Explosive Train Scale Shock Testing of New Energetic Materials

G T Flegg*, P J Frankl and T T Griffiths
QinetiQ, Fort Halstead, Sevenoaks, Kent, TN14 7BP, UK
Tel: 44 1959 515347
Fax: 44 1959516055
e-mail: ttgriffiths@qinetiq.com

Abstract

Insensitive munitions (IM) improve the survivability of both weapons and their associated platforms which can lead to a reduction in casualties, mission losses and whole life costs. All weapon systems contain an explosive train which needs to meet IM criteria but reliably initiate a main charge explosive. To ensure that these diametrically opposed requirements can be achieved, new higher power explosives with improved thermal stability and low response to both fragment and shock hazards are needed.

Most generic small-scale IM tests have been designed for use with main charge explosives and could give misleading responses due to scaling effects. QinetiQ has recently investigated the IM compliance of several new energetic materials using a test which has been designed to simulate the shock produced by a range of different stimuli. Applying the Bruceton Staircase technique allowed the thickness and standard deviation of the attenuator discs required to give a 50% initiation probability of different acceptor explosives by a pellet of Debrix 18AS to be determined. The work showed that the test is capable of screening IM explosive train materials for their response to shock initiation.

Introduction

The exploitation of IM technology leads to improved survivability, from accident or enemy action, of both weapon systems and their associated platforms. In addition, their use results in reduced casualties, mission losses and whole life costs, while still supplying the equivalent performance.

Both complex and general munitions contain a number of explosive sub-systems to provide reliable initiation and detonation transfer. As the main charge fillings for weapons have becoming increasingly insensitive to hazard threat stimuli, the size and power of the booster explosive used in the explosive train have increased. This has resulted in the explosive train becoming a significant factor in overall weapons vulnerability.

Developments on booster explosives have therefore been aimed at the provision of new materials and techniques that will initiate main charge explosive in the design mode reliably yet will not do so when accidentally initiated by an external hazard threat.

To ensure that explosive train materials can perform these diametrically opposed requirements, research is needed to develop new booster explosives with improved thermal stability, low explosiveness and low response to both fragment and shock hazards. It is important that new explosives can be tested at an early stage of the research to ensure that they have acceptable responses to IM tests before costly development and larger scale weapon testing is implemented.

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14. ABSTRACT
Insensitive munitions (IM) improve the survivability of both weapons and their associated platforms which can lead to a reduction in casualties, mission losses and whole life costs. All weapon systems contain an explosive train which needs to meet IM criteria but reliably initiate a main charge explosive. To ensure that these diametrically opposed requirements can be achieved, new higher power explosives with improved thermal stability and low response to both fragment and shock hazards are needed. Most generic small-scale IM tests have been designed for use with main charge explosives and could give misleading responses due to scaling effects. QinetiQ has recently investigated the IM compliance of several new energetic materials using a test which has been designed to simulate the shock produced by a range of different stimuli. Applying the Bruceton Staircase technique allowed the thickness and standard deviation of the attenuator discs required to give a 50% initiation probability of different acceptor explosives by a pellet of Debrix 18AS to be determined. The work showed that the test is capable of screening IM explosive train materials for their response to shock initiation.

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It is important that new explosives can be tested at an early stage of the research to ensure that they have acceptable responses to IM tests before costly development and larger scale weapon testing is implemented.

Current generic small-scale IM tests have been designed for use with main charge explosives and tend to use tens to hundreds of grams of explosive. These amounts of explosives are likely to be too costly and unavailable during the early stages of the energetic material synthesis and characterisation. Such quantities also require larger and more expensive test facilities. Additionally due to scaling effects, testing quantities of explosives significantly greater than that required for explosive train use can results in misleading responses.

The NATO standard STANAG 4439 [1] describes a suite of tests to determine the IM compliance of weapon systems which include slow cook off, fast cook off and shock. Experiments that simulate the slow and fast cook off tests at the scale of an explosive train have been used previously to examine a range of new explosives [2] [3].

This paper describes a shock test which aims to simulate the shock experienced by an explosive train as a result of small arms attack, fragmenting munition attack, behind armour debris from attack on armour and detonation in magazine/store/aircraft or vehicle. Research that used this test to study mitigation materials has been reported elsewhere [4] and all three tests have been used to study a number of other explosives [5].

Design Criteria

The test was designed to standardise as much of the equipment as possible with that of the slow and fast cook off tests, for this reason explosive pellets 15mm in diameter and 15mm long were used. The charge holder was made as simple as possible and based on the internal dimensions of the other charge holders (Figure 1). During the design phase, attenuator disc materials were chosen to allow the test to be conducted at both low and high temperatures. The optimum material for the attenuator discs was found to be aluminium. Initially the discs were punched out of aluminium sheet, however, the small raised lip around the edge of each disc was found to introduce an air gap that reduced the reproducibility and accuracy of the test. To overcome this, attenuators 15 mm in diameter and 0.4 mm thick were manufactured without the lipped edge using aluminium to BS 1470. A septum was placed between the attenuator discs and the acceptor explosive. This component represents the closure of an explosive housing and was made from steel to BS 970.

The test was also designed to investigate shock mitigation materials. In this test, a standard acceptor explosive would be used and the steel septum would be replaced with a sample of the mitigating material. The difference in the threshold for initiation when using a steel disc or the mitigating disc would indicate the effectiveness of the mitigation material.

Preliminary testing of an insensitive explosive showed that only a small number of attenuator discs were required to reach the ‘go’/’no-go’ threshold. The steel septum was therefore removed so that a longer column of attenuator discs was required. This allowed more flexibility to cover a range of insensitive booster explosives.

Charge holder

The charge holders were manufactured from mild steel; they had a wall thickness of 3mm and a 15 mm diameter cavity. For each test, an acceptor pellet was fitted into the bottom of the charge holder and the required number of attenuator discs was placed above. A donor pellet was inserted above the attenuators and a cardboard washer fitted into the top of the assembly to centralise the detonator. During the tests, the charge holder was positioned on a steel witness plate.

Explosive pellets

The donor pellets 15 mm in diameter and 15 mm long were manufactured from Debrix 18AS (RDX/wax/zinc stearate/aerosil® 95.3:2.7:1.5:0.5) [6] pressed at 22 kN to give a density of 1.66 g cm^{-3}. Acceptor pellets with the same dimensions were manufactured using Debrix 18AS, 2,6-diamino-3,5-dinitropyrazine (ANPZ), 2,6-diamino-3,5-dinitropyridine-1-oxide (DADNPO), picrylaminotriazole (PATO) and 2,6-diamino-3,5-dinitropyrazine-1-oxide(PZO or LLM 105).

Problems were experienced pressing the explosives PZO and PATO at a diameter of 15 mm. PZO failed to press into pellets with any structural integrity until 2.5% of the binder Viton was added. In the case of PATO, the addition of a binder failed to produce pellets which did not break during ejection from the mould.

Statistical Procedure

The Bruceton Staircase method [7] was used to determine the thickness and standard deviation in the thickness of an attenuator material required to give a 50% probability of initiation for the acceptor explosive. The procedure requires a number of initial experiments to establish the approximate number of attenuator discs required to reach the threshold of initiation for the test explosive. The number of attenuator discs used in each firing is varied by a set number called the 'Interval'. A full or partial detonation is designated a ‘go’ and a non-detonative response is designated a ‘no-go’.

For this study, the 'Interval' was set at four aluminium discs (1.64 mm) and the number of firings for a full Bruceton run was fixed at twenty.

Modelling

The QinetiQ Eulerian hydrocode GRIM2D was used to simulate the shock test; the simulations exploiting the symmetry of the test effectively observing a radial segment of the problem. Each simulation used a cell size within the computational grid of 0.025 mm^2. The aim of the work was to investigate the pressure profile that was created along the length of the attenuator and determine the shock pressure impacting the explosive for different attenuator lengths.

The schematic of the test for the modelling is shown in Figure 2. For simplicity, the aluminium attenuator was modelled as a single block of metal as opposed to individual disks that are used in the experiment, an assumption that will impact the accuracy of the prediction but which allowed the pressure profile to be more easily determined.

Results

The mass of the explosive pellets and their density are shown in Table 1; they follow a similar trend with:

DADNPO<PZO/Viton<ANPZ<<Debrix18AS

The density of the pressed pellets ranged from 1.58 g cm^{-3} for DADNPO to 1.66 for Debrix18AS.

A summary of the shock testing results is given in Table 2. The 50% initiation threshold for Debrix 18AS was 20.1 ± 1.7 mm of aluminium. For Debrix 18AS, tests conducted close to the threshold number of attenuator discs gave results which were difficult to classify as clearly a ‘go’ or a ‘no-go’. Since the explosive train scale shock test is designed to assess safety rather than the reliability of initiation when a partial ‘go’ was obtained it was treated as ‘go’. Photographs and a schematic or each type of event are shown in Figure 3.

The 50% initiation thresholds for ANPZ, the PZO formulation containing Viton and DADNPO were 7.4 ± 0.6 mm, 10.8 ± 0.8 mm and 11.8 ± 1.2 mm of aluminium, respectively.

All three materials are therefore considerably less sensitive to shock initiation than Debrix 18AS with ANPZ showing the least shock sensitiveness. The boundary between a ‘go’ and a ‘no-go’ on the witness record was much easier to interpret for these explosives than with Debrix 18AS. A ‘go’ was indicated by a large dent to the witness plate, whereas a ‘no-go’ resulted in considerable contamination of the witness plate with unreacted material and no denting.

The peak pressure profile across the aluminium along the axis of symmetry determined from the modelling is shown in Figure 4. There was a change in the slope of the profile at approximately 7.5 mm into the attenuator. This may have been caused by an interaction of the rarefaction waves which originate at the periphery of the aluminium. Table 3 summarises the 50% threshold values and the peak pressure determined using the model for each of the explosives.

The model suggests that the threshold shock pressure required to initiate PZO and DADNPO was approximately twice that for Debrix 18AS. Although ANPZ only required a few millimetres less attenuator than PZO and DADNPO, the threshold shock pressure for ANPZ was calculated to be almost three times that of Debrix 18AS.

Conclusions

Improving the tolerance on the attenuator discs and eliminating the steel septum allowed the shock sensitiveness for a range of very insensitive explosives to be established.

Each of three materials examined, ANPZ, PZO and DADNPO are considerably less sensitive to shock initiation than the conventional booster explosives Debrix 18AS.

When ranked by increasing sensitiveness, the order was:

ANPZ < PZO/Viton < DADNPO <<< Debrix 18AS

The low shock sensitiveness of ANPZ, PZO and DADNPO, and their performance in the fast and slow cook-off tests, indicate these materials would be suited for future IM explosive train applications.

The GRIM2D code allowed the shock test to be modelled but the effect of using individual attenuators needs to be examined and additional validation performed.

References

[1] STANAG 4439, Policy for Introduction Assessment and Testing for Insensitive Munitions (MURAT).

[2] G. T. Flegg, Explosive Train Scale Fast Cook-off Testing of New Energetic Materials Unpublished work, 2005.

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[5] A. Stoodley, M. Wright, G. Flegg and T. Vine Explosive Train Scale Safety Testing of Candidate Booster Materials, 16th APS Topical Conference on Shock Compression of Condensed Matter, 2009.

[6] R. J. Spear, V Nanut and I. J. Dagley, Department Of Defence, Materials Research Laboratories Report MRL-R-1015, RDX-Polyethylene Wax Formulations As Potential Replacements For Tetryl In Fuze Leads, Boosters and Magazines, 1986. available from http://www.dtic.mil/cgi-bin/GetTRDoc?AD=ADA174828&Location=U2&doc=GetTRDoc.pdf

[7] J. W. Dixon and A. M. Mood, A Method for Obtaining and Analyzing Sensitivity Data, Journal of the American Statistical Association, 43, 109-126 1948.

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Tables

Material	**Mass (g)**	**Density (g cm^{-3})**
Debrix 18AS	4.34	1.66
ANPZ	4.22	1.60
DADNPO	4.14	1.58
PZO/Viton (97.5:2.5)	4.17	1.59

Table 1: Pellet mass and density for each of the explosives.

Material	**Median thickness of aluminium (mm)**	**Standard deviation (mm)**
Debrix 18AS	20.1	1.7
ANPZ	7.4	0.6
DADNPO	10.8	0.8
PZO/Viton (97.5/2.5)	11.8	1.2

Table 2: Median attenuator thickness and standard deviation.

Material	**50% Threshold level by experiment (mm)**	**Calculated pressure at 50% threshold (GPa)**
Debrix 18AS	20.1	9
ANPZ	7.4	25
DADNPO	11.8	17
PZO/Viton (97.5/2.5)	10.8	19

Table 3: Summary of 50% threshold values

Figures

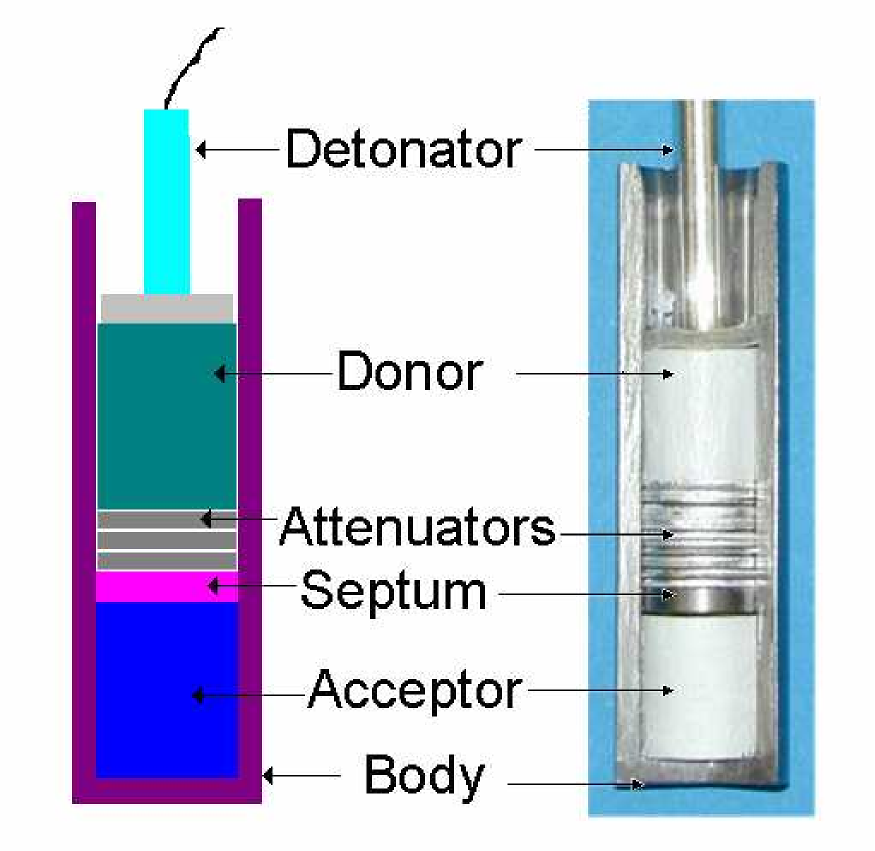


Figure 1: Shock test schematic and photograph.

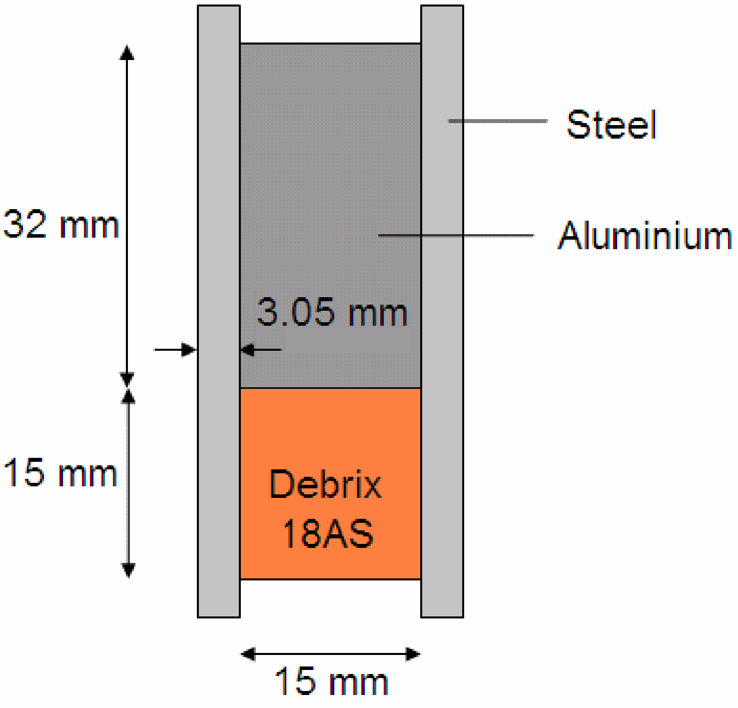
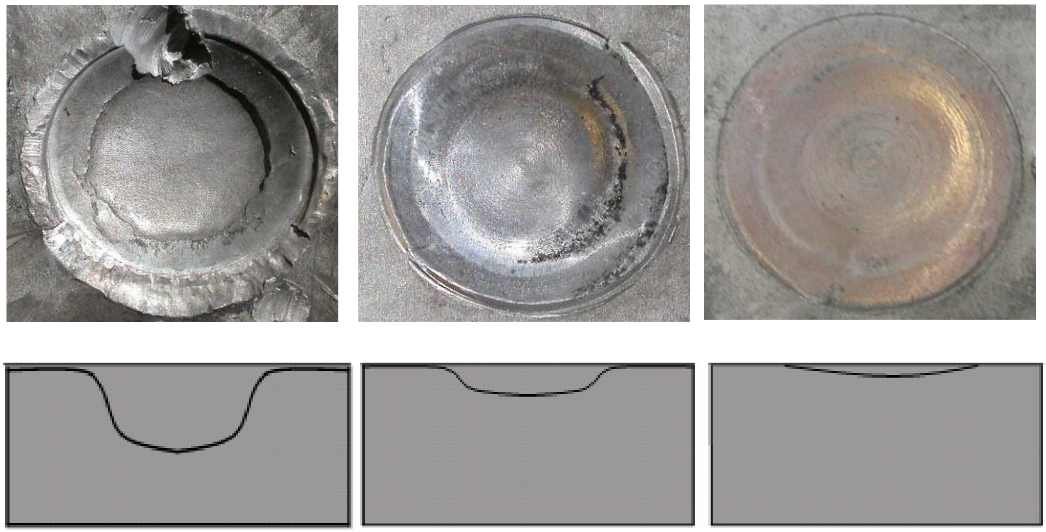


Figure 2: Schematic of the test for the modelling.



‘Go’ Partial ‘go’ ‘No-go’

Figure 3: Photograph and schematic of the witness plates.

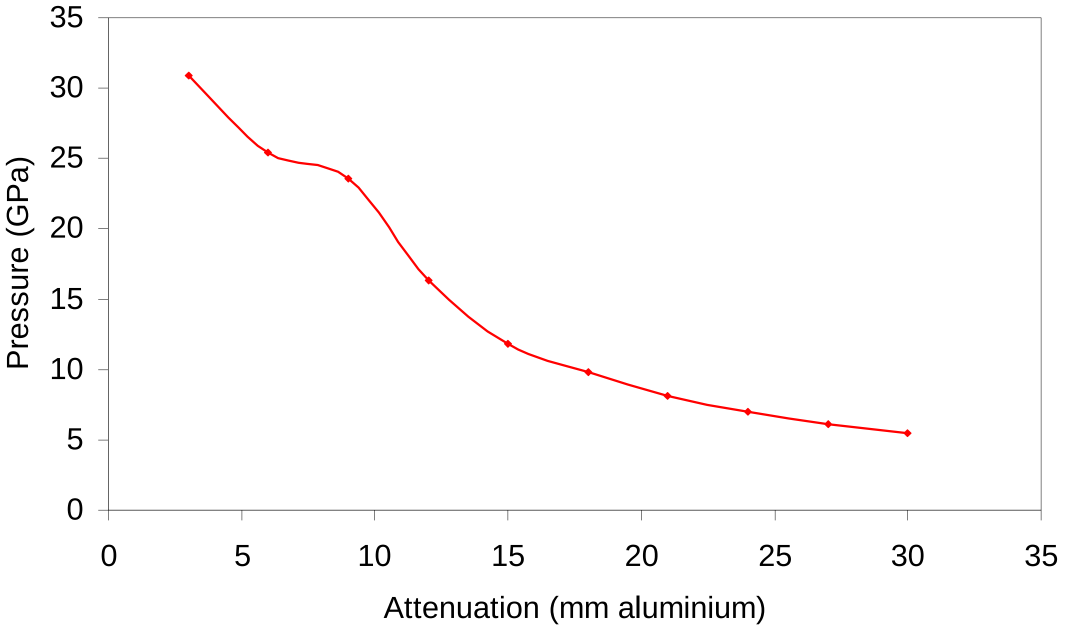


Figure 4: Results of the GRIM2D modelling study.

Explosive Train Scale Shock Testing of New Energetic Materials

T T Griffiths
A presentation to: DDESB Seminar 2010

QINETIQ/10/01614

15th July 2010

QinetiQ

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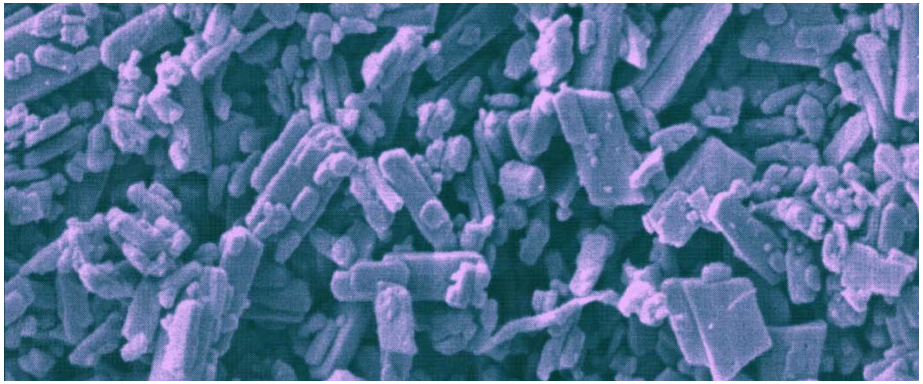

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Terry Jordan who devised and developed the explosive train scale test regimes

Catherine Fisher and David Belsham who manufactured the test samples and performed many of the practical tests

2 Introduction

Insensitive munitions (IM) offer

- Improved survivability of weapon systems and platforms
- Reduced casualties, mission losses and whole life costs

Both complex and general munitions contain explosive sub-systems to provide reliable initiation, detonation transfer and amplification

As the main charge fillings for weapons have becoming increasingly insensitive to hazard threat stimuli, the size and power of the booster explosive used in the explosive train have has increased

This has resulted in the explosive train becoming a significant factor in a weapons overall vulnerability

2 Introduction

NATO STANAG 4439 details a suite of tests for munitions to determine IM compliance

Potential threats to munitions include:

- Magazine, Store, Aircraft or Vehicle fuel fire
- Fire in Adjacent Magazine, Store or Vehicle
- Small Arms Attack
- Fragmenting Munition Attack
- Shaped Charge Weapon Attack
- Behind Armour Debris from Armour Attack
- Detonation in Magazine/Store/Aircraft or Vehicle

2 Introduction

To meet these requirements a suite of explosive train scale tests has been designed

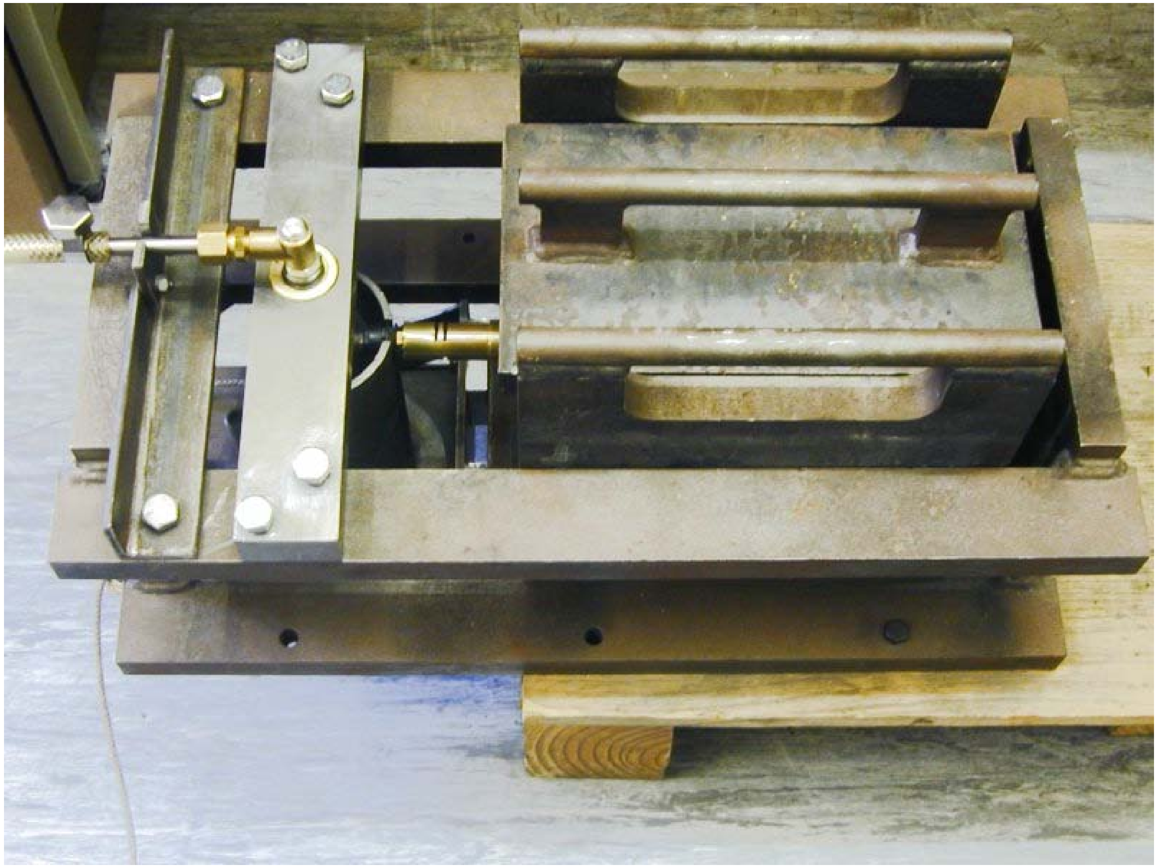
- Fast Cook-Off Test
- Slow Cook-Off Test
- Shock Test

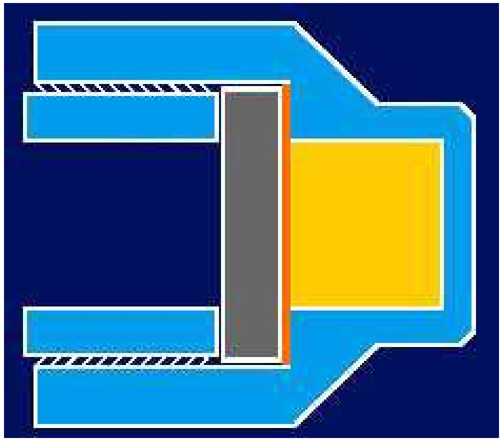
Tests have been designed to

  - Standardise the charge holders and test equipment
  - Use low cost components

2 Introduction

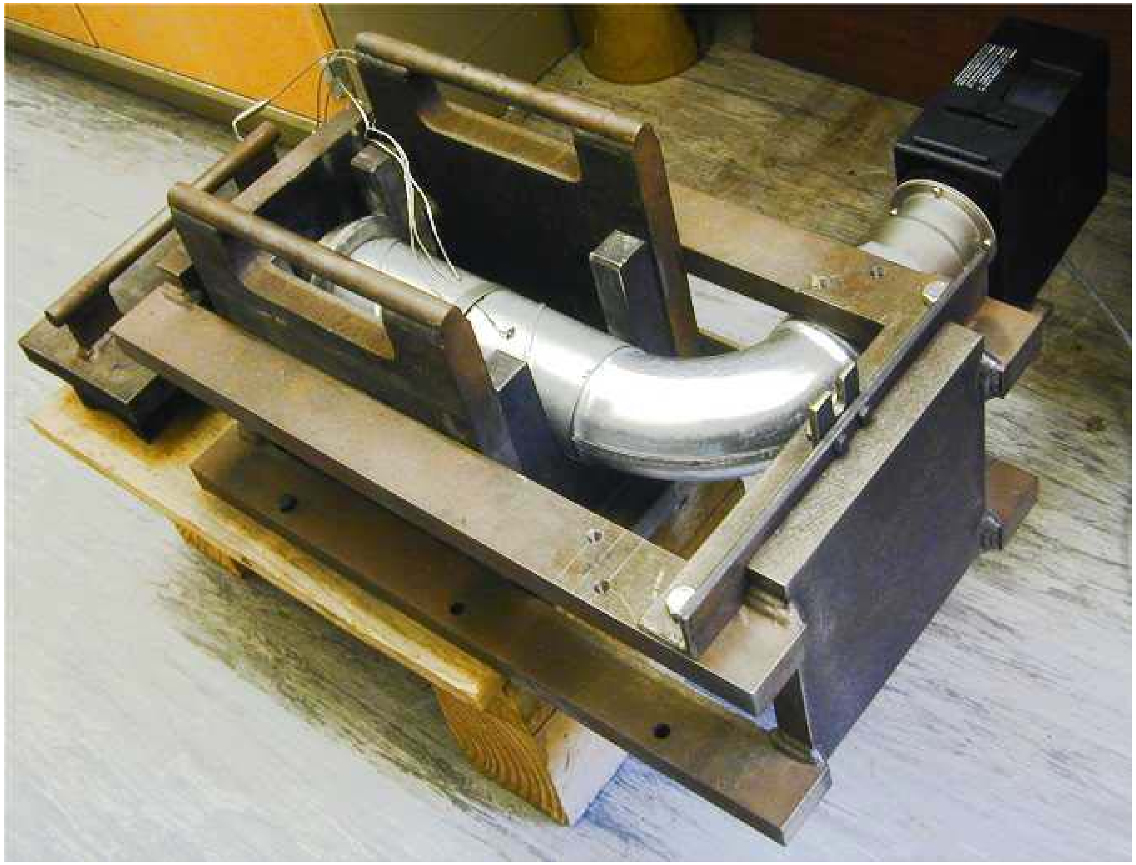
Fast Cook-Off Test

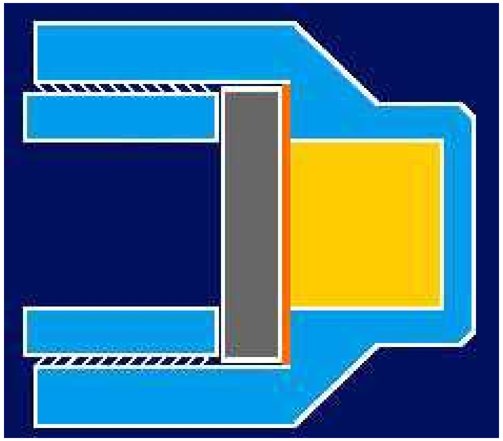




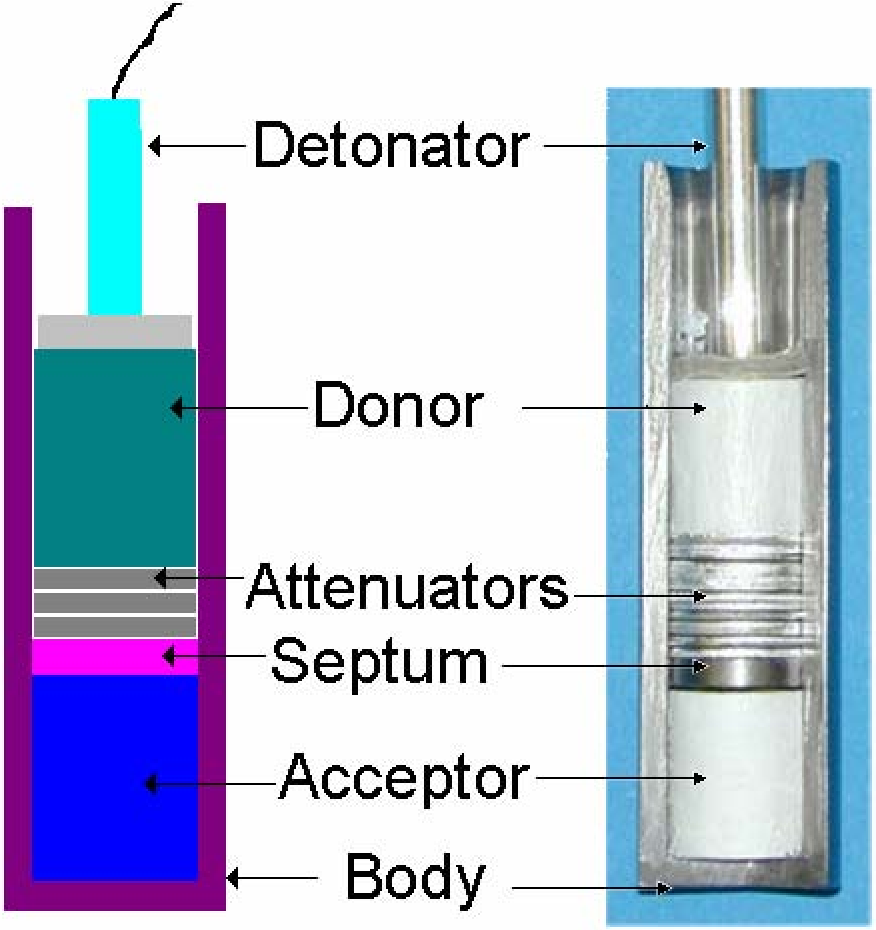
2 Introduction

Slow Cook-Off Test





3 Experimental



Shock test

- Charge holder
  - Mild steel 3 mm thick
- Attenuator discs
  - 0.4 mm thick aluminium
  - Machined to avoid edge lip
- Septum
  - Steel
  - Shock mitigation material
  - Not used
- Explosive donor and acceptor pellets
  - 15 mm in diameter and 15 mm long
  - Approximately 5 g

3 Experimental

Donor Explosive

- Debrix 18AS (RDX/Wax/Zinc Stearate/Aerosil)

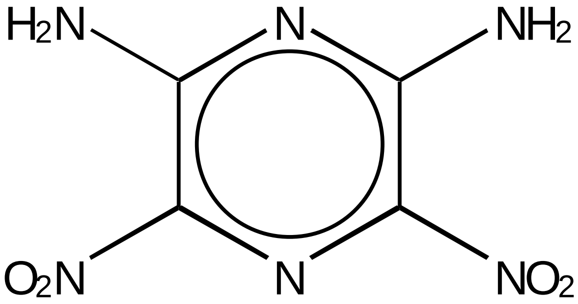
Standard Acceptor

- Debrix 18AS

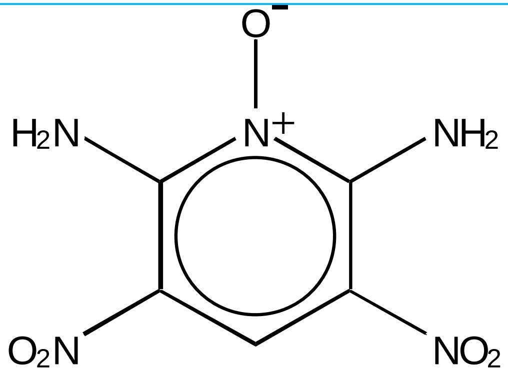
IM Explosives

- ANPZ (2,6-diamino-3,5-dinitropyrazine)
- DADNPO (2,6-diamino-3,5-dinitropyridine-1-oxide)
- PATO (Picrylaminotriazole) (LLM 105)
- PZO (2,6-diamino-3,5-dinitropyrazine-1-oxide)

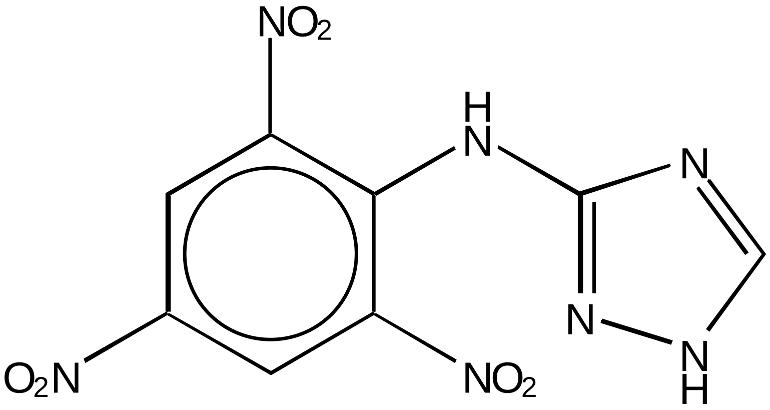
3 Experimental



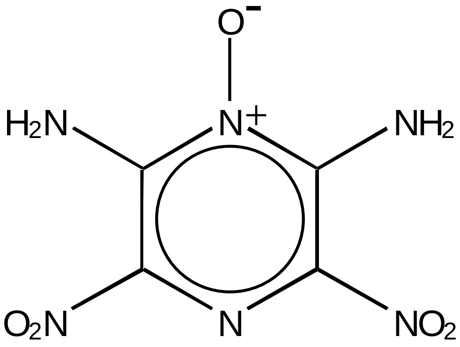
ANPZ
(2,6-diamino-3,5-dinitropyrazine)



DADNPO
(2,6-diamino-3,5-dinitropyridine-1-oxide)



PATO
(Picrylaminotriazole)



PZO
(2,6-diamino-3,5-dinitropyrazine-1-oxide)

3 Experimental

Used the Bruceton Staircase technique to determine

- Median thickness
  - 50% probability of initiation for the acceptor explosive
- Standard deviation in the thickness
  - Perform experiments to establish the approximate number of attenuator discs
  - The 'Interval' was set at four aluminium discs (1.64 mm)
  - A full or partial detonation was designated a ‘go’
  - Non-detonative response a ‘no-go’
- Twenty tests for full Bruceton

4 Results

Explosive	**Mass (g)**	**Density (g cm^{-3})**
Debrix 18AS	4.34	1.66
ANPZ	4.22	1.60
DADNPO	4.14	1.58
PZO/Viton	4.17	1.59

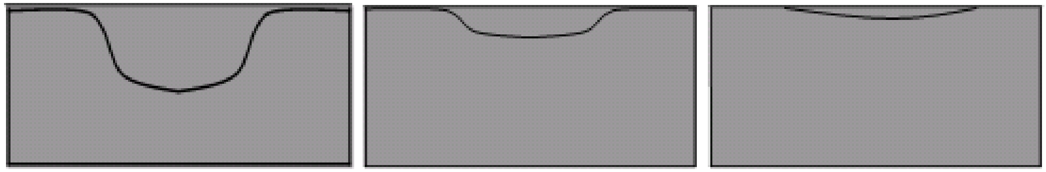
PATO – Unable to manufacture robust pellets

4 Results

Explosive	**Median Thickness of Aluminium (mm)**	**Standard Deviation (mm)**
Debrix 18AS	20.1	1.7

Approximately 50 discs

sd – 9%



Witness plates

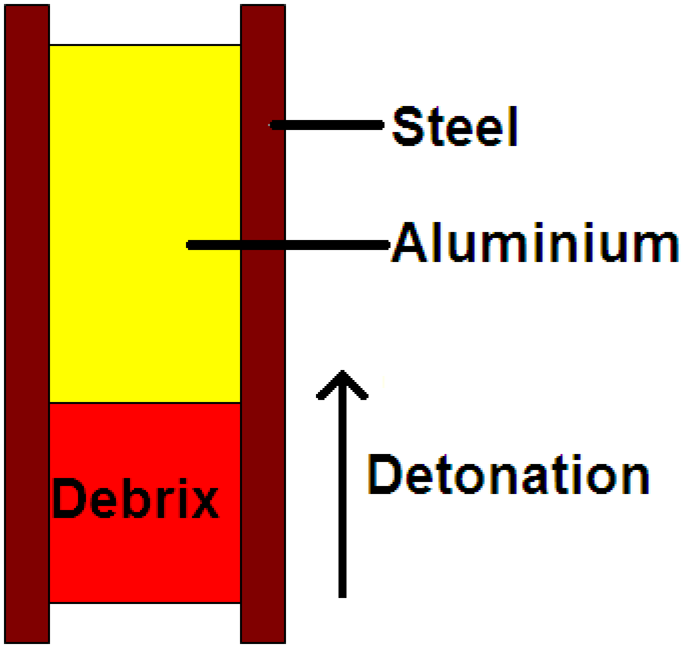
4 Results

Explosive	Median Thickness of Aluminium (mm)	Standard Deviation (mm)
Debrix 18AS	20.1	1.7
ANPZ	7.4	0.6
DADNPO	11.8	0.8
PZO/Viton	10.8	1.2

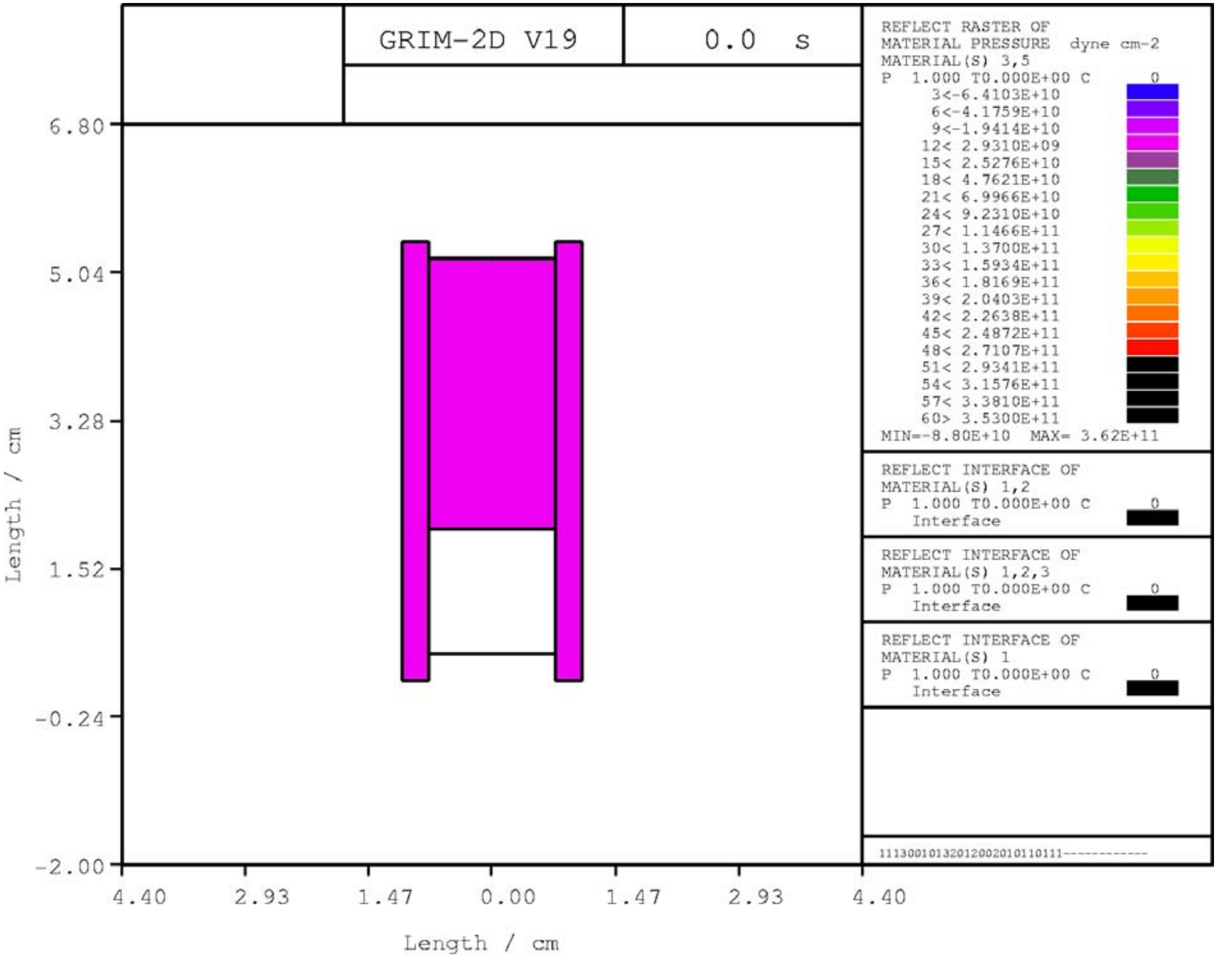
5 Modelling Study

QinetiQ Eulerian hydrocode GRIM2D

- Simulation computational grid of 0.025 mm^2
- Determine the shock pressure impacting the explosive for different attenuator lengths
- The aluminium attenuator was modelled as a single block of metal as opposed to individual disks



5 Modelling Study

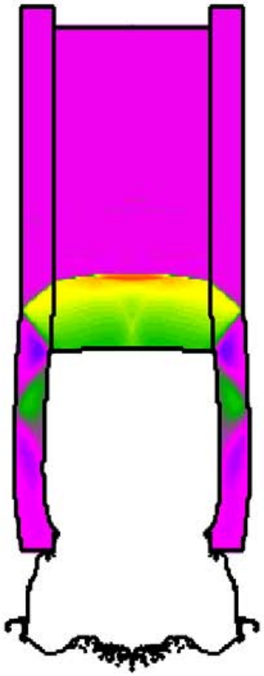


Gap Testing Concept 1 - Aluminium

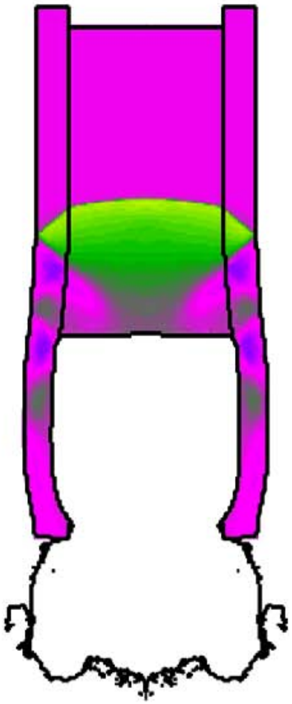
Pink = Ambient pressure.

5 Modelling Study

Shockwave moving through the attenuator

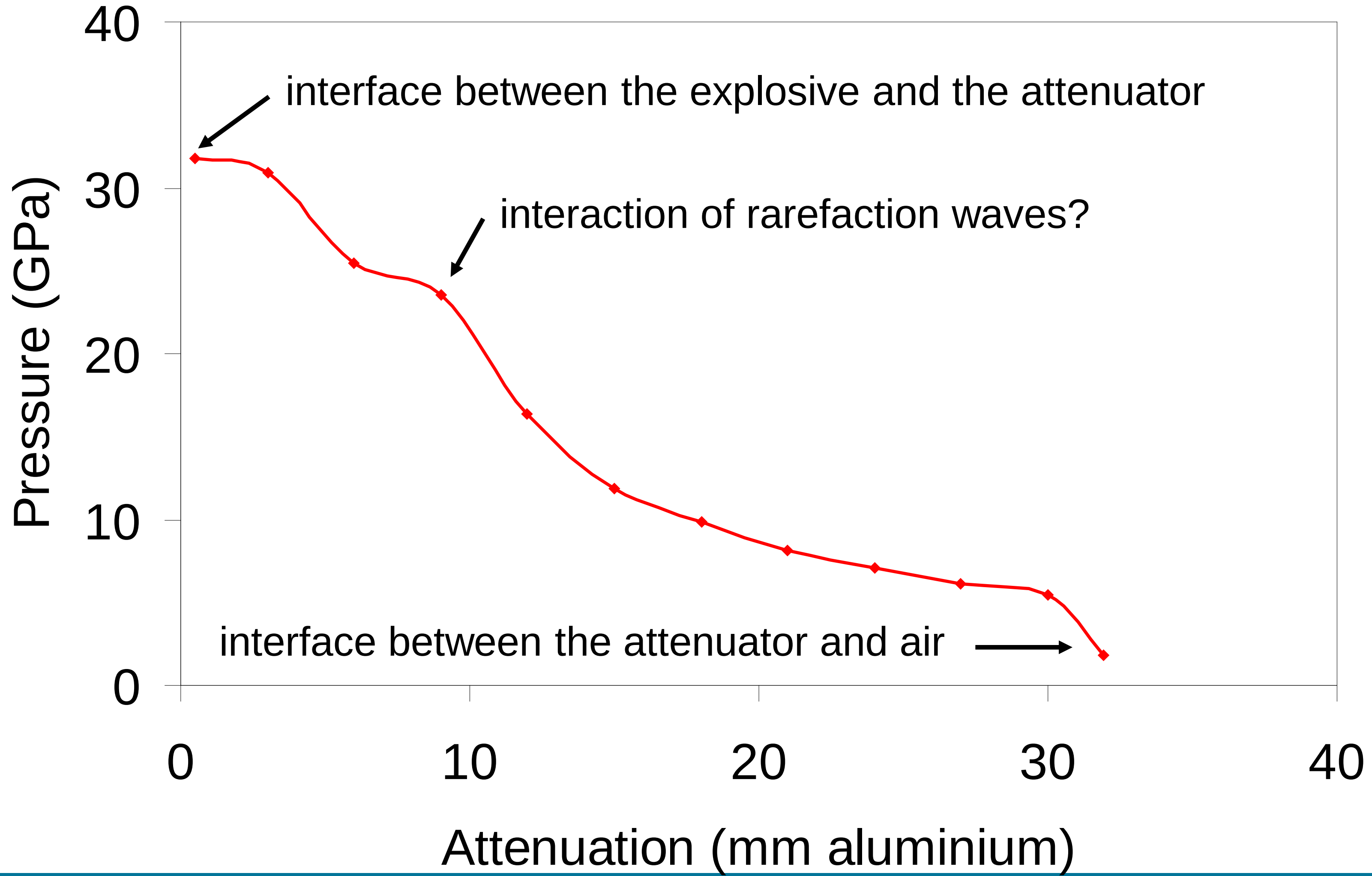


Release waves returning from the edges



Pink = Ambient pressure.

5 Modelling Study



5 Modelling Study

Explosive	**Median Thickness of Aluminium (mm)**	**Calculated Pressure at 50% Threshold (GPa)**
Debrix 18AS	20.1	9
ANPZ	7.4	25
DADNPO	11.8	17
PZO/Viton	10.8	19

6 Conclusions

The new test allows the shock sensitivity for a range of very insensitive explosives to be established

ANPZ, PZO and DADNPO are considerably less sensitive to shock initiation than Debrix 18AS.

When ranked by increasing sensitiveness

ANPZ < PZO/Viton < DADNPO <<< Debrix 18AS

All three tests explosive train tests shows that ANPZ, PZO and DADNPO are suitable for future IM explosive train applications.

The GRIM2D code allowed the shock test to be modelled but the effect of using individual attenuators needs to be examined www.QinetiQ.com