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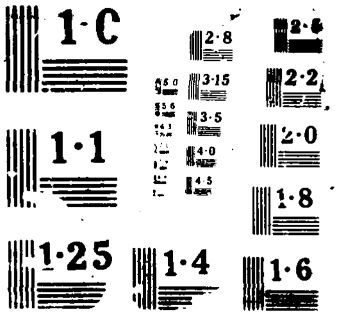
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DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

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MELBOURNE, VICTORIA

REPORT

MRL-R-1094

A COMPARATIVE ASSESSMENT OF US AND UK EXPLOSIVES QUALIFIED AS REPLACEMENTS FOR TETRYL

Robert J. Spear and Victor Nanut

Approved for Public Release

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ABSTRACT

Three UK and seven US production formulations qualified as replacements for tetryl in fuzes have been obtained through TTCP WTP-1. Characterisation of powders - Rotter impact sensitiveness, temperature of ignition, vacuum thermal stability and electrostatic spark sensitivity - and of pressed charges - shock sensitivity - has been carried out at MRL. Our results are compared with UK and US published data, to produce probably the most complete comparative set published for production booster explosives.

Approved for Public Release

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CONTENTS

A COMPARATIVE ASSESSMENT OF US AND UK EXPLOSIVES QUALIFIED AS REPLACEMENTS FOR TETRYL

1. INTRODUCTION

The use of tetryl in munition filling operations has largely been phased out in Western countries. The US has ceased manufacture and filling with tetryl, and the UK is designing and filling all new stores with alternative explosives. The principal reason for these decisions has been the pollution and environmental problems associated with manufacture of tetryl, together with the possible associated health risks to personnel engaged in filling operations.

The US and UK have qualified or are in the process of qualifying a number of materials as replacements for tetryl. A listing of US formulations is given in Table 1, together with the UK Debrixes and RDX/wax 8 formulations. The Debrixes are a generic series developed at RO Bridgwater; Debrix 11, 12 and 18AS were selected because they are the principal choices for fuze lead and booster applications. France and Germany have also qualified a number of materials, principally of the RDX/wax type. A complete list can be found in Table 13 of Ref. [1].

Australia has never manufactured tetryl and stock held in storage was sufficient for requirements for a number of years at current usage rates. As a consequence, replacement of tetryl received low priority, but in 1985 MRL was tasked to investigate and recommend suitable materials. The task was carried out as two parallel studies. One study was to investigate and recommend formulations suitable for Australian production and use. This has been completed [2-4] and recommendations on candidate formulations have been accepted by Office of Defence Production (ODP) for pilot batch production and qualification.

The second study was to comparatively assess US and UK qualified formulations. Under the auspices of TTCP Technical Panel WTP-1 (Terminal Effects), formal approach was made to Royal Armament Research and Development

Establishment (RARDE) in the UK and Naval Surface Warfare Center (NSWC), Whiteoak, in the US to supply production samples of formulations listed in Table 1. As a result ten formulations were subsequently received in addition to US tetryl.

The formulations were characterised both as powders and as pressed charges. The powders were characterised for impact sensitiveness, ignition temperature, vacuum thermal stability and electrostatic spark sensitivity, the pressed charges for shock sensitivity. The data represent probably the most complete comparative set published for production booster explosives. Normally comparison of results between laboratories is difficult because different tests are used to assess response to a particular stimulus, or in some cases the tests exhibit a significant degree of operator dependency. Results obtained from other laboratories, where available in the open literature, are cited and critical comparison is made.

2. MATERIALS

Three UK and eight US formulations were received in quantities ranging from about 1 kg to about 5 kg. All were production batches; they are individually listed with origin in Table 2. Their physical appearance ranged from granular, eg PBXN-5, PBXW-7 and A-3, through free flowing, eg RDX/wax powders, to very fine particles in the case of the HNS samples. All samples were used as received.

3. RESULTS AND DISCUSSION

3.1 Impact Sensitiveness

3.1.1 MRL Test Method: Rotter Impact Sensitiveness [5a, 6]

Impact sensitiveness was determined on a Rotter apparatus. The sample of about 30 mg confined in a brass cap fitted over a polished steel anvil was impacted by a 5 kg weight falling from a preset height. Go/no-go was delineated by > 1 mL gas evolution from the sample for a positive result. Impact heights were varied in a typical Bruceton procedure [7] with a total of 50 caps being tested. The resulting Figure of Insensitiveness (F of I) is quoted relative to RDX Grade F = 80 and is rounded to the nearest 5 units. Gas evolution represents the average for all positive results.

3.1.2 Discussion

Rotter impact sensitiveness data determined at MRL for the complete series of formulations, together with corresponding UK data [8-10], are listed in Table 3, columns 2 and 3. US Impact sensitiveness data [11-14] are listed in Table 3, column 4. The US data are derived from the ERL Impact Machine [15a]; this test differs from the Rotter test in that the sample is unconfined on either sandpaper (Type 12) or roughened steel (Type 12B) and impacted by (usually) a 2.5 kg weight. In addition, initiation is defined by visual effects detected by the operator (smoke, flash etc) coupled with a sound recorder. Although data are available from other tests such as the LANL impact test [11,12], only data from the ERL/NOL test are quoted because this represents the most complete set for the US formulations under study.

Of the RDX/wax compositions, the UK Debrixes and US A-5 and CH-6 all have high RDX contents and Rotter impact sensitiveness (F of I) spans the narrow range of 100-120 (MRL data) and 85-110 (UK data). This can be compared with the minimum accepted figure for tetryl of 90 [6,16] upon which UK fuze safety guidelines are based [17]*. A-3, with its significantly higher wax content, shows the expected increase in F of I and is also rated the least sensitive formulation in the US data. The Rotter data for gas evolution decrease in the order Debrix 11 (18 mL) > A-5 > CH-6 > Debrix 18AS > Debrix 12 > A-3 (1 mL) and correspond exactly with increasing wax/desensitizer content. It is normally accepted that gas evolution indicates the degree of propagation [6] and thus these results amply illustrate suppression of propagation by increased wax content [2,18,19].

Viton A is used as the binder in both US formulations PBXN-5 and PBXW-7. The F of I values (Table 3) confirm the poor desensitization by fluoropolymers such as Viton A, Kel-F and PTFE (used in PBXW-7 Type I and its UK equivalent BX-4 [10]) observed previously [20,21]; PBXN-5 is as sensitive as binderless HMX [6] while PBXW-7 is only slightly less sensitive than binderless RDX. The US data is not so clear cut; using Type 12 tooling, PBXN-5 is rated less sensitive than tetryl (Table 3) or HMX (0.37 m) [12], but while still slightly less sensitive than HMX (0.32 m) [12] using Type 12B tooling it is rated as more sensitive than tetryl (Table 3). Data for PBXN-6 (RDX/Viton A 95:5) on Type 12 tooling (0.21-0.23 m) [13] indicates sensitization relative to RDX (0.28 m) [12]. Clearly much of these ordering differences between MRL, UK and US data relates to the surface on which the explosive is impacted coupled with confinement differences and definition of

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* Although F of I for both crystalline and granular tetryl is often as high as 110, as was observed in MRL testing (Table 3), granular tetryl in particular shows significant batch to batch variation down to a minimum of 90 [16] which is the figure accepted for comparison [17].

an initiation (see earlier comments)*. Nonetheless PBXN-5 would not meet the UK (and by definition Australian) fuze safety criterion on impact sensitiveness, ie. no greater than tetryl [17], while PBXW-7 would be only just acceptable. The moderating effect of the TATB in PBXW-7 can be seen from the evolved gas figure (4 mL) which indicates suppression of propagation.

The F of I for both HNS Type IB and IIB was 90. This places HNS of these types as equal in sensitiveness to tetryl, which was somewhat unexpected since the US data (Table 3) indicates decreased sensitiveness relative to tetryl. The F of I of HNS/Kel-F 95:5 has been found to be 90 [10], supporting the MRL results.

In summary, the MRL/UK Rotter data would in a number of instances result in a different ordering of sensitiveness than the US ERL data. This is generally of only academic significance [22]. However, in cases where sensitiveness is comparable with tetryl, pass/fail for fuze safety guidelines may depend very much on which data are selected.

3.2 Thermal Stability

3.2.1 MRL Method: Temperature of Ignition [5b]

Temperature of Ignition (T of I) was determined on an instrument built to specification for the ERDE T of I test [5b]. Samples of 200 mg in glass test tubes were heated at $5^{o}C$/min till ignition occurred. Ignition was defined by either visible signals such as smoke/flame or audible hiss/bang. The T of I is the temperature at which this event occurred and is the average of duplicate samples.

3.2.2 MRL Method: Vacuum Thermal Stability [23]

The test procedure consisted of placing duplicate 5 g samples in glass sample tubes, attaching to a mercury filled manometer and evacuating. The sample tubes were then placed in a heated bath at $120^{o}C$, and a 1.5 h period allowed for temperature equilibrium. The volume of gas evolved was then monitored for 40 h. The quoted result is gas evolved in mL/5 g at $120^{o}C$ for 40 h and is the average of duplicate samples.

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* Smith [22] has previously pointed out for a series of explosives covering a wide range of sensitiveness (PBX-9404 to Explosive D) that there is only a very general/poor correlation (coefficient 0.19) between Rotter F of I and Bruceton ERL results.

3.2.3 Discussion

Assessment of thermal stability in both Australia and the UK is based on two tests: vacuum thermal stability [23] and temperature of ignition (T of I) [5b]. The latter is in effect an accelerated stability test. The vacuum thermal stability test used in the US for qualification testing [24] is very similar to the Australian/UK method. Results are also widely available from other US vacuum stability test methods [12,13]. There is no corresponding US test to the T of I test; data available for the explosion temperature test [15b,c] are cited as the best comparison. The combined vacuum thermal stability and ignition/explosion temperature data are listed in Table 4.

The T of I of all the RDX-based formulations covers the narrow range of 211-220°C (MRL results) or 214-220°C (UK results). This can be compared with RDX which has a T of I of 219 ± 3°C [25] and indicates that these binders have only a secondary effect on this parameter. PBXW-7 Type II (and the UK BX-4) behaves very much like RDX in this test despite the presence of 60% TATB. PBXN-5 has T of I 273°C which is consistent with the higher ignition temperature of HMX, 273 ± 3°C [25].

Both HNS samples have T of I in excess of 300°C, as does HNS/Kel-F 95:5 [10]. This is mainly attributable to the high melting point of HNS, 315-318°C [12].

The US explosion temperatures [15d] are determined by lowering 0.02 g of the test substance in a blasting cap into a Wood's metal bath held at a preset temperature. The time to explosion is determined for a range of bath temperatures and plotted to give a temperature at which explosion occurs in 5 s. The UK/MRL T of I results are determined on a large mass (0.2 g) heated over a longer period and consequently are lower than the US explosion temperatures. The differing fundamentals of this test relative to the T of I test can be seen by the fact that tetryl is rated as more stable (or less explosive) than A-3 by the US data whereas the T of I data clearly reverses this order.

Both the MRL and UK vacuum thermal stability test results for the RDX and HMX formulations indicate good thermal stability; all evolved gas volumes are well under the normally accepted pass/fail criteria of 5 mL per 5 g. HNS is characterised by minimal decomposition consistent with its use in high temperature environments. All the formulations show better thermal stability than tetryl. Although US tetryl gave unacceptably high gas evolution, the Australian [26] and US [24] specifications call for testing at 100°C, not 120°C as used here.

The US vacuum thermal stability results are often available only at 100°C which is the recommended qualification test temperature [24]. The results for 120°C/22 h are derived from a modified LLNL test [12]. All results have been converted from mL/g or mL/0.25 g to mL/5 g for direct comparison with MRL/UK data. There is a general concurrence between the MRL and US figures except for CH-6 which gave high gas evolution (US data); this may reflect a particular batch rather than a general property.

3.3 Electrostatic Spark Sensitivity

3.3.1 MRL Method: Electric Spark Test [5c]

The test procedure consists of filling the sample into a 0.25 inch hole in a polythene strip backed with a strip of copper foil. The sample is then enclosed at the top by a piece of copper foil. The lower copper strip acts as a common electrode and energy from a capacitor is discharged through the sample by placing a second electrode in contact with the top piece of copper. Testing commences using a 0.1 μF capacitor charged to give an output of 4.5 J. A complete test requires a total of 50 discharges. If any discharge results in ignition, defined as explosion or consumption of the sample, a new sample is then retested using a 0.01 μF capacitor charged to give an output of 0.45 J. If any of these tests results in ignition, a further test is carried out at 0.001 μF/0.045 J. Passage of the spark through the sample normally results in some localised charring, particularly at 4.5 J. The samples are inspected after 10 discharges and replaced if charring is excessive. A non-ignition requires that 50 discharges have not resulted in ignition.

3.3.2 Discussion

Booster and secondary explosives are typically relatively insensitive to electrostatic discharge; most detailed studies have, as a consequence, dealt with the more sensitive primary explosives [15d]. Both Australia and the UK use the ERDE Electric Spark test [5c] as a screening test to determine ignitability at 4.5 J, 0.45 J and 0.045 J. A description of US test methods can be found in [15d]. US qualification [24] requires a pass/fail test for 10 kV/0.01 μF (0.5 J), hence all qualified booster explosives have a threshold above this energy.

MRL, UK and US data are listed in Table 5. The MRL/UK results for the explosives under study show they usually do not ignite at the highest test energies, i.e., the only results obtained are that the ignition thresholds are > 4.5 J. US data for PBXN-5 shows that the ignition threshold is > 12.5 J [13].

The only materials tested at MRL which ignited at 4.5 J were Debrix 11, CH-6, HNS and tetryl. UK data, with the exception of Debrix 11, is consistent with these observations. HNS/Kel-F 95:5 has also been reported to ignite at 4.5 J [10].

It should be noted that all the materials under test gave partial ignitions at 4.5 J as evidenced by localised charring, smoke or audible effects. However none of these partial ignitions propagated to explosion except HNS, CH-6, Debrix 11 and tetryl and under the criteria for the test are defined as a non-ignition.

3.4 Shock Sensitivity

3.4.1 MRL Method: MRL Small Scale Gap Test

The small scale gap test (SSGT) used at MRL has been described in detail by Wolfson [27] and is very similar to the AWRE Scale 1 Gap Test [5d]. The donor is a UK Mk 3 exploding bridgewire detonator attenuated by laminated brass shim. The acceptor is two 12.7 mm diameter x 12.7 mm high pressed cylinders of the explosive under study and detonation is confirmed using a mild steel witness block. The results were obtained from 25-30 firings using the Bruceton staircase method [7] and are quoted as mm of brass shim for 50% detonation probability, 95% confidence limits and standard deviation. The acceptor pellets were pressed to the specified density using an Instron Universal Testing Machine adjusted to operate as a press [18]. Densities were determined by accurate dimensional measurement and weight.

3.4.2 Discussion

The Australian (MRL) and UK AWRE [5d] and RARDE [5e] SSGT all use the same unconfined acceptor, and the same attenuator (gap) material. The only difference is that the RARDE SSGT uses a larger donor of a pressed 12.7 mm diameter x 12.7 mm high tetryl cylinder initiated by an L2A1 detonator. Results for all tests are quoted as mm of brass shim attenuator to give a 50% probability of detonation; calibration in terms of incident shock pressure has not been made. MRL data at 90-91% theoretical maximum density (TMD) for all the formulations are listed in Table 6, and available RARDE SSGT data [8-10] are listed in Table 7, column 2.

A number of gap test methods [11,12] are used in the US and a large volume of data is available [11,12,28-31]. The two methods most applicable to booster explosives are the NOL [28,31] and LANL [29] SSGT. The most significant difference between these tests and the MRL/UK tests is that the acceptor is confined; in the NOL test the acceptor is 5.095 mm diameter x 38.1 mm length in 25 mm diameter brass, while the LANL SSGT uses a wider diameter acceptor in plastic confinement. For the explosive formulations being studied here, most data is available from the NOL SSGT and this is listed in Table 7, column 3; only data for materials around 90 %TMD was chosen so that a direct comparison with the MRL data could be made. Some of these data have been converted from the original Decibangs (Dbg) to GPa using the appropriate formula [31]. Data for A-3 are derived from the NOL Large Scale Gap Test (LSGT) [11,12,30,31]; at these shock pressures the LSGT 50% figure will be lower than for the SSGT [31]. Little of the published LANL SSGT data are for formulations studied here, and are usually at higher %TMD.

The MRL data (Table 6) for materials used in fuze leads, ie Debrix 11, A-5, CH-6 and tetryl crystalline, show all to be comparable in shock sensitivity. Tetryl crystalline has the highest shock sensitivity. Booster explosives such as Debrix 12 and 18AS, with their higher wax levels, show the expected decrease in shock sensitivity, as does PBXN-5, but to a lesser extent. PBXW-7 Type II has substantially reduced sensitivity and there would thus be a penalty in using this material. All are substantially more sensitive than A-3. The two HNS samples show high shock sensitivity, particularly Type IIB which is the larger particle size material [32]. Gap test data often indicate decreased shock sensitivity for very fine materials [15e].

The UK data (Table 7) broadly parallel the MRL data although the gap thickness range over the series is more compressed. The differing %TMD for the compositions makes exact comparison difficult.

The US data (Table 7) for shock pressures in GPa to give 50% probability of detonation at about 90 %TMD are A-5 (1.03), CH-6 (1.1), tetryl (1.3), PBXN-5 (1.9) and PBXW-7 (2.1). This broadly follows the MRL data except for tetryl, which was rated marginally more sensitive than A-5 and CH-6, while the decrease in sensitivity for PBXW-7 appears to be less from the NOL SSGT data than the MRL data. Although the shock pressure for A-3 is about 1.5 GPa from the LSGT, conversion to SSGT pressure would yield a value above 2 GPa.

The NOL SSGT for HNS clearly differentiates the finer particle size (< 10 μm) HNS Type IB [32] as substantially less shock sensitive than the coarser (approximately 100 μm) HNS Type IIB [32]. Although the MRL data are in the same relative order they would appear to marginally overestimate the sensitivity of HNS Type IIB and grossly overestimate the sensitivity of HNS Type IB.

It should be stressed that a more complete comparison of shock sensitivity between explosive formulations should be carried out using a series of determinations over a wide density (%TMD) range. The MRL SSGT is a very labour and material intensive test and does not lend itself readily to generating this data. As a consequence data were only generated at around 90 %TMD, a figure chosen because it represents a typical density achieved in production pressing operations.

4. CONCLUSIONS

The data generated during this study form a consistent set derived within the one laboratory using the same operator for each individual test. As such they provide an invaluable basis for comparison of candidate tetryl replacements being prepared for Australian service qualification and introduction. In addition they will serve as a valuable reference for studies which may be carried out in the TTCP member countries.

The formulations studied fall into clearly defined classes. Debrix 11, A-5 and CH-6, which were developed as replacements for tetryl, are similar in impact sensitiveness to tetryl, have better thermal stability, similar or better electrostatic sensitivity and show slightly diminished shock sensitivity. The other formulations based on RDX with higher wax/desensitizer levels, i.e. Debrix 12, 18AS and A-3, have much diminished impact sensitiveness and shock sensitivity, while thermal stability and electrostatic sensitivity are comparable with or better than Debrix 11, A-5 and CH-6.

The formulations with Viton A binder have high impact sensitiveness; PBXN-5 would not be acceptable under current fuze-safety guidelines as used in Australia. Thermal stability and electrostatic sensitivity are good. PBXW-7 has reduced shock sensitivity over A-5, CH-6 and PBXN-5; the MRL data possibly overemphasises this reduction.

The HNS data were quite a revelation to us. Both types display excellent thermal stability but with impact sensitiveness and electrostatic sensitivity identical with tetryl. Shock sensitivity for Type IIB is comparable with tetryl but Type IB is lower; there is quite a discrepancy between MRL and NOL SSGT results for this formulation. HNS is thus very much like a thermally stable tetryl.

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TABLE 1

Compositions Qualified or Undergoing Qualification in the US and UK as Replacements for Tetryl

Composition	Country of Origin	Formulation	Specification
A-3	US	RDX (91.0%), wax (9%)	MIL-C-440
A-4	US	RDX (97.0%), wax (3%)	MIL-C-440
A-5	US	RDX (98.75%), stearic acid (1.25%)	MIL-E-14970
CH-6	US	RDX (97.5%), polyisobutylene (0.5%), graphite (0.5%), calcium stearate (1.5%)	MIL-C-21723A(OS)
PBXN-5	US	HMX (95%), Viton A (5%)	MIL-E-81111
PBXN-6	US	RDX (95%), Viton A (5%)	WS-12604
PBXW-7 Type II	US	RDX (35%), TATB (60%), Viton A (5%)	
DIPAM	US	DIPAM	WS-4660
HNS Type IB or IIB	US	HNS	WS-5003
Debrix 11	UK	RDX 1B (99.0%), wax No. 10 (1.0%)	TS 50282
Debrix 12	UK	RDX 1B (95.8%), wax No. 10 4.2%)	TS 50283
Debrix 18AS	UK	RDX 1B (95.3%), wax No. 10 (2.7%), zinc stearate (1.5%), aerosil (0.5%)	TS 50290
RDX/Wax 8	UK	RDX, wax No. 8; ratio 88:12, 91:9, 93:7	CS 4390A

TABLE 2

Origin of UK and US Formulations Received
for Comparative Assessment

FORMULATION	LOT/BATCH IDENTIFICATION
Debrix 11	RO Bridgwater Mix 2, Lot 765
Debrix 12	RO Bridgwater Mix 10, Lot 765
Debrix 18AS	RO Bridgwater Mix 1, Lot 766
A-3	NSWC X-955, Lot # HOL 32-138
A-5	NSWC X-828, Lot # HOL 015-42
CH-6	NSWC X-963, Lot # HOL 78C-900-032, Batch # 4R-18-7
PBXN-5	NSWC ID # 579
PBXW-7 Type II	NSWC ID # 3409
HNS Type IB	NSWC X565 Lot 11138-7
HNS Type IIB	NSWC X580 Lot 11138-20
Tetryl	NSWC X682

TABLE 3

Powder Impact Sensitiveness Data for UK and US Formulations
Qualified as Tetryl Replacements

Formulation	MRL IMPACT SENSITIVENESS		UK IMPACT SENSITIVENESS		US IMPACT SENSITIVENESS (m/2.5 kg)[c]	
	Rotter F of I[a]	Evolved Gas (mL)[b]	Rotter F of I[a]	Evolved Gas (mL)	Type 12	Type 12B
Debrix 11	110	18	100[d]	21.4[d]		
Debrix 12	120	7	110[d,e]	5.2[d]		
Debrix 18AS	120	10	100[f]			
A-5	110	16	100[d] 90[d,g]	9[d] 7[d,g]		
CH-6	100	15	85[f]		0.33[j], 0.27[n]	
PBXN-5	60	12			0.40[k,l], 0.44[m] 0.35 (5kg)[k,l]	0.35[k,l]
PBXW-7 Type II	90	4	100[e,h]		0.52[n]	
HNS Type IB	90	7			0.54[k,o]	0.66[k,o]
HNS Type IIB	90	12				
A-3 ex US	140	1			0.81[k]	2.45[k]
A-3 ex Australia	140	1				
Tetryl ex US	110	11			0.37[k] 0.28 (5 kg)[k]	0.41[k]
Tetryl ex Australia	105	15	90[d] 86[i]	13.6[d] 12.8[i]		

TABLE 3

(continued)

a Relative to RDX Grade G = 80, and represent 50% probability of ignition.

b Average gas evolution for all positive results.

c Results are in m for 2.5 kg drop weight, and represent 50% probability of ignition. Results for 5 kg drop weight are indicated.

d Data from Ref [8].

e Data from Ref [10].

f Data from Ref [9].

g Data for UK A-5.

h Data for BX-4 which is equivalent to PBXW-7 Type I ie PTFE rather than Viton A binder.

i Data from Ref. [6] for UK tetryl. Australian tetryl was originally ex UK.

j Data from Ref [11].

k Data from Ref [12].

l Data for LX-10 which is equivalent to PBXN-5.

m Data from Ref [13].

n Data from Ref [14].

o Type of HNS not specified.

TABLE 4

Thermal Stability and Ignition Temperature Measurements on UK and US Formulations Qualified as Tetryl Replacements

FORMULATION	MRL TEST RESULTS		UK TEST RESULTS		US TEST RESULTS	
	Ignition Temp. (T of I, °C)	Vacuum Stability mL/5g, 120°C/40h	Ignition Temp. (T of I, °C)	Vacuum Stability mL/5g, 120°C/40h	Vacuum Stability mL/5g[a] (°C,h)	Explosion Temp 5s, °C
Debrix 11	213 (smoke)	0.15	218[b]	0.8[b]		
Debrix 12	211 (smoke)	0.1	215 (flame)[b,c]	0.8[b],0.77[c]		
Debrix 18AS	220 (smoke)	0.1	217[d]	0.9[d]		
A-5	220 (flame)	1.2	215[b] 214[b,e]	3.0[b] 1.6[b,e]		
CH-6	220 (smoke)	1.0	200,212[d]		5.5(100,48)[g]	
PBXN-5	273 (fizz)	0.15			0.52(100 and 120, 48)[h]	309[h]
PBXW-7 Type II	225 (smoke)	1.15	220 (smoke)[c,f]	1.28[c,f]	1.5(100,48)[g]	
HNS Type IB	328 (smoke)	0.05			0.2(120,22)[i]	
HNS Type IIB	320 (smoke)	0.05				
A-3 ex US	222 (smoke)	0.6			3.0(120,48)[i]	250[j]
A-3 ex Australia		0.3				
Tetryl ex US	185 (smoke)	8.0			1.1(100,48)[i] 2.8(120,22)[i]	257[j]
Tetryl ex Australia	176 (smoke)	2.6	183[b],174 (smoke)[c]	6.9[c] 1.0(100°C)[b]		

TABLE 4

(Continued)

[a] US test results are typically quoted as mL/g. These figures have been multiplied by 5 for direct comparison with MRL and UK figures.

[b] Data from Ref [8].

[c] Data from Ref [10].

[d] Data from Ref [9].

[e] Data for UK A-5.

[f] Data for BX-4 which is equivalent to PBXW-7 Type I ie PTFE rather than Viton A binder.

[g] Data from Ref [14].

[h] Data from Ref [13].

[i] Data from Ref [12].

[j] Data from Ref [15c].

TABLE 5

Electrostatic spark sensitivity of UK and US Formulations Qualified
as Tetryl Replacements

FORMULATION	ELECTRIC SPARK TEST MRL Results	 UK Results	US electrostatic Results
Debrix 11	Ignition 4.5 J No ignitions 0.45 J	No ignitions 4.5 J[a]	
Debrix 12	No ignitions 4.5 J	No ignitions 4.5 J[a,b]	
Debrix 18AS	No ignitions 4.5 J	No ignitions 4.5 J[c]	
A-5	No ignitions 4.5 J	No ignitions 4.5 J[a] No ignitions 4.5 J[a,d]	Ignition threshold >0.5 J[f]
CH-6	Ignition 4.5 J No ignitions 0.45 J		Ignition threshold >0.5 J[f]
PBXN-5	No ignitions 4.5 J		Ignition threshold > 12.5 J[g]
PBXW-7 Type II	No ignitions 4.5 J	No ignitions 4.5 J[b,e]	Ignition threshold > 0.5 J[g]
HNS Type IB	Ignition 4.5 J No ignitions 0.45 J		Ignition threshold > 0.5 J[f]
HNS Type IIB	Ignition 4.5 J No ignitions 0.45 J		Ignition threshold > 0.5 J[f]
A-3 ex US	No ignitions 4.5 J		Ignition threshold >0.5 J[f]
A-3 ex Australia	No ignitions 4.5 J		
Tetryl ex US	Ignition 4.5 J No ignitions 0.45 J		Ignition threshold 4.68 J[h]
Tetryl ex Australia	Ignition 4.5 J No ignitions 0.45 J	Ignition 4.5 J No ignitions 0.45 J[a,b]	

TABLE 5

(Continued)

[a] Data from Ref [8].

[b] Data from Ref [10].

[c] Data from Ref [11].

[d] Data for UK A-5.

[e] Data for PBXW-7 Type I (US data) and BX-4 (UK data) i.e. PTFE rather than Viton A binder.

[f] Necessary condition to pass US qualification test [24].

[g] Data from Ref [13].

[h] Data from Ref [15d].

TABLE 6

Comparison of UK and US Formulations Qualified as Tetryl Replacements:
Shock Sensitivity Determined using MRL SSGT of Charges Pressed Nominally to 90.0% TMD

FORMULATION	DENSITY		SHOCK SENSITIVITY (SSGT, mm)		
	Mg/m^3[std.dev.]	%TMD	$M_{50\%}$	$L_{95\%}$	σ
Debrix 11	1.624[0.002]	91.0	2.715	2.807-2.624	0.043
Debrix 12	1.574[0.001]	90.6	1.730	1.801-1.661	0.033
Debrix 18AS	1.587[0.001]	90.9	1.496	1.544-1.450	0.022
A-5	1.581[0.001]	90.0	2.642	2.786-2.497	0.067
CH-6	1.597[0.002]	90.0	2.600	2.654-2.548	0.025
PBXN-5	1.715[0.0015]	90.0	2.383	2.548-2.220	0.076
PBXW-7 Type II	1.710[0.0015]	90.0	1.415	1.448-1.382	0.015
HNS Type IB	1.567[0.004]	90.1	2.438	2.525-2.352	0.040
HNS Type IIB	1.565[0.004]	90.0	2.822	2.873-2.769	0.024
A-3 ex Australia[a]	1.520[0.002]	90.9	0.498	0.513-0.480	0.007
Tetryl ex Australia[a]					
Granular	1.557[0.001]	90.0	3.259	3.315-3.203	0.021
Crystalline	1.557[0.001]	90.0	2.814	2.858-2.771	0.026

[a] US samples were not tested.

TABLE 7

UK (RARDE SSGT) and US (NOL SSGT) Shock Sensitivity Data for Formulations Qualified as Tetryl Replacements

FORMULATION	UK RARDE SSGT Density (Mg/m^3)[%TMD] gap (mm)[a]	US NOL SSGT Density (Mg/m^3)[%TMD] pressure (GPa)[b]
Debrix 11	1.62[91.0] 7.0[c]	
Debrix 12	1.65[95.0] 6.3[c,d]	
Debrix 18AS	1.64[93.9] 6.0[e]	
A-5	1.68[95.0] 7.4[c] 1.68[95.0] 6.6-7.4[c,f]	1.599[89.7] 1.03[g]
CH-6		1.579[89.0] 1.08[g] 1.597[90.0] 1.22[g] 1.59[90.1] 1.08,1.06[g] 1.602[90.3] 1.21[g] 1.603[90.4] 1.16,1.15[g] 1.605[90.5] 1.25[g]
PBXN-5		1.658[87.3] 1.81[g] 1.719[90.5] 1.98[g] 1.749[92.0] 1.99[g]
PBXW-7		1.670[87.9] 1.95[h] 1.767[93.0] 2.37[h]
HNS Type I		1.546[88.9] 2.50,2.52[g] 1.555[89.4] 2.49[g] 1.586[91.1] 3.15[g] 1.590[91.4] 2.63[g]
HNS Type II		1.545 [88.8] 1.55[g]
A-3		1.451[86.8] 1.6[i] 1.501[89.9] 1.5[i] 1.551[92.0] 1.4[i]
Tetryl	1.50[86.7] 7.86[d] 1.60[92.5] 7.63[d]	1.549[89.5] 1.31[g]

TABLE 7
(Continued)

[a] mm brass shim for 50% probability of detonation of the acceptor.

[b] Incident pressure for 50% probability of detonation of the acceptor.

[c] Data from Ref [8].

[d] Data from Ref [10].

[e] Data from Ref [9].

[f] Data for UK A-5.

[g] Data from Ref [29].

[h] *Data from Ref [13] for* PBXW-7 Type I ie. PTFE rather than Viton A binder.

[i] Data from Ref [31] from NOL LSGT.

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ABSTRACT

Three UK and seven US production formulations qualified as replacements for tetryl in fuzes have been obtained through TTCP WTP-1. Characterisation of powders - Rotter impact sensitiveness, temperature of ignition, vacuum thermal stability and electrostatic spark sensitivity - and of pressed charges - shock sensitivity - has been carried out at MRL. Our results are compared with UK and US published data, to produce probably the most complete comparative set published for production booster explosives.

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