# EXPLOSIVE BOOSTER SELECTION CRITERIA FOR INSENSITIVE MUNITIONS APPLICATIONS

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## Introduction

Boosters play an essential role in the safe functioning of the majority of explosive-filled ordnance by propagating and magnifying the detonation wave from initiator to main charge. Booster explosives formulated for Insensitive Munitions (IMs) applications must fulfil a number of exacting and often apparently conflicting requirements. For example, the booster must be shock sensitive enough to reliably take over from the detonator and at the same time must possess reduced vulnerability towards hazardous stimuli as represented by the threats described in STANAG 4439. Consistent performance and survivability under in-service conditions must also be maintained throughout the lifecycle of the munition. This necessitates preservation of physical integrity, thermal stability and resistance to ageing, particularly if the explosive is to be subjected to high–g environments during launch or retardation.

## Selection Criteria

This paper describes the rationale and methodology adopted in the United Kingdom for the assessment and selection of candidate pressable booster formulations as part of a systems approach to meeting IM requirements. The Insensitive Munitions Assessment Panel (IMAP) reviews available data on design features, such as boosters, beginning at an early stage in a project's life. These reviews are undertaken to assess the IM compatibility of proposed design options and choices of energetic materials with a view to defining the IM signature for the munition. The criteria employed for selection by the munition designer include performance and fitness for purpose, hazard and IM compatibility, processability and environmental survivability. Much of the data used for selection is derived from material qualification programmes.

## Explosive Formulations

The explosive formulations discussed in this paper are pressable in nature, that is, the materials are first produced as granulated moulding powders which are then fabricated into pellets by a compaction process. The energetic filler can take many forms such as RDX, HMX, hexanitrostilbene (HNS) or TATB. Typically, pressable booster compositions contain in the region of 5%m/m binder although the range may extend from 1 to 8% and some boosters consist of pure explosive without any binder present, eg tetryl.. The binder not only improves the physical integrity of pellets but it also acts as phlegmatiser and granulating agent. The binder can take the form of hydrocarbon waxes, thermoplastic elastomers (TPEs) and fluoropolymers. Nominal formulations of some booster explosives are given in Table 1.

| **Ingredients** | **Booster Explosive Formulations** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Debrix 18AS** | **HNS II /Binder** | **PBXN-5** | **RF-68-01** | **RF-68-02** | **ROWANEX 3600** | **ROWANEX 3601** |
| RDX (%) | 95 | | | 35 | 35 | 35 | 35 |
| HMX (%) | | | 95 | | | | |
| HNS (%) | | 96 | | | | | |
| TATB (%) | | | | 60 | 60 | 60 | 60 |
| Binder (%) | 5 | 4 | 5 | 5 | 5 | 5 | 5 |
| Binder Type | Wax | FP* (KelF 800) | FP* (Viton) | FP* (Hostaflon) | FP* (Fluon PTFE) | TPE (XBS 6005) | FP* (Viton) |

*FP: Fluoropolymer

Table 1: Nominal Formulations of Some Booster Explosives

## Qualification Programmes

In the UK booster explosives are first qualified to STANAG 4170 as a means of assessing their safety and suitability for introduction into service. The assessment programme associated with qualification involves evaluation of a range of properties including small scale hazard, shock sensitiveness, chemical stability, mechanical properties, explosiveness and ageing characteristics. The qualification programme establishes a set of baseline data for the explosive that can then be used to assess any changes occurring throughout its service life. A typical qualification programme for a booster explosive is given in Annex A.

## Performance and Fitness-for-Purpose

In a safety critical application such as a booster it is essential that the pressed explosive is fit for purpose in terms of its performance attributes including its ability to take over from the initiator/stemming and transmit detonation to the main charge. Other important performance parameters are critical diameter and velocity of detonation. An appropriate balance must be struck between the critical diameter of a booster explosive and its response to hazardous stimuli. A relatively small critical diameter whilst implying relatively higher shock sensitiveness means that the booster can function as a small pellet and is easier to protect in an overall IM systems context. A booster explosive with a larger critical diameter may appear intrinsically less hazardous but its size may be make it impractical to include in a fuzing configuration and present significant difficulties when considering mitigation requirements. An indication of the relative shock sensitivities of booster compositions can be gained from gap test results. The UK large-scale gap test (EMTAP 22) is based on the US NOL large-scale gap test, and is used to measure the shock detonation sensitiveness of a wide range of explosive materials. Results are expressed as the pressure Pg just inside the attenuator at the attenuator/acceptor interface resulting in a 50% probability of detonation of the acceptor. A comparison of the gap test results of a range of booster explosives is given in Table 2.

| LSGT Results | Booster Explosives | | | | |
|---|---|---|---|---|---|
| | RF-68-01 | RF-68-02 | HNS II/Binder | ROWANEX 3600 | ROWANEX 3601 |
| Gap (mm) | 55.7 | 57.5 | 59.5 | 47.9 | 59.3 |
| 50% Pressure (GPa) | 1.6 | 1.5 | 1.40 | 2.2 | 1.40 |
| Density ($gcm^{-3}$) | 1.837 | 1.836 | 1.578 | 1.755 | 1.740 |

Table2: LSGT Results for Selected Booster Explosives

Greater confidence in take-over is achieved, however, by undertaking a series of trials on representative hardware under worst case conditions. As part of a Land Systems artillery projectile development programme it was necessary to assess initiation of the ROWANEX 3600 booster from a range of in-service fuzes. Trials were conducted using sections of shell containing ROWANEX 1100 main charge explosive and equipped with booster cavities and ROWANEX 3600 pellets. The trials arrangement is shown in Figure 1. Take over tests were then conducted with fuze set-ups representative of CX23 (4.5"shell, Debrix 18As pellet) and L106 (155mm shell, tetryl pellet) both of which were initiated by a length of MDF connected to an L2A1 detonator. The L2A1, being a powerful detonator, was separated from the fuze assembly so that it did not dominate take-over behaviour. Both fuze types were found to fully initiate the ROWANEX 3600 pellet and ROWANEX 1100 main charge as recorded by penetration of steel witness plates positioned below the shell hardware.

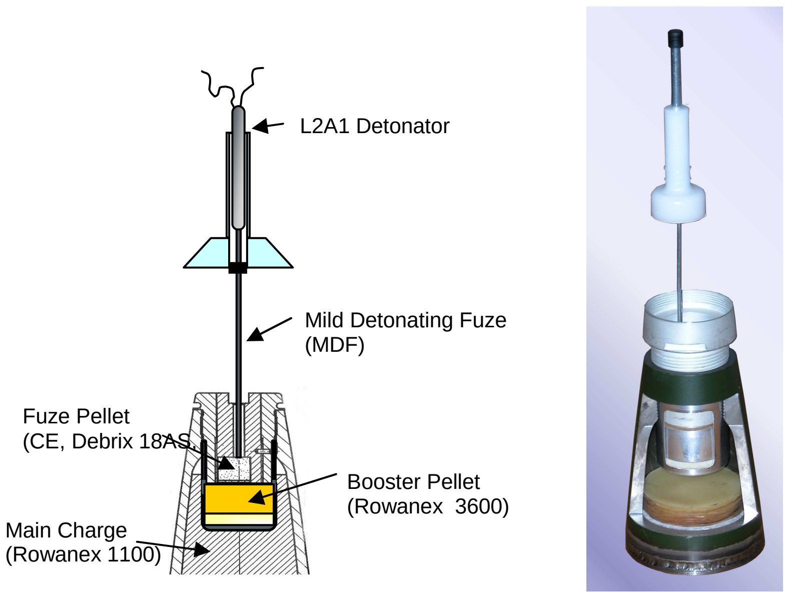
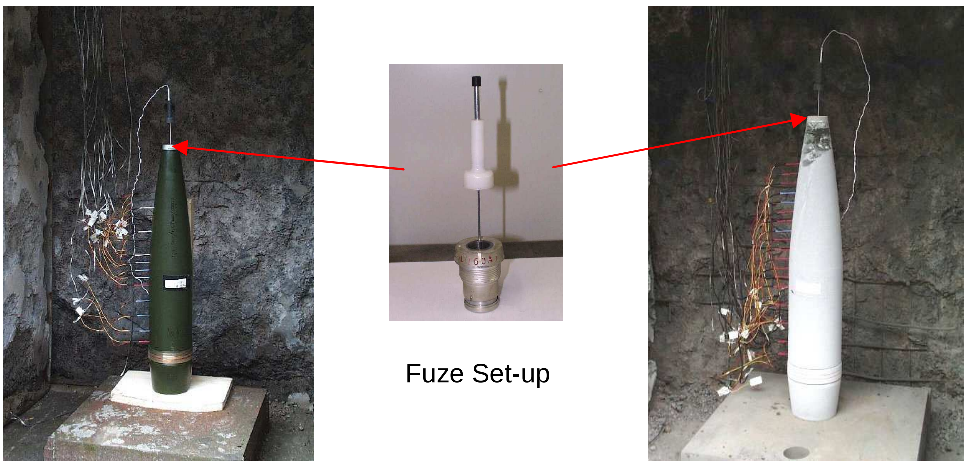



Figure 1: Artillery Projectile Fuze Take-over Trials

To represent worst case conditions and simulate the worst possible combination of factors three static firings were conducted with 105mm hardware to investigate correct take over of a ROWANEX 3601 booster pellet from the L116 fuze (which has lower output than L106 fuze) and from the booster onto the ROWANEX 1100 main charge. Firings were conducted at -46℃ with an air gap of up to 32mm between the ROWANEX 3601 and the ROWANEX 1100 and using the lowest density ROWANEX 3601 booster pellets likely to occur in production. All the firings provided evidence of correct detonation on the steel witness plates.

The booster pellet is potentially one of the most vulnerable components of a munition. It is therefore important that its size is optimised for efficient functioning to minimise the target area for impinging bullets and fragments. With this in mind Land Systems have undertaken a series of trials with 155mm shell at low (-46°C) and ambient temperature regimes to establish the relationship between booster output (in terms of booster size or the number of individual booster pellets) and the run-up distance to full detonation within the shell body (see Figure 2). Low temperature conditions are considered worst case as thermal contraction and resultant gaps in the initiation train are at a maximum. Ionisation probes inserted along the length of the shell body were used to measure velocity of detonation. One, two and three booster pellets were used in conjunction with both CX23 and L106 fuze set-ups. The results demonstrated that a single booster pellet was sufficient to cause prompt detonation in the ROWANEX 1100 main charge explosive.




Ambient Temperature Low Temperature

Figure 2: Run to Detonation Trials on 155mm Shell

Land Systems has conducted a series of arena lethality trials on a full range of projectile natures (105mm HEIM, 105mm HEIMER, 155mm HEIM and 4.5" IM) using the lower output L116 fuze booster. These munitions have the same generic internal design (ROWANEX 1100 main charge and ROWANEX 3601 booster), and all firings have achieved successful detonation and fragmentation patterns.

**Hazard and Insensitive Munitions (IM) Compatibility**

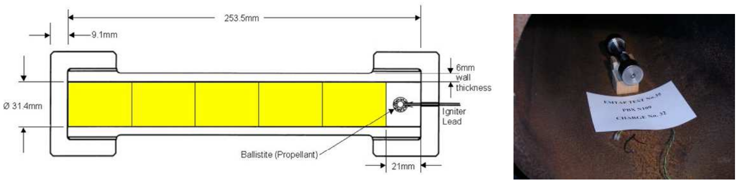
An important part of the assessment process for a candidate booster explosive is the evaluation of explosiveness in the UK series of EMTAP tube tests where responses give a clear indication of the propensity of the explosive to undergo deflagration to detonation transition (DDT). From these results conclusions can be drawn on the suitability of the booster formulations for IM applications. There are three variants of the tube test (see Figure 3).

(a) Internal Ignition (EMTAP No. 35). The explosive under test is ignited within the tube by means of a charge of propellant. Generally ten firings are conducted

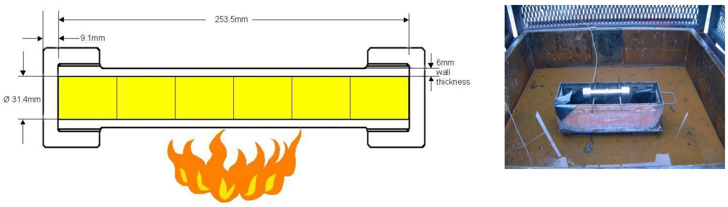
(b) Fast Heating (EMTAP No. 41). The tube and contents are heated by means of a petrol fire. The time to response is recorded. Generally ten firings are undertaken

(c) Electrically Heated (EMTAP No. 42). A sample of explosive, confined in a steel tube, is heated at various rates ( 3℃, 4℃ , 5℃, 7.5℃, 10℃ by an electrical heating tape. A single test vehicle is instrumented with an internal thermocouple to record the thermal profile in the centre of the explosive charge up to the onset of reaction. Generally five firings are performed.

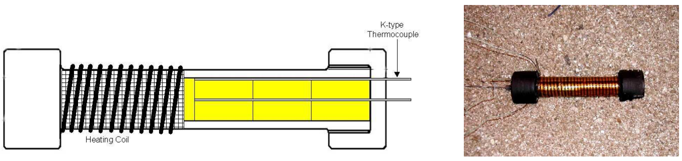
All variants of the test involve the same basic vehicle which consists of a steel tube containing approximately 350g explosive with screw-on steel end caps. The tubes are designed so that the wall of the tube fails before the end caps. The degree of fragmentation of the tube is used to assess the relative explosiveness of the composition under test. The proportion of recovered explosive is also used to ascertain the degree of reaction (see Table 3).




**EMTAP Test No 35**
**Tube Test Internal**




**EMTAP Test No 41**
**Tube Test Fast Heating**




**EMTAP Test No 42**
**Tube Test Electrically Heated**
**(Heating rates 3°,4°,5°, 7.5°, 10℃/min)**

Figure 3: Three Variants of the the EMTAP Tube Tests

| Reaction Category | Reaction Description | Observation |
|---|---|---|
| 0 | No Reaction | No mass loss |
| 0/1 | Burning /Decomposition | No disruption of test Vehicle |
| 1 | Pressure burst due to burning/decomposition | Test vehicle ruptured but one fragment approximates to original mass |
| 2 | Deflagration | 2 to 9 test vehicle body fragments |
| 3 | Explosion | 10 to 100 test vehicle body fragments |
| 4 | Detonation | > 100 test vehicle body fragments showing evidence of detonation |

Table 3: Tube Test reaction Categories and Descriptions

The results of a tube testing on selected booster explosives are given in Tables 4, 5 and 6. The tubes were filled with booster pellets having a sliding fit with the sides of the tubes and pellets were bonded to each other using a compatible cyano-acrylate adhesive. The average pressed filling densities are given in Table 2.

Table 4 shows results of tube testing internal ignition version on two candidate reduced vulnerability booster explosives ROWANEX 3601 and HNS II /Binder . The results of the conventional booster explosives Debrix 18 AS and Tetryl are included for comparison. Firstly it can be clearly seen that the response of the conventional boosters is much more violent than the IM boosters in terms of the number of fragments produced. Secondly, the results indicate that the burning/deflagration response of ROWANEX 3601 is more benign than the deflagration/explosion response of HNS II / Binder.

| Booster Composition | Reaction Category | Average Number of Fragments |
|---|---|---|
| ROWANEX 3601 | 5 off Cat 1<br>5 off Cat 2 | 1.4 |
| HNS II / Binder | 7 off Cat 2<br>3 off Cat 3 | 6 |
| Debrix 18AS | 10 off Cat 3 | 23 |
| Tetryl | 1 off Cat 1<br>3 off Cat 3<br>6 off Cat 4 | 200 |

Table 4: Tube Test Internal Ignition (EMTAP 35) Results for Selected Booster Explosives

Table 5 gives results of fast heating tube testing on a range of candidate booster explosives. The conventional booster explosive Debrix 18AS is included for comparison. In general the TATB-based boosters with low order category 1 and 2 responses with the average number of fragments ranging from 1.4 to 2. By contrast the HNS-based composition gives mainly explosion category responses and an average fragment number of 52 which is considerably more violent and casts doubt on the suitability of this booster for IM applications. The average time to reaction is over 100 seconds longer for HNS II / Binder than for ROWANEX 3601. This can be explained by the higher thermal stability of the HNS. The thermal stability of ROWANEX 3601 is limited by its RDX component which normally starts to decompose in the region of 200℃. The conclusion which must be drawn however is that gradual thermal decomposition of the energetic material at lower temperatures is preferable in terms of explosiveness to rapid decomposition *en masse* at higher temperatures.

| Booster Composition | Reaction Category | Average Number of Fragments | Average Time to Reaction (s) |
|---|---|---|---|
| ROWANEX 3601 | 4 off Cat 1<br>6 off Cat 2 | 2 | 136 |
| HNS II / Binder | 9 off Cat 3<br>1 off cat 2 | 52 | 243 |
| ROWANEX 3600 | 8 off Cat 1<br>2 off Cat 2 | 1.4 | 143 |
| RF-68-01 | 6 off Cat 1<br>4 off Cat 2 | 1.4 | 163 |
| RF-68-02 | 10 off Cat 2 | 1.4 | 167 |
| Debrix 18AS | 7 offCat 1<br>1 off Cat 2<br>2 off Cat 4 | | |

Table 5: Tube Test Fast Heating (EMTAP 41) Results for Selected Booster Explosives

Table 6 gives results of electrically heated tube testing on ROWANEX 3601 and HNS II / Binder compositions. Results show that the response of the HNS based formulation is generally higher order than that of the TATB-based composition producing explosions rather than deflagrations in each case. The average number of fragments is correspondingly higher with HNS II / Binder than with ROWANEX 3601; ie 12 compared with 8 .

| Booster Composition | Reaction Category | Average Number of Fragments |
|---|---|---|
| ROWANEX 3601 | 5 off Cat 2 | 8 |
| HNS II / Binder | 5 off Cat 3 | 12 |

Table 6: Tube Tests Electrically Heated (EMTAP 42) Results for Selected Booster Explosives

These charge scale tests have proved invaluable in elucidating the likely cause of unexpected detonations during IM development trials on a major UK lethal mechanism development programme and a change to the choice of booster explosive was made as a consequence.

A series of fuel fire trials (STANAG4240) on 4.5” Naval projectiles clearly show the influence of booster explosive on the violence of the response of a weapon system (see Figure 4). A 4.5” IA non-IM round filled with RDX/TNT and fitted with a Debrix 18AS booster gave a high order response with severe disruption of the case . In contrast a 4.5” IAIM round filled with ROWANEX 1100 PBX and equipped with a ROWANEX 3600 booster merely burnt out in situ after ejecting the nose plug. However, a non-ideal intermediate test configuration involving a ROWANEX 1100 main charge and a Debrix 18AS booster produced a deflagration reaction whereby the shell had split open from the nose end in banana skin fashion. There was no take-over to the main filling and more than 85% of the PBX was recovered. This comparison clearly indicates the benefits of a consistent approach to the selection of reduced vulnerability explosives for both main charge and booster components.

**RDX/TNT 60/40 Fill with Debrix 18AS Booster**

**ROWANEX 1100 and ROWANEX 3600 Booster**

**ROWANEX 1100 Fill with Debrix 18AS Booster**

Figure 4: Fuel Fire Trials on 4.5" IA Naval Shell Showing Influence of Booster Composition

## Gun-launch Survivability

When booster explosives are to be used in gun-launched applications it is necessary to have a good indication of how the composition will survive high-g environments at an early stage in the project. Evaluation of a new explosive in large calibre shell involves a high degree of risk unless prior assessment has taken place under representative conditions. At Land Systems new candidate explosives for boosters and main fill are first evaluated in gun firing trials in 30mm medium calibre Aden ammunition (see Figure 5). These trials are relatively inexpensive to organise and if an unexpected event occurs damage is restricted to a localised area and the barrel is expendable. Recovery trials were conducted on medium calibre rounds filled with ROWANEX 3600 and ROWANEX 3601 fired at a nominal acceleration level of 60,000g at -46℃ and +63℃. High speed cameras w ere used to take photographs during flight immediately after leaving the barrel and just before recovery. All rounds were radiographed before and after firing and selected recovered rounds were sectioned for more in depth examination. No evidence of damage or reaction was encountered in recovered rounds so raising confidence in the outcome of full scale gun launch trials on 4.5", 105mm and 155mm projectiles.

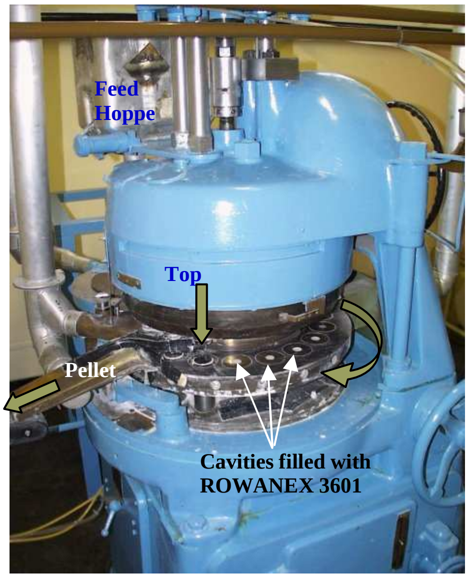
30mm Aden Barrel

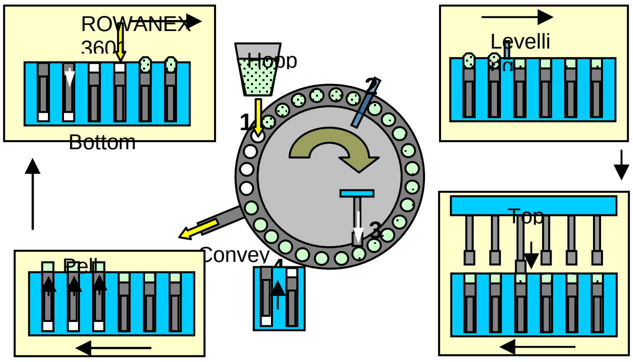
**Sectioned 30mm Aden Round after Gun launch )**

Figure 5: Gun-lunch Survivability Trials on ROWANEX 3600

## Processability

If a booster is to be mass produced in high volume, such as for artillery applications, the formulation must demonstrate adequate processability through all stages of the pellet pressing operation. This commonly involves flow of the moulding powder from a hopper into an automatic rotary press compaction to form the pellet then rapid ejection (see Figure 6). In consequence, the composition must flow without clogging and consolidate under a given pressure to give pellets which are uniform in density and demonstrate a high degree of physical integrity. To this end the granulation of the moulding powder composition is critical and will dictate how the powder pours, its bulk density and its pressing characteristics. ROWANEX 3601 has undergone a comprehensive range of producability trials which have evaluated the relationship of pellet density and dimensions with pressing conditions. Lower volume production in single action conventional presses is much less demanding in terms of requirements for granulation and flow properties of the moulding powder.




1. ROWANEX 3601powder enters cavity created by the lowering bottom punch
2. ROWANEX 3601powder inside the cavity is then spread level
3. ROWANEX 3601powder is pressed by the top punch pressing down onto the cavity
4. Pellet is ejected from the cavity by the rising bottom punch

Figure 6: Rotary Pressing of ROWANEX 3601 Pellets

## Environmental Survivability and Ageing

Table 7 summarises the results of a 6 months duration accelerated ageing trial on ROWANEX 3601 at a constant 60℃. The explo sive was accessed in the form of both powder and pellets (25.4mm right cylinders). The parameters monitored comprised sensitiveness (impact and friction), thermal stability (VS and DSC), and physical properties (mass, density, compressive). No significant changes in sensitiveness and thermal stability were observed over the course of the trial. Negligible reductions in pellet mass and density were recorded. Average maximum stress values exceeded the recording range of the test equipment at –40℃. Accelerated ageing sho wed no significant variation in average maximum stress values at +25℃ and +60℃ up to 3 months. Thereafter, increases in average maximum stress were recorded at +25° and +60℃ of 8.2% and 17.0%, respectively, tak en over the six month ageing period. No clear trends or significant variations were observed in the average deformation values of pellets at –40°,+25° and +60° over the course of the 6 months trial. In conclusion, apart from an increase in compressive strength no deleterious affects were observed as a result of accelerated ageing which in very approximate terms equates to a period of 8 years storage at 20℃.

| **Test** | **Sample** | **0 month** | **3 months at 60℃** | **6 months at 60℃** |
|---|---|---|---|---|
| Sensitiveness to Impact (F of I) | Powder | 90 | 80 | 80 |
| Mallet Friction (Steel on Steel) | Powder | 0% | 0% | 0% |
| Vacuum Stability ($cm^3$ / gram) | Powder | 0.10 | 0.09 | 0.07 |
| DSC (℃) | Powder | | | |
| Exotherm Onset | | 190.65 | 190.03 | 188.57 |
| Extrapolated Peak | | 206.30 | 205.92 | 203.85 |
| Average Pellet Mass (g) | Pellet | 23.40 | 23.36 | - |
| (average of 20 pellets) | | 23.42 | - | 23.37 |
| Average Pellet Density ($g/cm^3$) | Pellet | 1.824 | 1.815 | - |
| (average of 20 pellets) | | 1.823 | - | 1.816 |
| Average Pellet Shore A Hardness (average of 20 pellets) | Pellet | 96 | 96 | 97 |
| Average Max. Stress ($N/mm^2$) | (average of 5 pellets at each temperature) | | | |
| at –40℃ | Pellet | > 19.73 | >19.73 | >19.73 |
| at +25℃ | | 9.04 | 8.96 | 9.79 |
| at +60℃ | | 6.42 | 6.71 | 7.51 |
| Average Deformation (mm) | (average of 5 pellets at each temperature) | | | |
| at –40℃ | Pellet | 1.26 | 1.17 | 1.34 |
| at +25℃ | | 1.42 | 1.34 | 1.45 |
| at +60℃ | | 1.62 | 1.52 | 1.51 |

Table 7 Summary of Accelerated Ageing Trial Results on ROWANEX 3601

In order to demonstrate reliability of functioning after being subjected to a three year DOSG sequential test programme a series of five 4.5" IA IM rounds fitted with L106 fuzes were fired at temperatures of -18°C and + 49°C. These rounds have the same internal generic design as the 105mm HEIM shell, ie ROWANEX 1100 main charge and ROWANEX 3601 booster, and all were observed to function full order. Similarly a series of seven 4.5" IA IM rounds fitted with NC23 fuzes (same output as fuze L116) were fired at temperatures of -18°C and +49°C after being subjected to a ten year DOSG sequential environmental test programme. Again these rounds have the same internal generic design as the 105mm HEIM shell and all were observed to function full order

## Insensitive Munitions and Hazard Division 1.6

By way of a final comment attention is drawn to the disparity between the technologies required to give IM compliance and those needed to achieve Hazard Division 1.6. UN Hazard Division 1.6 is directed at extremely insensitive articles which do not have a mass detonation hazard and is considered by some to be the most appropriate hazard classification for insensitive munitions. However, the requirements for HD 1.6 are over prescriptive in the sense that a 1.6 article may only contain explosives that are classed as Extremely Insensitive Detonating Substances (EIDS). Substances are judged to meet EIDS criteria if they have passed UN test series 7 and in particular the test 7a the EIDS cap test and test 7b the EIDS Gap test. In consequence, the majority of munitions which contain booster explosives which have to be relatively shock sensitive to fulfil their function, are excluded from HD 1.6 even though the overall system demonstrates a negligible probability of accidental initiation or propagation . It has been proposed that UN test series 7 should be revised to place more emphasis on the demonstration of low explosiveness and consistency of response

## Typical STANAG 4170 Qualification Programme for a Booster Explosive

| Test | Test Version | UK EMTAP Reference | NATO Reference | |
|---|---|---|---|---|
| | | | STANAG | AOP7 Edition 2 |
| Dropweight impact | Rotter Impact | 1A | 4489 Annex B | |
| Small scale explosiveness | Rotter Impact | 1C | | 201.01.003 |
| Grit sensitisation | Rotter Impact | 1D | | 201.01.004 |
| Friction sensitiveness | Rotary friction | 33 | 4487 Annex B | |
| | Mallet friction | 2 | | |
| Temperature of ignition | | 3 | 4491 Annex B1 | |
| Ease of Ignition | Bickford fuze | 4 | 4491 | |
| Train test | | 5 | | 202.01.003 |
| Electric spark test | | 6 | 4490 Annex A | |
| DSC | | | 4515 Procedure 2 | |
| Vacuum Stability | | | 4556 | |
| Density | | | | |
| Uniaxial Compressive | | | 4443 | |
| Shock Sensitiveness | Large scale gap test | 22 | 4488 | |
| Tube Tests | Internal ignition version | 35 | | 202.01.005 |
| | Fast heating version | 41 | | 202.01.006 |
| | Electrically heated version | 42 | 4491 | |
| Accelerated Ageing (6 months duration at constant 60℃. Testing on unaged material at at intervals of 3 and 6 months) | Mass, dimensions and density at 0,3 and 6 months | | | |
| | Sensitiveness to mechanical impact (F of I) and friction (mallet) at 0,3 and 6 months | 1A, 2 | 4489 Annex B | |
| | Compressive properties (compressive strength at –40°, +25°, +60℃) at 0,3 and 6 months | | 4443 | |
| | DSC (30-400℃ @10℃/min) | | 4515 Procedure 2 | |
| | Vacuum stability (100℃ for 48 hours) at 0,3 and 6 months | | 4556 | |
| Fitness for Purpose | Take-over tests | | | |
| | Critical diameter | | | 302.02.002 |
| | Gun-launch trials | | | |