in pulse frequency.

These experiments use a checker lamp for the UVTron (Hamamatsu L9657-03) in place of an alpha source in order to test the response of the UVTron detector and to provide a robust experimental method which can be applied to experiments using active alpha sources. It has a spectral distribution of 185 to 400 nm. There are two advantages to using the lamp at this stage. The first is that it does not cause radiation which could affect the detector system electronics. The second is that it will emit a far greater number of photons than an alpha source suitable for use in a laboratory experiment. Once the experimental set up has been verified and the UVTron characterised, the checker lamp will be replaced by an alpha source in the laboratory and if successful here, thence in the field.

4. Results

Experiments were carried out indoors in close proximity to a double glazed external window. Internal lighting was provided by modern strip lights. No attempt was made to attenuate the room or natural lighting, and experiments were carried out during the day. The background count level was measured in these conditions over a 20 minute period. The location of the detectors was varied, including pointing at the window in close proximity and pointing directly at internal



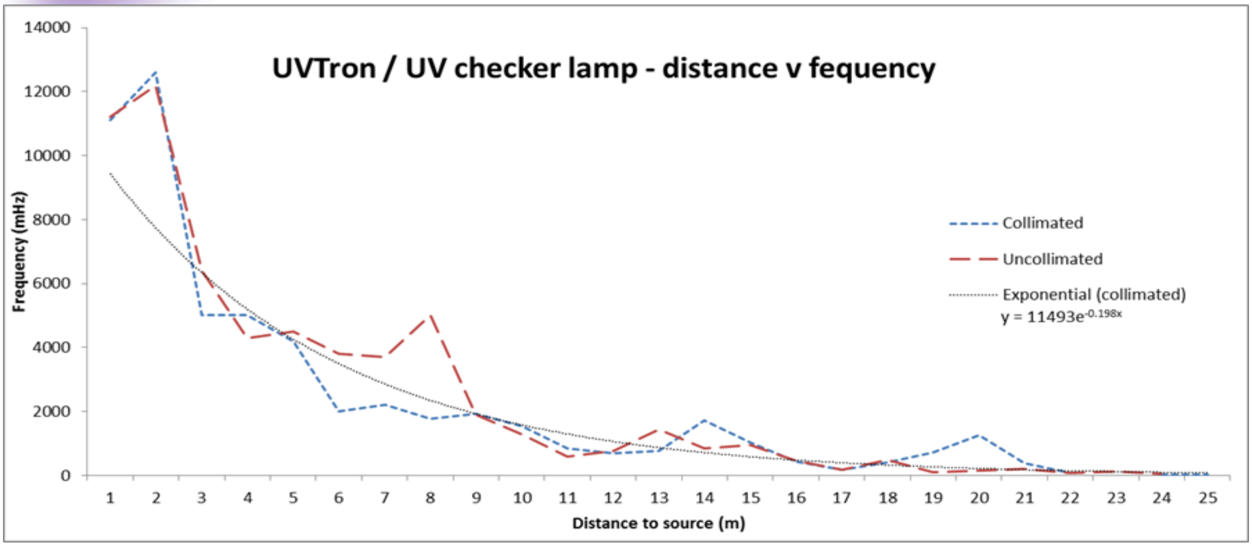


Figure 3. Frequency variations with respect to distance to source from the detector.

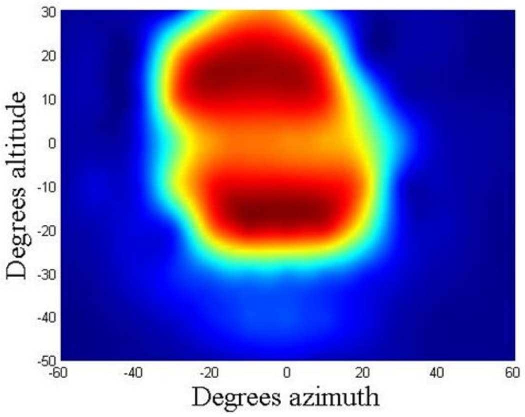
lighting. Whilst the UV checker bulb was not within the field of view of the detector, the driver circuit did not emit any pulses. There was therefore, no background count.

The first experiment carried out was to determine the furthest distance over which the UVTron could detect the checker lamp. The driver circuit output was connected to an oscilloscope, which was manually read at each distance. An approximate average of the output over 15 seconds was recorded. The aim of this experiment was not to provide a detailed count at each distance, but to simply determine the furthest distance over which the UVTron would detect the UV photons from the UVC lamp. The results are shown in figure 3. As can be seen there is an overall drop in frequency of pulses as the distance between detector and lamp is increased.

During the experiment a cover was placed at random intervals between one of the detectors and the source. This led to a cessation of the output signal pulse from that detector driver circuit, verifying that the pulses were due to the detection of UV photons. At 27 m, which is the maximum space available for the experiment, pulses from the driver circuits were still clearly visible on the oscilloscope screen, showing that the UVTron detectors were still detecting the photons at this distance. Although these pulses were sporadic and infrequent, it indicates that the detector will work over significant distances.

In decommissioning it will be important that alpha contamination be not only detected, but that the location be determined. To test the suitability of the UVTron for this purpose a pan and tilt device was devised which included the collimation of the detector it housed. A pair of stepper motors were used to provide the motion, with the Arduino controlling the motors and carrying out the count of the pulses.

The detector was placed directly in front of the source, at (0,0) degrees position, and scans were carried out with a step of 10 degrees, from -90 to 90 degrees azimuth and -30 to 30 degrees altitude. At each location data collected for 10 second and results for two cases are shown in Figures 4. The counts per second (cps) at each of the point of the scan has been allocated a colour, where dark red show the area of greatest signal intensity as a hotspot. A double hotspot is observed due to the angular sensitivity of the UVTron [13]. It can be seen that the maximum intensity area of the hotspot become smaller the further the detector is from the checker lamp. A clear hotspot (or the centre of gravity of the double hotspot) is indicating that the UVTron could be viable for detecting the location of UVC emissions source.



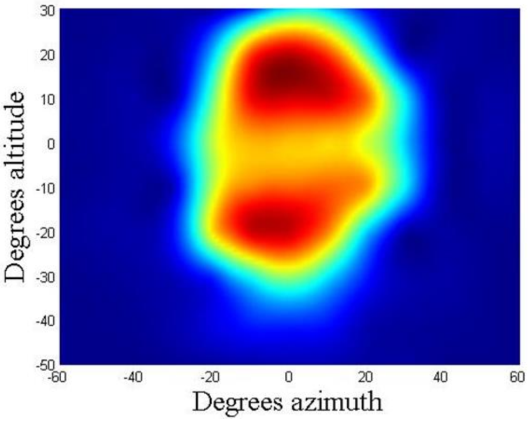


Figure 4. Localisation of the UVC light source for detector source separation of 1 m (top) and 2 m (bottom).

5. Summary

It can be seen from the above results that the UVTron does appear to have the potential to detect alpha-induced fluorescence in the field, though there is a great deal of work to do in order to develop this into a robust detection system. The output of the UV checker bulb in the UVTron sensitivity wavelength range requires quantifying in order that the sensitivity of the UVTron can be characterised. This should include a spectral analysis so that the different wavelengths within the range can be considered. As alpha-fluorescence photons have different wavelength intensity peaks, being able to map the sensitivity of the UVTron against different wavelengths would be useful in designing a detector system.

As distance increased, there appears to be a greater fluctuation in the cps over time and this should be investigated further to determine if this is a general phenomenon and if so, how this effect is generated in order to characterise the performance of the UVTron detector. Further scans will be carried out to test and improve the ability of the UVTron to locate the source of UVC photons. This will include collimation and orientation to take into account the angular sensitivity of the UVTron to give the best sensitivity and remove the double hotspot effect. This will eventually provide more accurate positioning of the detector and a better resolution.

Results from the two detectors, indicate that there is variation between UVTron detectors and this requires further investigation. Upon completion of the characterisation of the UVTron, it will be possible to determine if it is theoretically possible to use the UVTron to detect alpha-induced air fluorescence.

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