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THE APPLICATION OF MULTISPECTRAL LIGHT DETECTORS TO GAUGE DETONATIVE EVENTS BY MEANS OF THEIR EMITTED LIGHT SIGNATURE

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It is well known that reacting explosives emit light of varying intensity across the light spectrum. Measurement of this emitted light could have many applications, *i.a.* the creation of a database of characteristic light signatures at specific wavelengths for explosive configurations and munitions. Such information may enable the recognition of certain events, or the comparison of events with previous ones for consistency (*i.e.* gauging). This will assist in explosive event research and the development of new generation explosives, *e.g.* Insensitive Munition *etc*. To investigate the previously mentioned, the CSIR LS executed explosive tests with propriety in-house developed single-wavelength light detectors. Arbitrarily, two wavelengths were chosen for discussion at which the detonative emitted light measurements were performed. The captured signatures of PE4, Composition B and other explosive charges, of various mass and geometry, are compared and discussed.

1. INTRODUCTION

Diagnostic measurement during explosive tests plays an important role in the post analysis of explosive events and enables parameter calculation pertaining to the event. These parameters are compared to theoretical values to validate the models and advance the understanding of energetic materials. It is, in particular, of importance to know whether an explosive fully detonated, especially during the research and development of new generation explosives or insensitive explosives.

During a detonation, light of significant intensity is emitted across the spectrum ranging from ultra-violet to infrared (Mostert and Olivier 2011), with a specific time signature depending upon the charge constraint. By applying cost-effective light detectors in a novel way, it is postulated that this phenomenon could be used to gauge detonation events (full detonation and similar to previous ones confirmation) during research and development and during quality acceptance activities.

The CSIR Landward Sciences competency area executed various explosive tests (PE4, Composition B and others) with single-wavelength light detectors to capture the emitted light. It has previously been shown that for bare charges, two distinct regions in time can be distinguished for the light emission, namely, light from the early time frame (while the charge is detonating and slightly beyond – UV dominant in the shock and ionisation phase), and light from the expanding products of the explosive (the fireball – Visible and IR dominant in the Blackbody Emission phase)(Olivier, Perold and Mostert 2012) – see Figure 1.

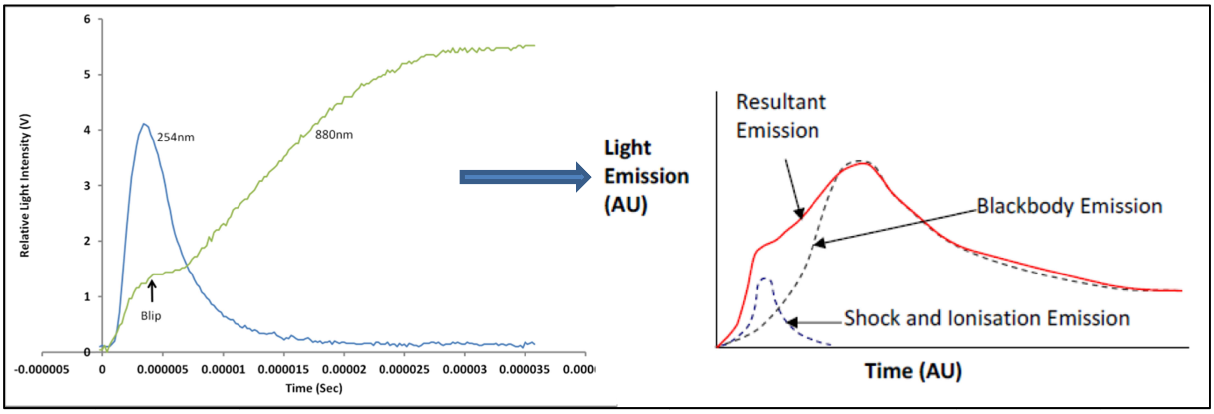

Figure 1: Distinct light emission regions in time: Shock and Ionisation region (left blue) and Fireball region (left green). Resultant emission in red to the right (Olivier, Perold and Mostert 2012).

For the purpose of this paper, two wavelengths (280 nm and 600 nm – one in the UV and one in the visible spectrum) were arbitrarily chosen because of Figure 1 for comparison and discussion.

2. EXPERIMENTAL PROCEDURE

The CSIR single-wavelength light detector plays a pivotal role in all of the experiments. The 280 nm Silicon Carbide and 600 nm Silicon Photodiode detectors both have a ±5 nm full width at half-maximum rated interference type narrow bandpass filter. The emitted light from the detonation decays rapidly in the UV region due to absorption and scattering, necessitating a trans-impedance amplifier for the 280 nm detector. These detectors are cost-effective, capture the continuous emitted signal (bandwidth > 2 MHz), and can be used in destructive tests – something that is not possible with e.g. spectrometers (expensive and not fast enough over desired timespan of > 1 ms – Ultrafast Systems). Optical fiber has been used by others to relay the light signal to a protected spectrometer, but the bandwidth is not sufficient in the UV region (Thorlabs Inc 2016: up to 2.5 dB/m attenuation at ca 300 nm). The detectors are packaged in robust housings with sensor, filter, CaF_2 window, amplifier and battery mounts designed for protection against blast, shock, dust and EMI (see Figure 2).

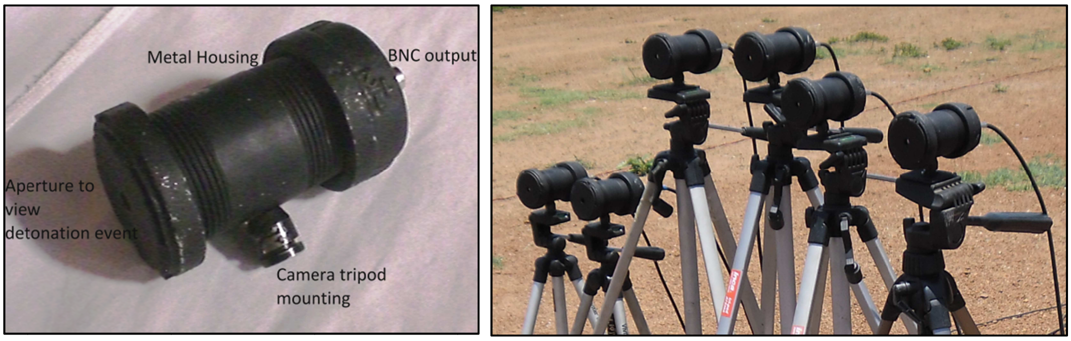

Figure 2: Rugged Detector (left) and Array of Light Detectors (right) to capture detonative emitted light in the UV to IR spectrum

Among others, PE4 and Composition B charges, of various mass and geometry, were detonated at the CSIR Detonics, Ballistics and Explosives Laboratory in Paardefontein, RSA. A selection of 6 shots is shown in Table 1 which is analysed and discussed in this paper.

Explosive Type	Geometry	Constraint	Nett Explosive Content (kg)	No of shots	280nm Detector	600nm Detector
Comp B	Cylindrical Length/Diameter=1 Cast	Open air	2	3		Figure 4
PE4	Spherical Hand moulded	Open air	4	3	Figure 5	

Table 1: Charges utilised in some tests at DBEL

A typical test setup is shown in Figure 3, with the detectors placed at an equal standoff distance to capture the whole event. The charges are usually suspended above ground (to eliminate reflections during the ca 1 ms period of interest). The data is captured by digital data acquisition systems (e.g. Oscilloscopes, Graphtec, etc.) and post-processed i.t.o. arbitrary light units and time.

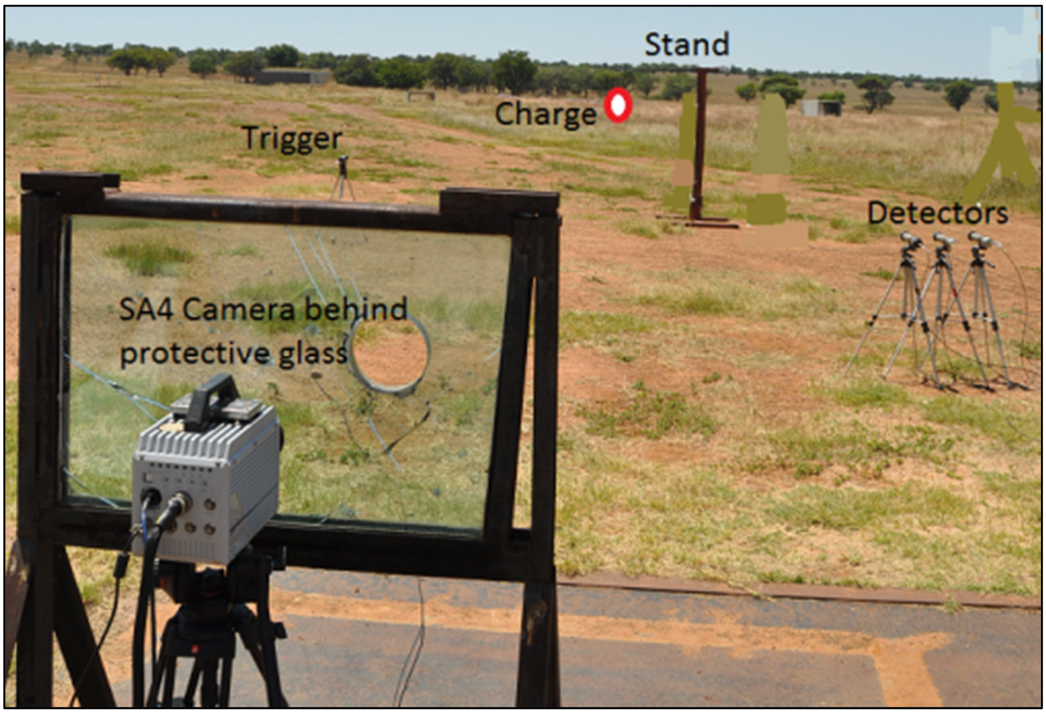

Figure 3: Typical test setup with detectors, trigger and suspended charge

3. RESULTS

The captured light traces at 600 nm from the detonation of 2 kg of Comp B are shown in Figure 4. The charges were cast in moulds to be cylindrical with length over diameter ratio of 1. Of interest is to note that these measurements were performed up two years apart and in different seasons as well.

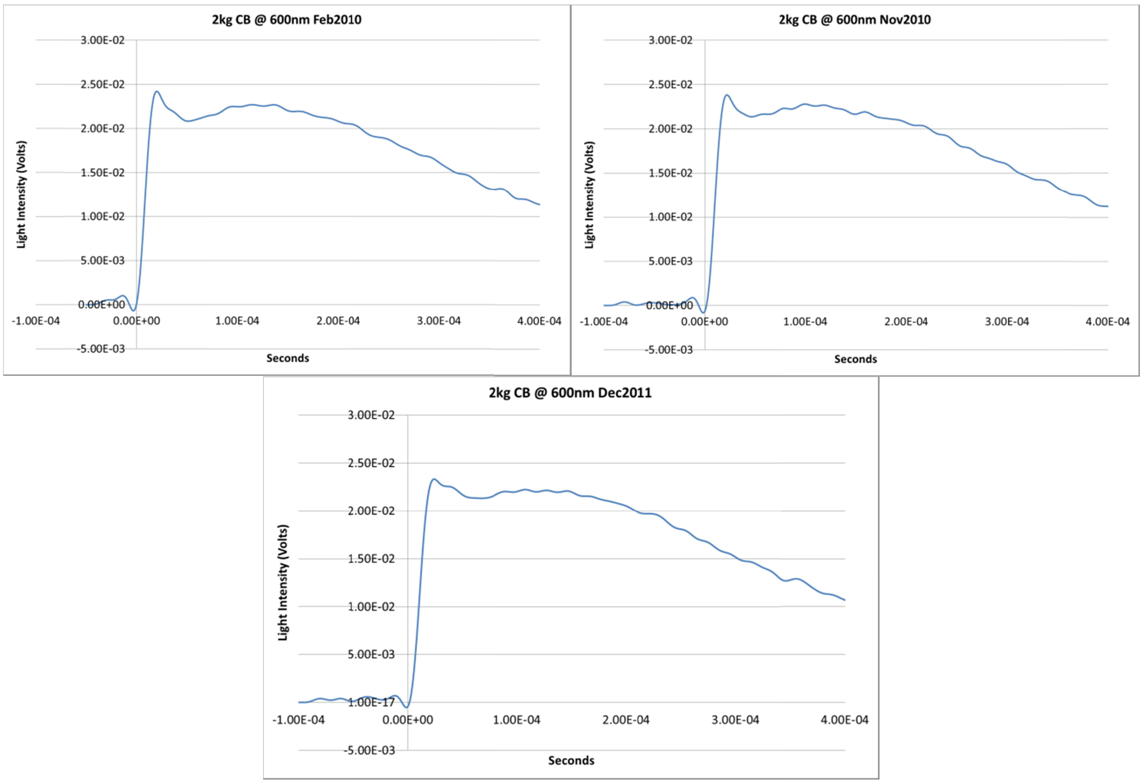

Figure 4: Emitted light captured from detonating 3 of 2 kg Composition B at 600 nm wavelength in Feb 2010, Nov 2010 and Dec 2011 (low pass filtered at 50kHz)

The captured light traces at 280 nm from the detonation of 4 kg of PE4 are shown in Figure 6. The charges were spherically hand moulded with diameter of 17 cm (a density of ca 1.55 g/cm³ was used). These tests were executed on the same day.

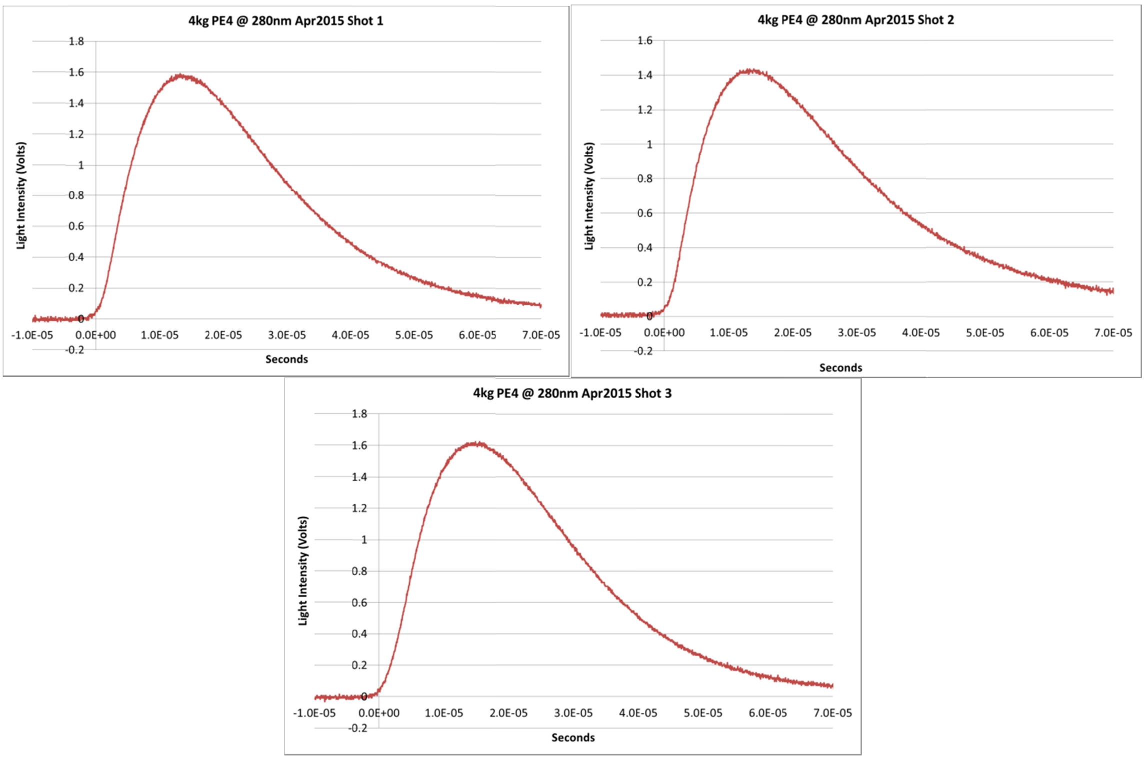

Figure 5: Emitted light captured from detonating 3 shots of 4 kg PE4 at 280 nm wavelength in April 2015

4. DISCUSSION

It was of interest to compare the obtained emitted light signatures from these different tests at the two chosen wavelengths. Figure 6 shows the results of the different 2 kg Comp B tests (measured at 600 nm wavelength) performed over a lengthy period of time:

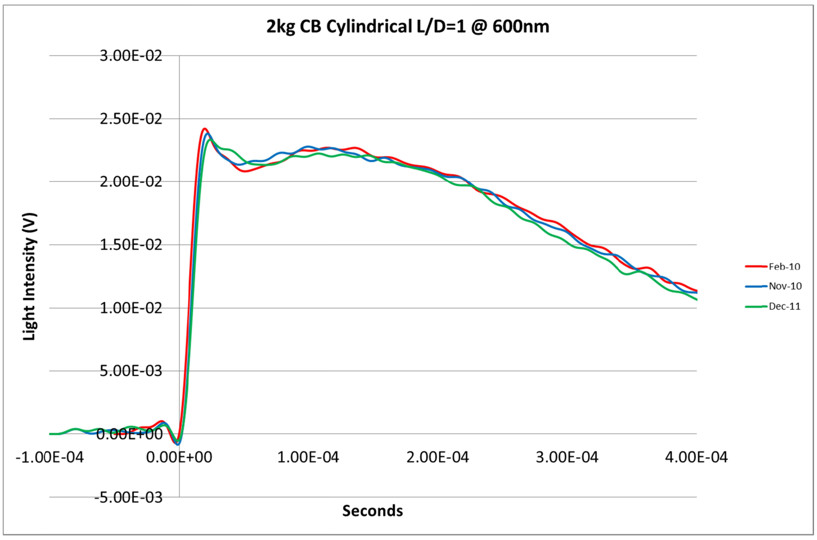

Figure 6: Emitted light in Time signature of 2 kg Comp B cylindrical charges at equi-distances

From Figure 6 it is clear that the time response of the three signals resemble each other closely, with a mere ± 1.05% maximum amplitude deviation (0.5 mV). This indicates a very consistent casting and detonation process. It also seems that absorption, scattering, temperature, humidity, etc. play a minor role as far as the emitted light signature is concerned.

As for the 2 kg Comp B case, the comparison of the obtained 4 kg PE4 light signatures at 280 nm wavelength is shown in Figure 7.

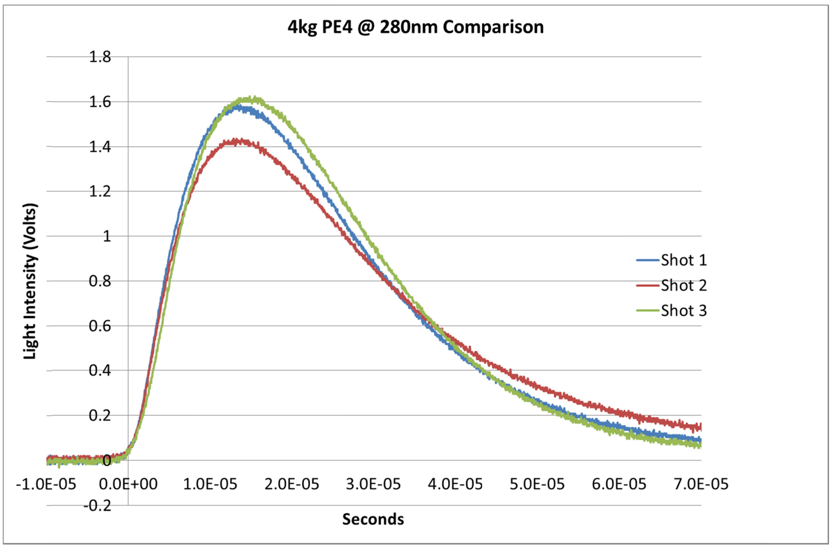

Figure 7: Emitted light in Time signature of 2kg Comp B cylindrical charges at equi-distances

Once again, the three signatures follow each other closely in time and amplitude, with a maximum amplitude deviation of ± 5.6%. This (larger) deviation can be ascribed to the fact that these charges were all hand moulded (not cast), and the geometry was not exactly the same for each charge. Full detonation for each shot was confirmed by side-on pressure measurement.

It is interesting to confirm again that the shorter wavelength event (280 nm) is of a much shorter duration (µs region vs ms region) than the longer wavelength event (600 nm) coinciding with Figure 1 (see Figure 8 below):

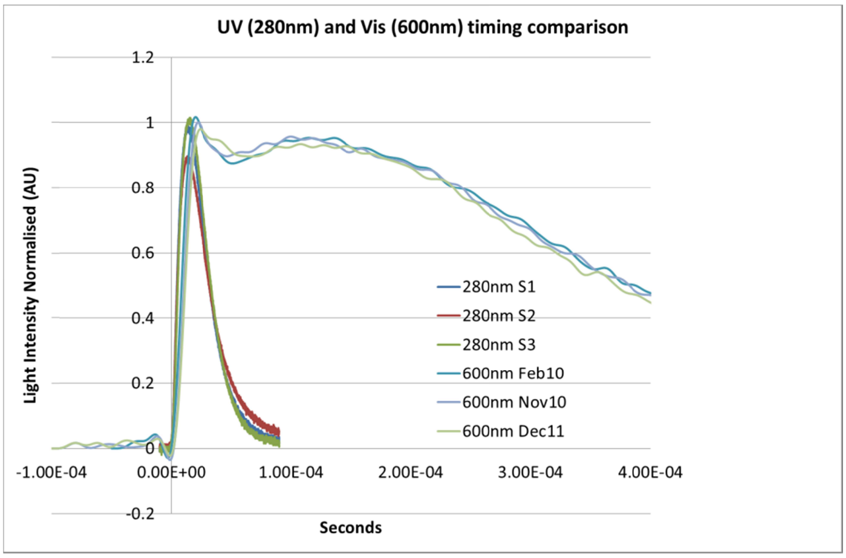

Figure 8: Emitted light signatures of UV and Visible emissions (amplitudes normalised to nominal 1)

From Figure 6 and Figure 7 it is clear that these cost-effective light detectors render consistent data at discrete wavelengths w.r.t. the emitted light emanating from a detonation. The signatures of identical charges (same explosives and geometry) can be compared directly to a pre-existing database of signatures, and differences will indicate deviations in the explosives and/or detonation process. This is substantiated by the increase in deviation of the 4 kg PE4 charges above, where the imperfect hand mould process was identified.

With the above practical knowledge at hand, some more tests were performed, i.a. with 650 and 940nm detectors. Figure 9 depicts the characteristic signatures of Comp B and TNT cylindrical cast charges with L/D of 1 at 650nm:

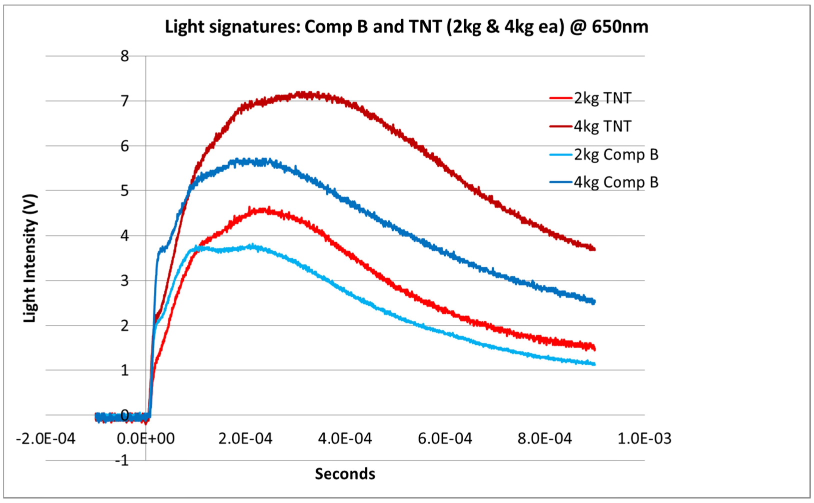

Figure 9: Emitted light signatures at 650nm for 2kg and 4kg of Comp B and TNT charges, cylindrical and L/D of 1

From Figure 9 one can see the difference in the signatures as a function of the explosive type: the TNT is consistently higher in ultimate amplitude (after ca 250 µs), but slower on the rise than Comp B. As expected, the nominal amplitude of both explosives will rise as a function of the mass$^{1/3}$ (Mostert and Olivier 2011).

In Figure 10 some measurements at 940nm (IR) are shown, comparing homemade explosives (ANFO and Nitromethane) to PE4:

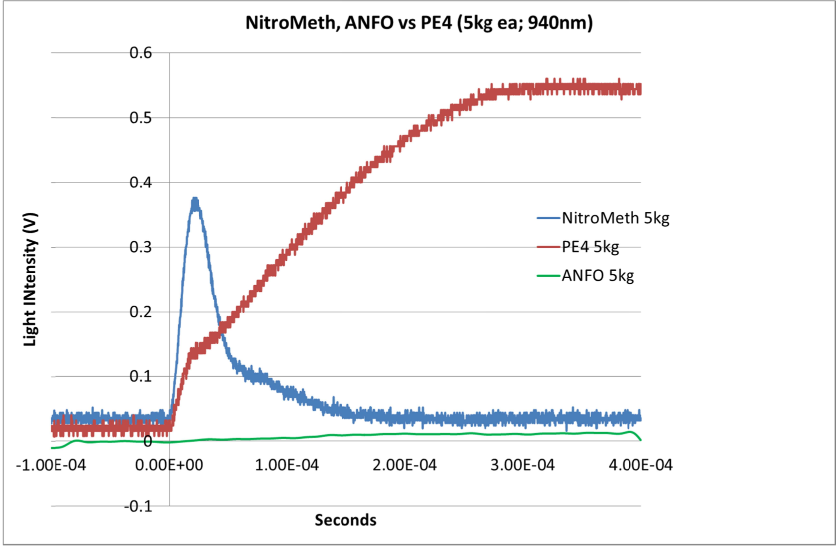

Figure 10: Signatures at 940nm for 5kg of Nitromethane, ANFO and PE4 (L/D of approximately 1)

Once again, the differences in light signatures are clearly visible, with the Nitromethane exhibiting a short burst of IR light. This is superseded by far by the PE4, whilst the ANFO is hardly visible. What becomes clear, is that the signatures are distinctively different.

All these attributes could be contained in the characteristic signature databank of charges and munitions, and used as comparison baseline for e.g. acceptance testing. For new generation explosives (including Insensitive Munitions), such a databank could also be created to compare the various energetic events against one another in support of research activities.

For the purpose of gauging detonation events utilising the detectors as described above, one would recommend the simultaneous usage of e.g. two detectors: one in the Ionisation and Shock phase (UV), and one in the Blackbody Emission phase (Visible to NIR). This will enable a gauging decision with a higher confidence level.

Furthermore, placing e.g. 4 detectors 90 degrees apart in a circular fashion around the detonation will ensure the capture of the complete light radiation (360 degrees) in a doughnut pattern. This might be of use for solid encased munitions with non-predictable fragmentation and/or breakup.

5. CONCLUSION

It is concluded that detonation events can be compared to prior identical detonation events w.r.t. their emitted light signature, and that the CSIR developed a single wavelength detector that can be used for this purpose, i.e. to gauge detonation events:

- renders consistent data for identical events
- indicates full detonation
- light signatures for the same detonation at different wavelengths is not the same
- small differences in geometry can be detected
- consistency of casting / press / machining process can be verified
- different explosive types render different signatures
- a database of characteristic light emission(s) at certain wavelength(s) can be compiled for every detonative event by using these detector(s)
- it can be used during research and QA

Detecting at two wavelengths (one in UV, and one in the Visible to IR/NIR) will increase the level of confidence of the resulting gauging decision. This will be a valuable tool during acceptance activities, but will also play an important role during the research and development of new generation explosives, e.g. Enhanced Explosives and Insensitive Munitions.

6. REFERENCES

1. F.J. Mostert and M. Olivier. Scaling of light emission from detonating bare Composition B, 2,4,6-trinitrotoluene [C7H5(NO2)3], and PE4 plastic explosive charges. Journal of Applied Physics, vol. 110, no. 8, p. 084905, 2011
2. M Olivier, WJ Perold and FJ Mostert. The Conceptual Design and Development of Novel Low Cost Sensors for Measuring the Relative Light Emission in the Pre-millisecond Stages of Detonating Explosive Charges. Stellenbosch University, December 2012
3. Thorlabs Inc 2016. https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=7062
4. Ultrafast Systems 2016. http://ultrafastsystems.com/halcyone-femtosecond-fluorescence-spectrometer/