



James Burton

Risk assessment and ALARP Justification

University of Wales Trinity Saint David
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Supervisor: Austin Clark

Abstract

This report is to utilise hazard identification (HazID) and hazard operability (HazOP) techniques to perform an in-depth risk assessment of a 115mm large calibre gun. It includes a task description, hazard description, pre-control risk estimate, list of controls and mitigations, post-control risk estimate, the manufacture to target disposal sequence and an 'As Low As Reasonably Practicable' (ALARP) justification.

Keywords:

ALARP, HazOP, HazID, Hazard, Risk, Risk Assessment

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List of Abbreviations

ALARP	As Low As Reasonably Practicable
HazID	Hazard Identification
HazOP	Hazard Operability
MTDS	Manufacture To Disposal Sequence
PPE	Personal Protective Equipment

1 Risk Assessment

1.1 Task Description

For the first part of the report, a complete Hazard Identification (HazID) and risk assessment was conducted on the 115mm large calibre gun, specifically during its field use phase with regards to the phase in which was analysed in the manufacture to disposal sequence (MTDS).

Initially the group involved undertook an exercise of identifying the hazards, any justification for the identification and cause where an event might take place, in relation to the hazard identified. This can be seen in [Appendix 1](#).

Each member described and discussed the description of their hazard, how the hazard may present itself and what the likeliness, severity and overall risk classification would be if the hazard was uncontrolled.

1.2 Hazard Descriptions

The six hazards identified can be described as follows:

1.2.1 Explosion

Explosive hazards are primarily associated with the munition, where the munition could be subject to unintentional detonation for the following reasons:

- Incorrect handling of the munition
- Incorrect storage of the munition
- System suitability, i.e. does the munition fit inside the weapon system and is the system designed to handle the pressure generated by the firing of that munition
- The environment that the munition is used in
- How the munition is disposed of

If any of these things are not compatible with the munition, then explosion risk is probable and the severity would be catastrophic, potentially leading to the deaths of multiple people.

1.2.2 Electrical

Electrical Hazards were identified into two categories, either electrical shock to the person, or electrical damage to the system which in turn could lead to harm of a person or people operating the system. An electrical hazard could also easily lead to an explosive incident in the event it caused unintentional initiation of the system.

1.2.3 Toxicity/Fumes

Toxic fume hazards are associated with the firing of the weapon system, where gases are produced from the initiation of any propellant, which could lead to asphyxiation or poisoning of a person or people in the vicinity.

1.2.4 High Pressure Gas

Another byproduct of firing the weapon system is high pressure gas, which is produced as a result of the initiation of propellant. This was identified as a hazard which could cause physical harm to a person or people, where it can lead to extreme pressure exposure to a person's body, maybe even penetrating the skin in some circumstances.

1.2.4.1 Heat

As a result of firing the system, heat is generated both in the atmosphere and in the system, usually through the barrel but occasionally through other components also. This could lead to severe burns if exposed to a person or people.

1.2.5 Noise

Noise was identified as something associated with all weapons systems and is one of the most widespread hazards across the defence sector. It can lead to reduced hearing capacity and even deafness, but also the inability to hear other possible issues which may present as sound. Whilst not normally fatal, it is something which is guaranteed regardless of any controls and mitigations and needs to be understood on how to mitigate to the best ability.

1.3 Pre-Control Risk Estimate

A pre-control risk estimate was discussed and described within the group, where external factors were considered to inform the decisions made.

1.3.1 Explosive

Explosives are inherently dangerous due to detonative factors, therefore not incorporating any control measures was deemed extremely dangerous as an explosion would almost certainly cause multiple fatalities, although it is assumed that the explosives were unlikely to detonate unintentionally under normal conditions.

1.3.2 Electrical

Electrical hazards, whilst an incident would also be critical to the system and its operators, they were deemed improbable to take place due to modern ISO standards and use case situations, such as artillery and mechanically triggered and driven systems.

1.3.3 Toxicity/Fumes

Fumes were identified as a frequent likelihood of occurrence due to being produced during every single shot from the propellant, with the severity of the effect classed as severe due to potential issues such as asphyxiation and long-term toxic exposure poisoning

1.3.4 High Pressure Gas

Similarly, when fumes are produced, they are produced at high pressures due to the nature of the propellant requiring high force to drive the projectile. High pressure gas injuries were deemed critically dangerous as they could lead to a long-term injury or even death of an individual.

1.3.5 Heat

Heat was also identified as another byproduct of propellant use, where repeated action and production of hot gas was deemed frequent, transferring to structure

materials creating hot surfaces on the weapon system, which could lead to severe burns and long-term injuries.

1.3.6 Noise

Noise was also considered frequent due to the firing of the weapon system and is well understood due to its loudness as a long-term health hazard.

1.4 Risk Assessment Application

Combining the HazID from [appendix 1](#), the hazard descriptions in [appendix 2](#) and the pre-control risk estimate, a full risk assessment was conducted on the use of the 115mm large calibre gun, including classification of hazards when uncontrolled, then any controls and mitigations, and how those controls may reduce the likeliness, severity and therefore risk classification as a result. This can be seen in [Table 1](#).

Hazard	Description	Uncontrolled Hazard Probability	Uncontrolled Hazard Severity	Uncontrolled Risk Class	Controls	Mitigations	Controlled Hazard Probability	Controlled Hazard Severity	Accident	Controlled Risk Class
Explosion	Unintended Initiation of the munition.	Remote	Catastrophic	B	Ensure Explosive train is out of line/an interrupter isolates the detonator from the main charge [5]. Ensure explosives have sufficient thermal liners and venting features to prevent cook off [6]. Ensure ammunition contains high frequency shielding and electrostatic discharge safeguards [5].	Strict exclusion zones [1]. Identify and avoid reactive ground [2]. Carry minimum explosive quantity requirements [3]. Discard used or misfired explosives correctly [4]. Distance between munition stores and munition quantities as per HSE Explosives Regulations 2014 [20]	Incredible	Catastrophic	Death of personnel due to explosion Grievous injury from shrapnel debris	C
Electrical	Electrical discharge from the system during use.	Improbable	Critical	C	Ensure system has suitable faraday shielding enclosures around any electronic fuzes and electrical primers [7]. Ensure the system is fitted with the correct electrical safety breaks and in-line isolation [8].	Restricting or shutting off high power radio, radar and electronic countermeasure transmitters on the system during ammunition and gun loading phases [9].	Incredible	Marginal	Electric shock to personnel Unintended initiation of firing system Damage to firing system circuitry	D
Toxicity/Fumes	Fumes produced by deflagration of propellant within the firing.	Frequent	Critical	A	Ensure sufficient venting of system during use [10].	Strict Exclusion Zones [1].	Incredible	Negligible	Asphyxiation Poisoning	D
High-Pressure Gas	High-Pressure gases produced by deflagration of the propellant.	Frequent	Critical	A	Ensure sufficient and suitable venting of system during use [10].	Strict Exclusion Zones [1].	Incredible	Negligible	Physical harm to affected personnel	D
Heat	Hot byproducts of firing, particulates and residual heat on weapon system.	Frequent	Marginal	A	Thermal Sleeves and Shrouds [11]. Chemical wear-reducing propellant additives [12].	Active cooling operations [13].	Improbable	Negligible	Burns	D
Noise	Noise produced by the use of the weapon system.	Frequent	Critical	A	Muzzle blast deflectors and brakes [14]. Acoustic turret isolation bulkheads [15].	Double layer hearing protection (PPE) [16, 17].	Improbable	Negligible	Loss of hearing	D

Table 1 - Risk Assessment

2 ALARP Justification

As Low As Reasonably Practicable (ALARP) is the practice of reducing risk to the minimum possible within the confines of the task specification. What this means is that judgement needs to be made as to whether a risk reduction control or mitigation is seen as valuable to the task as given, and that control or mitigation is measured against safety, such as is described by the risk matrix, as well as cost, with the only absolute being that no risks can be classified as intolerable. [18]

For this part of the report, the task will be broken down into components, justifying the control measures and mitigations which were applied to the explosion hazard in the risk assessment, as well any control measures and mitigations which weren't included in the risk assessment and why they were not.

2.1 List of Controls and Mitigations

For this section, instead of listing hazards and their associated controls and mitigations, the actual controls and mitigations themselves have been listed, and their associated hazards have been attributed, allowing multiple hazards for some controls and mitigations, as well as a list of controls and mitigations which weren't applied, with justification. It is important to note that whilst not all the controls and mitigations listed below are direct controls for the explosion hazard, they can lead indirectly to the unintended initiation of the explosive.

2.1.1 Controls

Controls are proactive, preventative measures implemented to reduce the likelihood of an unwanted event happening.

2.1.1.1 Explosive Train Out of Line/Interrupter

Ensuring that the explosive train is kept out of line, or the introduction of an interrupter, particularly during transport and storage, prevents any accidental event from compounding by halting the process where initiation of sensitive aspects of the munition would lead to detonation of the insensitive element, causing a greater explosion. This is applied to the explosion hazard only [5].

2.1.1.2 Thermal Liners and Venting

Thermal Liners and sufficient venting mechanisms prevent heat build-up which may lead to cook off of the explosive, which is the unintentional detonation due to thermal energy buildup surpassing the initiation requirement, as well the transfer of heat through other materials in the weapon system, which could cause component damage and make the system operate unintentionally [6,10,12]. This control can be applied to the manufacture of the munition as well as the in-service phase of the munition's lifecycle, for maximum safety at all stages.

2.1.1.3 High Frequency and Electrostatic Discharge Shielding

Shielding from high frequency radio waves and electrostatic discharge is important as it creates a barrier where electrical systems, either in the environment or as part of the system, may lead to unintended firing of the weapon system, damage to the weapon system, or in worst case scenario premature/unintended detonation of the munition. [5,7].

2.1.1.4 Electrical Safety Breaks/in-line isolation

Electrical safety breaks and in-line isolation components also prevent unwanted electrical discharge through the system, by sending unintended electrical signals either to ground or halting them in their tracks and maintaining them within an isolated system. This reduces risk of any electric shocks to the operators and/or sensitive munitions and therefore reduces the chance of unintended initiation [8].

2.1.1.5 Chemical Wear Reducing Propellant Additives

Chemical wear reducing propellant additives assist in three ways:

- Prevention of wear and therefore reduction in hot particulate byproducts
- Thermal shielding on the components, where the additive acts as a barrier which removes heat quickly, similar to active cooling.
- Reduction of friction across the barrel, both reduction friction induced heat and wear of the barrel.

In turn, this control can dramatically reduce the heating and heat related hazards of the weapon system, which could lead to cook off of the munition [12].

2.1.1.6 Human Physical Interposition

Human physical interposition is the act of having someone manually watch, from close range, the operation of the system, checking that munitions have successfully fired or casings have been discarded from the barrel. This was a control measure which was not introduced as it is deemed far too unsafe for the individual, as they would have to sit inside any exclusion's zones and at close proximity to a live weapon firing.

2.1.2 Mitigations

Mitigations are reactive protective measures, designed and implemented to reduce the severity of a hazard, should it present itself.

2.1.2.1 Exclusion Zones

Exclusion zones form the basis of most safety mitigations across all hazards, where there will be areas where personnel are either strictly unable to occupy, or where there is a controlled access to, reducing the number of personnel affected by any hazards which may unfold [1].

2.1.2.2 Identifying and Avoiding Reactive Ground

It is important for personnel who may be operating or controlling the operation of to understand the environment in which the weapon system is operating, in order to identify and avoid reactive ground which could cause the munition to unintendedly or prematurely detonate [2].

2.1.2.3 Carry Minimum Munition Quantity

Carrying the minimum required munition quantity ensure that in the event of an unintended detonation, the minimum amount of explosive damage is done to the weapon system, personnel and environment [3].

2.1.2.4 Discarding of Used or Misfired Munitions

Ensuring that used or misfired/faulty munitions are discarded in the appropriate manners is important so not to cause any unintentional damage to the system, where they may jam the weapon, cause residual heat within the weapon system which may lead to unintentional detonation or even unintendedly detonate in the

event of a misfire [4]. This specific mitigation also applies to the safe disposal of the munition

2.1.2.5 Maintain Safe Distances Between Munitions

As per HSE Explosives Regulations 2014, it is important to maintain safe distances between stored munitions, reducing any chain reactive effect which may occur [20,21].

2.1.2.6 Equipment Shut Off

Ensuring high power equipment such as radio, radar and electronic countermeasures reduces any disruption in electronic signals sent through the weapon system, therefore reducing electrical hazards which may lead to unintended initiation of the munition [9].

2.1.2.7 Active Cooling Operations

Active cooling operations dramatically reduce the buildup of heat in the system by removing any heat through a cooling medium, as well as creating a barrier. This mitigation acts in a similar way to the chemical wear reducing additive control [13].

2.1.2.8 Training

The training in handling, use and disposal of the munition by personnel, whilst not explicitly listed, forms a large part of the mitigation process. As per the Explosive Regulations 2014, the Health and Safety at Work Act 1974, and The ministry of Defence JSP 482 Explosive Handling Regulations, there is a legal requirement for employers to ensure personnel involved with any stage of the munitions lifecycles are competent, appropriately supervised and adequately trained to handle, any explosive munitions [20, 21, 22, 23], JSP 482 and the Health and Safety Executive also state that adequate training should be given, where required, on how to safely dispose of any explosive munitions [23, 24].

2.1.2.9 Correct Labelling of Sensitive Munitions

Ensuring all sensitive munitions are labelled correctly assists in the prevention of misunderstanding or misidentification of sensitive munitions. This is stated as

something which must be done prior to leaving the manufacturing site or entering the UK [21].

2.1.2.10 Remote Operation

Remote operation was a mitigation which hasn't been implemented as a remotely operated munition would be far too expensive to design and manufacture, especially against any extra safety it would bring compared to using other, much cheaper to implement mitigations.

2.2 Post-Control Risk Estimate

The explosion hazard poses the single greatest threat to the weapon system, its operators and any nearby personnel involved with the operation or as part of the operation, such as escorts. As a result, the control measures had to be robust enough to ensure the munition would remain safe under any circumstances, with the mitigations ensuring that in the event of an unintended initiation, the minimal number of people would be harmed through the manufacture, in service use and disposal stages of the lifecycle of the munition. Although strict control measures have been put in place to reduce the likeliness of an unintended detonation of the munition to near zero, even with all mitigations in place, an accidental event could easily still lead to the deaths of one or more personnel throughout the munitions lifecycle, therefore the post risk control estimate still sits within the C category.

Some mitigations, training and labelling, were not explicitly included in the risk assessment against the explosion, as the provision of this is either considered common sense, or forms part of the legislation from the manufacture and does not necessarily form part of the use of the weapons system.

It is also important to note that one control, human physical interposition, and one mitigation, remote operation, were analysed in detail and concluded that the cost in both human safety and munition design and manufacture costs in comparison to the safety provided by the other controls and mitigations.

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4 Appendices

4.1 Appendix 1 - HazID Group Exercise

Hazard	Owner	Justification	Causal Pathway (Accidents/causes)
Explosion	Tom	Complete failure of the system, potential for multiple unintended casualties.	1. Electrostatic Discharge 2. Low Drop (Unpackaged) 3. Insensitive Munition Threats (Fragmentation attack, Bullet Impact, Shaped Charge Jet, Sympathetic Reaction, slow and fast heating) 4. Electromagnetic Radiation 5. Hangfire and Misfire
Electrical	George	Required for firing the system, has the potential to cause an unintended injury/fatality.	1. Damage from animals 2. Lightning 3. Electromagnetic Radiation 4. Environmental effects (Inclement weather/exposed cabling) 5. Degradation (Maintenance) 6. 6. Water Ingress
Asphyxiant/Toxicity	James	A byproduct of using the system that has the potential to cause serious harm to personnel.	1. Toxic fumes from propellant

High Pressure Gas	Joseph	A byproduct of using the system that has the potential to cause serious harm to personnel.	1. Misfire 2. 2. Breach failure (Obturation, firing at increased temperatures, damaged (aged) munition, poor assembly, Seal wear)
Heat	Pippa	A byproduct of using the system that has the potential to cause harm to personnel.	1. Repeated Use 2. Hot casing 3. Residual heat in system 4. Electrical fault 5. 5. Hot gases and particulate
Noise	Charlotte	A byproduct of using the system that has the potential to cause serious harm to personnel, and general public perception.	1. Firing the system creates noise 2. Projectile Explosion 3. 3. Breach mechanism

Table 2 - Hazard Identification, Justification and Causal Pathway

4.2 Appendix 2 - Risk classification matrix and definitions of terms

Likelihood ↓	Severity →	Catastrophic	Critical	Marginal	Negligible
Frequent		A	A	A	B
Probable		A	A	B	C
Occasional		A	B	C	C
Remote		B	C	C	D
Improbable		C	C	D	D
Incredible		C	D	D	D

Table 3 - Risk Classification Matrix

Frequent	1.0×10^{-2}
Probable	1.0×10^{-3}
Occasional	1.0×10^{-4}
Remote	1.0×10^{-5}
Improbable	1.0×10^{-6}
Incredible	1.0×10^{-9}

Table 4 - Likelihood Definitions

Catastrophic	Multiple fatalities of associated personnel and/or single fatality of non-associated personnel. Long-term environmental impact or complete loss of a facility.
Critical	Single fatality of associated personnel and/or a long-term injury to non-associated personnel.
Marginal	Medium-term injury to associated personnel and/or short-term injury to non-associated personnel.
Negligible	Short-term injury to associated personnel.

Table 5 - Severity Definitions

A	Intolerable risk, not possible to assign ALARP status. Activity only to be authorised during operations under a critical necessity for the activity.
B	Tolerated risk on agreement there is work ongoing to reduce the risk class through controls and mitigations before considered ALARP.
C	Tolerated risk with a higher severity.
D	Tolerated risk with a low severity.

Table 6 - Classification Definitions