Hazard Re-classification
of 76mm Naval Gun Ammunition following UN Test Series 6

ABSTRACT

The hazard classification of ammunition has a significant impact on the maximum quantity allowable and minimum safety distance required for its storage and transport. The 76mm Multi-role Oto Munition and Semi-armour Piercing Oto Munition rounds are gun ammunition used onboard the Republic of Singapore Navy platforms. The manufacturers assigned the rounds to Hazard Division (HD) 1.1. In comparison, US Navy 76mm rounds with identical Comp A3 high explosive fillings were classified as HD 1.2. DSTA suspected that the 76mm round's hazard classification was conservative. Thus, a series of confined and unconfined sympathetic detonation and fast cook-off tests were conducted on rounds in storehouse packaging (wooden crates) and storage afloat packaging (plastic containers, referred to as octovals) in December 2007. The test results indicated that the hazard classification could be reduced to HD 1.2. Other than safety improvements and risk reduction, the benefits of a reduced hazard classification were enhanced emergency response and platform survivability, easing of berthing constraints and increased storage flexibility and capacity. This paper describes the motivating factors, test programme and results.

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INTRODUCTION

Class 1 Explosives comprise six hazard divisions (HD), HD 1.1 to 1.6, with HD 1.1 as the most hazardous and requiring the largest separation distances for its safe storage. According to the UN Model Regulations (United Nations, 2007), it is mandatory for explosive substances and ammunition to be classified into one of the six hazard divisions before they are transported.

Hazard Classification Methods. With reference to current practice in the US and the UK, the hazard classification of new ammunition should be assigned by a qualified explosives expert on the basis of testing or by analogy.

a. Hazard Classification by Testing. The test procedures from the UN's Manual of Tests and Criteria (United Nations, 2003) provide the necessary information for the competent authority of each country to assess the hazard of explosive substances and articles, such that an appropriate classification for transport can be made.

b. Hazard Classification by Analogy. The hazard classification of new ammunition may be assigned by analogy in terms of similarities in explosive filling, design features and packaging (Department of Defense Ammunition and Explosives Hazard Classification Procedures TB-700-2 Review Draft, 2005) to those that have already been hazard classified. This is the prerogative of the country's competent authority. Analogy using analytical studies is a common way of assigning a hazard classification to ammunition.

c. Hazard Classification by Conservatism. When neither tests nor analytical studies have been done, ammunition may be conservatively assigned to HD 1.1 – the most hazardous division in Class 1. A conservative hazard division leads to larger safety distances required for the storage and transport of ammunition and greater operational constraints than are necessary based on the ammunition's true hazard.

Review of Applicable Tests for 76mm Rounds Hazard Classification Reduction. A series of tests (Series 1 to 8) described in the Manual of Tests and Criteria have been devised to determine if substances or articles are candidates for Class 1 Explosives and the hazard division they belong to. Series 1 to 8 also determine how sensitive explosives are to energetic stimuli such as friction, impact, heat, and shock. However, it was determined that only Series 6 tests were applicable to justify the revision from HD 1.1 to HD 1.2.

MOTIVATING FACTORS FOR THE 76MM ROUNDS HAZARD RE-CLASSIFICATION TEST

Cost. Additional expenditure was incurred only for actual hazard re-classification testing and packaging re-labelling. The 76mm rounds tested were reaching the end of their shelf-life and due for disposal. Therefore, the ammunition cost was not a significant factor.

Benefits. One of the benefits of hazard classification reduction is the relaxation of the quantity distance (QD) criteria required during the ammunition life cycle shown in Figure 1 (Parsons et al., 2000). QD is the safe separation distance required during the storage and transportation of explosives to minimise injury to people and damage to property in the event of an explosion. The QD criteria are greatly influenced by the explosive hazard classification. For the Republic of Singapore Navy, hazard classification reduction of the 76mm rounds resulted in greater operational flexibility during ammunition storage and wharf-to-ship transportation, since the safe separation distance required for those activities was decreased.

Reduced hazard classification of ammunition confers advantages other than safety improvements and risk reduction. Enhanced platform survivability, increased storage capacity, storage flexibility and easing of berthing constraints are the other benefits (Barnes & Cheese, 2000).

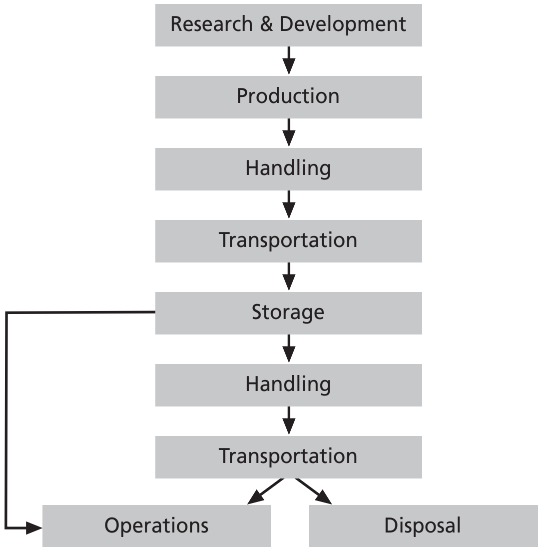

Figure 1. Ammunition life cycle

a. Safety improvements/risk reduction. HD 1.1 has a mass detonation hazard, whereas HD 1.2 has a projection but not a mass explosion hazard. Therefore, the risks to personnel from storage, handling and operations involving HD 1.2 are lower.

b. Emergency response. Sympathetic detonation (i.e. unintended detonation of an explosive charge by exploding another charge adjacent to it) and fast cook-off (i.e. direct exposure to an intense fire e.g. liquid fuel fire) timing and consequences may be derived from the mandatory Series 6 tests. The cook-off time and response of ammunition may be listed in a compendium of safety data which would aid the ship's crew during an emergency. In particular, the US Navy and Royal Navy have already established information flow channels and awareness in the ship's crew on the cook-off behaviour of specific shipboard ammunition. For example, the Royal Navy compiles ammunition safety data as a Ship Explosives Safety Store Instruction (JSP 430, 2005).

c. Easing of warship berthing constraints. According to rules governing the mixing of hazard divisions, regardless of the quantity of explosives, when HD 1.1 is stored together with lower hazard divisions, the entire load is subject to HD 1.1 QD criteria. This poses a constraint on the ship's berthing requirements. With hazard classification reduction, the QD criteria for storage and transport would be relaxed. Explosive loading piers and wharves in proximity to on-base or publicly exposed sites will also benefit from the easing of QD requirements.

d. Increased ammunition storage flexibility. With hazard classification reduction, 76mm rounds may be stored with HD 1.2, 1.3 and 1.4 items and the load treated collectively as HD 1.2. This represents a greater storage flexibility than a HD 1.1 load, particularly when the majority of the items belong to a lower hazard division. Storage of lower hazard division ammunition also requires less facility hardening. This translates to lower infrastructure demand.

e. Increased storage capacity. Risk reduction leads to less stringent QD criteria. With the existing munitions infrastructure i.e. unchanged separation distance and building structures, more HD 1.2 explosives may be stored than HD 1.1 and more combat ships may be supported.

Parameters	HD 1.1	HD 1.2	Remarks
QD Criteria for Storage	K22.2 = 403m	350m	Assuming an earth-covered storehouse with 6 tons Net Explosives Quantity
QD Criteria for Warship (Un)loading	K16 = 291m	90m (fixed)	Assuming a ship loaded with 6 tons Net Explosives Quantity
Individual Risk	$2.1e^{-7}$ fatalities per year	$4.5e^{-8}$ fatalities per year	Assuming a 50-feet separation between an open storage site and an open exposed site

Table 1. Benefits of hazard classification reduction from HD 1.1 to HD 1.2

f. Enhanced platform survivability. The operational asset loss (i.e. ship's damage) incurred in the event of an accident or a hostile action is smaller for HD 1.2 than HD 1.1. Hazard classification reduction would lead to lower consequential risks to the ship from the stored ammunition.

g. Overall benefits. These are shown in Table 1 using generic inputs. K22.2 refers to the safety factor applied for inhabited buildings while K16 refers to the safety factor applied for warship loading and unloading.

TEST METHOD

The UN Series 6 tests were planned for implementation as follows:

Type 6(a): Single Package Test. A test on a single package to determine if there is mass explosion of the contents.

Type 6(b): Stack Test. A test on packages of explosive articles to determine whether an explosion is propagated from one package to another.

Type 6(c): Liquid Fire/External Fire Test. A test on packages of explosive articles to determine if there is mass explosion or a hazard from dangerous projections, radiant heat and/or violent burning or any other dangerous effects when involved in a fire.

Possible Waiver. According to Series 6 procedures, it is not always necessary to conduct all the tests. The Stack Test can be waived if in the Single Package Test:

a. the exterior of the package is not damaged by internal detonation and/or ignition, or

b. the contents of the package fail to explode, or explode so feebly that propagation of the explosive effect from one package to another in the Stack Test is excluded.

Test Packaging. It is a UN Series 6 requirement to test articles in their realistic forms of transport. Packaging and stacking configurations affect results due to the differential absorption of energy. The 76mm all-up rounds are stored in two types of packaging: wooden crates in storehouses and octovals onboard ships. The wooden crate packaging (see Figure 2) is from the original equipment manufacturer and comprises two rounds in a head-tail (projectile to cartridge) layout, each packed in a fibrous cylinder. One

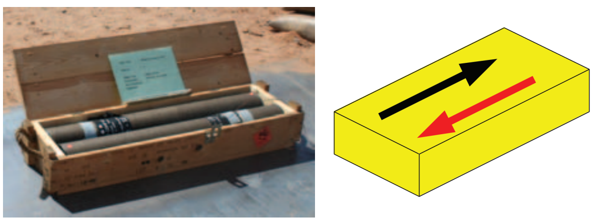

Figure 2. Wooden crate packaging schematic

wooden crate contains two cylinders. Octoval packaging (Figure 3) comprises two rounds in a head-head (projectile to projectile) layout packed into a high impact acrylonitrile butadiene styrene plastic container.

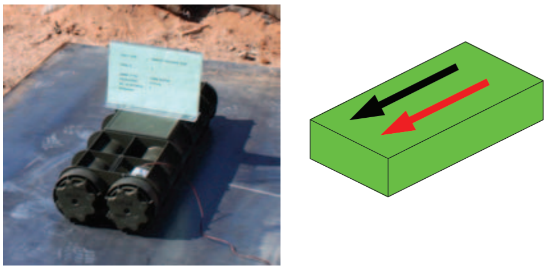

Figure 3. Octoval packaging schematic

SINGLE PACKAGE SYMPATHETIC DETONATION TEST

Definitions. The 76mm Multi-role Oto Munition (MOM) round contains pre-formed fragments while the 76mm Semi-armour Piercing Oto Munition (SAPOM) round contains a penetrating warhead. All 76mm rounds comprise a projectile (containing the high explosive warhead which delivers the weapon effect) joined to a cartridge case (containing the propellant which propels the round). Each test package comprises two rounds in either the wooden crate or octoval packaging. One round is known as the donor, since it is purposely initiated and 'donates' the blast. The other round is known as the acceptor. During the sympathetic detonation testing of rounds, the assessment is based on the response of the projectile and not of the cartridge. This is because the high explosive is contained in the projectile. There are three types of tests prescribed by UN Series 6, namely 6(a) Single Package Test, 6(b) Stack Test and 6(c) Liquid Fuel/External Fire Test. However, the Single Package and Stack Test have multiple trials (e.g. Single Package Test trial 1, Single Package Test trial 2). The Liquid Fuel/External Fire Test has one trial each. UN Series 6 prescribes the number of trials for each test type.

Set-up. A mild steel witness plate was placed below the test package (see Figure 4). The test package and witness plate were confined within a metre of sand on all sides (see Figures 5, 6 and 7) and the donor projectile was initiated. The witness plate and acceptor round

Figure 4. Test package on witness plate

Figure 5. One-metre sand confinement

Figure 6. Levelling sand

Figure 7. Completed confinement set-up

Figure 8. MOM in wooden crate – confined trial 1

were later recovered for analysis. Four sets of tests were conducted (MOM in wooden crate; MOM in octoval; SAPOM in wooden crate; SAPOM in octoval) with three trials each according to the requirements of UN Series 6. Of the three trials, two were confined and one was unconfined.

Summary of Results. The 76mm rounds passed the single package sympathetic detonation tests. Only one crater with a diameter not substantially larger than 76mm was found on each witness plate. This indicated that only the donor projectile detonated. All acceptor projectiles were recovered dislodged from their respective cartridge cases. For the MOM, rows of preformed fragments surrounding the high explosive core were observed, which showed that the acceptor high explosive did not react. For all confined tests, there was a gentle disruption and scattering of sand. Greater sand disruption was observed for MOM due to its higher Net Explosives Quantity (NEQ).

For the MOM, the acceptors were recovered intact for the wooden crate tests and sheared for the octoval tests. This was due to the head-head ammunition configuration in the octoval, as compared to the head-tail ammunition configuration in the wooden crate, as well as the thin skin of the fragmenting warhead.

For the SAPOM, the acceptors were recovered intact in both wooden crate and octoval single package tests. This was due to its lower NEQ and the thicker skin of the penetrating warhead.

MOM in Wooden Crate – Test Results

a. Confined trials **–** A white gas followed by a brown gas was observed. This is due to burning of the nitrogen-based propellant. Large pieces of the cartridge case, cardboard canister and the intact acceptor were recovered (Figure 8). Identical results were observed for trials 1 and 2.

b. Unconfined trial **–** The intact acceptor projectile was thrown eight metres away. Large pieces of the wooden crate, cartridge case and cardboard canister were recovered (Figure 9).

Figure 9. MOM in wooden crate – confined trial

MOM in Octoval – Test Results

a. Confined trials **–** Identical results were observed for trials 1 (Figure 10) and 2 (Figure 11). The projectile case was ruptured and displaced. However, the high explosive did not react.

b. Unconfined trial **–** The acceptor projectile was found intact on the sandbank 12 metres away (Figure 12). The projectile case was displaced and rows of preformed fragments were revealed (Figure 13).

Figure 10. MOM in octoval – confined trial 1

Figure 11. MOM in octoval – confined trial 2

Figure 12. MOM in octoval – confined trial

Figure 13. Close-up of projectile case

SAPOM in Wooden Crate – Test Results

a. Confined trials – A crater not substantially larger than the diameter of SAPOM was found on the witness plate (Figure 14). Large pieces of the cartridge case and intact acceptors were recovered (Figure 15). Identical results were observed for trials 1 and 2.

Figure 14: SAPOM in wooden crate – confined trial 1

b. Unconfined trial – The intact acceptor projectile was dislodged from its cartridge and thrown onto the left sandbank 10 metres away. Large pieces of the wooden crate, cartridge casing and cardboard canister were recovered (Figure 16).

Figure 15: SAPOM in wooden crate – confined trial 2

Figure 16. SAPOM in wooden crate – unconfined trial

Figure 17. SAPOM in octoval – crater from confined trial 1

Figure 18. SAPOM in octoval – fragments from confined trial 1

Figure 19. SAPOM in octoval – crater from confined trial 2

Figure 20. SAPOM in octoval – fragments from confined trial 2

SAPOM in Octoval – Test Results

a. Confined trials – A crater not substantially larger than the diameter of SAPOM was found on the witness plate. Large pieces of the cartridge case, octoval and the intact acceptor projectile are shown in Figures 17, 18, 19 and 20. Identical results were observed for trials 1 and 2.

b. Unconfined trial – The intact acceptor projectile was dislodged from its cartridge case, as shown in Figure 21. The acceptor cartridge in its octoval was found 60 metres from the test site as shown in Figure 22.

Figure 21. SAPOM in octoval – unconfined trial

Figure 22. SAPOM in octoval – unconfined trial

STACK SYMPATHETIC DETONATION TEST

Since the 76mm rounds passed the Single Package Test, the Stack Test was not conducted. This is permissible according to UN Test Methods & Criteria.

Figure 23. Fast cook-off test set-up

LIQUID FIRE/EXTERNAL FIRE (FAST COOK-OFF) TEST

Set-up. A stack of nine packages (18 rounds) was encircled with a steel strip for support and positioned on a grid test stand above a fuel receptacle, which extended beyond the grid by one metre. It was filled with sufficient Jet A1 fuel for a fire lasting 30 minutes. The distance between the grid platform and receptacle was half a metre. Vertical witness screens were erected on three quadrants, four metres from the edge of the ammunition stack. When the wind speed was less than 6m/s, the fuel was ignited simultaneously on two sides, one on the upwind side. Cook-off was indicated by flying burning debris seen or explosions heard during the test. After the test, the remaining ammunition was collected for analysis. The passing criteria was no mass explosion (no simultaneous detonation of more than 50% of acceptors). Four tests were done (MOM in wooden crate; MOM in octoval; SAPOM in wooden crate; SAPOM in octoval) as required by UN Series 6. Figure 23 shows the test set-up.

Summary of Results. For all tests, sporadic explosions were observed and more than nine acceptors out of the 18 rounds were recovered. This meant that less than 50% of the acceptors exploded simultaneously. Thus, there was no mass explosion. This showed that the 76mm rounds passed the fast cook-off test. Table 2 summarises the quantity of projectiles which reacted for each fast cook-off test. The fast cook-off response was an explosion of the propellant in the cartridge case. The fast cook-off time was less than two minutes.

S/N	Ammunition Type	Packaging	Initial Quantity of Rounds	Quantity of Projectiles Recovered		Quantity of Projectiles Reacted	Result
				Inside Pit	Outside Pit		
1	MOM	Wooden Crate	18	12	2	4	No Sympathetic Detonation
2	MOM	Octoval		6	3	9	
3	SAPOM	Wooden Crate		11	3	4	
4	SAPOM	Octoval		10	7	1	

Table 2. Summary of liquid fuel/external fire (fast cook-off) test results

S/N	Ammunition Type	Packaging	Single Package Test		Stack Test	Fast Cook-off	Hazard Classification
			Confined	Unconfined			
1	MOM	Wooden Crate	No Sympathetic Detonation		Not Required (passed Single Package Test)	No Sympathetic Detonation	HD 1.2
2	MOM	Octoval					
3	SAPOM	Wooden Crate					
4	SAPOM	Octoval					

Table 3. Summary of UN Series 6 test results

Table 3 summarises the UN Series 6 test results for the 76mm MOM and SAPOM rounds in the wooden crates and octoval packaging.

CONCLUSION

The 76mm MOM and SAPOM rounds in the wooden crates and octoval packaging passed the UN Series 6 tests. This justified a reduction of the hazard division from HD 1.1 to HD 1.2. Safety data on the fast cook-off timing and response were obtained as a useful by-product. The land use savings enabled by the hazard classification reduction is significant for a small country such as Singapore. The planning and conducting of the full UN Series 6 tests was a valuable learning opportunity. Future work includes the testing of other ammunition that may be over-classified.

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BIOGRAPHY

Audrey Lao Linmei is a Senior Engineer (Armament Systems – Explosives Safety). She has prepared safety assessment reports for the safe storage of explosives onboard surface ships and submarines and has conducted hazard classification testing of ammunition. She is presently developing a hazard classification implementation policy and is leading the development of the risk-based explosives safety siting in the Singapore Armed Forces (SAF). She graduated with a Bachelor degree in Chemical Engineering (Honours) from the National University of Singapore in 2005.

Yen Chong Lian is a Senior Principal Engineer and Head (Armament Systems – Explosives Safety). He manages the licensing of military explosive facilities in the SAF and is the Chairman of the Explosives Safety Technical Sub-Committee of Explosives Fire and Chemical Safety Committee. He is also the President of the Institute of Explosives Engineers (Singapore) and a consultative member for the Control of Strategic Goods. He holds a postgraduate engineering diploma in Explosives Ordnance Technology from Cranfield University, UK.

Ng Cher Chia is a Deputy Commander and concurrently the Head of the System Office in the SAF Ammunition Command. He has substantial work experience from his appointments in operational units, infantry brigades, general staff departments, Army Logistics and in the SAF Ammunition Command. Cher Chia was awarded the Defence Technology Prize Award in 2008 for his contributions to the Underground Ammunition Facility project. He has a Master in IT Management and a Master of Engineering (Technology Management) from the University of South Australia.