

FOREIGN MUNITION IDENTIFICATION AND DISPOSAL

EXPLOSIVE REMNANTS OF WAR, FORT MORBUT, ADEN

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TASK CONTEXT

Located in a district of the Yemeni city Aden, a legacy munition stockpile has been identified in a tunnel beneath an abandoned naval and coastal defense fort. The stockpile contains fifty un-identified explosive remnants of war (ERW). Brimstone Consultancy LLC. Has tasked the OME Level 4 HNC cohort the provide technical advice and a safety case to enable the safe disposal of the munitions.

Role requirements	Personnel
Identify the munition and the component parts	Marcus Baker-Wells & Kieran Wusthoff
Generate safety distance using International Ammunition Technical Guidelines (IATG)	Alexander Halliday
Relevant legislation and guidelines in an 'ideal' scenario	Ben Palmer-Drury
Test and Evaluation of the explosive compositions present	Tom Volpato
Disposal plan and movement	Kris Bhudoye
Render Safe Procedure	Kris Bhudoye & Ben Palmer-Drury

TABLE 1 - TASK ALLOCATION

Table 1 contains the allocations for research and the presentation of the group's finding. However collaborative working was conducted throughout the projects lifecycle.

Yemen has been embroiled in conflict for much of its recent history, particularly from 2014 onwards. The civil war has killed 377,000 and displaced 2.79 million as of September 2023 [1], with over 100,000 located in Aden. In 2015 Aden was declared as the 'temporary' capital following the Houthi insurgency taking over the nation's capital of Sanaa. After further conflict that is outside the scope of this report; the United Arab Emirates backed Southern Transitional Council has held control of Aden since 2018. The primary source of income for the local population is the local port which has been intermittently blockaded, contributing considerably to the famine which has caused two thirds of the deaths attributed to the civil war.

The coastal defense fort is located in Attawahi district, a densely populated area consisting of 92,686 people in 2019 and a large concentration of cultural and religious heritage sites [1]. During British colonial occupation of Aden, it was known as Fort Morbat and housed gun emplacements. In the course of the Aden Emergency (1963-1967), there were allegations the fort was used as a detention centre for insurgents and torture was carried out [2].



FIGURE 1 - LOCATION OF ADEN, YEMEN [2] AND THE STORAGE LOCATION WITHIN ADEN [3]

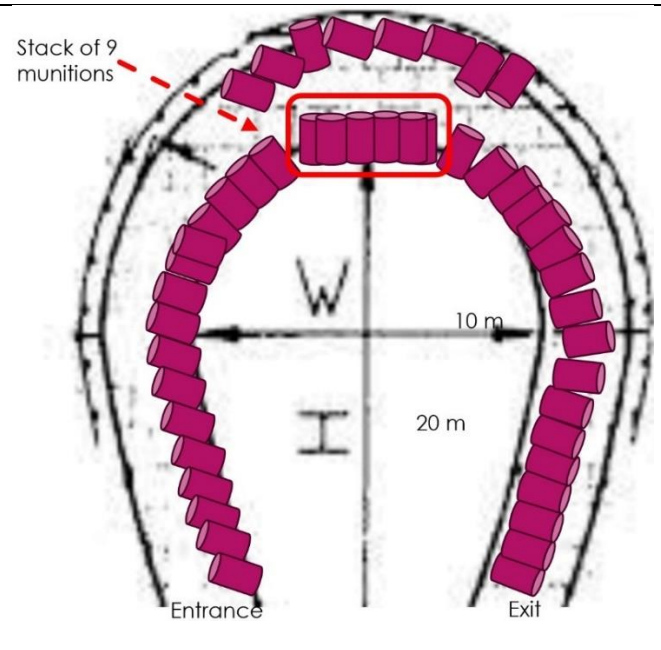


FIGURE 2 - LOCAL AREA AND MUNITION STORAGE LAYOUT

The bunker does not meet the minimum requirements of the International Ammunition Technical Guidelines (IATG) risk reduction process level 1 [4] as it is insecure to any external actors or actions; there is no mitigation for any potential causes of explosion such as lightning strike or contraband; the ammunition is not accounted for nor is there any routine inspection to understand chemical stability; there is also significant civilian infrastructure such as schools, mosques and hospitals within the area that would be affected by mass detonation, seen in Figure 2.

Following the withdrawal of British forces from Aden in 1967, a soviet presence emerged. In 1981 there were reports by the CIA of the soviets running an amphibious training school for guerilla proxy forces in the neighboring Ma'alla district [6]. It could be theorized that the depth charges in question were stored at Fort Morbat around this time meaning they would have been in situ for 43 years.

The philosophy and of Explosive Ordnance Disposal will underpin the OME students recommendations; namely saving lives, preservation of property, removal of threat and returning the situation to normality. To conduct the operation in an As Low As Reasonably Practicable (ALARP) risk profile the principles of EOD will be adhered to: Non remote Render Safe Procedures (RSPs) are used in the last resort, any EOD operators will be exposed to harm for the minimum amount of time and at a single person risk, mandatory safe waiting periods will be observed [8].

MUNITION IDENTIFICATION

The following technical information has been provided:

- The markings on the case translate to BB-1
- Packaging dimensions are 700mm diameter x 800mm length
- Case dimensions are 432mm diameter x 711mm length
- All-up weight is estimated at 166kg
- A 'pistol' (Fuze) of 115mm diameter and 305mm length appears to be fitted to all but one munition
- Fine yellow crystals are apparent on the visible threads around the fuze



FIGURE 3 - UNIDENTIFIED MUNITIONS IN STORAGE BUNKER



FIGURE 4 - MARKINGS ON MUNITION PACKAGING

Using this supplied data and the Russian markings the munitions corresponds with the specification of the Soviet BB-1 Depth Charge, the primary anti- submarine munition used by the soviet navy in WW2 [4].

	BB-1 Reference	Supplied Measurements
Length [mm]	712	711
Diameter [mm]	430	432
All-up weight [kg]	165	166
Main fill NEQ [kg]	135	-

TABLE 2 - SPECIFICATION COMPARISON TO BB-1 DEPTH CHARGE [5]

The storage density of the munitions, particularly in the double-stacked area is of great concern due to the risk of sympathetic detonation. As detailed in a later section, the munitions contain a main fill of TNT which has a 50% probability of detonation in the “Super” Gap Test at 5 – 6 inches [11] which appear to be an achievable distance within the storage bunker.



FIGURE 5 - BB-1 DEPTH CHARGE ON DISPLAY [5]

The BB-1, or 'Bomb Big, First Model' was first adopted in 1933 and consists of a thin case steel drum filled with 135kg of melt cast TNT. Interestingly, given the depth charges role in Anti-Submarine Warfare; the Soviets did not develop blast enhancing aluminized main fills until 1965 onwards. Aluminum provides a secondary fuel that is consumed in a blast, lengthening the impulse of a blast wave and increasing energy and gas products; thereby producing more damaging underwater blast waves. An expert on foreign munitions; particularly of Soviet origin, was consulted and they stated the markings indicate that these charges are export articles which could be conjectured as to have poorer quality control than domestic articles which might affect both the fuzing and main fill. The BB-1 depth charges have a sink rate of 2.3 ms^{-1} , depth setting from 10 to 330m in 10m increments.

The BB-1 was supplied with a range of fuzes depending on the manufacture date. Initially VGB fuzes were issued but were found to be unreliable and unsafe [6], therefore they were replaced in 1940 by the K-3 fuze [4]. In 1953 the K-3 fuzes were upgraded to the K-3M model. The supplied measurements of 115mm diameter and 305mm length indicate that fuze is a K-3M model (113mm diameter x 314mm length). This must be confirmed on site by inspection and possible x-ray (see Disposal methodology) as this will inform the handling and render safe procedure (RSP). The K-3M consists of a striker fired friction sensitive primer composition (unknown but likely to be similar to small arms primers of the era); the flame front of which travels through adjustable channels; this ignites a gunpowder delay leading to a primary initiator that will deflagrate to detonate. A breakdown expert proposed that this initiator would be similar to the British VH2, VH4 or RD1651 compositions with the primary chemicals of concern being Lead Styphnate and Barium Nitrate. This initiator would provide a sufficient shock front to initiate a detonative shock wave in the following four 80g Tetryl pellets which in turn provide a shock impulse to the main fill of TNT.

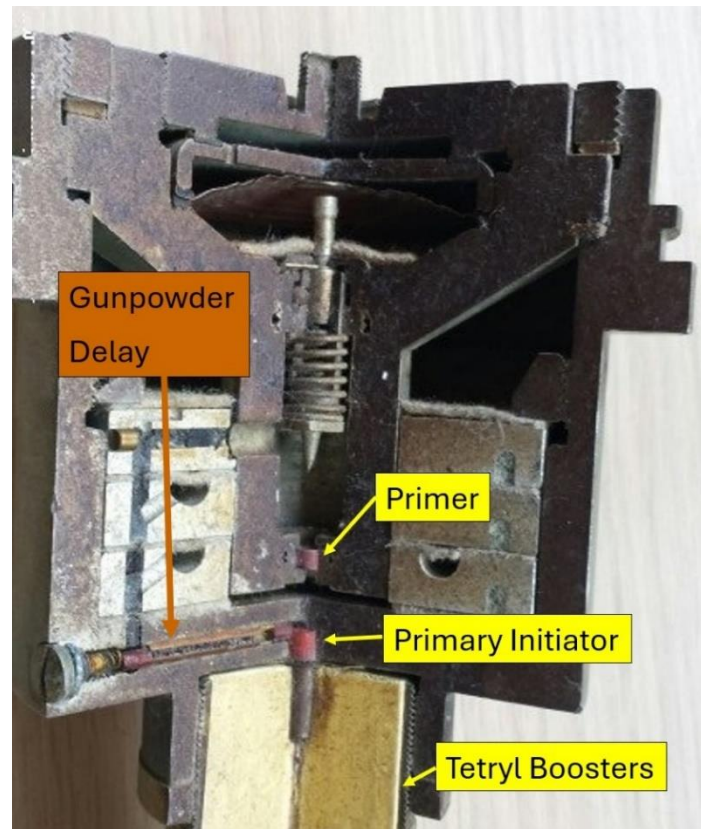


FIGURE 6 - K-3M SAFETY AND STRIKER MECHANISM

Fuze safety is ensured by the ring cocking mechanism [1 to 6 in Figure 7] and the hydrostat [7 to 9], meaning that the depth charge must be armed and reach a minimum depth (barometric pressure) of 10m before the striker can release and initiate the primer composition. The hydrostat is held in place with a leather gasket which could have degraded to the point of seizing or conversely allowing no resistance to the movement of the striker.

The fuze once set would not be screwed into the fuze well directly but retained by a 'combat plate' with three bolts attaching it to the case body. The single inspected munition had the combat plate fitted and the armed or even fuze status of the remaining charges is unknown without further individual inspection.

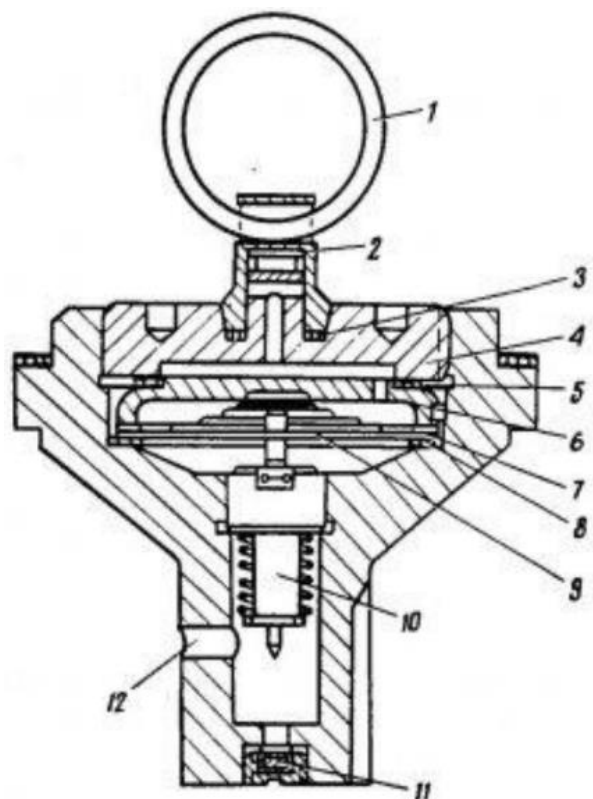


FIGURE 7 - K-3M SAFETY AND STRIKER MECHANISM

As the fuzes are designed to be used in a naval environment, the primary compositions are protected from moisture ingress by being contained in a metal cap sealed with a Shellac varnish to minimize degradation reactions with any contaminants and migration of the sensitive composition into proximal fuze components. As Lead Styphnate is highly hygroscopic, temperature and humidity have an accelerated aging effect leading to decreased sensitivity to spark, flame and mechanical insult [12].

SAFETY DISTANCES

As the construction and depth of the bunker cannot be accurately determined without invasive and destabilizing investigations, safety distances will be calculated according to the worst case scenario of an open mass detonation of all 50 charges. In reality the blast and fragmentation of a mass detonation would be reduced somewhat by the surrounding earthworks and the Southernly / South Easterly direction the entrance/exits to the bunker point; but as previously mentioned, quantifying this would be invasive, dangerous and of little potential mitigation of safety distances.

The following safety distances were calculated using the tools of the UN SaferGuard developed International Ammunition Technical Guidelines. These tools were chosen due to their evidence based development, organizational reputation of the GICHD and other contributors as well as them being a UN backed standard.

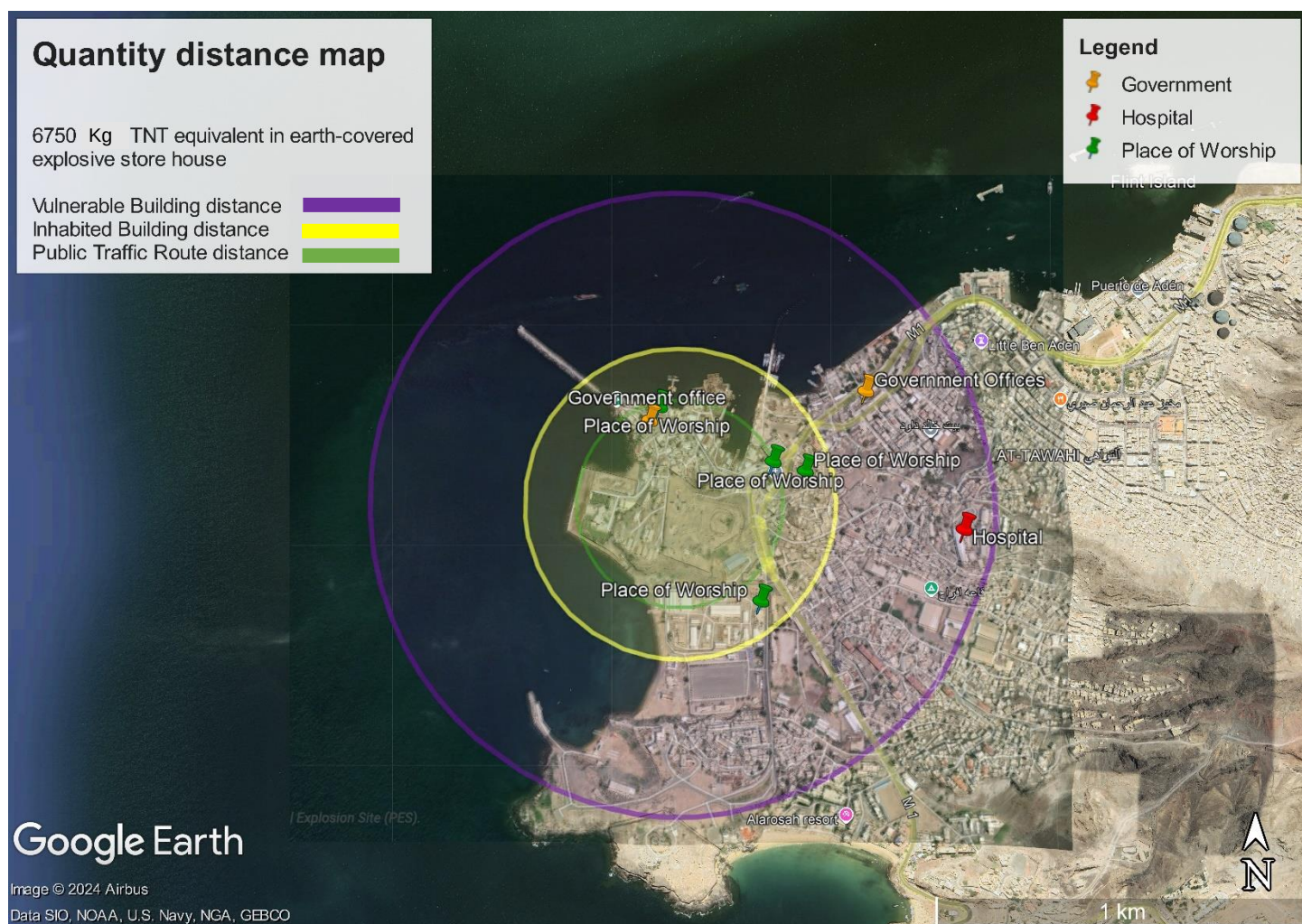


FIGURE 8 - IATG QUANTITY DISTANCE MAP [7] OVERLAYED TO A SATELLITE IMAGE [3]

Figure 8, are based upon international guidelines [4] in order to mitigate the risk of injuries and fatalities to a 'tolerable' level in the vicinity of a Potential Explosion Site (PES). The number of people, buildings and sites of importance within the quantity distance are considerable due to the topography of the peninsula 'pushing' the population into concentrating around the coast.

Vulnerable Building distance refers to a building deemed vulnerable 'by nature of it's construction or function' and as such has the largest radius from the PES. Notable buildings located within the identified area are the Basuhaib Military Hospital, the Ministry of Planning and International Cooperation Office of Aden, multiple places of worship and numerous residential properties of primarily single skinned cinder block construction, Figure 9.



FIGURE 9 - VIEW OF THE SOUTH SECTION OF THE VULNERABLE BUILDING DISTANCE AREA AS VIEWED FROM THE BASUHAIB MILITARY HOSPITAL [10]

The Inhabited Building distance states the minimum allowable distance between the PES and non-associated buildings that require a high degree of protection due to their occupation status.

The Public Traffic Route Distance is the minimum permissible distance from the PES to any public traffic routes such as footpaths or roads that would be subject to 'intolerable danger' in the event of an accidental initiation of energetic material.

		Affected area radius [m]	
Blast Damage category		1 Charge (135.32kg TNT)	50 Charges (6766kg TNT)
Ground Vibration		372.25	2632.18
Window shatter	Small	133.48	491.76
	Medium	215.63	794.38
	Large	482.59	1777.89
Injury / Fatality	Fatality	11.85	43.65
	Lung Damage	18.78	69.19
	Eardrum Rupture	48.29	177.9
Structures	House completely demolished	8.61	87.82
	House badly damaged beyond repair	12.73	129.91
	House uninhabitable, repaired with extensive work	22.23	226.88
	House uninhabitable, repaired reasonably quickly	38.19	389.72
	House habitable, requires repairs	76.7	779.44

TABLE 3 - BLAST DAMAGE DISTANCES

The Fort's footprint is roughly 160m by 140m therefore the physical damage to structures beyond it's footprint would be limited to broken windows should a single charge unintentionally detonate in a central disposal location, see Disposal methodology - Site preparation.

		Danger area radius [m]		Equation
		1 Charge (135.32kg TNT)	50 Charges (6766kg TNT)	
Fragmenting munitions when public access is possible		1437	2758	$D [m] = 634(AUW)^{1/6}$
Fragmenting munitions when public access is denied		1007	1931	$D [m] = 444(AUW)^{1/6}$
Bare exposed explosive only		668	2459	$D [m] = 130(AUW)^{1/3}$

TABLE 4 - FRAGMENT DANGER AREA

While the munitions are thin walled to maximize blast underwater by reducing the energy consumed by rupturing the case; Table 4 contains danger areas for fragments in the principle of ALARP as fragments could be generated from the case, surrounding equipment and structures and cause secondary and quaternary fragmentation injuries.

Noise Danger Area [m]			Equation
	1 Charge (135.32kg TNT)	50 Charges (6766kg TNT)	
140dB	1103.81	4066.45	$D = 215(NEQ)^{1/3}$

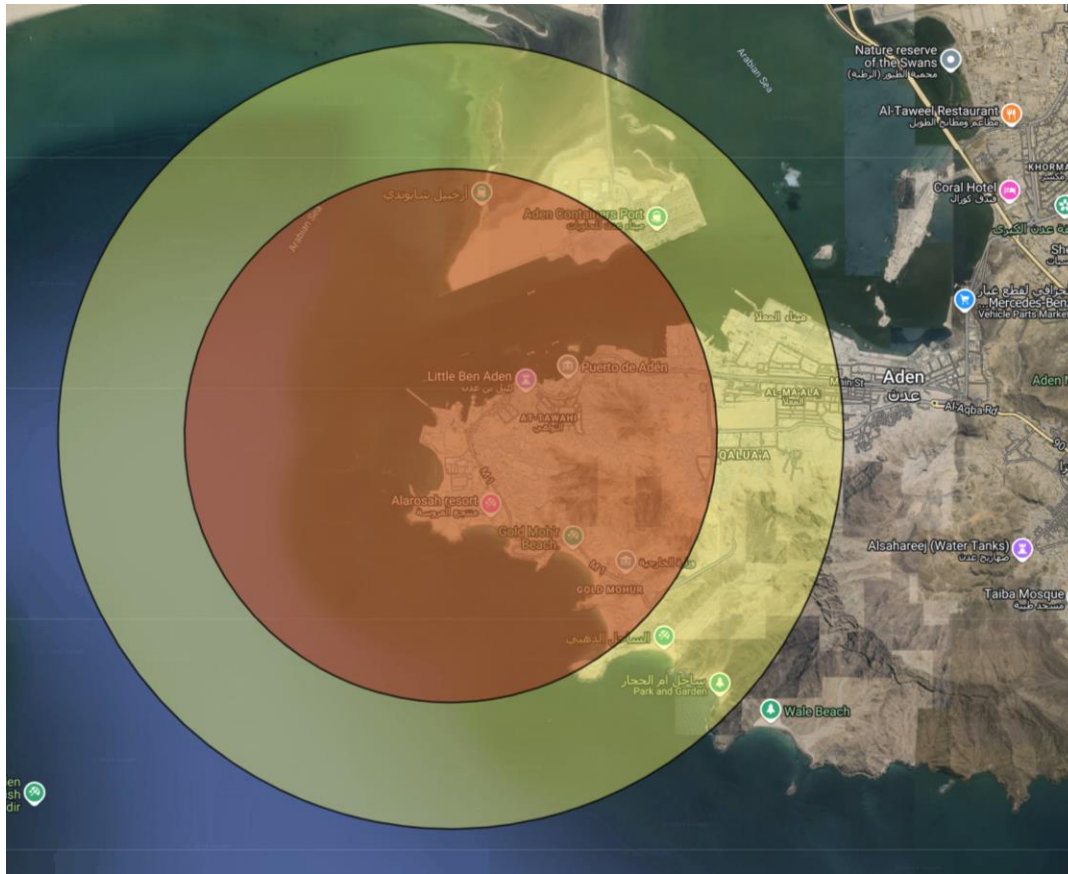


FIGURE 10 - OVERLAY OF 140DB DANGER AREA (YELLOW) AND FRAGMENTATION DANGER AREA (RED)

Figure 10 highlights the high hazard potential of an all up detonation, confirming the need for a disposal plan and strong mitigations to reduce the risks to the surrounding population.

BREAKDOWN METHODOLOGY

As will be discussed in the disposal methodology section, a full munitions breakdown, sectioning and testing regime would be far outside the requirements to inform the procedure and would add unreasonable risk due to the evidence of leaking explosives from the fuze which could either be the main fill, booster or in worst case scenario, the primary compositions. However, elements of this investigation will be explored as a hypothetical to inform the reader of the licensing, regulations, personnel protection and method that inform the approach and mentality behind the disposal method. As Yemen does not have their own standards for explosives processing and storage the standards and regulations discussed will be following international and British law.

At all times the principle of 'As Low As Reasonably Practicable' (ALARP) is applied to risk tolerance.

FACILITY AND LICENSING

Any work must be carried out in appropriately licensed buildings. The licensing authority is the Health and Safety Executive and they will issue limits on hazard type, Net Explosive Quantity (NEQ) and processes that may be conducted. The limits will be decided upon the construction of the building siting compared to existing facilities, quantity distance and potential harm to the public. Local police forces must be applied to for an 'Acquire and Keep Explosives certificate'. The overarching legislation for the licensing system alongside security and record keeping and many other factors are the 'Explosive Regulations 2014'. Any explosive movements must be approved by the relevant national governing body (the HSE in conjunction with the Department for Transport) with the explosive material being packaged appropriately according to a schedule set out within the Competent Authority Document. The electrical installations and equipment are controlled by the Dangerous Substance and Explosives Atmospheres Regulations (DSEAR) and the European 'ATEX' explosive atmosphere directives. Access to explosive areas must be strictly controlled along with contraband controls to prevent unqualified persons accessing explosives with potential sources of initiating the explosives.

TOOLS AND PERSONAL PROTECTIVE EQUIPMENT

Anti-static precautions operate in a similar manner to the hierarchy of safety controls. Any static-generating tooling or materials should first be substituted, then static generation should be prevented and finally if the other stages have failed then any static charges must be dissipated. A base requirement, or first degree precautions for the handling of explosives is to be wearing non static generating clothing i.e. cotton and the avoidance of exposed, isolated conductors in addition to the earthing of all large conductive objects [4]. Anti-static conditions require a minimum relative humidity level of 40% and flooring with a resistance between 10^6 and 10^9 ohms to dissipate any charge. Conducting conditions require a relative humidity of greater than 65% alongside with flooring of less than 10^6 ohms resistance [5].

PROCESS

Assessments for Risk, Work Instruction and COSHH substance must be carried out and peer reviewed to an appropriate level of responsibility. Activities must follow the work instructions set out and 'STOP' criteria must be robust and understood by the operators. It is best practice to follow a 'route card' method with records of awareness and sign off's at each stage of the process.

TEST AND EVALUATION OF ENERGETIC FILLING

CHEMICAL TESTS

Chemical testing will be conducted to determine what explosive is leaking out of the depth charges. TNT deteriorates as it ages with a small percentage of eutectics forming with decreased melting temperature; Di and Mono nitrotoluene have multiple possible isomers with a range of melting temperatures, as low as -10.4°C for 2-Nitrotoluene. This decomposition would be accelerated by the high average summer temperature of over 33°C [2] and the diurnal cycling over time in conjunction with exposure to humidity. Melting of the explosive lead to recrystallization of the TNT into larger crystals that are therefore more sensitive to fracture and friction [18].

Another potential source for the leaking is the Tetryl contained within the booster or, more unlikely, the primary fuze compositions

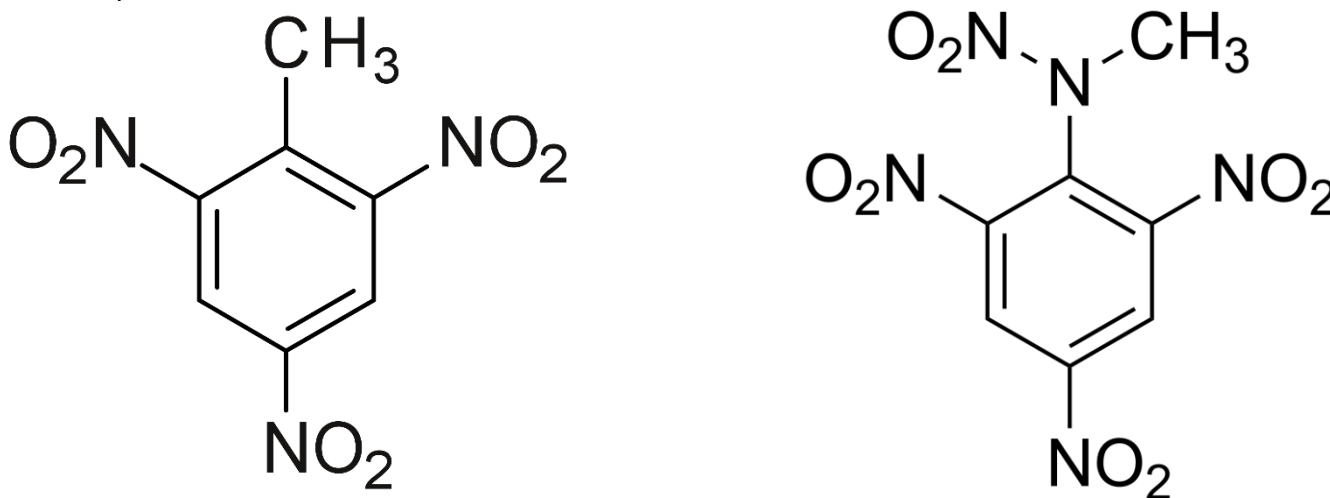


FIGURE 11 - CHEMICAL STRUCTURE OF TNT (LEFT) AND TETRYL (RIGHT)

As Tetryl is more friction and impact sensitive than TNT and could detonate in a high friction environment such as a screw thread, it is critical to determine what explosive is leaking. Explosive swabbing may prove to be inconclusive as it may not be sensitive enough to distinguish between the two explosives when they are both present. As seen in Figure 11 both Tetryl and TNT consist of a benzene ring with three nitro (NO_2) groups. TNT has one additional Methyl (CH_3) group; whereas, Tetryl has the additional Methyl group bonded to a N- NO_2 group. Therefore a secondary confirmation method must be used. Handheld RAMAN or FTIR would therefore be used, handheld FTIR is preferable as RAMAN is less accurate with darker materials/backgrounds.

Handheld RAMAN is more widely available can provide a quantitative analysis of what compound is present and provide certainty to inform the EOD operator of which procedure to carry out. This method of spectroscopy uses a single wavelength laser. When these photons transfer their energy to a molecules bond and excites it to a higher energy level, most of this energy will be emitted as a photon that is scattered elastically when it returns to the original ground state. $0.1 \times 10^{-6}\%$ of these interactions result in the bond returning to a different energy level and thus scattering the emitted photon to a different frequency [3]. This discrepancy is similar for different atom to atom bonds but unique to individual molecules. The main advantage of RAMAN is that little sample preparation is required and it can be more portable, although it is more expensive.

MOLECULE IDENTIFICATION

Between the 4000-1500 cm^{-1} wavelengths the functional groups such as hydroxide (OH) within the molecule can be identified. This region is useful for identifying what the molecule is comprised of but cannot specifically identify compounds. Less than 1500 cm^{-1} wavelengths are known as the 'fingerprint region' and can specifically identify compounds under analysis due to their unique values [4]. Reference material for bond wavelengths and fingerprint regions are widely available and many spectrum analysis software integrate libraries of this data for quick analysis of samples.

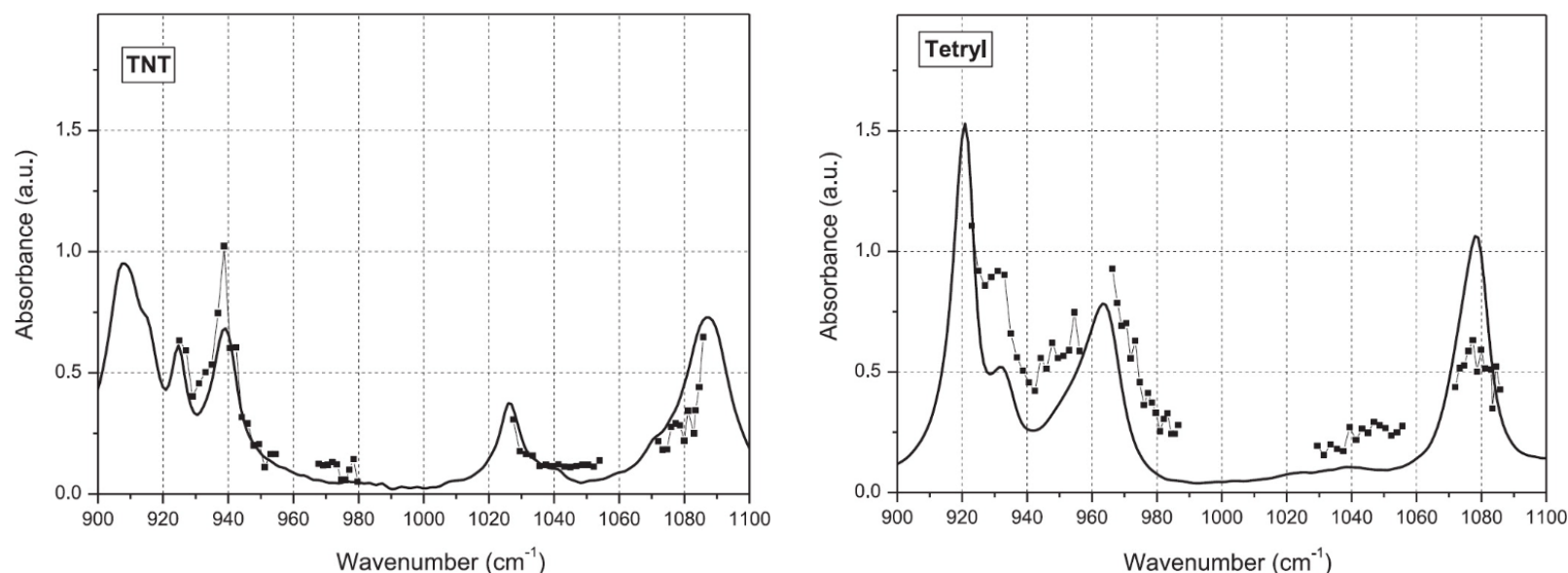


FIGURE 12 - IR SPECTRUM OF TNT AND TETRYL [5]

Further IR Spectroscopy could be used to determine the percentage of eutectics that have formed but this approach is considered above and beyond what is required for the disposal operation as all procedures will follow As Low As Reasonably Practicable (ALARP) tolerance for risk; meaning the exact proportion of decomposition products is inconsequential to the handling techniques used.

HAZARD TESTING

Hazard testing is required to determine the sensitiveness of an energetic material to a variety of stimuli; primarily impact, friction, heat and electric spark. If we are to treat this disposal event as we would in the United Kingdom, then we would test the material under the UN Manual Testing for the Classification of Dangerous Goods. Energetic material must be assigned a classification by the nations Competent Authority; the Health and Safety Executive for commercial energetics the UK, prior to carriage by road or storage [2].

Military explosives are classified by the delegated authority of the Secretary of State for Defence by the Defence, Ordnance, Munitions and Explosives Safety Regulator also known as the Explosive Storage and Transport Classification (ESTC) Committee. Classification is awarded to a material as a result of testing following the Energetic Materials Testing Assessment Policy Manual of Tests (EMTAP). The purpose of EMTAP testing is determine that the material will remain safe and suitable for service when exposed to a normal service life [3].

A basic test regime that can be used to inform the handling and disposal of the material will include, Electric Spark (Test 6), Temperature of Ignition (Test 2), Rotter Impact (Test 1) and Rotary Friction (Test 33). The addition of mallet impact testing would aid the EOD operators in understanding the interaction of various tooling materials with unsympathetic handling of the energetic material. The results of this testing will be collated into an Explosive Hazard Safety Data Sheet.

Spark testing will be conducted first to determine the Electro-static precautions that are required for further handling of the material. Static dissipation levels are determined by the output of the spark test and whether the material requires anti-static or conducting conditions. No ignitions at 4.5J are classified as the material being insensitive to spark. Ignitions at 4.5J but not 0.45J require the material to be handled anti-static conditions. Ignitions at 0.45J but not 0.045J require the material to be handled in conducting conditions.

Tofl testing requires two test tubes containing 200mg of the material. It is then placed in a heating apparatus and subjected to a roughly 4 degree per minute temperature rise. The apparatus is observed and timed when a reaction takes place. Expected outcomes are explosion, flame, smoke, sound or decomposition.

Rotter impact testing determines the impact sensitivity of the explosive by way of 50% probability of initiation at the stated energy. A 5kg mass is dropped onto a brass cap containing a measured volume of 3mm³ of the material within a sealed anvil that is connected to a gas burette to measure the volume of evolved gas. A 'no-go' is recorded by a gas evolution less than 0.5mm³ whereas a 'go' is recorded when gas evolution is greater than 1.0 mm³ or between 0.5 and 1.0 mm³ in addition to a secondary sign of decomposition such as smoke. A Bruceton analysis is conducted where drop height is increased following a 'no-go' and decreased following a 'go' over 50 shots. From this data a Figure of Insensitiveness is calculated to allow comparison between other explosives.

Figures of Insensitivity	
Very Sensitive	Fofl <= 50
Sensitive	50 > Fofl < 100
Comparatively Insensitive	Fofl > 100

TABLE 5 - FIGURE OF INSENSITIVITY COMPARISON TABLE [10]

Rotary friction takes a volumetric amount of sample and places it between a roughened steel block and wheel. The sample is compressed to a set level (40 psi) and a variable speed (following the same Bruceton staircase procedure as the Rotter impact test) flywheel impinges upon the test wheel to impart shearing frictional forces upon the test sample. The Figure of Friction generated from this testing allows for comparison of friction energies between explosives with a value range decreasing in sensitivity from 0 to 6 with the midpoint 3 being the Figure of Friction (F of F) RDX standard. For primary explosives a more sensitive version of the same test is conducted with the pressure reduced to 5 PSI.

Mallet impact is the most 'hands-on' test for the EMTAP operator. It comprises of 60 'shots', 20 of which are conducted with a steel tipped mallet striking a steel anvil on the floor with a glancing blow. The remaining shots are conducted with nylon on steel, hard wood on York stone, hard wood on hard wood and finally hard wood on soft wood. 2 operators conduct the test, doing half of the shots each.

Material	Spark	T of I	Rotter Impact (F of I)	Rotary Friction (F of F)	Mallet Impact
Tetryl	Ignitions at 0.45J but not at 0.045J	183°C	84-108	3.5-5.4	Ignitions Steel on Steel, nil on else
Aged Tetryl	Ignitions at 4.5J but not at 0.45J	174°C	93-114	3.45-4.25	Ignitions Steel on Steel, nil on else
TNT	Ignitions at 0.45J but not at 0.045J	265-302°C	90-120	4.1-4.3	Ignitions Steel on Steel, nil on else
Gunpowder	No ignitions at 4.5J	305-323°C	126-170	Out of range	Nil on Steel
Lead Styphnate (Dry)	Ignitions at 4.9μJ, not at 3.6μJ	268-269°C (Explodes)	19	1.7	
Lead Styphnate (Wet)	Ignitions at 0.9μJ	269-271°C (Explodes)	94	5.8	
VH4	Ignitions at 127μJ but not at 93.6μJ	279°C (Explodes)	7-12	0.1-0.2	

TABLE 6 - HAZARD TEST DATA FOR EXPECTED EXPLOSIVES [23]

This operation would benefit from further research into the effect of aging upon the sensitivity of TNT to various stimuli, though there is some evidence that sensitivity increases with aging [26].

An established method of reducing an explosives sensitivity, wetting, is demonstrated in the results of Table 6 with wetted lead styphnate. Wetting utilizes a solvent to dissolve and lubricate explosive crystals which may be an important mitigation technique that could be employed in the disposal operation.

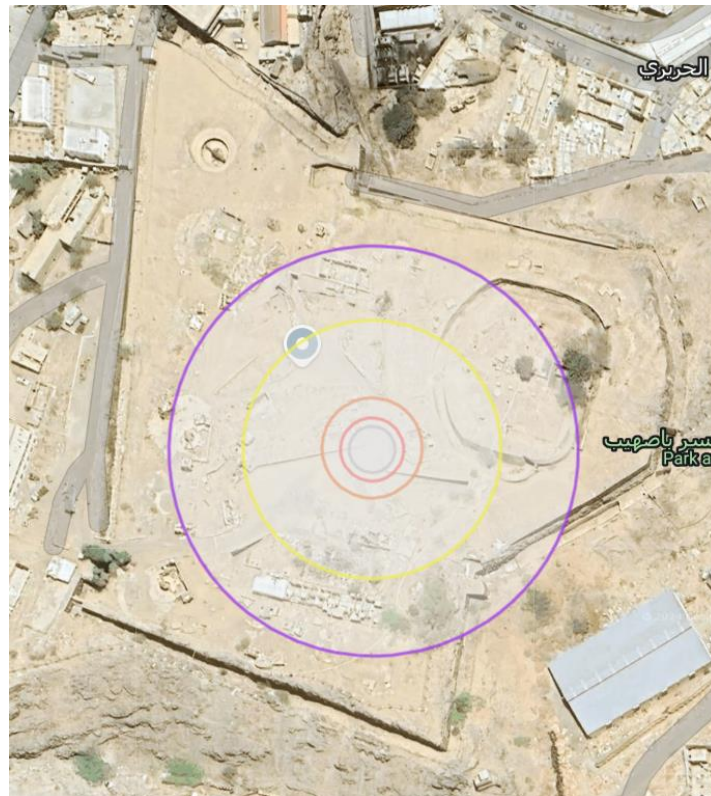
As the fuzes would not be broken down to the level of exposing the primary explosives, and the gunpowder is relatively insensitive; the primary results in Table 6 are that of the secondary explosives TNT and Tetryl. The data informs us to use anti-static handling precautions due to the ignitions of Tetryl at 0.45J but not 0.045J alongside careful handling techniques and non-sparking tools due to ignitions with steel on steel contact. Further to this there is evidence that Tetryl becomes more friction sensitive following aging therefore both factors lead to the recommendation of avoiding fuze removal due to the potential pinching of explosive crystals within the screw threads of the combat plates.

DISPOSAL METHODOLOGY

SITE PREPARATION

Prior to any disposal operations, enabling works must be carried out to facilitate the activities. Subject to site investigation, a command point should be constructed in the north east quadrant; utilizing the existing casemates dependent on their condition, reinforced with 'Hesco' type walls and earth traverses if necessary in order to protect personal from blast and fragmentation in the event of an accidental initiation the potential of which will be highest during the movement of any munitions.

The proposed disposal location is a central point within the fort, latitude 12° 47' 7.12"N longitude 44° 58' 28.99"E; chosen such that in the event of an accidental initiation, serious consequences such as fatalities, injuries and structure damage are contained within the boundaries of the fort as seen below in Figure 13. Further blast mitigation measures are recommended, primarily the construction of a G shaped blast chamber with 'Hesco' type walls and earth traverses. The entrance of this blast chamber can be placed such that the majority of any blast waves can be directed away from the munition storage bunker. The disposal operation being carried out on a single munition at a time reduces the quantity distances to 180m for public traffic routes, 230m for vulnerable buildings and 400m for inhabited buildings seen in Figure 14 keeping the risk As Low As Reasonably Practicable (ALARP). The construction of the burn cell and the topography of the area would mitigate any blast and fragmentation by redirecting the energy upwards and not outwards however the safety traces will remain as unmitigated values to allow for a margin of error.



Damage type	Key – circle colour
Structures demolished	Grey
Fatality	Red
Lung damage	Orange
Eardrum rupture	Yellow
Structures habitable, require repairs	Purple

FIGURE 13 - PROPOSED BURNING GROUND AND KEY

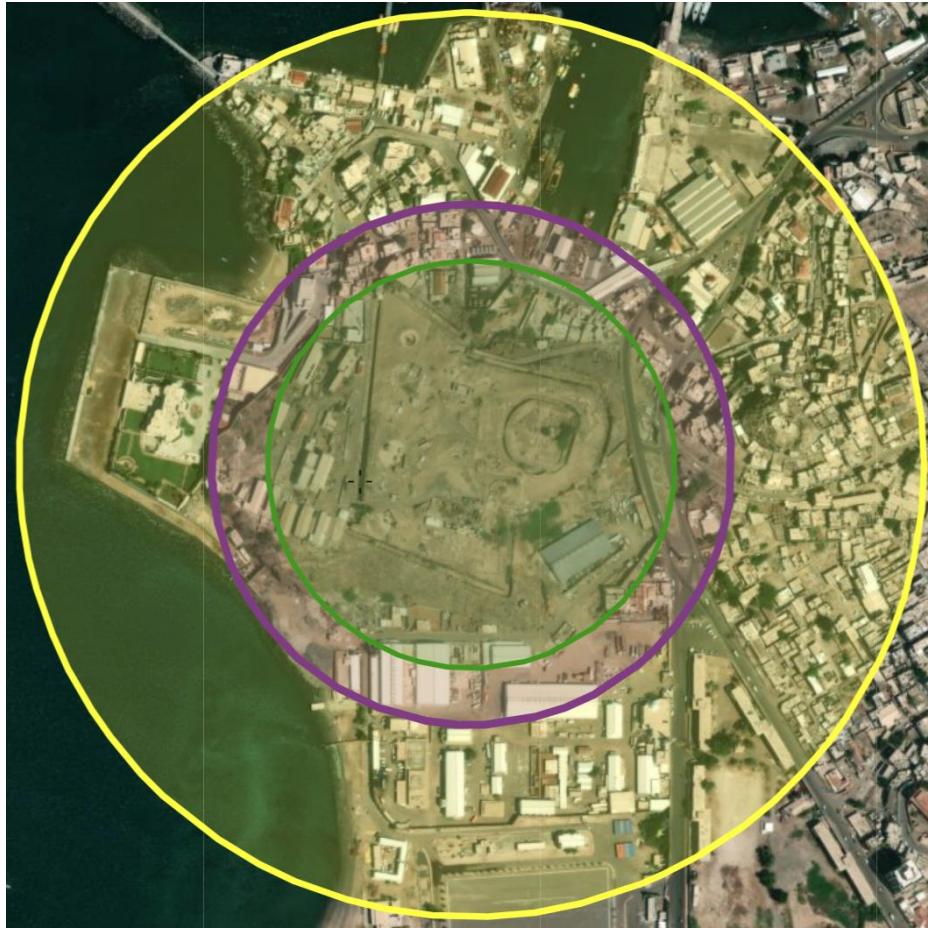


FIGURE 14 - SINGLE MUNITION QUANTITY DISTANCE CENTERED ON PROPOSED DISPOSAL LOCATION

Depending on the impact upon the removal of the munitions; additional blast walls should be considered within the storage bunker or at the openings. Given the large total NEQ contained in the bunkers, blast walls will likely do little to prevent sympathetic detonation. Spacing of the munitions to be greater than the 50% detonation probability distance of 5-6 inches could be implemented however that would introduce substantial additional handling risks and potential chances of errors in conjunction with the layout of the bunker reducing access to carry these maneuvers out.

As is made evident by the QDs in Figure 14, collapsible cordons would need to be in place during disposal operations to minimize potential harm to the public.

It is recommended that lightning protection masts be installed above the bunker and burn cell, however movement and disposal operations must be halted if there is a forecast of lightning in the local area due to the potential for a strike to initiate the munitions.

INSPECTION

Each munition will be inspected visually to ascertain if the fuze is fitted and there is any explosive leaking present. If this is the case then the aforementioned chemical testing will be conducted to determine the composition of the leaking.

Munitions with fuzes fitted will be examined using a portable X-Ray unit [24] to understand the armed status of the fuze. This will be determined by comparing the axial height of the striker cocking position with the information

in the training manuals that have been researched. A secondary examination will be to assess the condition of the hydrostat and striker as they may have degraded to the point of seizing. Any fuzes that are armed (cocked striker) will have the strikers immobilized with a Freeze Neutralising Kit [25] such that the strikers will not be able to penetrate the friction sensitive primer cap and therefore initiate the explosive train.

Any munitions that show signs of explosives leaking out of the combat plate screw threads will be swab tested as well as have handheld IR spectroscopy in order to determine what composition is present.

A formal inspection and safe to move decision flowchart can be found in Appendix A – Safe to move decision.

MOVEMENT

All actions will be conducted remotely with minimal operator intervention. Any operator actions would be reduced to a single man risk. A heavy duty Daksh ordnance removal robot, capable of lifting munitions up to 1000kg [24] will be utilised to remove each munition at a time. The DAKSH can be operated with the user at a 500m standoff using wireless communication which is possible as the munition does not contain any Electro-Explosive Devices. Should this method fail, a concern at the apex of the bunker's horseshoe, a traditional hook and line method will be employed. The munition will then be deposited in the centre of the G shaped burning cell. From what is observed in Figure 3 and Figure 4, the external banding of the packaging will then need to be cut and the munition rolled off onto an emplacement of sandbags with a roller mechanism such that the munitions can be rotated.

RENDER SAFE PROCEDURE (RSP)

Due to the aforementioned contamination around the threads of the combat plate the fuzes will not be removed from the munitions and any in an armed status will have their striker mechanisms immobilized by freezing. A consequence of the presence of the fuzes and the increased impact sensitivity of the degraded TNT, traditional low order deflagration techniques are unsuitable due to the increased chance of an accidental initiation [24]. These traditional techniques, using shaped or cutting charges such as 'Baldrick', operate on the principle of disrupting the case of the munition and imparting sufficient energy to the main fill to initiate a deflagration but not enough energy in the form of shock such that a detonation of the main fill occurs. These deflagration techniques routinely achieve a low order rate of 80% in traditional disposal operations [25].

Other techniques such as pyrotechnic and thermite based charges were considered due to low noise signature and reduced regulatory burden for shipping and storage as well as lower attraction to terrorist groups for theft; but the evidence of unreliability [31] and hazard to the fuze [32] ruled them out.

Movement to external disposal locations and demolition at sea are inappropriate due to the condition of the munitions, the hazard and disruption to the local people and area alongside the ecological consequences of water contamination and harm due to Sealife and shipping with underwater blasts.

As a result of these technical considerations alongside the desire to minimize disruption to the substantial local population; steaming out the main fill has been chosen as the recommended RSP. This method allows for the fuze to remain fitted and will not result in the noise and disruption of other methods.

To enable steaming access, pressure relief and drain holes must be cut into the case. The recommended cutting tool is ANT AG's abrasive waterjet cutting equipment MACE. This equipment has been specially developed for use on munitions which fuzes cannot be removed and the main fill may have chemically degraded as is the case in this scenario [26]. There is great confidence in this system particularly as it has been demonstrated to cut through detonators without initiating the primary explosives within.



FIGURE 15 - DAKSH UXOR FITTED WITH MACE CUTTING SYSTEM AND SECTIONED DETONATOR EXAMPLE [26]

DISPOSAL OF ENERGETIC MATERIAL

With the access, pressure relief and drain holes cut steaming out equipment such as the 'CSL 32 SG with SOE' from Richmond Defense Systems [27] will be fitted to the inlet hole. The steam at 100°C is considerably lower than the minimum temperature of ignition present within the munition of Tetryl at 183°C; allowing the TNT main fill to be melted out in the inverse operation of how the charge would have been filled (melt-cast) during manufacture. The liquid TNT would be drained during the steaming process into a metal catch tray. With the case empty of TNT, two open burns will be conducted to dispose of the energetic materials; one of the TNT in the catch tray and another of the munition case containing the fuze. These burns will be initiated using a pyrotechnic igniter and sufficient accelerant such that a complete combustion occurs. Should there be reason to believe that the fuzes still contain explosives, then a final demolition will be carried out using plastic explosive to ensure the fuze is rendered safe. Any demolition will occur on a last resort basis due to the disruption cause to the surrounding area.

DECONTAMINATION OF AREA

The de-militarized cases can be scrapped in a manner that may provide funds for the expenses of the operation and any explosive contaminated waste such as PPE will be disposed of by cage burns. While care must be taken during the steaming out process to prevent any TNT contamination of the surroundings, any explosive not contained within the catch tray must be subject to further disposal by burning.

CONCLUSION

The OME students were presented with a brief regarding the delivery of technical support to the disposal of Explosive Remnants of War. The group worked collaboratively and individually to deliver a presentation to a panel of academic and industry professionals alongside individual reports. They reviewed primary and secondary sources of information such as reports and industry experts to critically analyse information with their developing experience to develop a solution to the ERW disposal scenario. A proposed disposal method of steaming and open burning was developed with the justification for which evidenced and analyzed. This method was developed to minimize impact upon the local population which are vulnerable due to ongoing conflict, famine and displacement.

The group worked well together, dividing the workload appropriately, capitalizing on existing strengths and experiences while being exposed to new challenges and development.

While the GICHD Vietnam Aging Study was vital as reference material for this report, it too highlighted the lack of research and evidence regarding the aging and degradation of munitions and how this affects disposal operations. There is a clear need for further work to ensure EOD operators and the general public can be kept safe by establishing rigorously evidenced best practices.

The author has found this work to be a fulfilling conclusion to the OME course; however the knowledge that this scenario is real and not unique in the wider world has sparked concern and an interest in furthering their knowledge in the field of ERW clearance and the great work of organisations such as GICHD and the HALO Trust.

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APPENDIX A – SAFE TO MOVE DECISION

Safe to Move Decision

