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Insensitive Munitions Assessment of the 5"/54 Navel Artillery Shell Filled with ARX 4024 (U)

Matthew D. Cliff and
Matthew W. Smith

DSTO-TR-1514

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ABSTRACT

Melt-castable NTO/TNT formulations have been identified as suitable IM candidates to replace existing Composition B main charges within the Australian inventory. Of this family, ARX-4024 (65/35 NTO/TNT) has shown the greatest potential to pass IM criteria and allow Qualification for Australian service. It has shown processing properties suitable for large-scale production at ADI's Mulwala and Benalla plants.

This report details results obtained from an IM test series of the 5"/54 Naval projectile filled with ARX-4024. The assessments were carried out on projectiles in their plugged logistical configuration and comprised of IM Slow Cook-Off, Liquid Fuel Fire, Bullet Impact and Sympathetic Reaction tests. All four tests were successfully passed, with results providing a solid basis for further development.

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Insensitive Munitions Assessment of the 5"/54 Naval Artillery Shell Filled with ARX 4024

Executive Summary

Melt-castable NTO/TNT formulations have been identified as suitable Insensitive Munitions (IM) candidates to replace existing RDX/TNT filled ordnance within the Australian inventory. Of this family of explosives, ARX-4024 has shown the greatest potential to pass the IM criteria and Qualification for Australian service. Additionally, it has shown processing properties suitable for large-scale production at ADI's Mulwala and Benalla plants.

The potential of ARX-4024 to provide an IM solution for artillery and mortar projectiles has lead to tasking by JALO for its assessment as a main charge fill in the 5"/54 Naval artillery projectile. Current in-service 5"/54 (and 105-mm) artillery projectiles use Composition B main charges and fail all IM test criteria. Replacement with ARX-4024 would result in significantly less sensitive major line items in the ordnance inventory and, when combined with packaging, storage and fuzing strategies, provide a feasible solution for IM-compliance.

This report details results obtained from an IM assessment of the 5"/54 Naval projectile filled with ARX-4024. The assessments were carried out on projectiles in their plugged logistical configuration and comprised of IM Slow Cook-Off, Liquid Fuel Fire, Bullet Impact and Sympathetic Reaction tests. The assessments utilised a meltable capping plug designed to enable mitigation of induced events. All four tests were successfully passed and provide a solid basis for further development.

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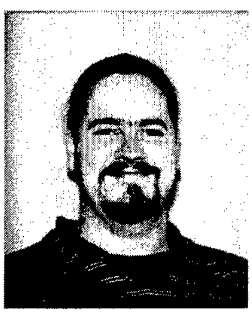

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1. Background

Implementation of Australia's Insensitive Munitions (IM) policy [1] has been hampered over the past decade by a lack of in-country industrial infrastructure to formulate and process Polymer Bonded Explosives (PBXs), the explosive composition class generally used to provide low vulnerability energetics for IM-compliant ordnance. Australian Defence Industries (ADI Ltd), the primary supplier of non-guided munitions to the ADF, is predominately equipped with industrial plant designed to process and fill TNT-based explosive ordnance. Faced with this restriction, DSTO's strategy in designing implementable IM options has largely centred on reduced vulnerability melt-castable explosives. Based on TNT, the explosive class has replaced the sensitive RDX component with NTO, a high energy insensitive secondary explosive [2, 3]. To date, several NTO/TNT compositions have been developed and are detailed in DSTO-TR-0998, DSTO-TN-0451, and Parari`01 [3-5]. The most promising composition, ARX-4024, consists of 65:35 NTO/TNT and has been extensively investigated [5]. The composition was chosen for further assessment as it is similar to Composition B in terms of explosive output, is intrinsically less sensitive to hazardous stimuli, and has processing properties suitable for large-scale production at ADI's Mulwala and Benalla plants.

The potential of ARX-4024 to provide an achievable, medium term IM solution for artillery and mortar projectiles has lead to tasking by the Joint Ammunition and Logistics Organisation (JALO) for its assessment as a main charge fill in the 5"/54 Naval artillery projectile. Current in-service 5"/54 (and 105-mm) artillery projectiles use Composition B main charges and fail all IM test criteria. Replacement with ARX-4024 would result in significantly less sensitive major line items in the ordnance inventory[1] and, when combined with packaging, storage and fuzing strategies, a feasible solution for IM-compliance.

This report expands on P&EE Port Wakefield Client Reports 98152.7395 [6] and 98152.9158 [7], detailing results obtained from an IM assessment of the Mk AN50 5"/54 naval projectile filled with an ARX-4024 main charge. The assessments were carried out on projectiles in their plugged (unfuzed) logistical configuration and comprised the IM Slow Cook-Off (SCO), Liquid Fuel Fire (LFF), Bullet Impact (BI) and Sympathetic Reaction (SR) tests. The assessments also utilised a capping plug designed to melt at elevated temperatures to enable mitigation of induced events. Successful completion and passing of the tests were vital for the ongoing development, and ultimately for weaponising and industrial production of ARX-4024.

[1] Estimated (2002) ADI production for the ADF - 1,500 5"/54 and 25,000 105mm.

2. Program Scope

The program aims were to:

1. Determine the ability of the Mk AN50 5"/54 projectile filled with an ARX-4024 main charge to pass the IM test series in its logistical (storage) configuration,
2. Determine the effectiveness of a newly designed Meltable Venting Plug (MVP) to mitigate induced energetic events.

3. IM Criteria and Pass Levels

The IM test pass criteria are given in Table 1 for Mil-Std-2105B and the NATO STANAG 4439, along with the French MURAT assignments for reference. Event classification definitions are given in Table 2. Events no greater than Type V *Burning* must be achieved for articles subjected to SCO, LFF and BI, and Type III *Explosion* for SR in order to pass the relevant IM tests.

Table 1. IM standard tests and pass criteria.

IM Test	Mil-Std-2105B	French MURAT Level			STANAG 4439
		*	**	***	
Slow Cook-off	V	III	V	V	V
Liquid Fuel Fire	V	IV	V	V	V
Bullet Impact	V	III	III	V	V
Sympathetic Reaction	III	III	III	IV	III
Shaped Charge Impact	III	I	I	III	III
Fragment Impact	V	I	II	V	V

Table 2. Event severity and IM classification

IM Response	Reaction
Type I	Detonation
Type II	Partial Detonation
Type III	Explosion
Type IV	Deflagration
Type V	Burning
NR	No Reaction

4. Test Articles

4.1 Projectiles

Mk AN50 5"/54 casings were obtained from in-specification stock from ADI Ltd. The casing interior was coated with Copal varnish and the exterior finished with the in-service paint scheme. Projectiles were filled with ARX-4024 as described in Reference [5], fitted with an aluminium fuze liner, felt pad and cavity spacer to replicate in-service storage, and fitted with an MVP (described in Section 4.3). Specific projectiles used for each IM test are shown below in Table 3 and are numbered sequentially as they were produced during a filling program developed in support of the Task [5]. All test projectiles passed the Quality Specification detailed in [8].

Table 3. Test projectiles and allocation to assessment program

Projectile Number	IM Test Allocation
9, 10	SCO
11, 12	LFF
13-15	BI
16	SR Donor - Test 2
17	SR Donor - Test 3
18	SR Acceptor Yellow - Test 3
19	SR Acceptor Orange - Test 3
20	SR Acceptor Red - Test 3
21	SR Donor - Test 4
22	SR Acceptor Yellow - Test 4
23	SR Acceptor Orange- Test 4
24	SR Acceptor Red - Test 4

4.2 ARX-4024

ARX-4024 is an insensitive melt-castable composition developed to enable production on existing ADI plant. The composition has a TNT matrix and 65% solids loading of the insensitive explosive 3-nitro-1,2,4-triazol-5-one (NTO). A bimodal NTO mixture, comprising 85% Fine grade (30-110 μm) and 15% Medium grade (200-400 μm) particle size distributions, is used to optimally balance cast density, processability, explosive performance and shock sensitivity. Key sensitivity and performance data are given in Table 4 for ARX-4024, the current in-service 5"/54 main charge Composition B, and PBXN-107A, an artillery shell main charge assessed in the 5"/54 by DSTO in the early 1990s [9].

ARX-4024 shows considerable reductions in shock sensitivity over both Composition B and PBXN-107A. Cook-off tests for Composition B in both SSCB (Super Small Scale Cook-Off Bomb) and SCB (Small Scale Cook-Off Bomb) resulted in high order events with complete consumption of the explosive. Cook-off response of ARX-4024 showed reduction of event severity, generally with recovery of quantities of unconsumed explosive. [4, 10, 11].

Table 4. Explosive Properties of ARX-4024 and Composition B.

Property	ARX-4024	Composition B	PBXN-107A
VoD (m/s)	7810	7890	8160
P_{CJ} (GPa)	25.9	28.7	-
D_{crit} (mm)	17.8 - 20.0	3 - 4	8
Density (g/cm)	1.80	1.71	1.6
LSGT			
- Shock Sensitivity (GPa)	5.24	2.69	4.2
- PMMA Gap (mm)	26.4	45.9	36.5
Cookoff Response (SSCB)			
- fast heating	Deflag	Detonation	Mild Burn
- slow heating	Burn - Deflag	Detonation	Deflag
Cookoff Response (SCB)			
- fast heating	Deflag - Expl	Detonation	-
- slow heating	Expl	Detonation	-

4.3 Meltable Venting Plug (MVP)

To allow mitigation of induced events, the in-service steel Plug Mk AN1 (Figure 1) was replaced with a Surlyn MVP designed at DSTO. Surlyn 9250 (Dupont, mp 96°C by DTA) is a high strength ionomeric copolymer of ethylene/methacrylic acid. It was formed into blanks under pressure and the MVPs machined using an NC controlled lathe (Figure 2). Unlike the Plug Mk AN1, MVPs are able to soften and melt at elevated temperatures to allow venting of decomposition gases through the projectile nose. An AutoCAD schematic of the MVP is shown in Figure 3.

Compatibility assessment *via* thermal vacuum stability testing (100°C/48 hrs) of Surlyn 9250 with NTO, RDX and TNT showed no incompatibility issues (Table 5).

Table 5. Compatibility assessment of Surlyn 9250 with NTO, RDX and TNT.

Material	Gas Evolution (ml/g)
Surlyn 9250	0.16
NTO	0.13
Surlyn / NTO	0.08
RDX	0.09
Surlyn / RDX	0.08
TNT	0.05
Surlyn / TNT	0.08

5. Test Procedures

5.1 IM Test Specification

All IM testing was performed as closely as possible to the methods described in MIL-STD-2105B [12]. Deviations from the test standard are noted in the description of each test.

5.2 Test Configuration

All testing was performed on the 5"/54 in its unfuzed (plugged) logistical configuration. The only energetic material present was the ARX-4024 main charge. No booster pellets were fitted to the projectiles. The projectiles spend approximately 80-90% of their service life in this configuration [13] and are stored vertically on a 48-round pallet with four, 12-round sub-pallets.

No testing of the standard Composition B filled projectiles was conducted at this time due to resourcing constraints. Similar testing completed in the early 1990s showed standard Composition B 5"/54 All-Up Rounds (AUR) failed the IM test series [9].

Projectiles were tested vertically rather than in a horizontal position as the projectiles are stored vertically when palletised. IM tests completed on the projectile were Slow Cook-Off, Liquid Fuel Fire, Bullet Impact and Sympathetic Reaction. All tests were conducted in duplicate at a minimum. Shaped Charge Jet Impact was not conducted due to its questionable relevance in the maritime environment. Fragment Impact was not conducted as there were insufficient resources available to develop and conduct the test successfully.

6. Test Results

6.1 Slow Cook-Off (SCO)

6.1.1 Experimental Set-Up

A schematic of the trial site is shown in Appendix A. Projectiles were mounted vertically within a metal frame and placed within a purpose built oven that had been previously calibrated to provide even heating of the test article at 3.3°C per hour (Figure 4). Two thermocouples were attached to the projectile surface mid-way along the length and a further four positioned approximately 150 mm from the projectiles surface at 90° intervals from this position.

A disposable, low cost lipstick camera was mounted at a glass window on the side of the oven to observe the MVP and subsequent reactions and the interior of the oven was illuminated. Pressure transducers were placed at 5 and 10-m intervals from the oven to record blast overpressures and the oven sheltered by a tarpaulin to protect the test assembly in the event of rain. VHS video was used to record events during the test.

6.1.2 Mil-Std-2105B Deviations

Test articles were heated to approx 30°C for 3-5 hours prior to commencement of the test rather than preconditioning for 8 hours at the munition's upper environmental limit.

6.1.3 Results

Projectiles 9 and 10 were heated at 3.3°C per hour from start temperatures of 31.3 and 30.0°C respectively. In each experiment, the MVP was seen to soften/deform at above 96°C with molten explosive subsequently observed to exude from beneath the deformed/softened plug. The projectiles caught fire at casing temperatures of 190-195°C and were observed to burn out completely through the nose of the round. In each experiment no blast overpressure was recorded on any of the eight pressure transducers and the projectiles were recovered from the ovens intact. Projectile 9 post-test is shown in Figure 5. Temperature profiles for Projectiles 9 and 10 are shown in Figures 6 and 7 respectively.

6.1.4 Summary

The MVP plugged 5"/54 gave Type V *Burning* reactions when subjected to the Slow Cook-Off IM test.

The projectile in its storage configuration is concluded to have *Passed* the SCO IM test.

6.2 Liquid Fuel Fire

6.2.1 Experimental Set-Up

A schematic of the trial site is shown in Appendix B. The projectile was suspended vertically from a frame over the centre of a 2.5-m diameter pit containing 600 litres of Jet A-1 aviation fuel. Water was added to the pit in order to vary the height of the surface of the fuel (Figure 8). An array of eight pressure transducers was arranged around the pit to record blast overpressure.

Flame temperatures were recorded by thermocouples at four locations:

1. In a centre line, approximately 160-mm directly above the projectile,
2. In a centre line, approximately 160-mm directly below the projectile,
3. On the east flank mid-way along the length at a distance of approximately 160-mm,
4. On the west flank mid-way along the length at a distance of approximately 160-mm.

The fuel fire was ignited *via* a burning cloth and continued to burn for 22-28 minutes once ignited.

6.2.2 Mil-Std-2105B Deviations

Nil.

6.2.3 Results

Liquid Fuel Fire Serial 1 (Projectile 11)

Test temperature profiles for Serial 1 are shown in Figure 9. The required fuel fire temperatures were not achieved on any of the four thermocouples as directed in Mil-Std-2105B (Ave flame temperature at least 870°C at all valid thermocouples [12]) despite the projectile being fully engulfed within the flame. From Figure 9, the projectile fill was shown to ignite approximately 4 minutes, 45 seconds after the commencement of the test. The main charge could be seen burning fiercely from the top of the projectile, with small amounts of burning material ejected (Figure 10). No high order events occurred and the empty projectile was recovered intact at the completion of the test (Figure 11). Test variables are shown in Table 6.

Table 6. Test Parameters from LFF Serial 1 (Projectile 11).

Wind speed	1.8 knots
Wind direction	3350-mil
Distance from projectile to fuel surface	651-mm
Duration of burn	22 min
Time to main charge ignition	4 min 45 sec

Liquid Fuel Fire Serial 2 (Projectile 12)

In an effort to increase the temperature experienced by the test projectile, the fuel surface was raised approx 250-mm by additional water pumped into the pit. During this experiment, however, the fuel failed to burn evenly and the projectile was not engulfed within the flame for the majority of the test. The recorded temperature profiles for the four thermocouples is shown in Figure 12.

Despite the required temperatures not being achieved, the MVP was ejected from the projectile and the main charge ignited after approximately 9 minutes, 50 seconds (from Figure 12). The fill was again observed to burn vigorously and the casing recovered intact (empty) at the conclusion of the test. No blast overpressure was recorded. Test variables are shown in Table 7.

Table 7. Test Parameters from LFF Serial 2 (Projectile 12).

Wind speed	2.2 knots
Wind direction	6400-mil
Distance from projectile to fuel surface	405-mm
Duration of burn	28 min
Time to main charge ignition	9 min 50 sec

6.2.4 Summary

Both tests failed to reach specification temperatures as outlined in Mil-Std-2105B. The MVPs were seen to melt and were ejected from the casing to allow venting of combustion gases. Both projectiles gave Type V *Burning* reactions in the Liquid Fuel Fire IM test and are deemed to have *Passed.* It is believed that the projectiles would still have *Passed* the test had the desired temperatures been achieved, as the MVP provided ample venting for the subsequent reaction.

6.3 Bullet Impact

6.3.1 Experimental Set-Up

A schematic of the trial site is shown in Appendix C. A 0.50 cal gun assembly, purpose built at DSTO, was fitted to a 25-pounder mount (Figure 13) and each barrel individually aimed along the central axis of the projectile. Impact points were top, centre and bottom of the explosive main charge and the rounds fired in that order. The 0.50 cal AP rounds used were fitted with electric primers to achieve an accurate firing interval of 80±40 ms and the powder quantity adjusted to provide a velocity of 850±60 m/s at impact. Ammunition was produced and tested at DSTO prior to the trial.

The target projectile was bolted firmly to a pendine block stack (Figure 14) to prevent movement upon impact. Bullet impact velocities were recorded by *Ekto-Pro* high-speed photography, and a series of pressure gauges were set at 5 and 10-m intervals from the target. Fragmentation screens were set 5-m from the target to record fragmentation patterns in the event of a high order reaction. The screens were to be compared to those used in a previous 5"/54 lethality trial in an effort to determine the severity of the event.

Prior to testing ARX-4024 filled projectiles, a series of HES-filled projectiles were used to calibrate the gun assembly and confirm aim point accuracy. Three tests were carried out on Projectiles 13-15.

6.3.2 Mil-Std-2105B Deviations

0.50 cal impacts were spaced evenly along the projectile main charge axis rather than at a single impact point. All three projectiles were tested in the same manner as the plugged rounds do not have 'above-the-shutter' mechanisms (fuzing, explosive train), and the most shock-sensitive filling below the shutter is the main charge.

6.3.3 Results

A summary of the three serials is given in Table 8. In all three tests, no high order events were observed and projectile casings were recovered from the mount intact.

Table 8. Bullet Impact Test Data.

Projectile No.	0.50 cal round fired	Interval betn impacts (ms)	Pressure time history ♦	Impact velocity (m/s)
13	1 (top)	50.752	No high order reaction	876
	2 (middle)	49.408		854
	3 (base)			*
14	1 (top)	50.688	No high order reaction	863
	2 (middle)	49.536		889
	3 (base)			*
15	1 (top)	50.688	No high order reaction	819
	2 (middle)	49.408		841
	3 (base)			*

♦ No high order overpressures recorded
* Third impact velocity not recorded as smoke emission obscured impact.

Serial 1 (Projectile 13)

Ekta-Pro high-speed photography of the impacting 0.50 cal rounds showed impacts 1 (top) and two (centre) enter the target with no/minimal reaction of the explosive main charge. Upon entry of the third round (base), the damaged fill was shown to ignite and eject the MVP and bulk of the explosive fill. After the initial fireball/ejection of fill, no further reaction took place and the target projectile casing was recovered intact with approximately 1/3 of the main charge fill remaining within the casing (Figure 15).

Serial 2 and 3 (Projectiles 14 and 15)

Serials 2 and 3 resulted in ignition of the damaged main charge fill upon impact of the second (centre) 0.50 cal round rather the third as seen in Serial 1. *Ekta-Pro* high-speed photography showed ejection of the MVP, fuze liner and approximately half the explosive charge fill within a fireball which was subsequently scattered over the trial site. No high order events occurred and the projectile casings were recovered intact containing a quantity of ARX-4024.

Explosives recovered from the trial site post testing showed that ejected material had been burnt on it's exterior surface during the fireball but had failed to sustain combustion (Figure 16). In all three serials, impacting 0.50 cal rounds failed to exit the rear of the target projectile.

6.3.4 Summary

The MVP plugged 5"/54 projectiles performed extremely well in the Bullet Impact test. For a single impact, *Ekta-Pro* high-speed photography showed *No Reaction* (NR) occurring. For the more severe triple impact used, the subsequent event is best described as between a *No Reaction* and Type V *Burning*, as the fireball consumed only a fraction of the fill, leaving the remaining charge either within the body of the casing or scattered over the trial site.

The projectile in its storage configuration is concluded to have *Passed* the BI IM test.

6.4 Sympathetic Reaction

6.4.1 Experimental Set-Up

A schematic of the trial site is detailed in Appendix D. Two series of pressure gauges were laid out to a distance of 44-m and four pendine block walls were constructed and positioned to 'catch' thrown shells and fragments. High speed and VHS video were used to record events.

A section of the 5"/54 pallet, shown in Figure 17, was chosen for assessment. Projectiles are palletised in lots of 48 consisting of four sub-pallets of 12 projectiles each. The five-round section was determined to be representative of the entire pallet with the exception of the centre four projectiles.

To aid post event recovery and identification, Acceptor rounds were painted Yellow (A1), Orange (A2) and Red (A3) (see Figure 18). The inert round (blue) was HES filled while the Donor round (Green) was filled with ARX-4024 and fired with a TR-1 booster/EBW assembly. The projectiles were positioned on a witness plate assembly and spaced as found on the pallet. Each witness plate was fitted with Time-of Arrival (TOA) piezoelectric pins to record the arrival of a detonation wave . The experimental set-up is shown in Figure 18 and the projectile case-to-case distances shown in Figure 19.

A total of four test serials were conducted:

Serial 1: Warmer shot containing 1 off Composition B uncased cylinder.
Serial 2: Donor round (ARX-4024) and 4 off Inert Acceptors to provide reference witness plates and Acceptor shell fragments.
Serials 3 & 4: Donor round (ARX-4024), 3 off Acceptors (ARX-4024) and 1 off Inert Acceptor (HES).

6.4.2 Mil-Std-2105B Deviations

Nil.

6.4.3 Results

Projectile Casing Recovery

Acceptor projectiles at position A3 were recovered intact post-event containing the ARX-4024 main charge. The shell casings were highly deformed and scarred from Donor fragment and blast impacts, however, no reaction of the Acceptor had taken place (Figure 20).

Acceptor projectiles at positions A1 and A2 had been broken into a small number of large fragments as shown in Figures 21 (Position A1) and 22 (Position A2). Approximately 70% of the Acceptor casings were recovered post-event. A large amount of unconsumed explosive main charge from the projectiles had been scattered over the trial site.

The recovered fragments from Serials 3 and 4 were similar to those recovered from Serial 2 (HES-filled Acceptors in all positions), indicating that the Acceptor casing break-up was as a result of blast/fragmentation impacts from the Donor projectile rather than from the Acceptor Main Charge sympathetically reacting.

Witness Plates

Witness plate arrays from Serials 2-4, as arranged pre-event, are shown in Figure 23. The Donor projectile witness plate shows heavy deformation in all three Serials. Acceptor projectile witness plates are relatively undamaged from Serials 3 and 4. No evidence of high order reactions was observed.

High Speed Photography and TOA Pins

High speed and VHS photography was unable to provide usable information to assist in event characterisation as the images were obscured within the fireball and subsequent dust/soot cloud of the Donor projectile. TOA piezoelectric pin data was not analysed fully due to time constraints. However this data was made redundant as the recovered projectiles and witness plates had provided a clear indication that a high order event had not occurred at any of the Acceptor positions.

Blast Overpressure Measurements.

Peak overpressure measurements for all four serials are detailed in [7]. No attempt was made to analyse the traces due to time constraints.

6.4.4 Summary

Acceptors at position A3 provided *No Reaction* responses to the SR test. It is most probable that Acceptors at positions A1 and A2 additionally gave *No Reaction*, as casing break-up was identical to that seen in HES-filled Acceptors from Serial 2 and quantities of the main charge was recovered from the trial site. Recovered explosive, however, was burnt on the external surface from either the Donor fireball (most likely) or else from an induced reaction that was subsequently quenched. It cannot be ruled out that a Type V *Burning* reaction occurred, albeit to a minor extent.

The projectile in its storage configuration is concluded to have *Passed* the SR IM test.

7. Discussion

IM evaluation in Australia is carried out infrequently, with the 'expertise' required having to be developed during each trial. Although the majority of the trial was planned and executed well, recording of blast overpressures and subsequent interpretation requires a more considered approach. The benign nature of munition responses recorded during these tests rendered most overpressure measurements redundant as no high order events were experienced. Had a detonation occurred, however, subsequent pressure/time traces would be difficult to interpret due to the trial layout. Problems identified were:

- Supporting structures, pendine block and splinter proofs were arranged with little consideration to blast overpressure measurements. Shock wave reflections from surfaces would complicate pressure readings and was particular evident for pendine blocks used for stands and walls for the BI and SR serials.
- Detonating a static round prior to commencing test serials to obtain baseline readings for high order events is required.
- An holistic approach to trial site design and equipment positioning was not undertaken. DSTO and P&EE staff need to interact to a greater extend in the early planning phases.

For the individual IM tests a number of observation to the design and execution can be made.

Slow Cookoff

- Placing of the lipstick camera to observe the interior of the oven was effective in assisting event analysis.
- Oven and shell cradle design for vertical projectile assessment was effective and provided a well-executed test with even heating.

- Venting of the oven is required to allow decomposition gasses/fumes to escape and not cloud the viewing port.

Liquid Fuel Fire

- Profiling of flame temperature gradients is required pre-test to enable Specification temperatures to be achieved at the test article.
- Layering of petrol over the main body of Jet A-1 aviation fuel would enable a more rapid combustion due to the higher vapour pressure.
- Larger fuel fires are required to ensure complete coverage of the test article, or investigation of gas-powered test rigs.
- The projectile clamp could possibly inhibit heat ingress to the explosive fill. A shell cradle similar to that used in the SCO is recommended.

Bullet Impact

- A separate projectile stand, fitted with witness plate and restraints, is required to allow for the witness plate to be 'punched' in the event of a Type I Detonation, and to minimise interference with pressure gauges.
- Redesign of the 0.50 cal gun system to allow for aiming in vertical and horizontal planes.
- Fabrication of a dedicated gun mount to firmly set the gun assembly rather than the 25-pounder mount used.
- *Ekta-Pro* high-speed photography focussed on the projectile was extremely effective in assisting to classifying event severity.
- *Ekta-Pro* high-speed photographic measurements of bullet velocities had limited success as combustion products obscured the third round in each serial.

Sympathetic Reaction

- Projectile recovery was the most effective means of classifying event severity.
- P&EE Port Wakefield was a poor site to complete the test as projectiles were difficult to recover from the surrounding salt bush.
- Projectile impacts onto pendine block walls may have lead to additional casing break-up. A 'soft' sandbag wall in front of the pendine blocks is recommended to cushion impacts.
- High-speed and VHS video provided minimal data for analysis as events were masked within the Donor projectile fireball.
- TOA piezoelectric pin data was not analysed but would possibly provide valuable data to determine event severity. Further development is required.

8. Conclusions and Future Work

A summary of test results is given in Table 9. The 5"/54 projectile, filled with ARX-4024, readily passed the IM test series conducted. Comparison to similar work on NTO/TNT-based ordnance conducted elsewhere had indicated that *Passes* could be expected for the SCO, LFF and BI test [14-16]. A *Pass* for the SR test, however, was not expected due to the severity of the test. Trial results showed that the 5"/54 in its palletised logistical configuration readily *Passed* and showed no evidence of events beyond limited burning of the main charge. Redesign of the pallet to prevent sympathetic reactions is not required for an ARX-4024 main charge fill.

Table 9. Summary of IM test program

IM Test	Mil-Std-2105B	Test Result	Pass
Slow Cook-off	V	V	✓
Liquid Fuel Fire	V	V *	✓
Bullet Impact	V	NR - V	✓
Sympathetic Reaction	III	NR - V	✓

* Specification temperatures not obtained

Fitting of MVPs to 5"/54 naval shells provided effective venting of combustion gasses for all IM tests. The MVP concept is simple and low cost, and would provide an enhancement in ordnance safety regardless of the main charge fill.

With IM testing complete, shell filling methodologies developed and lethality assessments for the 5"/54 showing satisfactory performance, studies directed at ARX-4024 introduction into service are required as a priority within DSTO. These include:

- Setback simulation assessment of ARX-4024.
- *Qualification* of ARX-4024 in conjunction with the OSG.
- Completion of the 5"/54 costed schedule of delivery [17].
- Submission for Minor's funding to enable S3 of an ARX-4024 filled 5"/54 projectile to be completed in conjunction with OSG, JALO and ADI.
- Active support to NTO plant construction as part of the Mulwala upgrade.

Further scientific studies to allow for the continued upgrade of the 5"/54 (and other artillery ordnance) would include:

- Selection and evaluation of insensitive boosters.

- Acquisition of IM fuzes for 5"/54.
- Evaluation of mitigation methodologies for an AUR.
- IM evaluation of the AUR

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10. Acknowledgments

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11. Figures

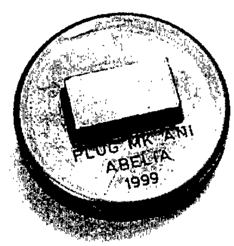

Figure 1. Current 5"/54 steel plug used for long-term storage

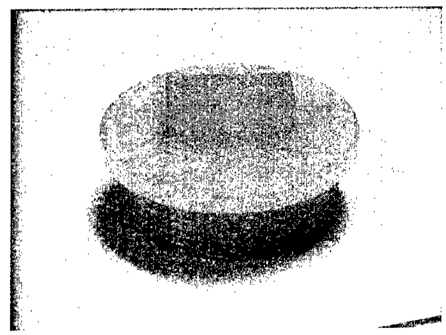

Figure 2. Surlyn Meltable Venting Plug to allow combustion gas venting

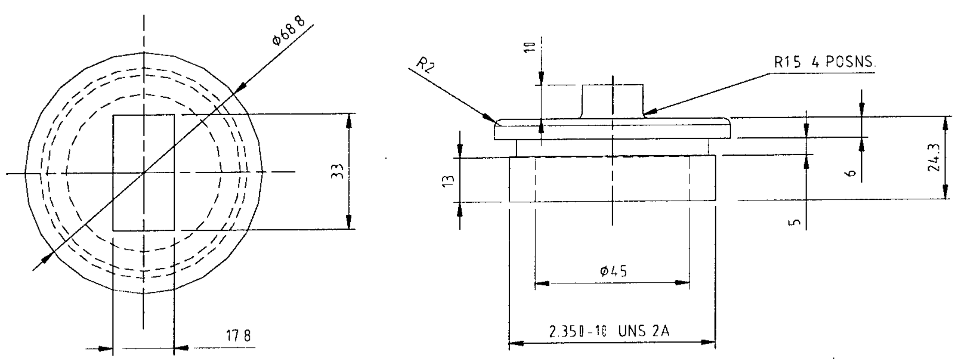

Figure 3. AutoCAD schematic of the Meltable Venting Plug

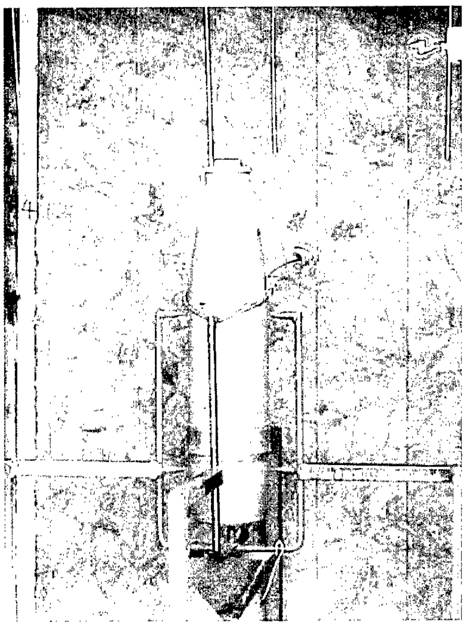

Figure 4. Projectile within oven prior to SCO. MVP is fitted to the top of the round

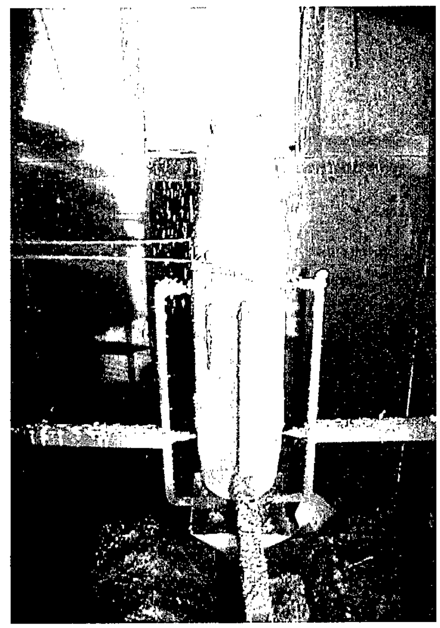

Figure 5. Projectile post-test. The main charge has burnt out leaving the casing intact

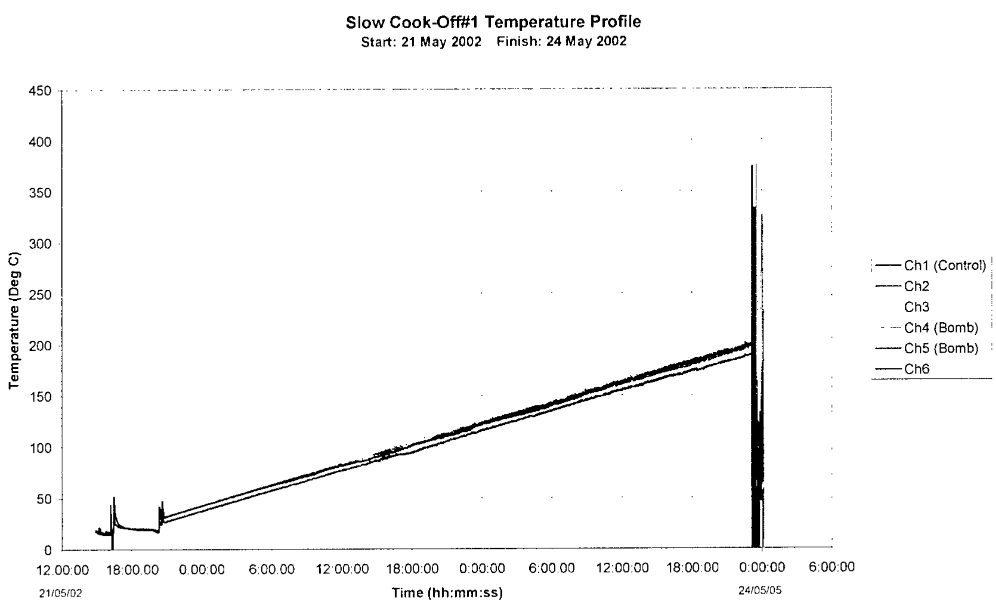

Figure 6. Temperature profile from thermocouples used for Projectile 9

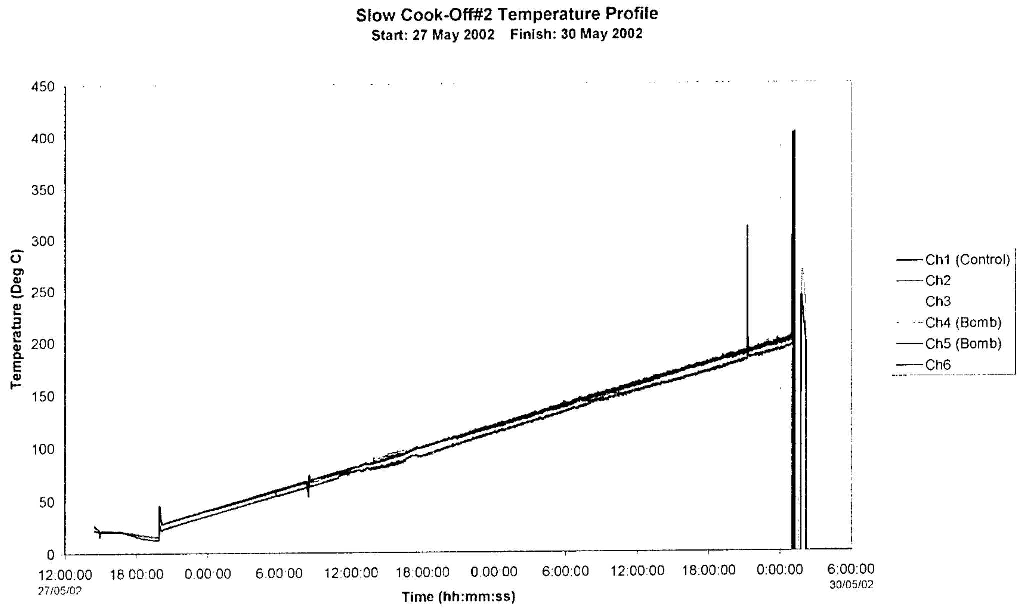

Figure 7. Temperature profile from thermocouples used for Projectile 10

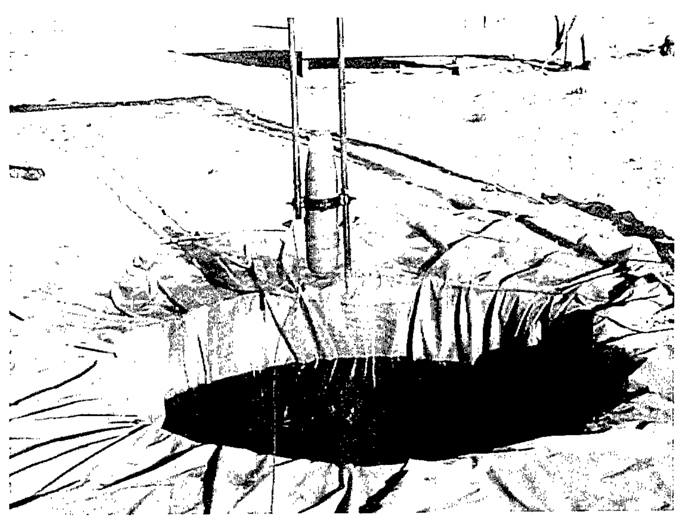

Figure 8. LFF test projectile 11 above fuel filled pit prior to ignition

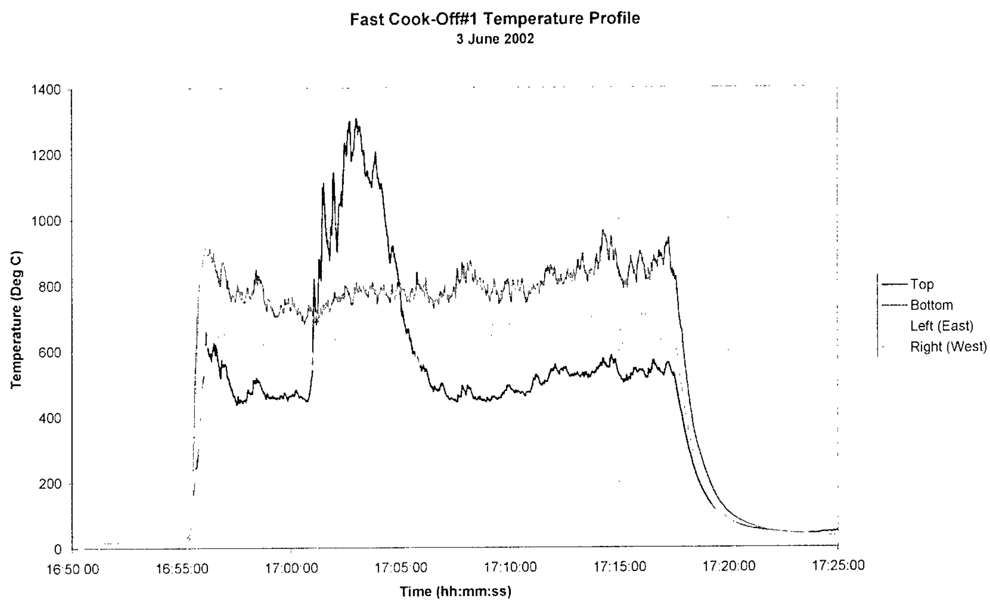

Figure 9. Temperature profile from thermocouples during projectile 11 assessment. The top (blue) thermocouple directly above the projectile shows that the main charge ignited approximately 4:45-min after the commencement of the test.

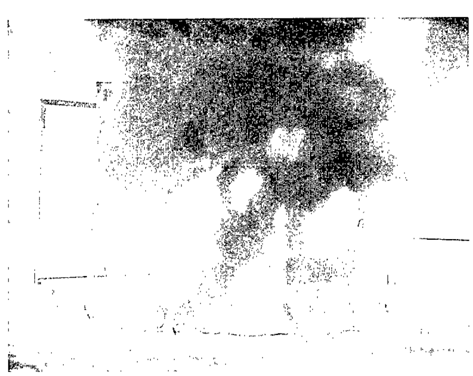

Figure 10. Projectile 11 engulfed within the fuel fire

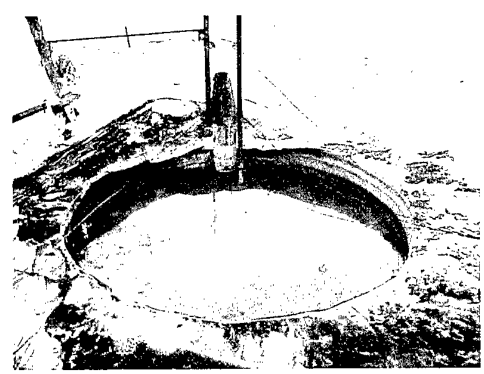

Figure 11. Casing recovered intact post-test with the main charge consumed

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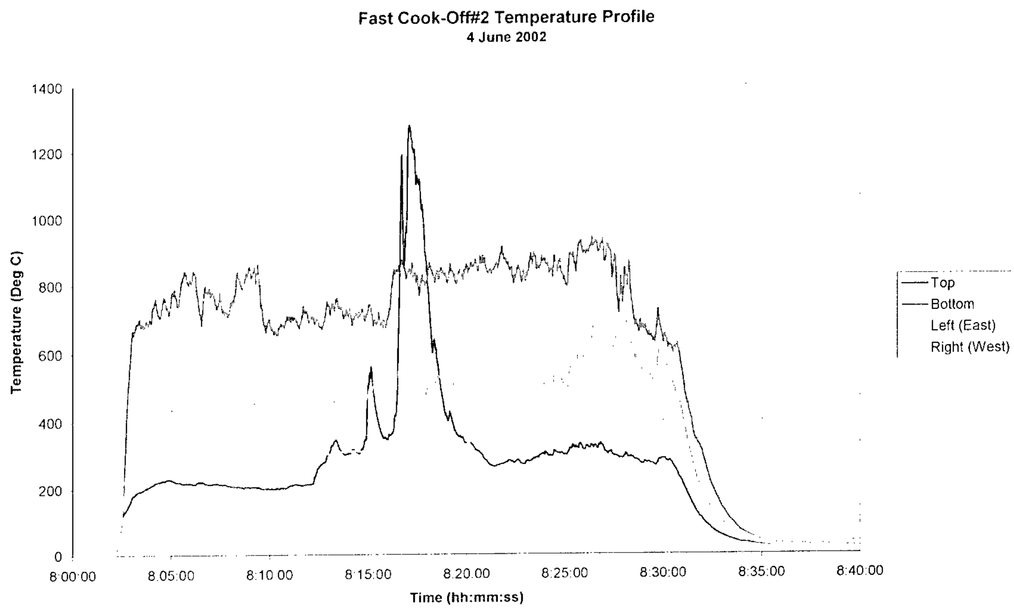

Figure 12. Temperature profile from thermocouples during projectile 12 assessment. Main charge ignition approximately 9:50-min after commencement of the test.

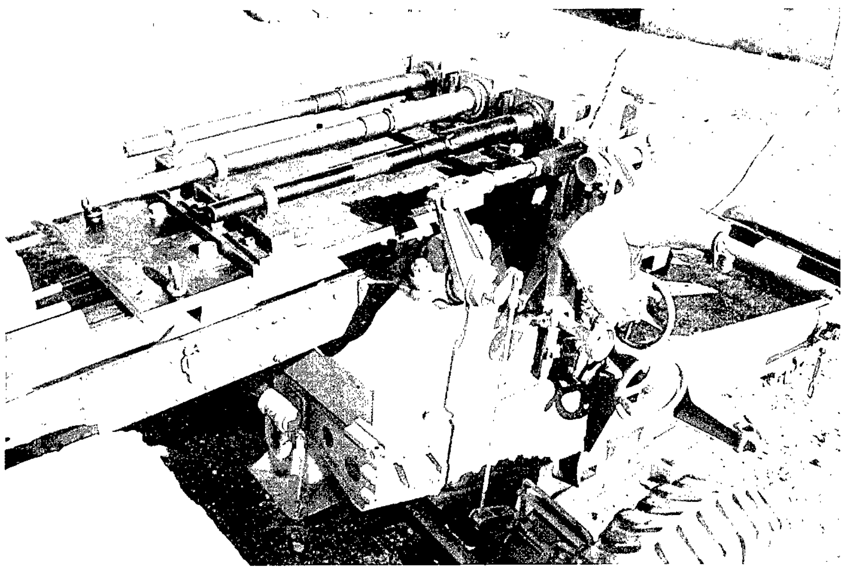

Figure 13. 0.50 cal gun assemble fitted to 25-pounder mount

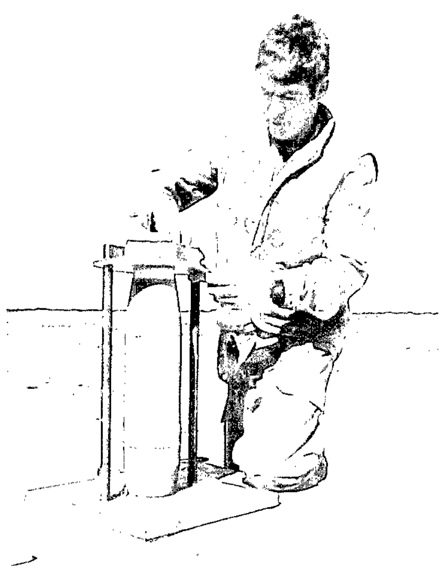

Figure 14. Projectile being fitted to pendine block mount prior to test

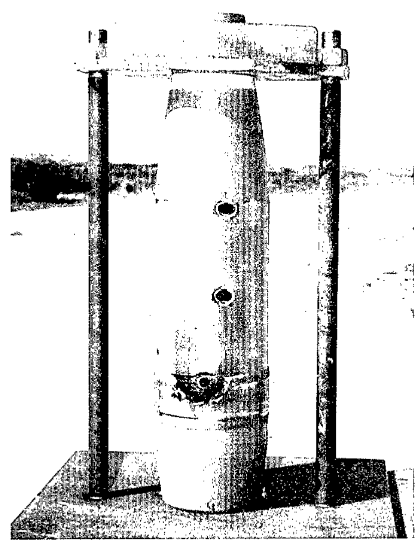

Figure 15. 5"/54 projectile post-test. Casing recovered containing approx half of the ARX-4024 main charge.

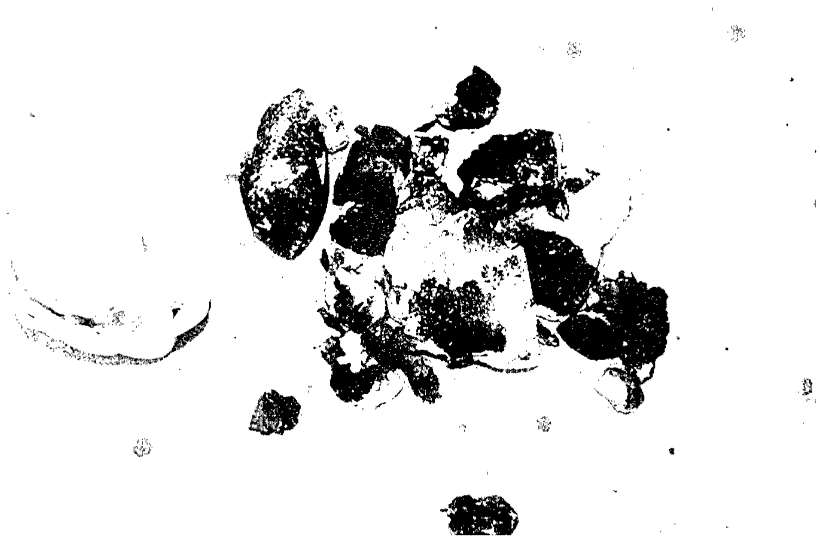

Figure 16. Fuze well cup and main charge recovered from the trial site. ARX-4024 fragments are burnt externally. Ignition was not sustained for the ejected explosive during any of the three serials.

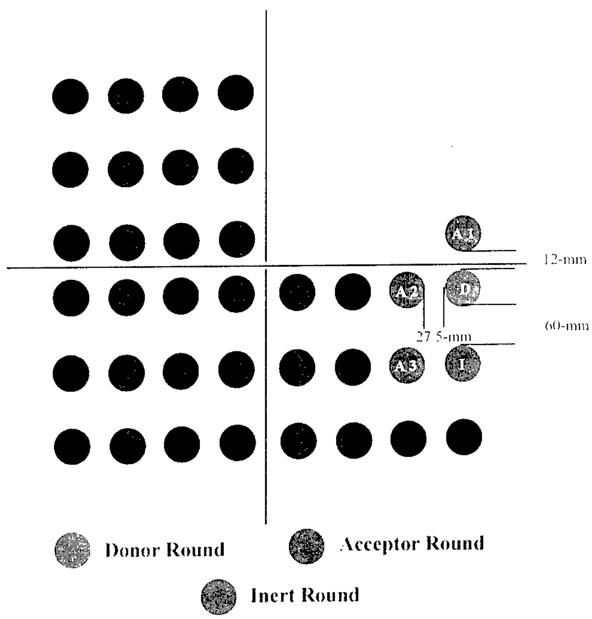

Figure 17. 5"/54 projectile storage pallet. Highlighted section used for SR assessment

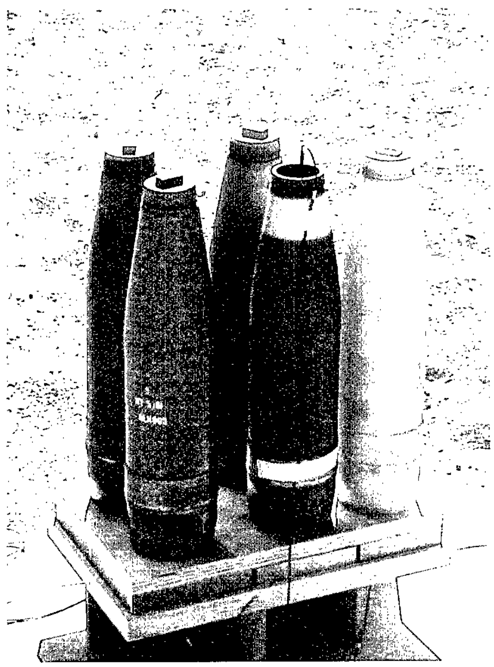

Figure 18. SR experimental set-up. Donor round (green) fitted with TR-1 booster.

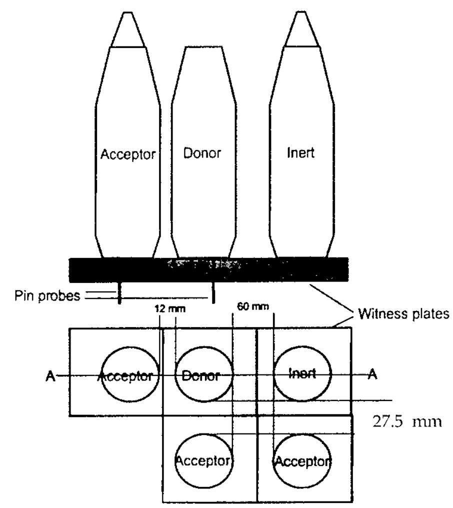

Figure 19. Projectile round-to-round spacing

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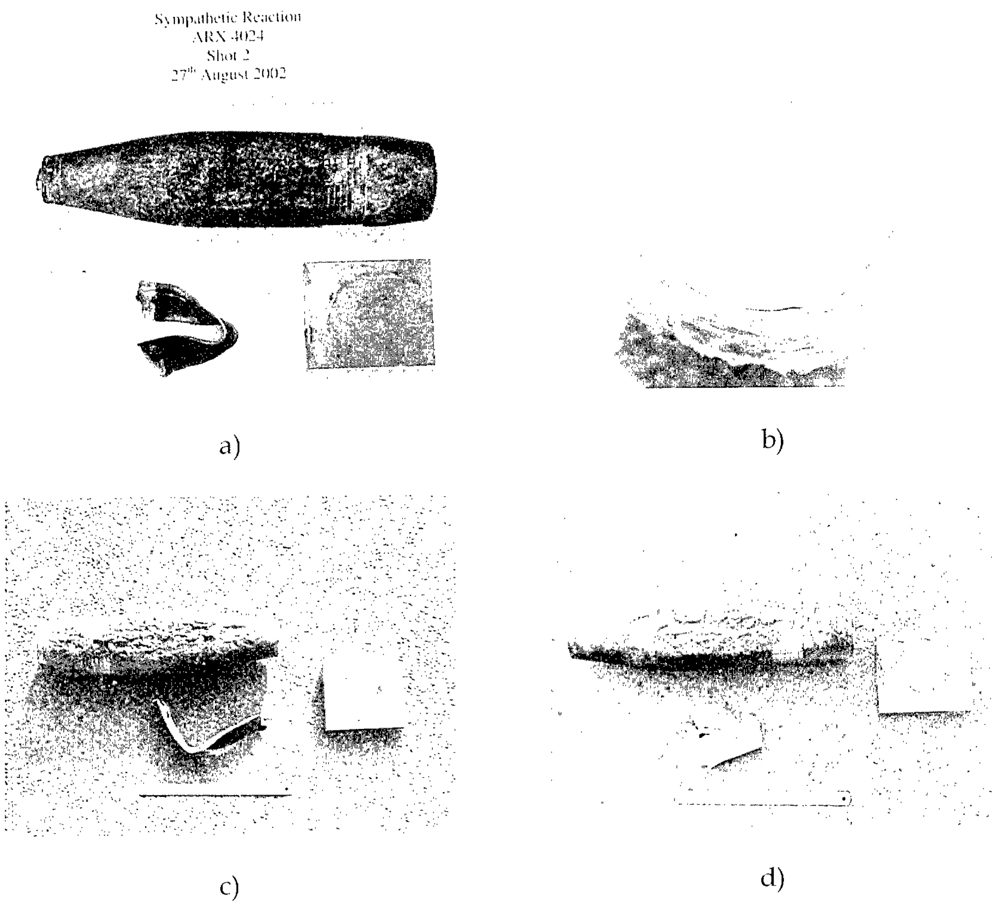


Figure 20. Recovered Acceptor rounds at position A3. ARX-4024 filled Acceptors from Serial 3 (20c) and 4 (20d) where identical to that recovered from Serial 2 (HES-filled, 20a) and contained unreacted main charge (20b).

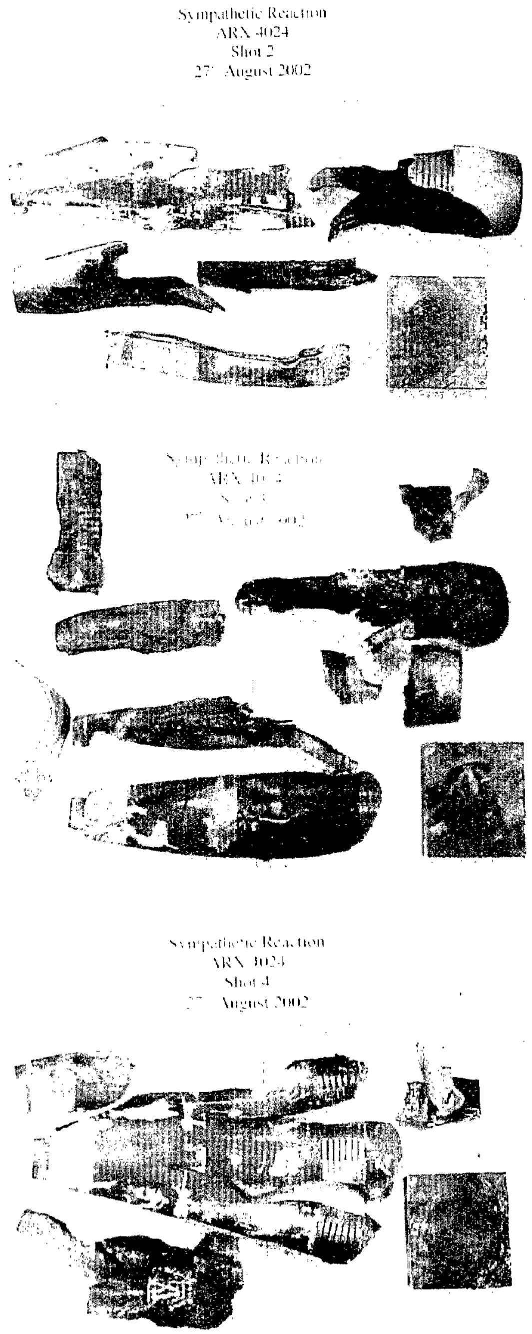


Figure 21. Acceptor fragments recovered from position A1 for Serials 2, 3 and 4 (top, centre, bottom respectively). Casing break-up due to blast and fragment impacts from Donor projectile rather than from sympathetic reaction of the Acceptor.

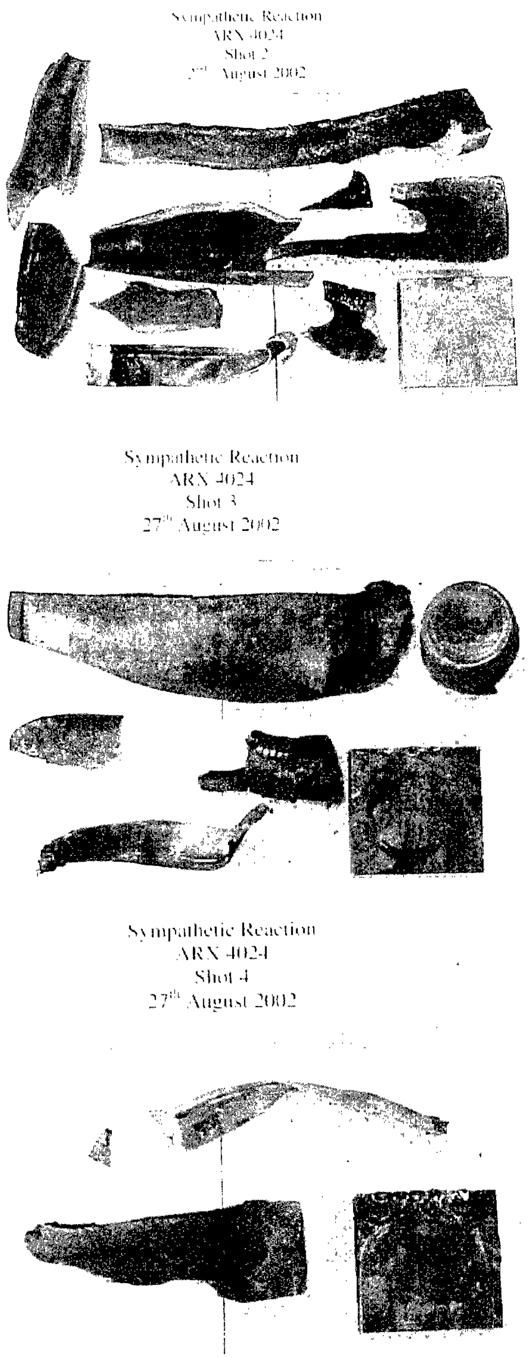


Figure 22. Acceptor fragments recovered from position A2 for Serials 2, 3 and 4 (top, centre, bottom respectively). Minimal fragments were recovered from the trial site from Serial 4.

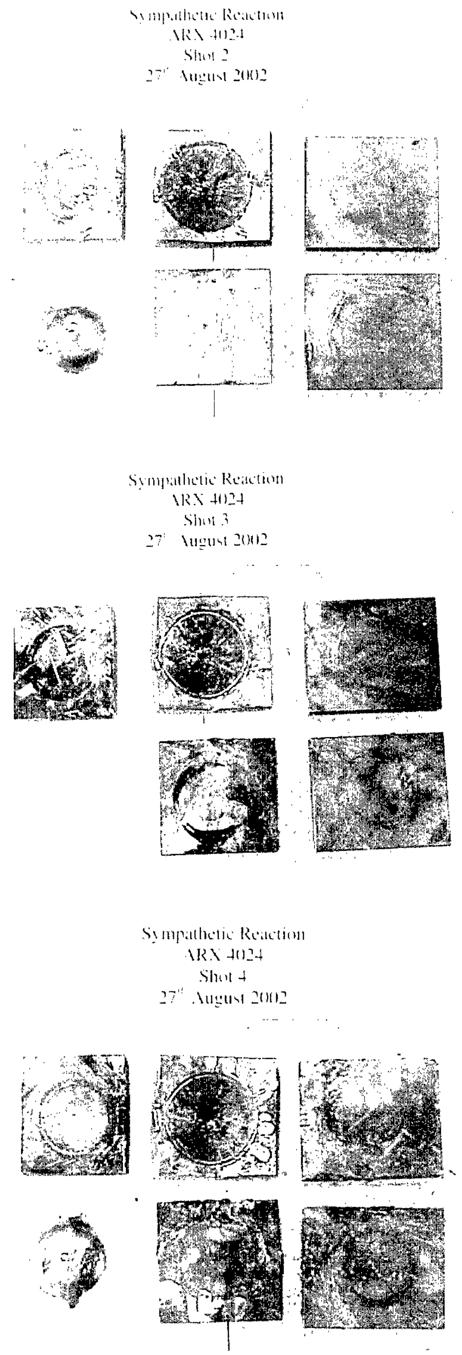
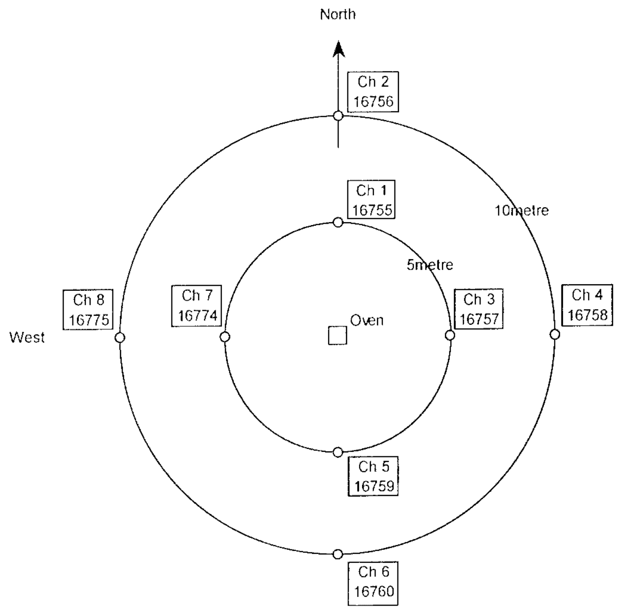
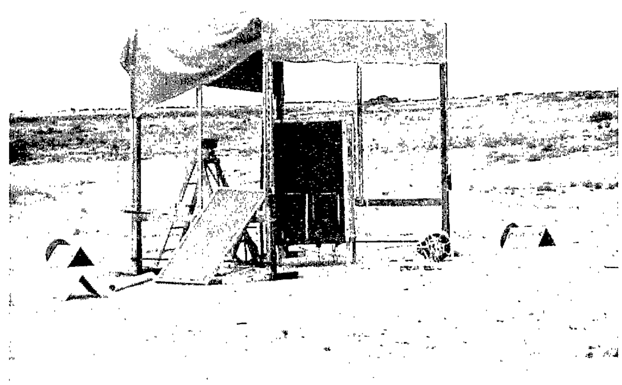


Figure 23. Witness plate arrays from Serial 2, 3 and 4 (top, centre, bottom respectively) positioned as for test. Donor witness plates (centre top plates) show heavy damage, with plates for Acceptors and Inerts having minimal damage.

Appendix A: Slow Cookoff

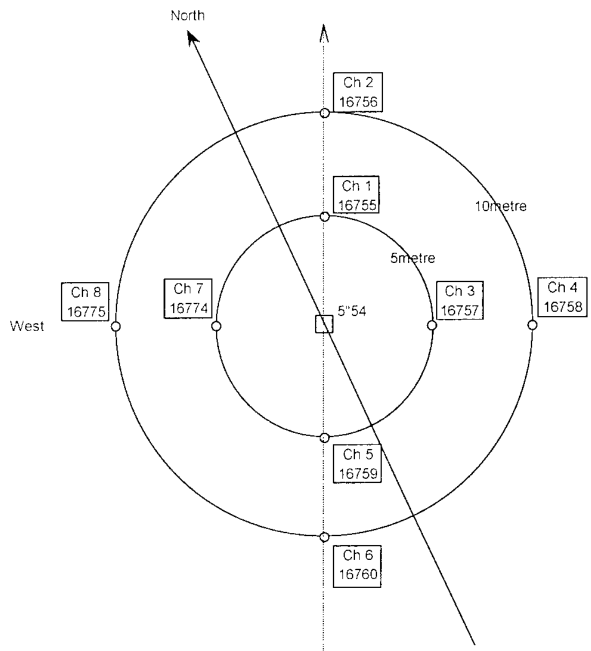
Pressure gauges arranged at 5 and 10-m intervals from oven. Test assembly sheltered with tarpaulin to prevent rain/moisture ingress.

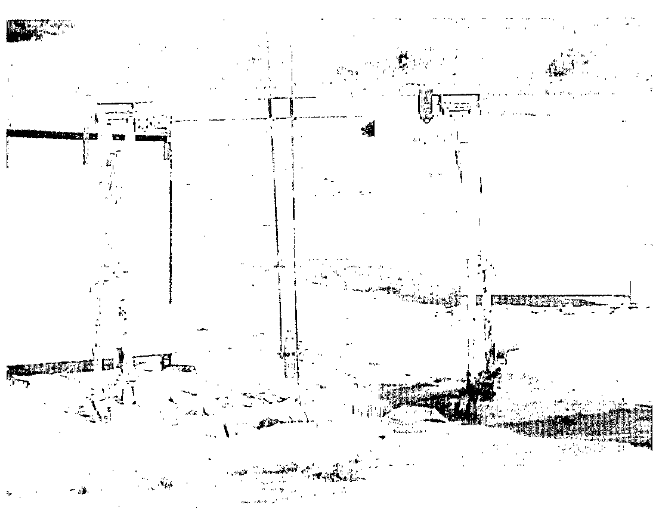




Appendix B: Liquid Fuel Fire

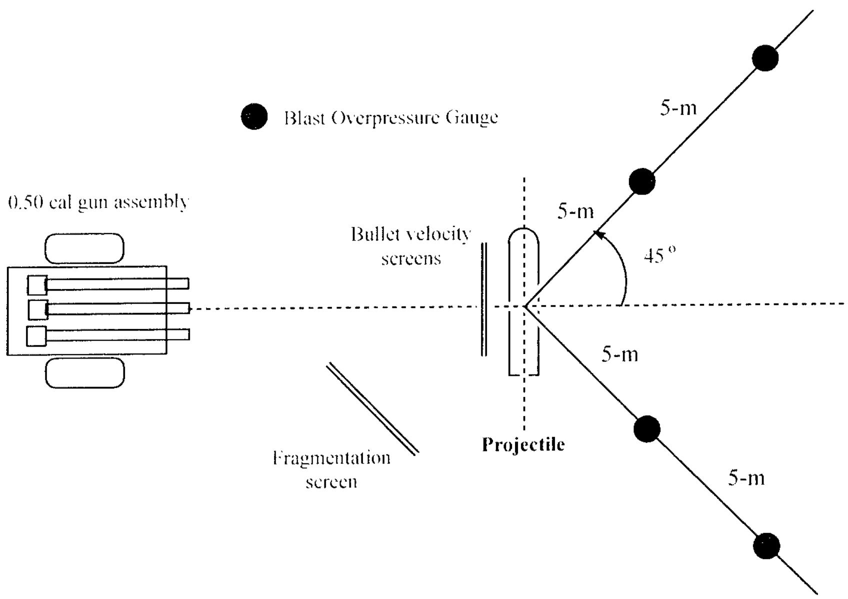
Pressure gauges arranged at 5 and 10-m intervals from oven. Fragmentation screens arranged at 5-m distances from projectile to record fragment strikes.

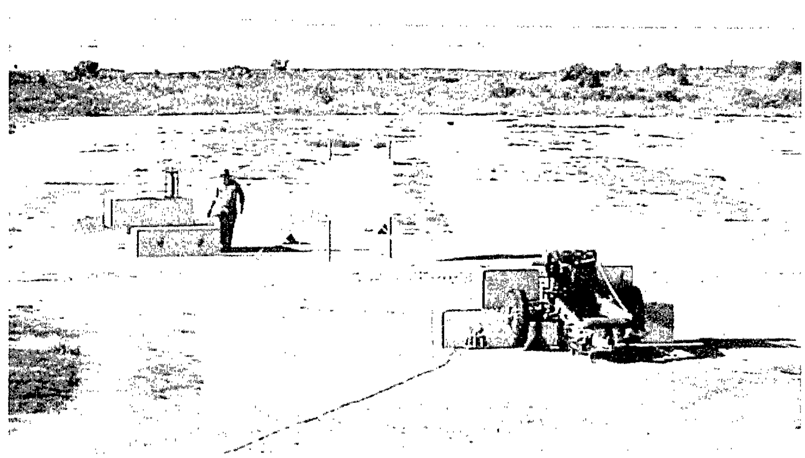




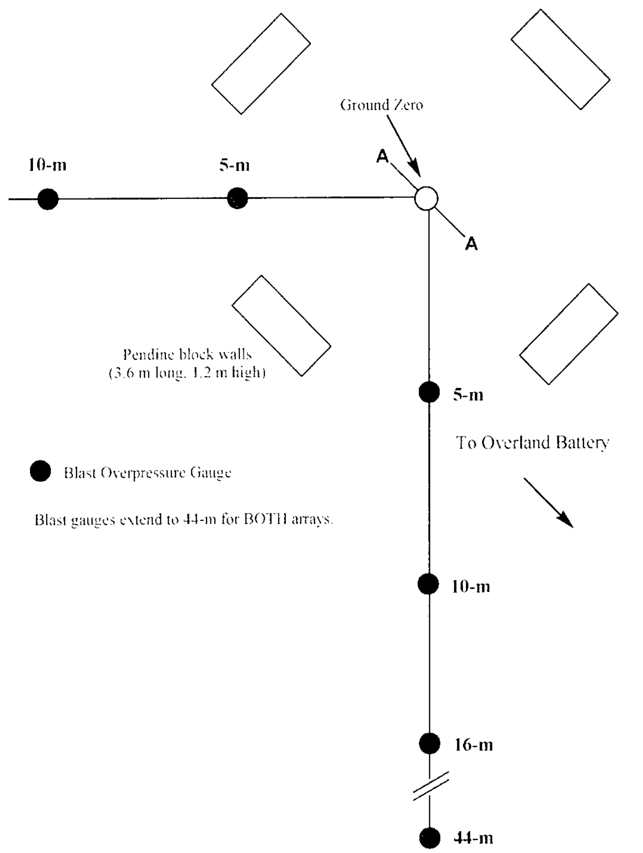
Appendix C: Bullet Impact

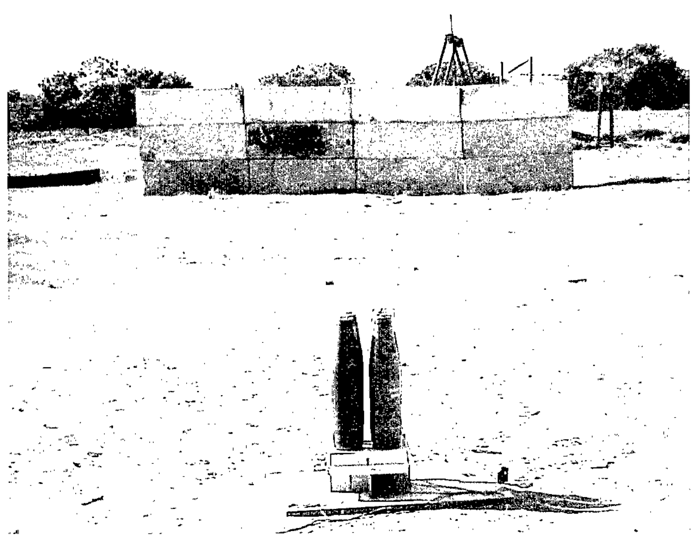
Target projectiles were held vertically on the pendine block and not horizontally as depicted below for illustrative purposes.





Appendix D: Sympathetic Reaction





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Artillary (weapons)
Naval guns

19. ABSTRACT

Melt-castable NTO/TNT formulations have been identified as suitable IM candidates to replace existing Composition B main charges within the Australian inventory. Of this family, ARX-4024 (65/35 NTO/TNT) has shown the greatest potential to pass IM criteria and allow Qualification for Australian service. It has shown processing properties suitable for large-scale production at ADI's Mulwala and Benalla plants.

This report details results obtained from an IM test series of the 5"/54 Naval projectile filled with ARX-4024. The assessments were carried out on projectiles in their plugged logistical configuration and comprised of IM Slow Cook-Off, Liquid Fuel Fire, Bullet Impact and Sympathetic Reaction tests. All four tests were successfully passed, with results providing a solid basis for further development.