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Laboratory Report: Data Capture and Analysis of an OME Item

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Abstract

This report presents the identification of an unknown ordnance item through the analysis of blast-fragmentation behaviour and explosive residue collected during a controlled arena trial at COTEC. Participants were not permitted to view the munition, requiring its classification to be inferred exclusively from experimental data. Fragmentation capture was achieved using straw-backed witness boards instrumented with time-of-arrival (TOA) foil sensors across a 118° sector. Ninety fragments were recovered, exhibiting an average mass of 0.826 g and thickness of 3.3mm. Extrapolation to a full 360° distribution, yielded an estimated total casing mass of approximately 227g, consistent with a small, thin-walled metal enclosure rather than a hardened military casing. FTIR spectroscopy of swabbed residue revealed nitramine-type absorption bands indicative of RDX-based energetic materials. A structured Red-Amber-Green (RAG) comparison against candidate munitions indicated poor alignment with air-dropped, mortar, artillery, or grenade-class systems, and strong consistency with a small pipe-type fragmentation device containing a mixed Plastic/RDX explosive fill. The combined evidence suggests the item was an improvised or low-grade pipe-type device rather than a conventional military munition.

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Table of Abbreviations

NEQ	Net Explosive Quantity
RDX	Triazinane
TNT	Trinitrotoluene
HMX	Tetraazacyclooctane
FTIR	Fourier Transform Infrared Spectroscopy
OME	Ordnance, Munitions and Explosives
PE 8	Plastic Explosive No. 8
DSTL	Defence Science and Technology Laboratory
TOA	Time of Arrival

1 Introduction

1.1 Objective of the Trial

The aim of this trial was to identify an unknown ordnance, munitions and explosives (OME) item using non-destructive blast and fragmentation evaluation supported by chemical residue analysis. Conducted at the COTEC arena and guided by DSTL methodologies, the trial made use of foil time-of-arrival (TOA) sensors, straw-backed witness boards, fragment mass measurements, and Fourier Transform Infrared Spectroscopy (FTIR) swab analysis. Participants were not shown the item on the range and were required to determine its identity solely from the captured data. The analysis focused on analysing casing material, estimating explosive mass, and classifying the munition against known candidates using a structured evidence-based approach.

2 Methodology & Materials

2.1 Trial Setup and Data Capture Tools

The trial was conducted under a licensed 10kg NEQ arena test, covering a 118° sector. The objective was to assess the characteristics of an unknown munition and gather data to support its identification. The class was divided into four specialist teams, each responsible for a distinct aspect of the experimental setup:

2.1.1 Strawboard and Foil Assembly Teams (Fragment Capture and Detection)

Witness boards with a depth of twelve strawboard panels were arranged to capture metallic fragments from the detonation. Each board was fitted with three velocity detection foils, resulting in a total of 12 foils. The foils were constructed from copper and configured as non-contacting, interleaved conductive circuits:

- Each foil consisted of two adjacent copper circuits: one connected to a +5V supply, the other to ground.
- In their default state, the circuits remained open. Upon impact by a conductive fragment, the circuit was completed, resulting in a state change detectable by a logic analyser.
- Foils were fixed horizontally to the strawboards using double-sided tape.
- Each foil and its associated wiring were clearly labelled using marker pens for traceability.
- Foil leads were routed into a 12-port junction box, with each foil occupying a dedicated port (1–12).
- Prior to the trial, each foil was functionally tested using a conductive probe to confirm that a state change was registered on the logic analyser, indicating operational readiness.

2.2 Wiring and Data Acquisition Team

Two primary cable types were used to interface the sensors with the control room:

- Velocity Foils: Connected via a multi-core data cable to the logic analyser in the control room.
- Pressure Gauges: Connected using BNC coaxial cables, which were:
- Routed through a wall port into the control room.
- Labelled at both ends to ensure correct identification and correlation with specific gauges.
- Protected along their length using steel I-beams and sandbags at vulnerable junctions to mitigate the risk of fragmentation damage.

2.3 Piezo Electric Pressure Sensor Placement Team

Three pressure transducers were deployed in front of the munition, but deliberately offset from a direct line to avoid sequential shockwave interference:

- This staggered arrangement ensured that the blast wave would not reflect or diffract from one gauge to the next, preserving the fidelity of pressure-time data.
- Sensor positioning was recorded and aligned with the expected blast propagation path within the 118° arena sector.
- Prior to the trial, each pressure sensor was functionally tested to confirm that a state change was registered on a pressure data capture software, indicating operational readiness.



Figure 1 Arina Trial Set-up

2.4 Trial Execution

Once all systems were verified and armed:

- The test team vacated the arena and relocated to the control room.
- The undisclosed munition was placed and initiated under controlled conditions.

2.5 Post Blast Data Capture

- Data from the logic analyser and pressure sensors were recorded for post-trial analysis.
- Fragment recovery was conducted manually from the strawboards, with each fragment catalogued and weighed.

Table 1 COTEC Given Munition Data

Potential Types of Munition	Charge Mass	Mass of case	AUW	Explosive	Average fragment area	Average fragment mass	Frag drag coefficient	Density of air	Frag Vi	Frag Vf	Frag V	Num of Frag	FRAG TYPE
Mk 83 air dropped munition	225 kg	229 kg	454 kg	Comp B	0.48 cm ²	0.115 kg	0.82	1.23 kg m ⁻³	1950ms ⁻¹	1911ms ⁻¹ at 92m			
M-67 grenade	185g	213 g	398 g	Comp B	1.0 cm ²	2g	0.5	1.29 kg m ⁻³			at 5m 1674 ms ⁻¹ at 15m – 1424 ms ⁻¹ at 230 m – 44 ms ⁻¹		Preformed
RGD-5 grenade	110 g	200 g	310 g	TNT	1.0 cm ²	0.12 - 0.46g	0.5	1.29 kg m ⁻³	1567 ms ⁻¹			350 pcs	Preformed
81 mm Mortar AR-M81	760 g	1.334 kg	4.15 kg	TNT			1.6	1.23 kg m ⁻³	1734 ms ⁻¹		at 1m – 1700 ms ⁻¹ at 4m – 1600 ms ⁻¹ at 20m – 1150 ms ⁻¹ at 32m – 900 ms ⁻¹ at 77m – 357 ms ⁻¹	1400 pcs	Natural
RPG PG-7VL	730 g	1600 g (Inc, rocket motor)	1975 g	RDX/TNT (95% HMX 5% wax)		0.1 g		1.29 kg m ⁻³	1831.5 ms ⁻¹				Natural
155 mm	1150 g	3105 g	4255 g	Comp B		2.1g		1.29 kg m ⁻³	1551 ms ⁻¹				Natural
Pipe Bomb	264 g	417 g	681 g	PE 8			1.6	1.29 kg m ⁻³	2047 ms ⁻¹		at 1m = 2022 ms ⁻¹ at 20m = 1602 ms ⁻¹		Natural

3 Results

Due to the NEQ limit imposed onto the range for the trial day being 10kg, the munition MK83 air-dropped munition can be discounted as a potential munition due to its all-up weight of 454kg, which far exceeds the allowable limits and is incompatible with the trials safety constraints

3.1 Fragmentation Analysis

Based on post-trial recovery and foil activation:

- Total fragments recovered: 90
- Average fragment mass: 0.826g
- Average fragment thickness: 3.3mm
- Total recovered fragment mass: 74.3g

Estimated total fragment mass (360° equivalent): Assuming 90 fragments represent 30% of the total fragmentation (based on 118° sector coverage), the extrapolated **total fragment count is approximately 300**, with an **estimated total mass of 248g**.



Figure 2 Recovered Post-Blast Fragmentation

The recovered fragments show consistent physical characteristics [1]: many retain curvature, indicating origin from a cylindrical or partially cylindrical structure; deformation patterns are predominantly ductile, with bending, tearing, and shear-lip features present. These traits imply a relatively ductile steel casing undergoing tensile failure due to the rapid pressure changes that can be observed in Figure 2, Although some fragmentation appeared to have copper present on its surface, seen in Figure 3, this does not indicate that the munition casing was made from copper but instead fusion occurred as the fragmentation passed through the copper break foils giving the appearance of soldering onto the metal [1].



Figure 3 Recovered Post-Blast Copper Fragmentation

No evidence of pre-formed fragmentation elements were identified. The fragments are irregular in geometry but generally, size and thickness remaining broadly uniform across samples, suggesting the casing wall had a consistent manufacturing profile.

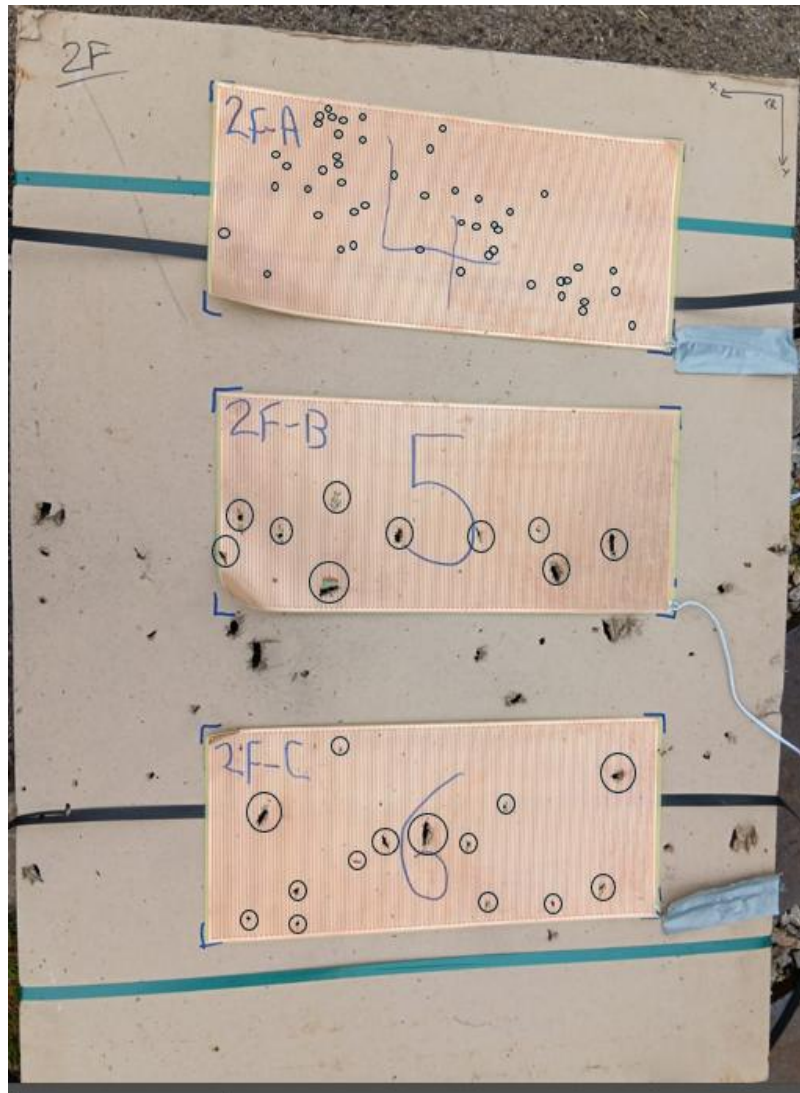


Figure 4 Projectile Impact Patterns

The distribution of perforations across the three foil witness plates demonstrates a clear anisotropic fragmentation pattern. Plate 2F-A exhibits a high density of fine perforations consistent with a large population of small, high-velocity fragments, while plates 2F-B and 2F-C contain fewer but larger perforations associated with heavier fragments with greater presented area on impact. The irregular hole geometry and evidence of fragment yaw indicate **natural casing** rupture rather than preformed fragmentation [2]. The absence of uniform spherical dispersion suggests that the munition was not a spherical grenade but more likely a cylindrical device producing a directional fragment cone, consistent with pipe-type or mortar-type casings.

Types of Munition	Mass of Case	Average fragment mass	Number of fragments	Average fragment type	RAG Rating
M-67 grenade	213 g	2g		Preformed	Average Fragment Type
RGD-5 grenade	200 g	0.12 - 0.46g	350pcs	Preformed	Average Fragment Type
81 mm Mortar AR-M81	1.334 kg		1400 pcs	Natural	Number of Fragments and case mass (Too high)
RPG PG-7VL	1.6 kg (Inc, rocket motor)	0.1 g		Natural	Unknown weight of rocket motor
155 mm	3.105 kg	2.1g		Natural	Mass of case, too great
Pipe Bomb	417 g	0.83g		Natural	Improvised weapon, partial values unknown due to user fill
Un-identified explosive	(360° equivalents of the recovered 90 frags at a 118° sector): Total case mass 248g approximately	0.826g	(360° equivalents of the recovered 90 frags at a 118° sector): 300 approximately	Natural	

Table 2 RAG Evaluation of Munition Types Against Observed Fragment Properties

A RAG table is a simple Red-Amber-Green visual tool used to indicate how well each item meets defined criteria. In this case, it compares munition types against [4] fragment mass, fragment count, and casing properties. The RPG PG-7VL cannot be ruled out because the rocket-motor mass is unknown, limiting confidence in exclusion as well as its primary function is a shaped-charge HEAT munition [3]. However, several items scored red: the 81 mm mortar [3] (AR-M81), due to extremely high fragment count and case mass [4], the 155 mm shell for excessive casing weight, and the RGD-5/M67 grenades for mismatched fragment characteristics [3]. Based on the available physical fragmentation properties, the item most consistent with the recovered evidence is the pipe bomb.

3.2 FTIR Swab Analysis

Residue characterisation was undertaken using FTIR spectroscopy on collected swab samples. The resulting spectra and interpretations are summarised in the following section. For full FTIR Spectroscopy data refer to Appendix A.

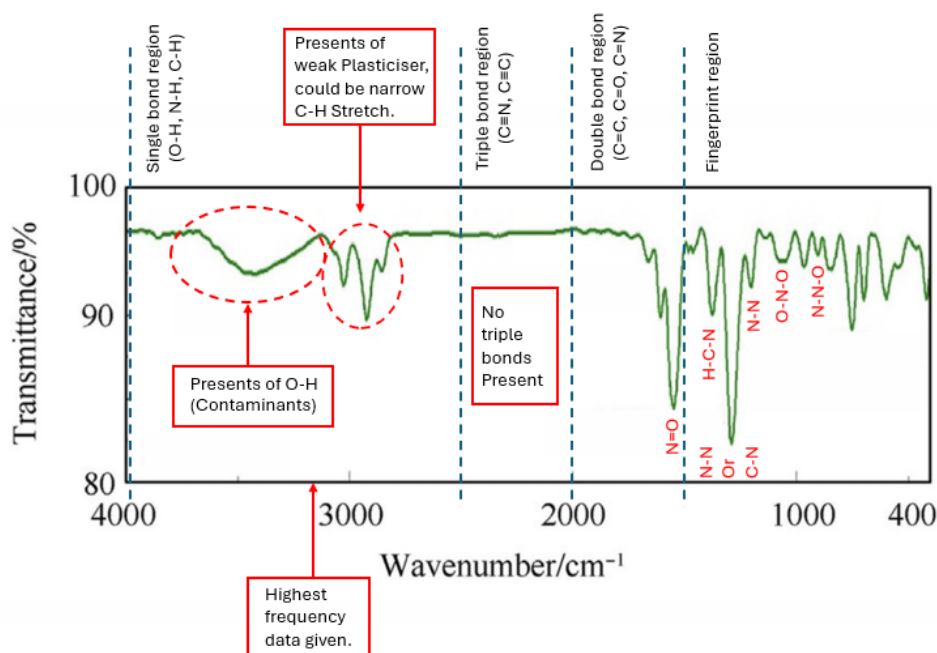


Figure 5 Annotated FTIR Spectrum, Transmittance/ Wavenumber Graph

The FTIR spectrum and annotated vibrational graph, Figure 5, show strong nitro / nitramine-related absorptions (notably intense C–N and N–N stretches in the 1400–1200 cm⁻¹ region and prominent N–N–O bending modes in the 1000–700 cm⁻¹ region), together with the absence of aromatic C=C and out-of-plane C–H features [8]. These observations are **consistent with a nitramine energetic** rather than a nitro compound where an aromatic ring would be present, example being TNT. Observations of the spectral pattern is strongly suggestive that RDX (or an RDX-dominant formulation) is the principal explosive component [1].

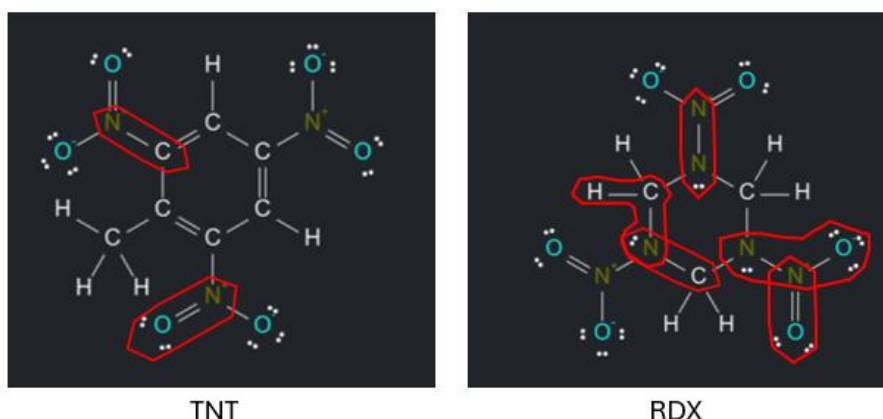


Figure 6 Lewis Structure of TNT and RDX with Identified FTIR Spectrum [1]

The Lewis structures in Figure 6 Lewis Structure of TNT and RDX with Identified FTIR SpectrumFigure 6, were used to support identification of the explosive composition by mapping chemical bonds directly to the spectral features. TNT and RDX were expected to appear in the FTIR spectra of any composition tested, due to one or both being present in each of the munitions. As the results clearly indicated the presence of RDX and no detectable TNT, this comparison was then used to inform the RAG rating Table 3; red for no detectable RDX, orange where both RDX and TNT were present (e.g., Composition B), and green for formulations such as PE8 where only RDX was identified [2].

Types of Munition	Explosive Composition	RAG Rating
M-67 grenade	Comp B	Partially Present
RGD-5 grenade	TNT	Not Present
81 mm Mortar AR-M81	TNT	Not Present
RPG PG-7VL	RDX/TNT (95% HMX 5% wax)	Partially Present
155 mm	Comp B	Partially Present
Pipe Bomb	PE 8	Present
Un-identified explosive	RDX Based	RDX Based

Table 3 RAG Evaluation of Munition Types Against

Overall, the spectral evidence is consistent with the material recovered from the pipe bomb and does not support alternative charge compositions.

3.3 Pressure Data Interpretation

Due to fragmentation strike, seen in Figure 7 the first pressure sensor was rendered inoperative shortly after detonation



Figure 7 Fragmentation Damage To Pressure Sensor One

Due to excessive noise and erratic signal behaviour from Gauge 1 (yellow, Figure 8). The dataset was filtered to include only Gauges 2 and 3, allowing for clearer interpretation and more reliable readings

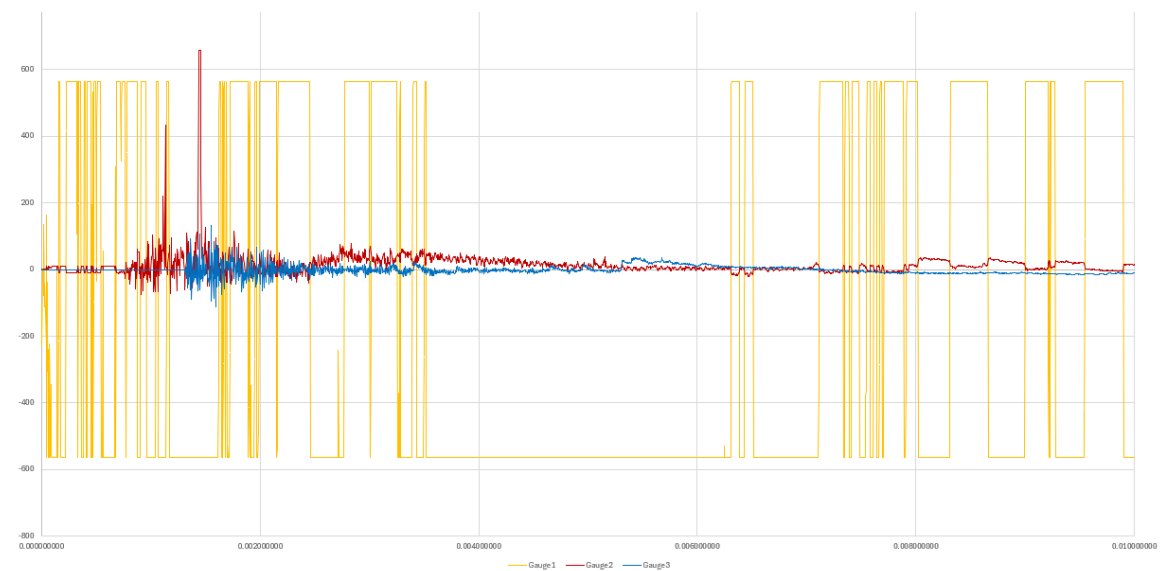


Figure 8 Raw Pressure Sensor Outputs for Gauges 1–3

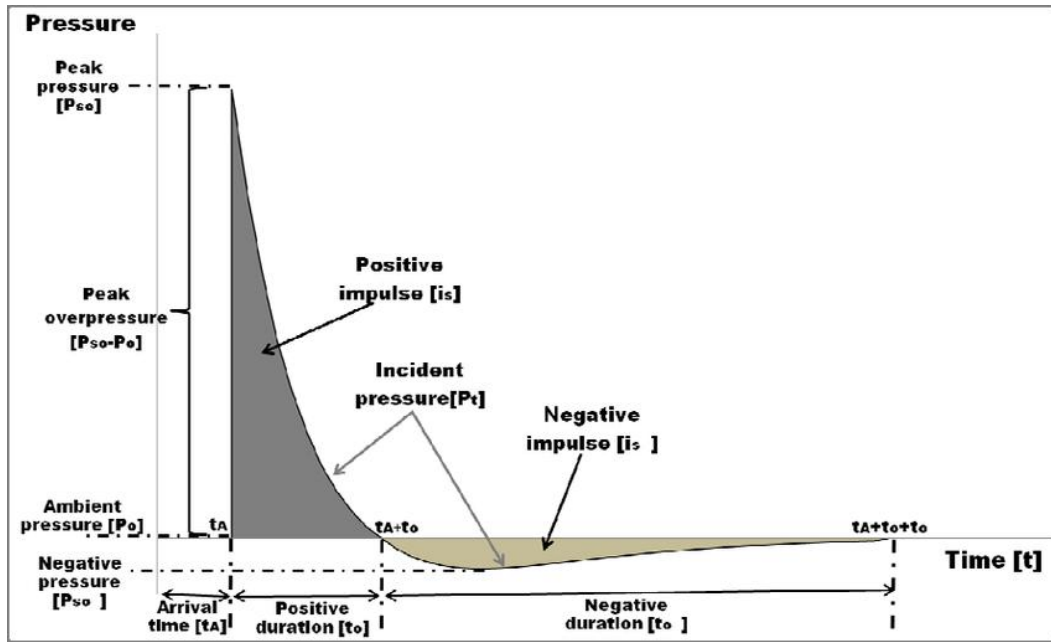


Figure 9 Ideal Blast Waves Pressure/Time Graph [1]

Pressure Gauge 2 in Figure 10, positioned at 2.075 m from the source, recorded a clear blast shock front followed by a well-defined positive phase, confirming a high-order detonation rather than a low-order deflagration [8].

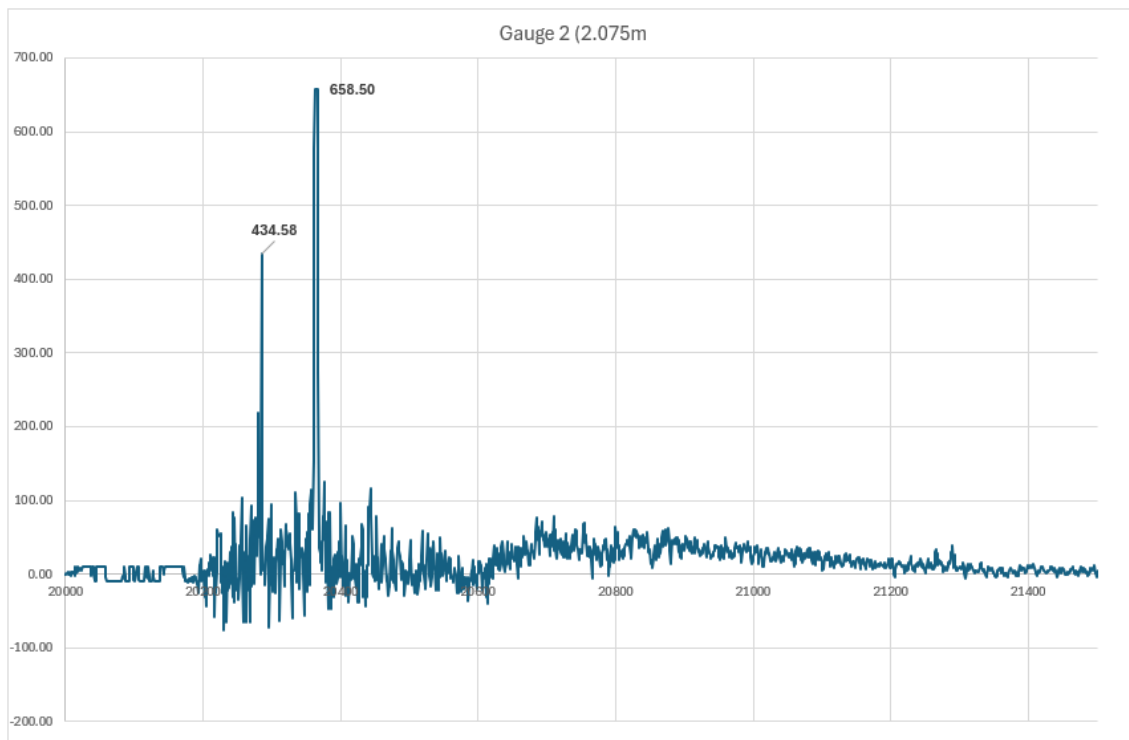


Figure 10 Blast Waves Pressure/Time Graph Results for Gauge Two

The waveform exhibited an incident overpressure of approximately 434 kPa with a subsequent reflected pressure producing a secondary amplification peak of 658 kPa. The two significant pressure peaks could be due to the blast being near ground, seen in Figure 11, forming a “double pulse” [13]. As the reflected shock, from the ground or nearby objects, merges with the incident wave. The second pulse being significantly higher suggests constructive interference, not sensor artefact [5].



Figure 11 Range Layout Highlighting the Detonation Origin and Potential Obstructions

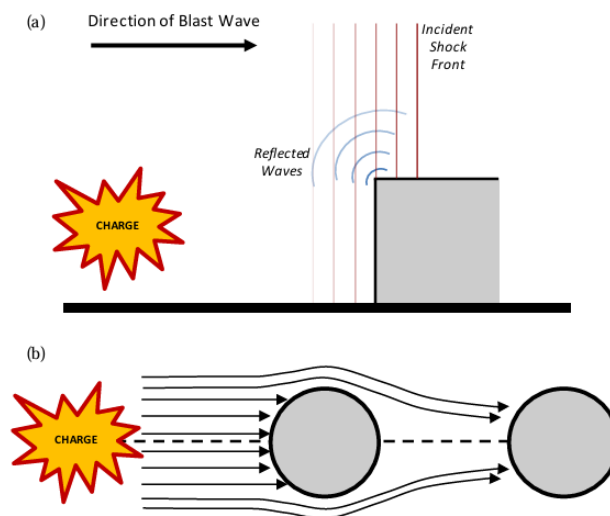


Figure 12 Blast Pressure Profiles [10]

The post-peak decay shows a short-duration positive phase followed by complex fluctuations associated with turbulent blast flow, structural reflections and fragment interaction.

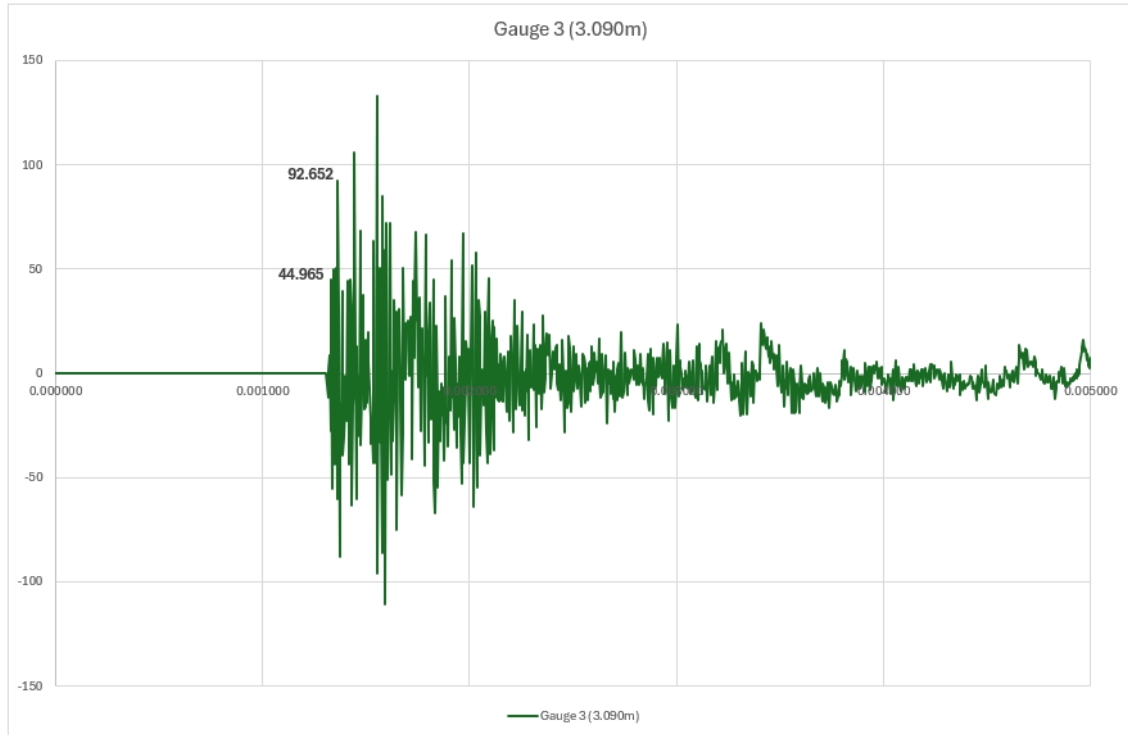


Figure 13 Blast Waves Pressure/Time Graph Results for Gauge Three

Gauge 3, Figure 13, positioned at 3.09m, recorded a significantly reduced peak overpressure of approximately 92kPa, demonstrating the expected rapid attenuation of the blast wave with distance [16].

Unlike Gauge 2, which captured a strong and well-defined double-peaked shock structure, Gauge 3 exhibited a weaker but still distinct shock front, followed by a prolonged oscillatory pressure field. This broader, more turbulent waveform reflects the transition from a highly coherent blast front to a more dispersed flow regime dominated by reflections, ground interaction and fragment-induced disturbances.

3.3.1 Blast Scaling and Charge Mass Estimation Using Kinney-Graham

Full Kinney and Graham Calculator Figures can be found in Appendix C.

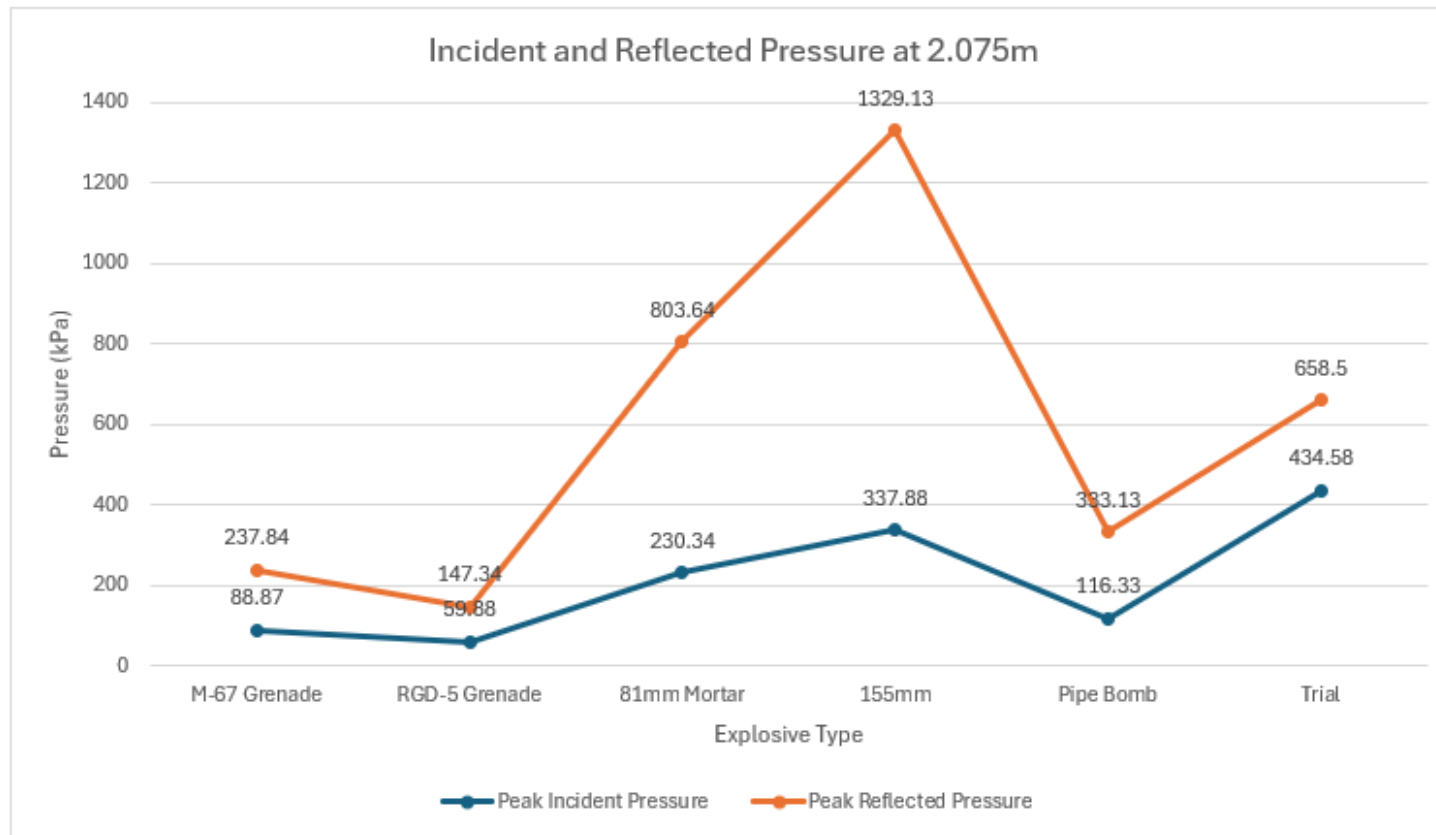


Figure 14 Results of Kinney & Graham Blast Calculator Munition Comparison, Gauge Two Graph

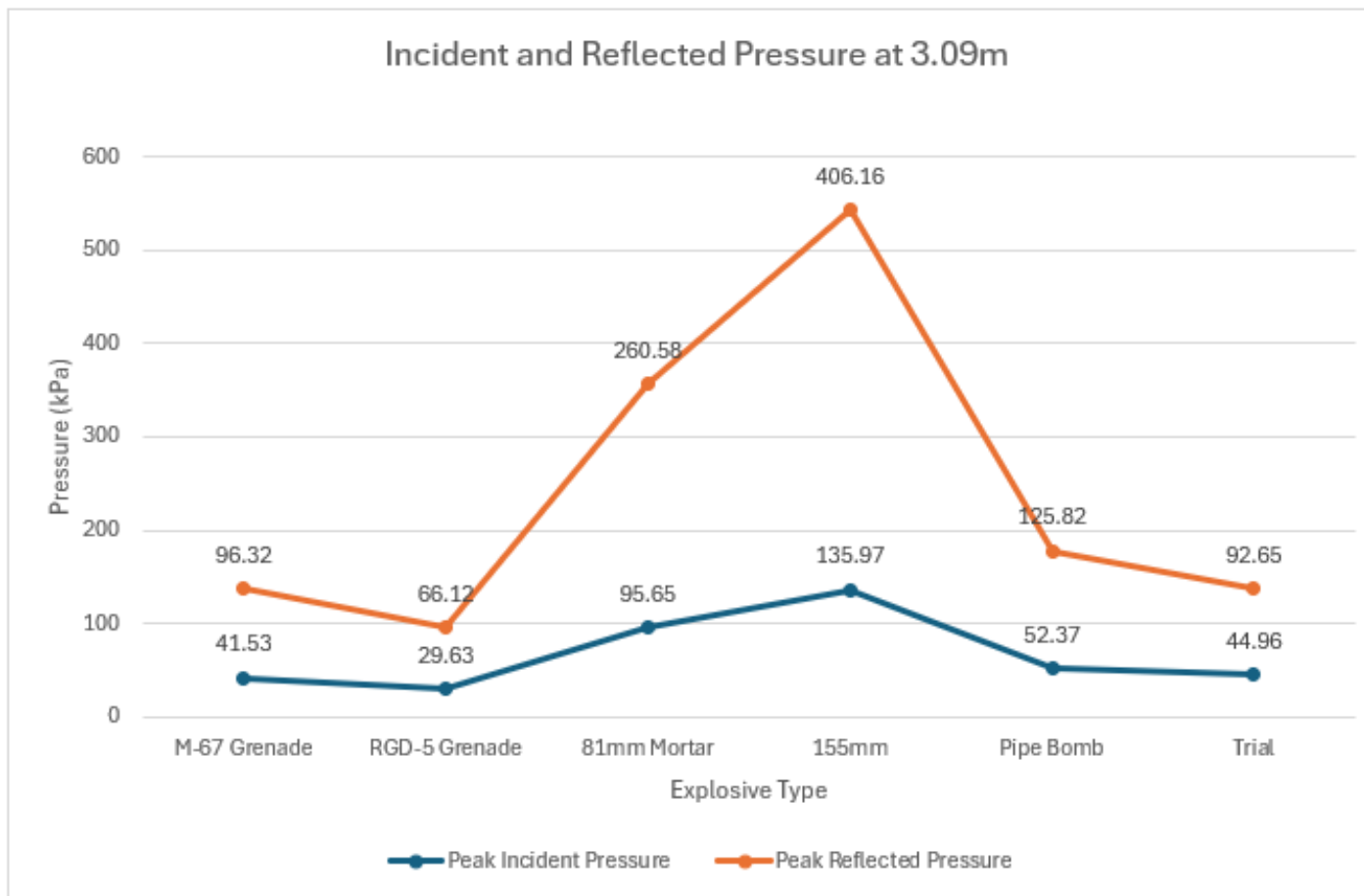


Figure 15 Results of Kinney & Graham Blast Calculator Munition Comparison, Gauge Three Graph

Figure 14 and Figure 15 were created to compare the trial blast results with the listed munitions to estimate the likely explosive mass.

The Kinney & Graham blast calculator, a summation of their book, was provided. Each candidate munition used the Net Explosive Quantity (NEQ), this was taken from

Table 1 along with its chemical compositions TNT equivalents, this was then calculated at both stand-off distances to Gauges 2 (2.075 m), and 3 (3.09 m). This provided predicted incident and reflected peak overpressures. These values were then plotted against the measured trial data to provide a comparative blast output assessment.

The resulting comparison demonstrates that the trial pressures sit centrally between small grenade-type munitions and large artillery/mortar ordnance, indicating a moderate explosive yield. By interpolating the trend within the comparative graph, the blast output is most consistent with a **TNT equivalent in the region of 200g**, which aligns closely with the expected output of a compact cylindrical device rather than a purpose-designed military munition.

It should be noted that the RPG-7 warhead was omitted from the comparison as its multi-component explosive fill of HMX and Wax makes conversion to a meaningful TNT equivalent unreliable in this context. Similarly, the pipe bomb prediction was generated using RDX TNT equivalence because PE-8 is predominantly RDX-based; this provides a reasonable approximation while acknowledging variability inherent in improvised devices.

Table 4 RAG Blast Pressure Results

Types of Munition	Gauge 2	Gauge 3	Gauge 2	Gauge 3	RAG Rating
	Incident Pressure	Incident Pressure	Reflective Pressure	Reflective Pressure	
M-67 grenade	88.87	41.53	237.84	96.32	
RGD-5 grenade	59.88	29.63	147.34	66.12	
81 mm Mortar AR-	230.34	95.65	803.64	260.58	
RPG PG-7VL					No TNT Equivalent
155 mm	337.88	135.97	1329.13	406.16	
Pipe Bomb	116.33	52.37	333.13	125.82	Improvised Explosive
Un-identified	434.58	44.96	658.5	92.65	

3.4 Fragmentation Velocity Interpretation

3.4.1 Velocity Foil Measurements

Table 5 Distance from Charge to Velocity Foil

Foil Number	Strawboard Number			
	1	2	3	4
A	1.462	1.411	1.452	1.499
B	1.337	1.358	1.392	1.439
C	1.327	1.354	1.39	1.430

Recorded distances in Table 3, were measured in metres from the detonation origin, positioned 0.5m above the ground, to the approximate central point of the velocity foil.

Table 6 Make Foil Fragmentation Strike Times

Foil ID	Initial Strike Time from Trigger (ms)	Apparent # of Strikes	Additional Strike Time from Trigger (ms)
1	4.5953	2	6.95548
2	1.71048	1	
3	1.72476	1	

Foil ID	Initial Strike Time from Trigger (ms)	Apparent # of Strikes	Additional Strike Time from Trigger (ms)	Additional Strike Time from Trigger (ms)
4	2.07088	2	3.15038	
5	1.76334	2	1.79764	
6	1.7305	3	1.76032	1.7996

Foil ID	Initial Strike Time from Trigger (ms)	Apparent # of Strikes	Additional Strike Time from Trigger (ms)
7	2.65346	0	
8	1.78502	1	
9	1.76556	2	1.7938

Foil ID	Initial Strike Time from Trigger (ms)	Apparent # of Strikes	Additional Strike Time from Trigger (ms)
10	2.6625	1	
11	1.7422	1	
12	1.7822	0	

Although a significant number of perforations were visually present on the foils, the number of electronically recorded strikes was comparatively low. Interpretation of the data indicates that fragmentation is not absent; rather, it reflects the limitations of foil timing capture. Only fragments that produced a clean perforation and distinct circuit break were logged, whereas partial penetrations, shallow-angle impacts, and strikes occurring within microseconds of each other were not individually resolved. High fragment density also could have caused electrical signal saturation, resulting in single recorded events representing multiple physical hits [15]. Furthermore, improvised devices tend to produce highly irregular fragmentation dispersions, leading to non-uniform strike patterns and localised clustering, seen in Figure 4 [1]. As such, the electronic strike count under-represents the true fragment population, with the dense perforation patterns visible on the panels confirming a substantially higher fragment output than recorded.

To further characterise the fragmentation behaviour, Appendix B provides full velocity calculations derived from time-of-flight measurements between the detonation point and the foil panels. Fragment velocity was calculated using the relation:

$$\text{Distance traveled} \div \text{Time to foil} = \text{Fragmentation Velocity} \quad (3-1)$$

The resulting velocities ranged from approximately 300–800m/s significantly lower than the typical 1200–2000 m/s associated with conventional, purpose-designed military munitions, but entirely consistent with the behaviour of improvised steel-cased explosive devices. The high degree of variability between individual fragment velocities is also characteristic of improvised fragmentation; unlike military grenades or artillery shells, which use engineered, heat-treated casings designed to fracture predictably, a pipe bomb produces highly irregular fragments of varying mass, shape, and drag coefficient. Differences in fragment trajectory, tumbling, air resistance, and casing inconsistency further contribute to the spread in velocities observed.

Rather than indicating measurement error, this variability supports the interpretation that the device was an improvised cylindrical charge rather than a conventional munition. While useful qualitatively, the velocity dataset carries inherent uncertainty and is therefore used as supporting evidence rather than a primary identification tool.

4 Discussion

The results of the arena trial collectively provide a coherent picture of the munition type, explosive composition, and approximate energetic output. Each evidence stream was first interpreted independently, then assessed holistically to determine which munitions data was most probable.

Fragmentation characteristics strongly indicated failure of a cylindrical steel casing rather than a purpose-designed military warhead. The retained curvature of many fragments, combined with consistent thickness and ductile tearing, supports rupture of a continuous steel tube rather than a pre-fragmented body. The distribution of perforations across the witness foils further suggests a directional fragment cylinder rather than spherical dispersal, reinforcing the interpretation of a pipe-type casing. Although electronic strike counts appeared comparatively low, this was assessed to be a limitation of foil response rather than an absence of fragments; the extensive visible perforation density confirms a substantially higher fragment population. The wide variability and generally lower fragment velocities (300-800m/s), are also consistent with improvised fragmentation where casing structure, fragment geometry and aerodynamic stability are uncontrolled, unlike military grenades or shells which are engineered to fragment predictably.

Blast pressure analysis provided further discrimination between potential munition types. Gauge 2 recorded a clear high order detonation waveform with a defined shock front and strong positive phase, while Gauge 3 demonstrated appropriate attenuation and turbulence with distance. When compared to Kinney-Graham predictions, the measured pressures positioned the device squarely between grenade-class and large artillery/mortar outputs, indicating a moderate explosive yield. Interpretation of the comparative plots suggests an approximate TNT equivalent of 200g. Although TNT equivalence introduces uncertainty, especially for non-TNT compositions, the relative position of the trial consistently aligned with a compact charge rather than a large military munition.

The defining evidence was provided by FTIR swab analysis. The spectrum presented distinct nitramine absorption features with no evidence of aromatic nitro compounds. This excludes TNT-dominant formulations and aligns instead with RDX-based energetics. Within the candidate munitions list, this supports PE8 over TNT-filled or Composition B systems, and it is notably consistent with the reported fill of the suspected pipe bomb.

Taken together, the fragmentation morphology, blast performance, velocity behaviour, and chemical composition mutually reinforce one another. While uncertainties remain, particularly relating to TNT equivalence conversion, fragment timing saturation, and improvised device variability, none of these undermine the overall interpretation. Instead, they align with known behaviour of improvised RDX-filled cylindrical charges, providing a strong evidential foundation for identification.

4.1 Limitations

There are several limitations that should be recognised when interpreting the results. TNT equivalence introduces uncertainty, especially for mixed composition explosives, so the estimated charge mass should be viewed as an informed approximation. Fragment velocity data were affected by foil saturation, simultaneous strikes and timing precision, meaning recorded values likely under-represent true fragment behaviour. Blast data were also influenced by Gauge 1 failure and near-ground reflections. Finally, the baseline munition data used for comparison were provided without verified references, so the accuracy of some comparative figures cannot be guaranteed. Despite these limitations, the remaining datasets aligned well and were sufficient to support a confident identification.

5 Conclusion

The combined physical, chemical and blast datasets demonstrate strong agreement and support a consistent interpretation. The fragmentation evidence indicates failure of a ductile cylindrical steel casing producing directional fragment dispersal; the blast pressure data indicates a moderate explosive yield compatible with a compact charge; and the FTIR analysis conclusively identifies an RDX-dominant energetic material. When viewed holistically, the evidence does not support identification as a conventional military munition. Instead, it is assessed with high confidence that the device was an RDX-filled cylindrical improvised explosive device (pipe bomb), with an estimated charge output broadly equivalent to 200g TNT.

5.1 Future Recommendations

1. Prioritise chemical residue analysis in future identification chains. FTIR provided the most decisive compositional discrimination and should be treated as a primary identification tool.
2. Enhance fragment velocity capture reliability. Consider improved foil sensitivity, distributed foil spacing, and supplementary high-speed imaging or radar to reduce strike saturation and improve velocity confidence [15].
3. Refine TNT equivalence methodology for non-TNT fills. Where possible, use validated equivalence data or multi-model comparison to reduce uncertainty, especially for polymer-bonded and nitramine charges.
4. Retain multi-panel witness plate configurations. Directional fragment behaviour proved critical and would likely be lost with limited panel coverage.
5. Continue explicitly documenting uncertainty. Clear acknowledgment of expected blast reflections, measurement tolerances and improvised device variability strengthens credibility and analytical defensibility.

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Appendix A

A.1 Full FTIR Spectroscopy Results

This table lists the experimentally observed vibrational frequencies and their corresponding molecular motions, providing a detailed breakdown of bond-specific IR activity. It supports the identification of nitramine functionality and the exclusion of aromatic features, reinforcing the conclusion that RDX is the dominant explosive component.

Table 7 Full FTIR Spectroscopy Result

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

Appendix B

Using the below equation, velocity of the fragmentation can be calculated from the data collated within **Error! Reference source not found.** and **Error! Reference source not found.**

A.2 Velocity Calculations

$$\text{Distance traveled} \div \text{Time to foil} = \text{Fragmentation Velocity} \quad (0-1)$$

$$1.462 \div 0.0045953 = 318.15 \text{ ms}^{-1}$$

$$1.337 \div 0.00171048 = 781.65 \text{ ms}^{-1}$$

$$1.327 \div 0.00172476 = 769.38 \text{ ms}^{-1}$$

$$1.411 \div 0.00207088 = 681.35 \text{ ms}^{-1}$$

$$1.358 \div 0.00176334 = 770.12 \text{ ms}^{-1}$$

$$1.354 \div 0.0017305 = 782.43 \text{ ms}^{-1}$$

$$1.452 \div 0.00265346 = 547.21 \text{ ms}^{-1}$$

$$1.392 \div 0.00178502 = 779.82 \text{ ms}^{-1}$$

$$1.39 \div 0.00176556 = 787.28 \text{ ms}^{-1}$$

$$1.499 \div 0.0026625 = 563 \text{ ms}^{-1}$$

$$1.439 \div 0.0017422 = 825.96 \text{ ms}^{-1}$$

$$1.43 \div 0.0017827 = 802.15 \text{ ms}^{-1}$$

Appendix C

A.3 Kinney & Graham blast calculations

Blast formulae from Kinney & Graham are used to establish empirical correlations between scaled distance and blast parameters (such as peak overpressure and impulse) for a standard explosive (TNT equivalence, or TNTe). By comparing the measured pressure and impulse data at known distances to the established TNT curves, the equivalent mass of TNT for the unknown OME charge can be calculated, thereby determining the explosive mass [17].

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by
Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	2.00
Nett Explosive Quantity (Q) [kg]	0.19
TNT Equivalence Figure	1.092

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	63.1812026	88.8715560
Incident Impulse (Is) [kPa.msec]	33.7173527	48.6587940
Peak Reflected Pressure (Pr) [kPa]	157.9876620	237.8454140
Reflected Impulse (Ir) [kPa.msec]	74.6958497	113.5288530
Shock Front Velocity (U) [m/msec]	0.4213395	0.4510354
Arrival Time (Ta) [msec]	2.8979022	2.5951533
Positive Phase Duration (T+) [msec]	1.6807101	1.8284796

Figure 16 M-67 Grenade Gauge 2

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	3.00
Nett Explosive Quantity (Q) [kg]	0.19
TNT Equivalence Figure	1.092

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	30.1350935	41.5398877
Incident Impulse (Is) [kPa.msec]	23.3477883	34.0833969
Peak Reflected Pressure (Pr) [kPa]	67.1428261	96.3276174
Reflected Impulse (Ir) [kPa.msec]	47.7143921	71.8816078
Shock Front Velocity (U) [m/msec]	0.3821467	0.3955939
Arrival Time (Ta) [msec]	5.4544672	5.0060639
Positive Phase Duration (T+) [msec]	1.9717734	2.2406498

Figure 17 M-67 Grenade Gauge 3

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by
Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	2.00
Nett Explosive Quantity (Q) [kg]	0.11
TNT Equivalence Figure	1

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	43.0321752	59.8822795
Incident Impulse (Is) [kPa.msec]	22.9566495	33.2978778
Peak Reflected Pressure (Pr) [kPa]	100.4901502	147.3400813
Reflected Impulse (Ir) [kPa.msec]	48.6653643	73.6153787
Shock Front Velocity (U) [m/msec]	0.3974964	0.4180488
Arrival Time (Ta) [msec]	3.2761134	2.9702683
Positive Phase Duration (T+) [msec]	1.4931660	1.6762814

Figure 18 RGD-5 Grenade Gauge 2

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F. Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	3.00
Nett Explosive Quantity (Q) [kg]	0.11
TNT Equivalence Figure	1

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	21.7045824	29.6365775
Incident Impulse (Is) [kPa.msec]	15.7849493	23.1537555
Peak Reflected Pressure (Pr) [kPa]	46.9731048	66.1243992
Reflected Impulse (Ir) [kPa.msec]	31.2982710	46.9904214
Shock Front Velocity (U) [m/msec]	0.3730500	0.3803203
Arrival Time (Ta) [msec]	5.9432656	5.5188456
Positive Phase Duration (T+) [msec]	1.7294121	1.9682634

Figure 19 RGD-5 Grenade Gauge 3

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	2.00
Nett Explosive Quantity (Q) [kg]	0.76
TNT Equivalence Figure	1

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	158.9884760	230.3408245
Incident Impulse (Is) [kPa.msec]	77.4416443	112.5359024
Peak Reflected Pressure (Pr) [kPa]	497.9014740	803.6453605
Reflected Impulse (Ir) [kPa.msec]	193.0530893	297.0851504
Shock Front Velocity (U) [m/msec]	0.5210169	0.5836189
Arrival Time (Ta) [msec]	2.0953477	1.8338135
Positive Phase Duration (T+) [msec]	1.8655096	1.9203308

Figure 20 81mm Mortar Gauge 2

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	3.00
Nett Explosive Quantity (Q) [kg]	0.76
TNT Equivalence Figure	1

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	67.8600518	95.6568502
Incident Impulse (Is) [kPa.msec]	54.1503436	78.1074539
Peak Reflected Pressure (Pr) [kPa]	172.1834563	260.5836462
Reflected Impulse (Ir) [kPa.msec]	121.0056933	184.0823674
Shock Front Velocity (U) [m/msec]	0.4267403	0.4583699
Arrival Time (Ta) [msec]	4.2447023	3.7930429
Positive Phase Duration (T+) [msec]	2.5697745	2.7733934

Figure 21 81mm Mortar Gauge 3

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

• "Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
 Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	2.00
Nett Explosive Quantity (Q) [kg]	1.15
TNT Equivalence Figure	1.092

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	230.7528020	337.8828788
Incident Impulse (Is) [kPa.msec]	106.5032373	156.0048898
Peak Reflected Pressure (Pr) [kPa]	804.7313863	1329.1316528
Reflected Impulse (Ir) [kPa.msec]	278.5189578	430.9233878
Shock Front Velocity (U) [m/msec]	0.5842567	0.6662471
Arrival Time (Ta) [msec]	1.8239594	1.5879401
Positive Phase Duration (T+) [msec]	1.8910582	2.1987144

Figure 22 155mm Gauge 2

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by
Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	3.00
Nett Explosive Quantity (Q) [kg]	1.15
TNT Equivalence Figure	1.092

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	95.4279882	135.9707977
Incident Impulse (Is) [kPa.msec]	74.1997610	107.0348945
Peak Reflected Pressure (Pr) [kPa]	261.4816316	406.1695227
Reflected Impulse (Ir) [kPa.msec]	173.0700035	264.4667061
Shock Front Velocity (U) [m/msec]	0.4573600	0.4994749
Arrival Time (Ta) [msec]	3.7763500	3.3424356
Positive Phase Duration (T+) [msec]	2.7639218	2.8506471

Figure 23 155mm Gauge 3

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

"Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	2.00
Nett Explosive Quantity (Q) [kg]	0.26
TNT Equivalence Figure	1.149

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	82.0464442	116.3366508
Incident Impulse (Is) [kPa.msec]	43.1085236	62.1509279
Peak Reflected Pressure (Pr) [kPa]	216.9805993	333.1305356
Reflected Impulse (Ir) [kPa.msec]	98.6313896	150.4157874
Shock Front Velocity (U) [m/msec]	0.4427527	0.4799475
Arrival Time (Ta) [msec]	2.6531871	2.3578963
Positive Phase Duration (T+) [msec]	1.7918104	1.8877909

Figure 24 Pipe Bomb Gauge 2

AIRBLAST PARAMETERS BY DISTANCE, BY NEQ & BY TNT EQUIVALENCE

Reference Documentation is:

• "Airblast Parameters from TNT Spherical Air Burst & Hemispherical Surface Burst" by Charles N Kingerey & Gerald Bulmash, Tech Report ARBRL-TR-02555 dated April 1984.
Gilbert F.Kinney, Kenneth J. Graham - Explosive Shocks in Air (2nd Edition)

INPUTS

Actual Stand-off Distance (D) [m]	3.00
Nett Explosive Quantity (Q) [kg]	0.26
TNT Equivalence Figure	1.149

OUTPUTS

	<i>Air</i>	<i>Surface</i>
Peak Incident Pressure (Ps) [kPa]	37.7679524	52.3751269
Incident Impulse (Is) [kPa.msec]	29.9862655	43.5949539
Peak Reflected Pressure (Pr) [kPa]	86.5280351	125.8289217
Reflected Impulse (Ir) [kPa.msec]	62.6897559	94.6838873
Shock Front Velocity (U) [m/msec]	0.3911823	0.4090183
Arrival Time (Ta) [msec]	5.1116300	4.6548996
Positive Phase Duration (T+) [msec]	2.1413818	2.4188288

Figure 25 Pipe Bomb Gauge 3