

L6 Data Capture and Evaluation - ACDA6021**Ryan Garry****Student Number: 2024366****Laboratory Report: Data capture and analysis of an OME item****Introduction:**

This report details the design and implementation of a small-scale arena trial to determine the nature of an unknown explosive article from a list of potential munitions. The design of the trial and equipment used within the trial will be presented, along with an overview of data gathered from the measurements made. This will be discussed with a view to determining the authors conclusions on the nature of munition employed, the composition employed within it and the mass of the charge used.

Trial location and design:

The trial was run at COTEC (Cranfield Ordnance Test and Evaluation Centre), staged at the forward battery on hard standing. The range is suitable for detonations of N.E.Q of up to 10 kg due to acoustic limitations on the site. The trial was undertaken in accordance with ITOP (International Test and Operating Procedure) 4-2-813 [1] and in accordance with COTEC on-site procedures.

The munition was detonated on a small stand approximately 400mm high from the hard standing of the range and the height of the charge measured an estimated further 103mm, making the height of charge approximately 450mm from the ground. The hard standing of the range is not perfectly level or consistent in material and a further variable level of noise is expected in overpressure readings as a result. The arena was set at a size of 1.5m diameter, with a 113° horizontal and 15° vertical fragment collection arc.

Sensors used/Data collected:

In order to collect sufficient data to identify the munition following detonation, various sensors and equipment were employed within the trial arena to capture fragments, data on the blast wave and chemical traces. Following detonation of the munition, parts of the area were then swabbed for trace samples to be used for Fourier Transform InfraRed (FTIR) Spectrographic Analysis.

The following section details the apparatus employed within the trial in order to capture sufficient data for analysis. These were arranged as per figure 1 below.

Pressure gauges – Three Piezo Electric pressure gauges numbered G1-G3 were arranged at distances of 1012mm, 2075.5mm, and 3094.mm from the munition (distances averaged from two measurements by laser range-finder), with each gauge offset radially by approximately +125mm from the preceding gauge in order to minimise interference from those in closer proximity. Pressure gauges were set at a height of 500mm from the hard-standing. These were mounted on steel frames with a rubber grip between the frame and gauge mounting. The gauges were mounted in mushroom mountings in order to shear the blast wave and provide an accurate reading across the face of the gauge.



Figure 1: Layout of Arena Trial

Fragment collection – Packs of strawboard panels 2-deep were positioned opposite the pressure gauges and arrayed in a 4 x 1 grid at ground-level in order to provide a suitable surface for the deployment of make-foils and in order to collect fragments for analysis. These were numbered 1F-4F (and 1-4B for the packs to the rear), and mounted in portrait orientation as per figure 2 below providing coverage of an approximately 110° span around the munition. Each pack comprised 20 straw board panels measuring 1050mm by 800mm and held together with polypropalene pallet strapping and the 2 deep packs were affixed to the frames in a similar fashion. Fragments were collected following detonation and weighed to ascertain the average fragment size and weight, as well as to provide samples for FTIR analysis. Strawboard alignment was not precisely measured and therefore were not set up in a perfect arc surrounding the charge. Approximate measurements to the centre of each pack can be estimated from measurements show below to the make-foils. Due to damp conditions and less-than ideal storage, the strawboard packs were slightly damp, which is likely to alter the material's properties and therefore would make fragment velocity calculations based on depth of penetration unreliable.

Make foils – 12 make-foils were arranged in landscape orientation in a 4 x 3 grid affixed to the 4 Straw-board packs, 3 foils per pack, as per figure 2. These were numbered with their position and port number and affixed to each pack by double sided tape. Distances from the munition to the centre of each foil are shown below in table 1. Upper and lower row measurements were calculated from laser rangefinder measurements taken horizontally to the centre of each foil to determine the approximate slant distance. Cables connecting the foils were taped down and run to the closest edge of the pack, and through to ports 1-12 respectively in the cable connection unit situated behind the straw boards, as per figure 3, in order to minimise the likelihood of fragment impact with cables and any resultant loss of data.

Foil measurements were recorded via a 5v open circuit. A pre-trial continuity check was performed on each foil by shorting each foil with a conductive object and verified on the logic analyser.



Figure 2: Numbering and positioning of make-foils



Figure 3: Cable connection unit

Foil No.	Foil ID	Location of foil		Distance from C.o.C. to centre of foil (m)
1	1F-A	Frag pack 1	TOP	1.473634962
2	1F-B		MIDDLE	1.3
3	1F-C		BOTTOM	1.315294644
4	2F-A	Frag pack 2	TOP	1.42411376
5	2F-B		MIDDLE	1.4
6	2F-C		BOTTOM	1.414213562
7	3F-A	Frag pack 3	TOP	1.533101432
8	3F-B		MIDDLE	1.4
9	3F-C		BOTTOM	1.414213562
10	4F-A	Frag pack 4	TOP	1.513274595
11	4F-B		MIDDLE	1.4
12	4F-C		BOTTOM	1.414213562

Table 1: Distance from Centre of Charge (CoC) to Centre of individual foils

Recording Equipment and trigger conditions:

An Agilent 16804A Logic Analyser was used to capture state-changes from the make foils and provide accurate cross-device timing.

The munition was triggered via PCI control panel and arming panel, with pre-trigger recording for the logic analyser collecting timing and make-foil impacts at 10% of the overall interval measured.

Pressure gauge data measurements were set to be triggered by the first gauge experiencing a significant change in pressure, with a sampling interval of 4 μ s. Sampling rate for the foils was set at 2000 per second, with a 500 micro-second interval between samples. The first sample was taken at -0.5 s, with the last taken at 4.4995s. Signals and data were transmitted to the data collection point via cat5 twisted pair cabling.

The munition was base detonated via a hole through the centre of the table using a L2A2 detonator comprising 0.98g of ASA/PETN.

Other information:

Swabs were taken from fragments recovered from the straw-board packs and from the foils, as well as other areas in the immediate vicinity and in line-of-sight of the explosive charge to recover explosive residue expelled from the munition on detonation. These swabs were then sealed in plastic bags and labelled with the details of the trial before being submitted for FTIR Analysis. All samples were soaked in a solution of Acetone overnight for analysis, and confusion from this was subtracted digitally from the spectra produced in order to provide the most accurate representation possible.

All cabling was routed under I-section steel to the rear of the blast packs and on to the data collection equipment via several IP65 cable connection units in order to minimise the likelihood of fragment impact with cables and any resultant loss of data.

Potential Munitions:

A list of potential munitions is presented at Annex A along with any additional information provided and discussed below. Information validated by external public sources is indicated here. Information provided on fragmentary velocity was not verifiable due to a lack of available information however is discussed in the analysis of fragmentary velocity below.

Results

Foil Data:

Results from make-foil timings are tabulated in Annex B. Only the initial strike on each foil has been graphed below in figure 4 as any subsequent strikes are more likely to be the result of rebounds or other objects. The result from foil 1FA has been discounted as it likely results from a rebound object or fragment. It is highlighted here in orange. A polynomial trendline to the order of 2 (quadratic) was applied to the remaining 11 results as the fragments will experience turbulent drag, although this must be considered critically with the limited number of data points in mind and the limited range of distance between the foils.

An average velocity of 679.17 m/s was recorded across the 11 strikes thought to be purely from thrown fragmentation.

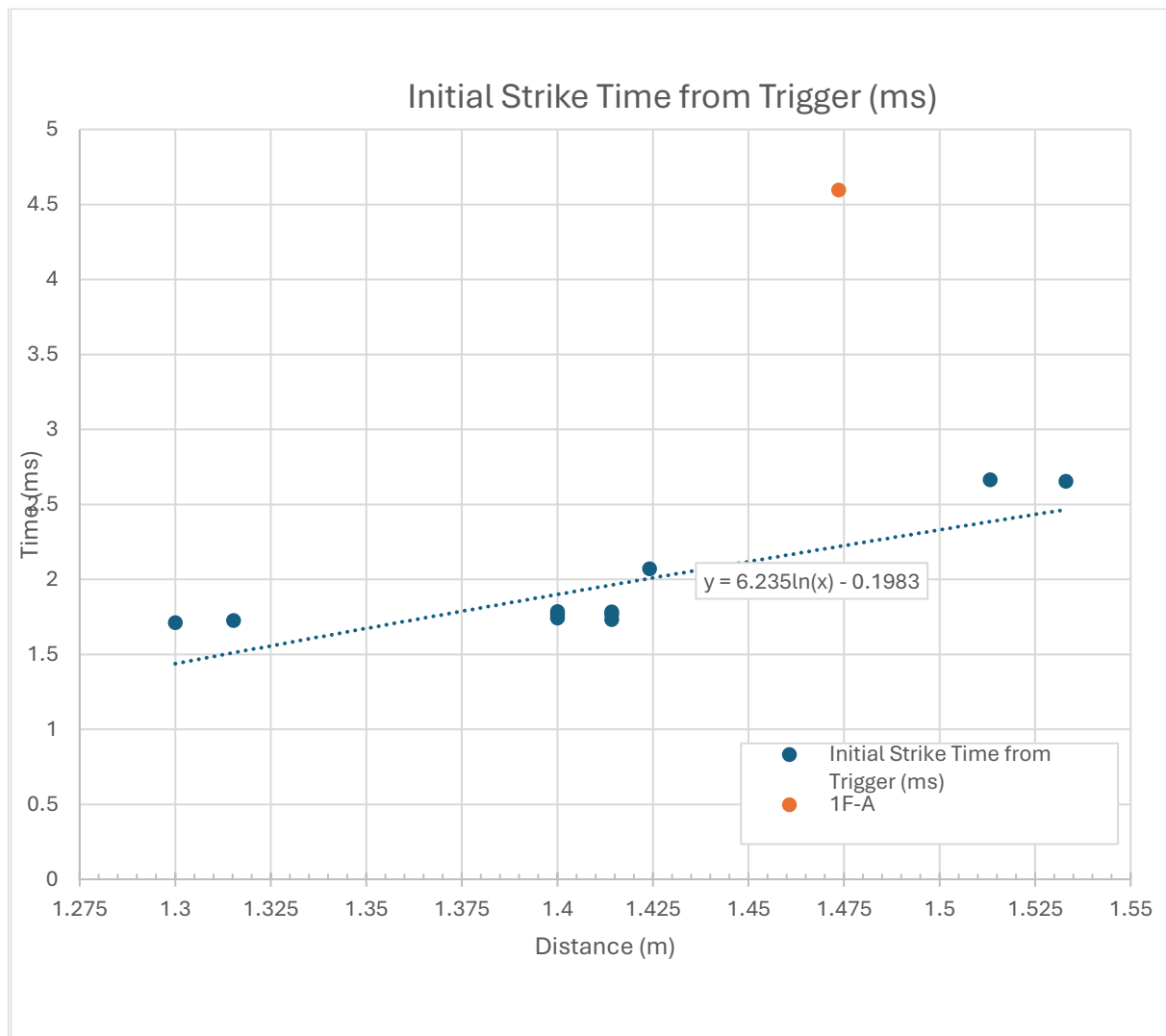


Figure 4: Graphed initial strike times for make-foils

Pressure Gauge results:

Pressure gauge 1 was impacted by a fragment prior to the impact of the pressure wave and physically destroyed. Data from this device is not included in the below graph. Data recovered from the remaining two gauges was filtered to remove missing data, and trendlines representing a moving average of 10 points in order to simplify the results, and is graphed below in figure 5:

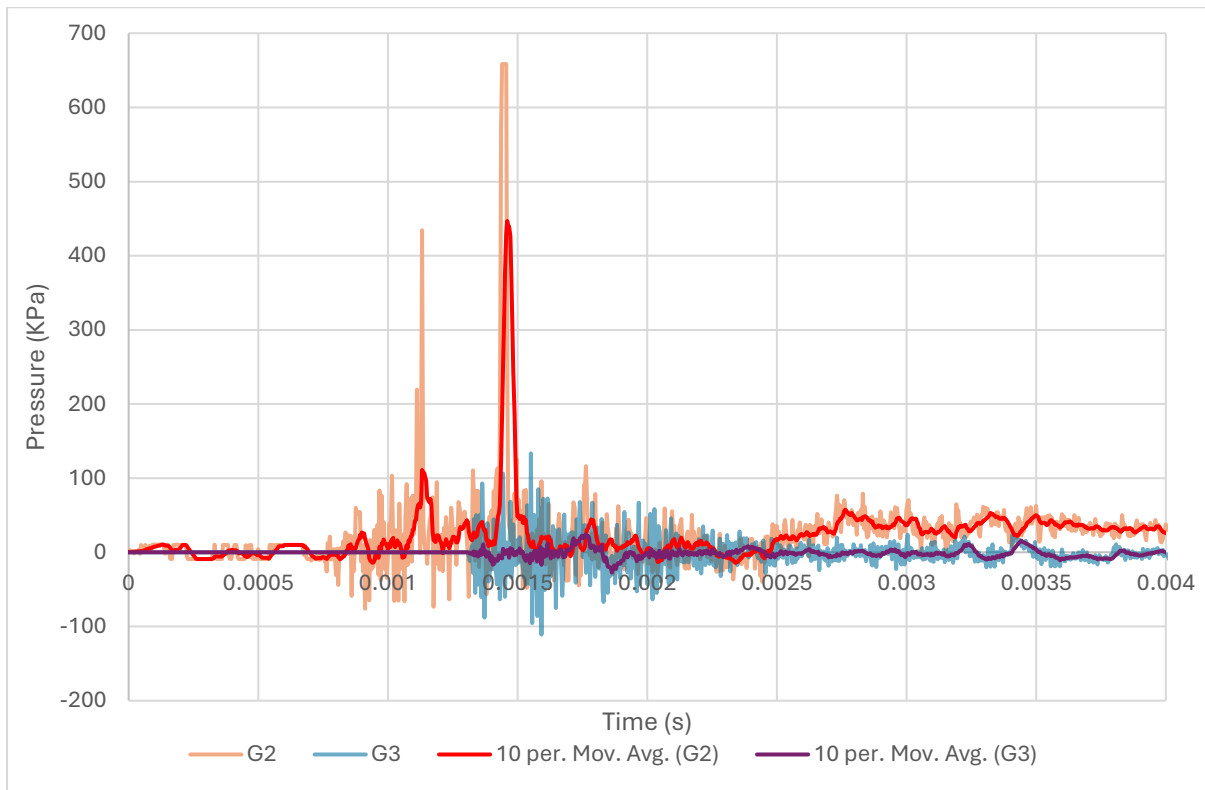


Figure 5: Measurements from Pressure gauges

As can be seen from figure 5, Gauge 2 (represented in orange) hits an initial overpressure of approximately 430Kpa. An initial reflected pressure spike can be seen approximately 13ms after with subsequent overpressures and noise. Gauge 3 records a much lower incidental overpressure of around 95Kpa, with successively higher reflected pressure waves following much sooner after, due to its increased distance from the detonation. These spikes in pressure can be seen in the moving average trendlines.

Noise seen prior to the initial overpressure wave can be seen in the trendline for Gauge 2 and likely results from the initial impact of fragmentation on gauge 1 and groundshock from the hard standing.

FTIR Data:

Figure 6 below shows the FTIR Spectra produced from analysis with Table 2 illustrating the frequencies observed:

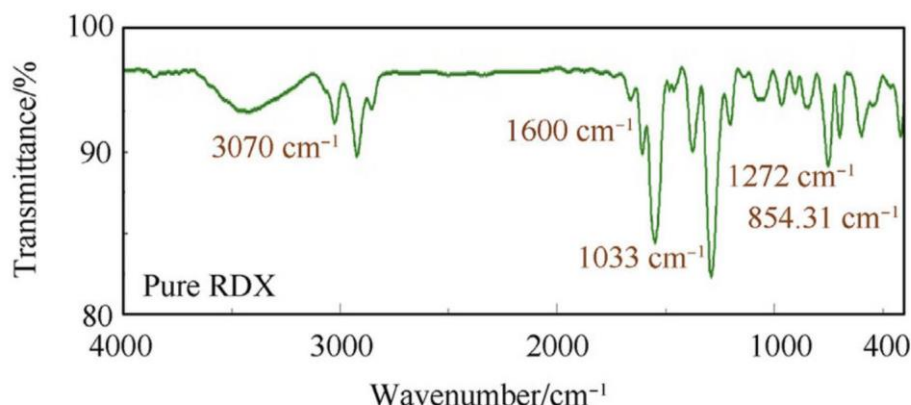


Figure 6: FTIR Spectra (Sample average) of swabbed material from trial arena

Interpretation of FTIR Spectra:

Single Bond Area:

There is a noticeable, rounded, broad peak in the 3400 cm^{-1} region, possibly indicating the presence of a Hydroxyl Group (OH) within the sample collected. This is a broad peak at the lower end of the grouping which would represent stronger H-bonds and polymeric bonding [2].

There is a strong forked stretch in the $3066\text{--}3070\text{ cm}^{-1}$ range, indicating the presence of symmetric and asymmetric C-H bonds and an aromatic ring, which is reinforced by the presence of a large N-O stretch at 1593 and 1574 cm^{-1} . This is a slightly higher frequency, indicating sp^2 hybridised CH bonds and therefore a 120° angle between pairings, and an aromatic ring structure, which is echoed at 793 cm^{-1} [3] [2] [4].

There are further weak peaks present at around $2900\text{--}3000\text{ cm}^{-1}$ (as well as at 1738 cm^{-1}), likely indicating the presence of a plasticizer within the sample. Comparison with the FTIR spectra of polyurethane shows corresponding peaks at 2865 cm^{-1} and 1713 cm^{-1} , as per figure [5], the use of which may explain some of the noise around these reasons. PBA is another possibility by comparison [6], however the limited amount present within the sample makes determining the exact plasticizer difficult.

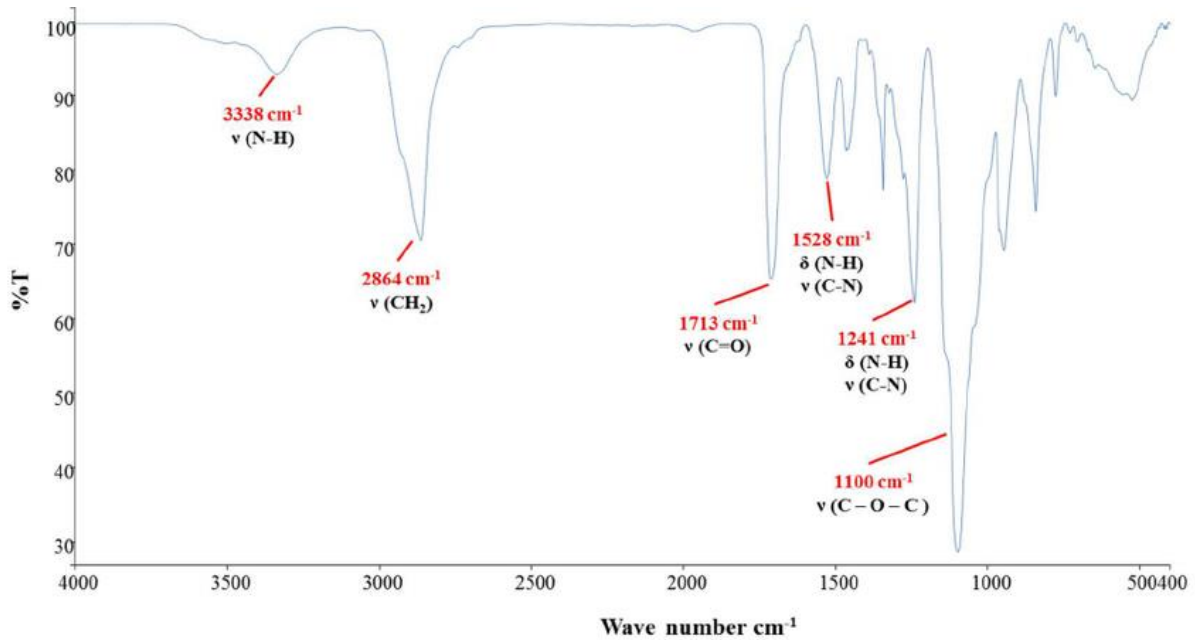


Figure 7: FTIR Spectra of Polyurethane

Triple Bond area:

There are no visible peaks in the triple bonded section of the spectrum, which can be expected from the majority of the compositions listed, however it does at least suggest the absence of some less stable primary explosives containing acetylene [4] that might theoretically be employed in improvised devices such as the pipe bomb.

Double bond area:

There is a strong N-O stretch at 1593 cm⁻¹, indicating an open-chain imino group [3]. This is considered to be middle of the range for the functional group in energetic materials, and specifically for HMX [7].

There is no peak at about 1600 that would indicate a double C-C bond, and otherwise no peaks that indicate C-C ring bonding.

As above, there is a weak indication at 1738 cm⁻¹ of a simple carbonyl compound, such as an ester, which is likely to be an element of the plasticizer used.

Experimental vibrational frequencies [cm ⁻¹]	Description of the normal modes of vibration	Comments
3075	CH stretch (s)	Strong
3066	CH stretch (a)	Strong
3001	Plasticizer	Weak
2930	Plasticizer	Weak
1738	Plasticizer	Weak
1593	NO stretch	Strong
1574	NO stretch	Strong
1533	NO stretch	Strong
1460	H-C-N bend (a)	Strong
1434	H-C-N bend (a)	Strong overlap
1390	C-N stretch	Strong
1351	C-N stretch	Strong
1312	N-N stretch	Strong broad
1269	C-N stretch	Very strong
1233	C-N stretch	strong Overlap
1218	C-N stretch	Strong overlap
1040	C-N stretch	Strong
924	O-N-O bend	Strong broad overlap
882	N-N-O bend	Medium
843	N-N-O bend	Medium
783	N-N-O bend	Strong
753	Ring distortion	Medium
604	Chair type ring distortion	Medium overlap
590	Ring distortion at carbon atoms	Medium overlap
461	Ring distortion	Weak
410	Ring distortion	Weak

Table 2: Observed frequencies in FTIR sample

Discussion/Analysis:

Information provided on potential munitions of interest:

Some of the information provided on potential munitions proved to be unverifiable, in particular relating to the Mk 83, however this munition has the distinction of being far above the N.E.Q of that permitted on the range used for the trial, and entirely unsuitable for such a small scale trial, and therefore can be discounted from deliberations.

The RPG warhead can also be discounted as it is a shaped charge warhead, and therefore falls outside of the permitted types of munitions suitable for testing in such an arena trial.

FTIR Data:

The FTIR spectra of the samples collected clearly indicates the presence of a nitrated aromatic ring element to the compound, such as that present in TNT, Nitrocellulose and RDX. This discounts nitrate esters such as pure PETN. Differentiating between these can be achieved via consideration of the other peaks present and not present within the spectra.

There are multiple indications of N-N-O bends within the fingerprint region of the spectra, as well as H-C-N bends within the double bond region, suggesting a compound containing RDX rather than pure TNT, or for the unknown composition of the pipe-bomb, nitrocellulose as the basis of the sample compound, both of which do not contain N-N-O bends. As far as potential munitions this may indicate from our list of potential interest, this discounts purely TNT filled munitions such as the RGD-5 grenade and RPG PG-7VL.

In a similar fashion, the lack of C-C ring bonds or other C-C bonds within the spectra indicates the absence of TNT from the sample. This reinforces the discussion above of other evidence to suggest that the sample tested represents none of the standard-build military munitions, which leaves only the pipe bomb under consideration.

As far as the exact composition used within the bomb, the combination of use of a likely plasticizer within the composition suggests the use of a binder, which given the likely presence of RDX, narrows the list of potential compositions down to a polymer bound explosive containing RDX as the primary energetic component, such as P8, Semtex or C4.

Comparison with FTIR spectra for these known explosives shows an almost exact match with C4 as per table 3 [8]. This is very similar to the composition listed for P8 as suggested for the composition employed within the pipe bomb, in both stoichiometry and in binder material.

Name of explosive	Experimental vibrational frequencies [cm ⁻¹]	Description of the normal modes of vibration	Comments
C-4 (composition 4)	3075	CH stretch (s)	Strong
	3066	CH stretch (a)	Strong
	3001	Plasticizer	Weak
	2930	Plasticizer	Weak
	1738	Plasticizer	Weak
	1593	NO stretch	Strong
	1574	NO stretch	Strong
	1533	NO stretch	Strong
	1460	H-C-N bend (a)	Strong
	1434	H-C-N bend (a)	Strong overlap
	1390	C-N stretch	Strong
	1351	C-N stretch	Strong
	1312	N-N stretch	Strong broad
	1269	C-N stretch	Very strong
	1233	C-N stretch	strong Overlap
	1218	C-N stretch	Strong overlap
	1040	C-N stretch	Strong
	924	O-N-O bend	Strong broad overlap
	882	N-N-O bend	Medium
	843	N-N-O bend	Medium
	783	N-N-O bend	Strong
	753	Ring distortion	Medium
	604	Chair type ring distortion	Medium overlap
	590	Ring distortion at carbon atoms	Medium overlap
	461	Ring distortion	Weak
	410	Ring distortion	Weak

Table 3: FTIR Emissions of C4

Pressure Data:

Analysis of information provided for the pipe bomb, in terms of its charge size, and mass, using Kinney-Bulmarsh equations for air-burst spherical munitions [9], shows a likely peak overpressure for a 0.26kg C4 charge with a TNT equivalence of 1.39 [10] at a distance equal to that from Gauge 2 of 427Kpa. This almost exactly matches the recorded peak pressure. PE8 is likely to exhibit a lower TNT equivalence based on publically available information, which is also suggested by [10].

Reflected overpressures calculated are considerably higher than those suggested, although this is likely to be due to the very low height of the detonation and therefore slight angle of incidence for the reflected blast wave, which in this case is close to 20° and would represent a reduction of peak pressure by a factor of approximately 1.4, which would bring predictions in very close accordance to recorded results. Likewise calculations carried out for gauge 3 predict a peak incidental overpressure of 88Kpa. In a similar fashion, the reflected overpressure predicted is considerably lower again, and varies by a higher ratio to the closer gauge, again reflecting the decreased angle of incident to the third gauge.

This validates the information provided as highly likely to be accurate.

Conclusions:

From the discussion and analysis above, it seems highly likely that the munition employed in the trial is a pipe bomb, and that the majority of the information provided is accurate, at least in terms of charge size and mass. From FTIR analysis and comparison, it seems likely that the PE8 composition listed either shares a near identical FTIR spectra with C4, or that

information provided is slightly incorrect and it is in fact C4 used as the primary composition. This is made more likely by the TNT equivalence of C4, which appears to be somewhat higher than the closest available comparison of PE8 (PE4) for overpressure [10].

References:

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Annex A: Types of Munition of Potential Interest

Name/ Designation	Charge Mass (kg)	Mass of Case (kg)	AUW (kg)	Explosive Fill	Average Fragment area (cm ²)	Average Fragment Mass (g)	Information Verified (Y=Correct/ NV = unverified/ X = Incorrect)
Mk 83 air dropped	225	229	454	Comp B (H6/PBXN- 109)	0.48	115	X
M-67 Grenade	0.185	0.213	0.398	Comp B	1	2	Y Partial
RGD-5 Grenade	0.11	0.2	0.31	TNT	1	0.12-0.46	Y Partial
81mm Mortar AR-M81	0.76	1.334	4.15	TNT			Y Partial
RPG PG-7VL (HEAT warhead)	0.73	1.6	1.975	RDX/TNT		0.1	Y Partial
155mm	1.15	3.105	4.255	Comp B		2.1	N/A
Pipe Bomb	0.264	0.417	0.681	PE 8		0.83	N/A

Table 4: Information Provided on munitions of potential interest

*Information has been verified where possible from public sources. Fragment data was not verified for any munitions due to unavailability of information. All information provided for Mk83 appears to be slightly incorrect (actual compositions thought to be currently employed in brackets), however remaining information has not been corrected for reasons stated in the main body of this report.

**Further information provided on Fragment velocity was provided but not possible to verify and has been discounted from this analysis.

Annex B:**Make foil results:**

Foil ID	Distance from charge stand to center of foil (m)	Initial Strike Time from Trigger (ms)	Comparable Speed of fragment (m/s)
1F-A	1.473634962	4.5953	320.6830809
1F-B	1.3	1.71048	760.020579
1F-C	1.315294644	1.72476	762.5957489
2F-A	1.42411376	2.07088	687.6853123
2F-B	1.4	1.76334	793.947849
2F-C	1.414213562	1.7305	817.2282938
3F-A	1.533101432	2.65346	577.7744649
3F-B	1.4	1.78502	784.3049378
3F-C	1.414213562	1.76556	801.0000013
4F-A	1.513274595	2.6625	568.3660451
4F-B	1.4	1.7422	803.5816783
4F-C	1.414213562	1.7822	793.5212447
		Average:	705.8924363

Figure 8: Initial strike times for make-foils

*Note: Highlighted results thought to be likely as a result of ricochets or rebounding material.