

The Combustion Continuum and Munition Reactions — Practical Implications for Army Engineers

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Abstract

Army engineers are often tasked with the most complex and dangerous aspects of explosive ordnance disposal (EOD), range clearance, and battlefield recovery. In these contexts, the clarity of terminology is not an academic nicety but an operational necessity. Ambiguity in describing explosive phenomena has historically led to inconsistent reporting, miscommunication between services, and avoidable risks in planning.

The *Combustion Continuum*, developed through recent research at Cranfield and applied in both academic and operational domains, provides a unified framework for understanding energetic reactions. By explicitly defining *burning*, *deflagration*, and *detonation* as points on a continuum, and tying transition points to observable shock phenomena, the model eliminates much of the long-standing confusion in the field. Extending the model to *munition outcomes* — distinguishing between *low-order* and *high-order* events — allows army engineers to consistently categorise and interpret EOD results.

This article sets out the continuum in detail, explains its application to munitions, and explores its implications for doctrine, training, and operational reporting. For Royal Engineers, this framework offers an evidence-based lexicon that can be embedded in field manuals, JSPs, and post-action analysis to improve safety, interoperability, and institutional learning.

Introduction: The Problem of Ambiguity

Few trades in the British Army operate under the same level of technical and tactical stress as the EOD operator. Decisions are made in seconds, often with incomplete information, and yet the consequences are profound. A disposal gone wrong may cost lives, damage infrastructure, or cause strategic embarrassment. In such an environment, a shared professional language is a vital safety mechanism.

Yet, even in authoritative documents, terms such as *burning*, *explosion*, *deflagration*, *detonation*, *low-order*, and *high-order* are often used loosely. JSP 364 (Joint Service EOD Manual) includes several overlapping scales for describing outcomes, and NATO's AOP-39 for Insensitive Munitions Assessment adds another taxonomy. Operators on the ground are left to interpret categories in ways that may not align across units or nations. Reports are filed that describe

“violent deflagrations,” “low-order detonations,” or “partial burns” — each meaning something slightly different to each reader.

This inconsistency is not benign. It leads to poor-quality lessons-learned cycles, makes cross-national reporting difficult, and, most importantly, increases the risk of misjudgement when planning future operations.

Table 1. Munition Reaction: EOD Reaction Codes (JSP 364)

RESULTS	Reaction Code Definitions	
	Code	Definition
No Chemical Reaction	A1	Case not Penetrated
	A2	Case Penetrated
	A3	Mechanical Breakup
Burn	B1	Burn Not Sustained
	B2	Burn Sustained to Burnout
	B3	Burn to Deflagration
	B4	Burn to Detonation
Deflagration	C1	Deflagration not sustained <15% of fill consumed
	C2	Deflagration 15-50% of fill consumed
	C3	Deflagration >50% of fill consumed
Violent Deflagration	D1	Violent Deflagration
	D2	Transition to Detonation
Detonation	E	Immediate, Full Detonation

It is worth noting that reactions such as B3 and B4 are considered to be Burns rather than partial deflagrations or partial detonations respectively which they arguably should be.

Somewhat confusingly, JSP 364 also has a second, alternative reaction scale. This scale is somewhat simplistic and while it might be ideal to find a completely empty munition casing, the reality of the vast majority of “ideal” EOD low-order techniques will result in a large percentage of the fill remaining or being scattered in the vicinity which would lie somewhere between Reaction Codes B and C.

Table 2. Alternative reaction codes

ALTERNATIVE REACTION CODES	
REACTION CODE A:	No reaction
REACTION CODE B:	From the EOD Operator's perspective, reaction is less than expected, the weapon partially open but a major portion of fill remains
REACTION CODE C:	From the EOD Operator's perspective, reaction idea, weapon open, remnants in the vicinity of original weapon location, no fill remaining

REACTION CODE D:

Reaction more violent than desired, fragments up to several hundred metres. Majority of fill consumed during deflagration.

NATO uses a different scale, primarily for insensitive munitions testing, which is given in AOP-39.

Table 3. NATO Guidelines for the Safety Assessment of Munitions in Response to Insensitive Munitions Testing

AOP-39 Reaction Scale		
Type I	Detonation	The worst-case: essentially full detonation of the munition.
Type II	Partial Detonation	Substantial detonation but incomplete; still violent.
Type III	Explosion	High-order explosion, violent but not a full detonation of the main charge.
Type IV	Deflagration	Rapid burning/deflagration, lower violence, casing fragments may occur.
Type V	Burning	Sustained burning, non-violent compared to detonation or explosion.
Type VI	No Reaction	Munition does not react violently to the threat stimulus.

The Combustion Continuum Explained

The *Combustion Continuum* addresses this disconnect by grounding definitions in observable physics.

At its heart, the continuum recognises that all energetic reactions are chemically similar oxidation processes. The variable is the rate of reaction.

- **Burning:** A surface-driven process where energy is released slowly enough that gases disperse without shock formation. Examples include open black powder or propellant grains on a bonfire. No explosion, only flame.
- **Deflagration:** Still a subsonic chemical process, but one that occurs fast enough, usually under confinement, to produce an atmospheric shock wave. This is the first moment one can properly call an *explosion*. The bang of confined black powder or a bursting cardboard tube exemplifies this regime.
- **Detonation:** A shock-sustained supersonic reaction where the shock wave itself drives decomposition of the unreacted explosive at the detonation front. This is the classical high explosive event, with velocities of detonation in the 6–8 km/s range for military explosives.

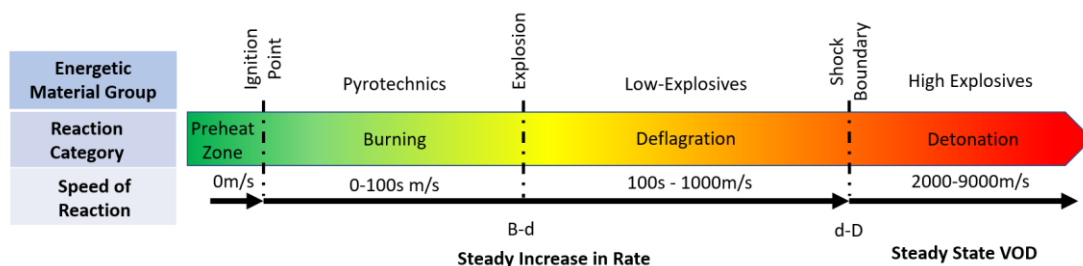


Fig. 1. The *Combustion Continuum*

The benefit of the continuum is that it anchors the *transition points* to things observable in the field. The step from burning to deflagration is not subjective “rapid burning,” but the *onset of a shock wave in the atmosphere*. The step from deflagration to detonation is the *formation of a detonation front within the explosive*.

For EOD Operators, this removes ambiguity. An operator can say: “the munition’s fill deflagrated” — and that statement can be corroborated by evidence of a modest shock wave, large fragment sizes, and absence of brisance effects.

Deflagration Redefined: A Critical Shift

For over a century, *deflagration* was loosely described as “rapid burning.” This was never sufficient. How rapid is “rapid”? How does one distinguish between a very fast burn and a deflagration?

The Continuum offers a precise operational definition:

Deflagration is an exothermic chemical reaction of a confined pyrotechnic, explosive or propellant, proceeding at a rate below the velocity of detonation of the material, the gas products of which produce an atmospheric shock wave as it explodes. (Alford et al. 2024)

For the first time, this places deflagration in terms of what engineers can observe: *an explosion that produces a shock wave but not a detonation front*. This definition is directly applicable to Army range incidents, cook-off events, or disposal actions that result in a bang without full fragmentation.

Detonation and the Deflagration-to-Detonation Transition (DDT)

Detonation, by contrast, has always been more straightforward to define: a supersonic shock-driven chemical process. But the pathway between deflagration and detonation - the DDT - is of enormous importance to explosive engineers.

When an explosive is confined, the pressure at the deflagration front can rise until it compresses unreacted explosive ahead of it. If conditions are sustained, the pressure “shocks up” into a detonation front. This explains why propellants in a sealed gun barrel can detonate, why munitions in fuel fires can escalate catastrophically, and why Insensitive Munitions design seeks to prevent such transitions.

Understanding DDT is critical for disposal planning. Many Low-Order Techniques (LOTs) deliberately aim for deflagration, but if conditions allow the reaction to run-up into detonation, the result may be catastrophic. The Continuum gives operators a framework to assess and mitigate this risk.

Extending the Combustion Continuum to Munitions

The *Combustion Continuum* clarifies reactions of *explosive substances*, but engineers rarely encounter free explosive. They encounter *articles* — bombs, shells, rockets, mines — which contain explosives within casings and mechanical systems.

Thus we must distinguish between:

- **Substance reactions:** burning, deflagration, detonation.
- **Article outcomes:** burn-out, low-order, high-order.

A munition *high-orders* when its explosive fill detonates and it functions as designed, producing fine fragmentation, large craters, and destructive blast. This contrasts with when a munition *low-orders*. In this case, the fill deflagrates, producing internal pressure through gas build-up, that bursts the casing into a small number of large fragments, usually with reduced collateral damage.

This distinction resolves long-standing confusion. *Deflagration* is a chemical term. *Low-order* is a mechanical outcome. They are linked but not synonyms.

Forensic Evidence: Reading the Aftermath

Army engineers cannot typically deploy pressure gauges and high-speed cameras when carrying out EOD operations. But with training and discipline, the aftermath of an event provides robust evidence.

- **Fragmentation pattern:** High-order events generate numerous small, high-velocity fragments scattered widely. Low-order events leave the casing in a handful of recognisable pieces.
- **Casing rupture:** A high-order casing is shredded; a low-order casing splits or bursts at weak points. Photographic documentation is invaluable.
- **Crater analysis:** High-order detonations produce deep, symmetrical craters. Low-orders produce shallow or absent craters.
- **Noise and shock:** High-orders produce far higher peak pressures (20 dB difference measured in underwater mine studies). Noise reports must be corroborated with physical evidence.
- **Residue and thermal cues:** Presence of soot, melted explosive, or ammonia odour indicates incomplete reaction.

This is illustrated in Fig. 2 which shows how the two phenomena are aligned.

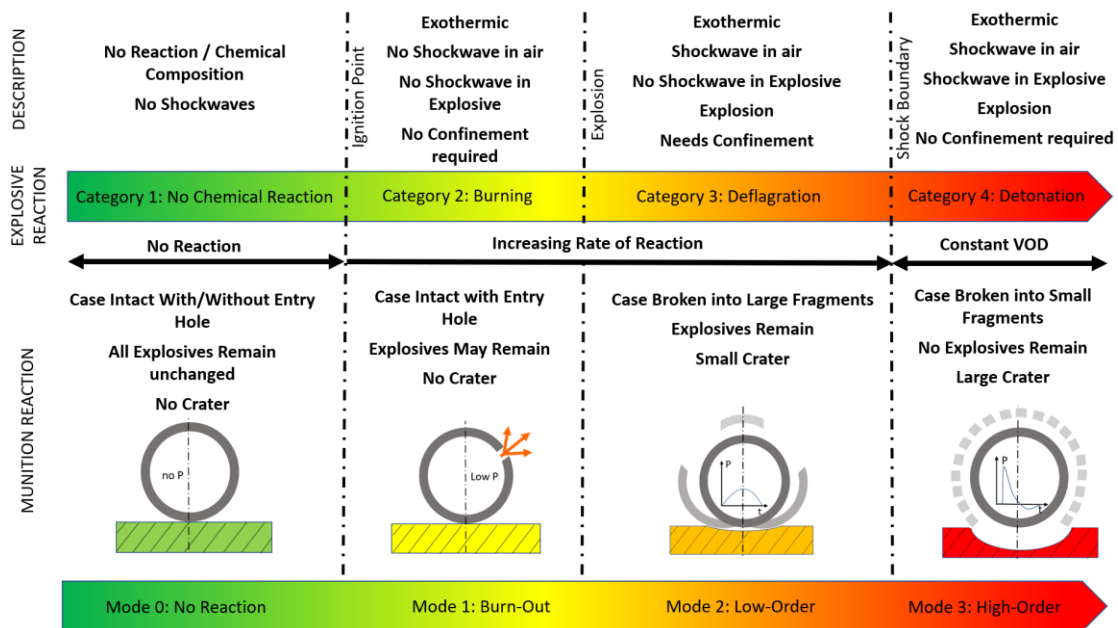


Fig. 2. Combined *Combustion Continuum*

Embedding this forensic checklist into EOD reporting ensures consistency across units and enables robust lessons-learned processes. When combined with the existing British and NATO scales into a single table (Table 4), the clarity brought by understanding the *Combustion Continuum* and be fully aligned with existing scales in a more logical and scientifically justified order.

Table 4. Proposed EOD Reaction Scale

Alford Reaction Category	Alford Reaction Code	Munition Reaction	General Description of Result	Explosive Reaction	Evidence	AOP-39 Reactions	JSP 364 Code
1	1A	No Reaction	All explosive remains, no crater, no shock wave	No chemical reaction	Case not penetrated, explosive intact	Type VI	A1
	1B	No Reaction			Case penetrated, explosive intact	Type VI	A2
	1C	Disruption			Mechanical break-up, explosive intact	Type VI	A3
2	2A	Partial Burn-Out	Slow combustion, munition case vented but not burst, no crater	Burn	Partial combustion, some/most explosive remaining, some paint burnt	Type V	B2
	2B	Complete Burn-Out			Full combustion, no explosive remaining, all paint burnt	Type V	B2
	2C	Burn to Low-Order	Slow combustion followed by explosion, possibly due to booster cook-off, munition case partially burst, no crater		Slow combustion transitioning to deflagration, some explosive may remain	Type V	B3
3	3A	Partial Low-Order	Explosion, explosive remaining, munition case split possibly broken into large fragments, little or no cratering, no detonation, no shockwave	Deflagration	Deflagration not sustained <15% of explosive consumed	Type IV	C1
	3B	Low-Order			Deflagration consumed 15%-50% of explosive	Type IV	C2
	3C				Deflagration consumed >50% of explosive	Type III	C3
	3D	Violent Low-Order			Deflagration, significant case breakup, some explosive may remain	Type III	D1
4	4A	Partial Detonation	Violent explosion, case fragmented into medium/small sized fragments, major cratering, detonation, shockwave, no explosive remaining	Detonation	Burn to detonation, no explosive remaining, less violent than full detonation	Type II	B4
	4B				Deflagration to Detonation Transition (DDT), no explosive remaining, less violent than full detonation	Type II	D2
	4C	High-Order			Immediate, full detonation	Type I	E

Implications for Doctrine and Training

Adopting the *Combustion Continuum* has practical consequences:

- Training syllabi:** EOD, UXO, and range staff courses must explicitly teach the Continuum distinction, reinforced with photographic case studies.
- Standardised reporting:** JSP 364 formats should be updated to include mandatory fields: fragmentation, casing, crater, acoustic evidence, and thermal residue.
- Low-Order First:** LOTs should always be attempted in the first instance. Just as PPE is never the principal form of safety protection, avoidance is, protective measures around a munition should be the secondary protection for when a LOT has not succeeded rather than being treated as a justification for not attempting a low-order.
- Interoperability:** Universal adoption of the *Combustion Continuum* terms allows British Army engineers to communicate consistently with NATO allies and civilian contractors.
- Environmental compliance:** In underwater disposal, Continuum-informed LOTs can reduce acoustic impact on marine life — a growing requirement in NATO and civilian EOD operations.

Operational Recommendations

For practical adoption, the following are recommended:

1. **Use *Combustion Continuum* terminology** consistently: burning, deflagration, detonation for fills; burn-out, low-order, high-order for munitions.
2. **Embed improved forensic evidence collection** in all EOD reports.
3. **Include *Combustion Continuum* concepts in doctrine** updates, training exercises, and SOPs.

Limitations

No conceptual model removes the need for professional judgement. Ambiguous cases - partial detonations, metastable detonation velocities — will still arise. But the *Combustion Continuum* provides a structured lens through which to interpret them, reducing subjective variation.

Conclusion

For Royal Engineers, the *Combustion Continuum* is more than an academic framework: it is an operational tool. By clarifying definitions, separating substance and article behaviours, and linking terms to observable evidence, it improves safety, reporting, and interoperability.

The adoption of this framework into doctrine and training would represent a significant step forward in professionalising the language of explosive engineering. It would allow EOD operators, range staff, and design engineers alike to communicate unambiguously about the most critical aspect of their work: the behaviour of explosives under stress.

In explosive engineering, clarity of language is clarity of thought. And clarity of thought can mean the difference between safe disposal and disaster.

THE COMBUSTION CONTINUUM AND MUNITION REACTIONS



Figure 3. Detonation 20 kg



Figure 4. LO Result – 155 mm projectile



Figure 5. LO Result – 155 mm projectile

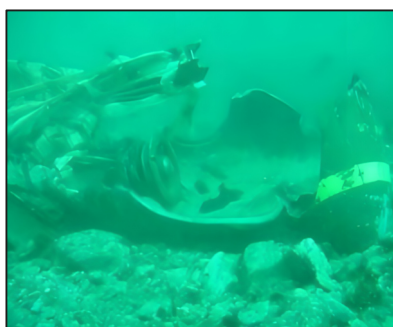


Figure 6. LO Result – Mk20 bomb underwater



Figure 7. LOT on 155 mm Projectile



Figure 8. LOT on 155 mm Projectile



Figure 9. LOT on Rocket



Figure 10. LOT on Sea Mine



Figure 11. LOT result – air-dropped bomb

This article is based on the following journal publications by the author and his collaborators:

Alford, R, Hazael, R & Critchley R. 'Introducing the combustion continuum to define the transition points between burning, deflagration and detonation regimes of energetic materials'. *Journal of Energetic Materials*, 1/17, 2024. Available at <https://doi.org/10.1080/07370652.2024.2446903> accessed on 2 December 2025.

Alford, R, Hazael, R & Critchley R, 'Using the combustion continuum to distinguish between explosive material and explosive article reactions for a unified scale in ordnance disposal categorization'. *Journal of Energetic Materials*, 1/16, 2025. Available at <https://doi.org/10.1080/07370652.2025.2472671> accessed on 2 December 2025.



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