

Safety & Hazard Assessment – 115mm Shell

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Figure 1 – Cross-section of 9x19mm bullet [1]

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List of Acronyms

ALARP	As Low as Reasonably Practicable
AOP	Allied Ordnance Publication
CDG	Carriage of Dangerous Goods
DSEAR	Dangerous Substances and Explosive Atmospheres Regulations
EMI	Electromagnetic Interference
EMR	Electromagnetic Radiation
HE	High Explosive
HERO	Hazards of Electromagnetic Radiation to Ordnance
HSE	Health and Safety Executive
MHE	Manual Handling Equipment
MSER	Manufacture and Storage of Explosives Regulations

Scope of assignment

This assignment aims to perform a Hazard Risk Analysis on a test case of a 115mm explosive shell used within a theoretical tank style platform. An analysis on the use of Haz ID, Risk Estimation, Control/Mitigation and the ALARP principle will also be conducted alongside the production of a hazard matrix.

1. Introduction to Safety Management and Hazard Assessment

The management of hazards within the UK explosives sector, typically in defence, requires a systematic and thorough approach to identifying, analysing and controlling hazards with the intent to reduce the risk to people and property. The driving concept surrounding the concept of 'have we done enough' revolves around the ALARP principle. This stands for As Low as Reasonably **Practicable**. Within that declaration, the keyword is practicable. Not all potential controls or mitigations for a hazard are appropriate to implement as in some situations the cost of the implementation is not reasonable for the duty holder to implement either due to lack of risk reduction or an extreme cost.

A control is a measure put in place to reduce the likelihood of the hazard presenting itself to associated and/or non-associated personnel to the activity.

A mitigation is a measure that reduces the severity/impact to those presented with that hazard whereby the controls did not prevent the cause. A failure to prevent a cause is not necessarily a disqualification of the controls put in place however an ALARP justification is required to be maintained as proof that as much as possible has been put in place to prevent such occurrences.

Within explosive engineering the following is a non-exhaustive list of important legislation and regulation surrounding the manufacture, storage, transport and use of explosives within the UK which should be referred to when assessing hazards for explosive devices:

- Explosive Regulations 2014.
- Health and Safety at Work Act 1974.
- Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR).
- The Manufacture and Storage of Explosives Regulations 2005 (MSER).
- The Carriage of Dangerous Goods Regulations (CDG).
- The Control of Explosives Precursors and Poisons Regulations 2023.
- The Control of Explosives Regulations 1991.

2. Risk Assessment

2.1. Task/System Description

The system to be covered is a 115mm HE (High Explosive) ammunition used within a smoothbore cannon. This cannon is assumed to be in use within a tank style vehicle and will have the hazards driven from such a use case. The scope of the hazard ID and hazard log is the firing of the munition from the vehicle only. To perform analysis of each hazard, the bowtie method was used to identify the causes of each of the hazards and allow for clear identification of where the controls and mitigations contribute to the safety of the user. A HazID was performed however the analysis of each identified hazards follow in the next sections of the report.

2.2. Identified Primary Hazards

2.2.1. Unintended Explosion

Unintended Initiation of the munition is a catastrophic event whereby the munition's propellant or explosive fill deflagrates or detonates. This is induced by unintended stimuli; to include static from ungrounded personnel, EMR from radars and other high-power systems, shocks from drops and threats from opposing forces. High Explosives are a Class 1 Explosive (1.1) as per the UN classification system and would require significant care during its operation. The worst-case consequence for this hazard is the immediate loss of vehicle and its crew putting this hazard as the most critical to cover within the assessment. A bowtie analysis of this hazard has been completed:

Threats	Controls	Mitigations	Consequences
ESD	- ESD insensitive primaries (immunity threshold). - Limit EMI within area. - Avoidance of insulating materials in design. - Grounding.	- Limit access to range area. - Limit personnel conducting task. - Distinguish appropriate NO FIRE/ALL FIRE currents. - Surge lockout for fire control. - Physical barrier between involved personnel and others.	- Premature Initiation. - Catastrophic damage to gun and turret. - Personnel casualties. - Vehicle destruction.
Drop	- Manual handling training/procedures. - Ensure design weight of munition meets HFI requirements. - Ensure munition is shaped in a carriable way.	- Limit access to range area. - Limit personnel conducting task. - Post-drop inspection.	- Premature Initiation - Personnel casualties
IM Threats	- Limit system exposure to operational threats. - Determine IM signature of munition. - Preventative barriers. - LOVA/IM complaint igniter/propellant materials. - Fire suppression system.	- Venting/Blow off panel. - Fire suppression system. - Appropriate storage to reduce sympathetic risk.	- Premature Initiation. - Catastrophic damage to gun and turret. - Personnel casualties. - Vehicle destruction.
EMR (HERO)	- ESR Tested primaries (immunity threshold). - Shielded design. - Grounding.	- Limit access to range area. - Limit personnel conducting task. - Distinguish appropriate NO FIRE/ALL FIRE currents.	- Premature Initiation. - Catastrophic damage to gun and turret. - Personnel casualties. - Vehicle destruction.
Hangfire / Misfire	- Reliability testing of design. - Suitable firing mechanism.	- Limit access to range area. - Limit personnel conducting task. - Ensure Hangfire/Misfire procedures followed. - Anti-Hangfire interlock	- Delayed Initiation - Unknown condition of munition.

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Table 1 - Bowtie hazard analysis of Unintended Explosion

2.2.2. Electrical

The electrical hazard of operating the system comes from the use of electronic firing circuits and/or fire control circuits which are located near the user during use of the system. Below is the bowtie analysis of the hazard represented using bullet points:

Threats	Controls	Mitigations	Consequences
Damaged Cables	- Frequent inspections. - Minimum bend radius. - Appropriate polarity marking. - Protected cabling.	- Circuit breaker installation. - Grounded chassis.	- Short circuit/Arc flash. - Electrical fires. - Unintended firing. - Shock to personnel.
Lightning Strike	- Lightning rod/dissipation mechanism. - Insulated crew compartment. - EMI resistant design	- Firing pulse lockout. - Self-test diagnostics.	- Damage to system. - Unintended firing. - Shock to personnel.
EMR	- Limit EMI within area. - EMI resistant design	- Firing pulse lockout. - System state retention.	- Unintended firing. - Shock to personnel.
Environmental Effects	- Environmental testing (00-035). - Robust design. - Vibration/Shock testing. - Sealed enclosure.	- Self-test diagnostics. - System state retention.	- Unintended firing. - Shock to personnel.
Water Ingress	- Sealed enclosure. - Cable routing to avoid floor/pooling. - Protected cabling.	- Firing pulse lockout. - Self-test diagnostics. - Self-test diagnostics. - System state retention.	- Short circuit/Arc flash. - Unintended firing. - Electrical fires. - Shock to personnel.

Table 2 - Bowtie hazard analysis of Electrical

2.2.3. Toxicity/Fumes

The hazard for Toxicity/Fumes is produced by the deflagration of the munition's propellant which produces a complex mixture of combustion products. High rates of fire heighten the risk by increasing the concentration of these fumes in the same area if not dealt with. Below is the bowtie analysis of the hazard represented using bullet points:

Threats	Controls	Mitigations	Consequences
Toxic Fumes	- Bore evacuator installed on barrel. - Ventilation system. - Lead-free/non-toxic compositions.	- Limitation of fire rate. - Respiratory protective equipment. - Air monitoring system.	- Lung damage. - CO poisoning. - Heavy metal poisoning.
Dust	- Good hygiene practices. - Equipment wipe-downs/cleaning. - Dedicated clothing for task.	- Limitation of fire rate. - PPE - Post exposure washing. - Decontamination of equipment.	- Lung irritation. - Skin irritation. - Heavy metal poisoning.

Table 3 - Bowtie hazard analysis of Toxicity/Fumes

2.2.4. High-Pressure Gas

High-Pressure Gas is a common hazard during the firing of the 115mm ammunition. The nature of the high energy propellants deflagrating within confinement produces very high pressures within the barrel.

Threats	Controls	Mitigations	Consequences
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Obturation Failure	- Robust design. - Self-sealing design.	- Inspection of munition for damage. - Replaceable sealing/seating components.	- Flashback. - Crew injury from high-pressure gas.
Firing of System	- Safe operating procedures.	- Exclusion zones.	- Crew injury from high-pressure gas.
Misfire	- Reliability testing of design. - Suitable firing mechanism.	- Limit access to range area. - Limit personnel conducting task. - Ensure Hangfire/Misfire procedures followed. - Anti-Hangfire interlock	- Delayed Initiation - Unknown condition of munition.

Table 4 - Bowtie hazard analysis of High-Pressure Gas

2.2.5. Heat

Heat is a byproduct of the system functioning due to the deflagration of propellant from the munition. Below is the bowtie analysis of the hazard represented using bullet points:

Threats	Controls	Mitigations	Consequences
Hot Particulates	- Bore evacuator installed on barrel. - Barrel cleaning.	- Fire suppression. - PPE. - Burn treatment facilities.	- Burn Injury - Unintentional initiation.
Hot Gas	- Bore evacuator installed on barrel. - Robust design. - Muzzle deflectors. - Positive pressure system.	- Fire suppression. - PPE. - Burn treatment facilities.	- Burn Injury
Hot Surfaces	- Thermal insulation. - Hazard markings. - Ejection systems.	- Fire suppression. - Burn treatment facilities. - PPE.	- Burn Injury
Electronics	- Use of correctly rated cables.	- PPE - Fire suppression system	- Burn Injury

Table 5 - Bowtie hazard analysis of Heat

2.2.6. Noise

Noise is a byproduct of the system functioning as intended and presents itself as a hazard within the use of the system. Below is the bowtie analysis of the hazard represented using bullet points:

Threats	Controls	Mitigations	Consequences
Firing of System	- Muzzle suppression. - Longer barrel. - Attenuation distance between user and spectators.	- Hearing protection. - Sound insulation in turret. - Hearing conservation limits.	- Deafness/Hearing loss - Headaches.
Projectile Explosion	- Attenuation distance between user and spectators. - Exclusion zones.	- Hearing protection. - Sound insulation in turret. - Hearing conservation limits.	- Deafness/Hearing loss - Headaches.
Breach Mechanism	- Acoustic baffles. - Regular maintenance.	- Hearing protection. - Hearing conservation limits.	- Hearing loss - Headaches.

Table 6 - Bowtie hazard analysis of Noise

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2.3. Risk Assessment

Hazard	Uncontrolled Probability	Uncontrolled Severity	Risk Class	Controls	Mitigations	Controlled Probability	Controlled Severity	Accident	Controlled Risk Class
Explosion	Remote	Catastrophic	B	- Limit EMI within area. - Avoidance of insulating materials in design. - Grounding. - Manual handling training/procedures. - Ensure design weight of munition meets HFI requirements. - Ensure munition is shaped in a carryable way. - Limit system exposure to operational threats. - Determine IM signature of munition. - Preventative barriers. - LOVA/IM complaint igniter/propellant materials. - Fire suppression system. - ESR Tested primaries (immunity threshold). - Shielded design. - Grounding. - Reliability testing of design. - Suitable firing mechanism.	- Limit access to range area. - Limit personnel conducting task. - Distinguish appropriate NO FIRE/ALL FIRE currents. - Surge lockout for fire control. - Physical barrier between involved personnel and others. - Post-drop inspection. - Venting/Blow off panel. - Fire suppression system. - Appropriate storage to reduce sympathetic risk. - Ensure Hangfire/Misfire procedures followed. - Anti-Hangfire interlock	Improbable	Catastrophic	Explosive Injury	C
Electrical	Improbable	Critical	C	- Frequent inspections. - Minimum bend radius. - Appropriate polarity marking. - Protected cabling. - Lightning rod/dissipation mechanism. - Insulated crew compartment. - EMI resistant design - Limit EMI within area. - Environmental testing (00-035). - Robust design. - Vibration/Shock testing. - Sealed enclosure. - Cable routing to avoid floor/pooling.	- Circuit breaker installation. - Grounded chassis. - Firing pulse lockout. - Self-test diagnostics. - System state retention. - Self-test diagnostics.	Improbable	Marginal	Electric Shock	D

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Toxicity/Fumes	Frequent	Critical	A	- Bore evacuator installed on barrel. - Ventilation system. - Lead-free/non-toxic compositions. - Good hygiene practices. - Equipment wipe-downs/cleaning. - Dedicated clothing for task.	- Limitation of fire rate. - Respiratory protective equipment. - Air monitoring system. - Limitation of fire rate. - PPE - Post exposure washing. - Decontamination of equipment.	Improbable	Marginal	Suffocation, Poisoning	D
High-Pressure Gas	Frequent	Critical	A	- Robust design. - Self-sealing design. - Safe operating procedures. - Reliability testing of design. - Suitable firing mechanism.	- Inspection of munition for damage. - Replaceable sealing/seating components. - Exclusion zones. - Limit access to range area. - Limit personnel conducting task. - Ensure Hangfire/Misfire procedures followed. - Anti-Hangfire interlock	Improbable	Critical	Explosive Injury	C
Heat	Frequent	Marginal	A	- Bore evacuator installed on barrel. - Barrel cleaning. - Robust design. - Muzzle deflectors. - Positive pressure system. - Thermal insulation. - Hazard markings. - Ejection systems. - Use of correctly rated cables.	- Fire suppression. - PPE. - Burn treatment facilities.	Improbable	Marginal	Burn Injury	D
Noise	Frequent	Critical	A	- Muzzle suppression. - Longer barrel. - Attenuation distance between user and spectators. - Exclusion zones. - Acoustic baffles. - Regular maintenance.	- Hearing protection. - Sound insulation in turret. - Hearing conservation limits.	Improbable	Negligible	Hearing Loss	D

Table 7 - Hazard Log for assigned hazard serials

2.4. Hazard Log definitions and metrics

	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 8 - Hazard Log matrix

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.

Definitions	
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}

3. ALARP Justification

3.1. Explosion

The risk of explosion through unintended initiation of the 115mm munition has been reduced to an ALARP level. The identified credible causes, as per Annex A, have been identified as: ESD, EMR/EMI, Drop/Impact, Hangfire/Misfire and IM threats. This hazard in all instances has a worse case scenario of a catastrophic event with multiple deaths of associated personnel.

3.1.1 ESD

ESD tested and characterised primary compositions are to be used as per AOP-7 [2] to ensure the ESD sensitivity of the primary maintains an acceptable margin of safety. The characterisation and ESD testing will provide an immunity margin for the appropriate stimuli, giving confidence for its safe use in the defined environment. This testing determines the Maximum No-Fire Stimulus the threshold below which the primary will not initiate, providing a quantifiable safety buffer against credible electrostatic threats encountered during handling, storage, and operational use. By establishing the MNFS, the testing enables the design of appropriate protective measures, ensuring that any potential ESD events within the anticipated environment fall safely below the initiation threshold, thereby minimising the risk of unintended electrostatic-induced initiation.

3.1.2 EMR/EMI

A shielded design for the munition, along with grounding and limiting EMI within the range area, reduces the risks associated with HERO and static charges. This approach aligns with MIL-STD-464C, which mandates electromagnetic environmental effects requirements including ordnance HERO safety certification, and MIL-STD-1901A, which establishes design safety criteria for munition ignition systems including electromagnetic environments, fail-safe features, electronic logic functions, and maximum no-fire stimulus requirements. The shielded design provides a physical barrier against external electromagnetic fields, while grounding ensures a low-impedance path for any induced currents or static charges, safely dissipating them away from sensitive energetic materials. Limiting EMI within the area reduces the overall electromagnetic threat environment, ensuring that potential emitters such as radios, radars, and other transmitting equipment are controlled or excluded during munition handling and firing operations. Together, these controls create multiple layers of protection, ensuring that the electromagnetic stimuli experienced by the munition remain safely below the established no-fire thresholds.

Secondary containment for the munitions to provide additional shielding has been considered but rejected due to cost, weight and the requirement for a new design of munition breach to handle such a munition. The financial implications of developing and fielding secondary containment would be substantial, requiring new manufacturing tooling, materials, and extensive testing to validate performance without compromising safety. The added weight would also reduce the systems maximum capacity as well as worsen logistics which affects its operational effectiveness, as heavier munitions reduce the number that can be stowed, increase the burden on handling personnel, and complicate resupply operations in the field. Furthermore, the requirement for a new breech design introduces significant technical risk, development timelines, and integration challenges, as the entire weapon system would need to be requalified with the modified munition. The marginal safety benefit of secondary containment against already improbable electromagnetic threats is therefore judged to be disproportionate to the costs and operational penalties incurred.

The use of exclusion zones within the range area as well as maintaining access control acts as both control and mitigation by reducing the number of personnel present as well as EMI emitters. By limiting personnel conducting the task to the minimum necessary, exposure to potential initiation events is minimised while the controlled environment reduces the likelihood of unauthorised electromagnetic sources being introduced. Exclusion zones ensure that non-essential personnel and equipment are

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kept at a safe distance, while access control measures restrict entry to only those qualified and authorised to be present. This dual-function approach provides a procedural safety net, reinforcing the engineering controls and ensuring that the operational environment remains within the defined safe boundaries.

3.1.3 Drop/Impact

Appropriate manual handling procedures and ammunition marking diagrams to display centre of mass and the present hazards of the munitions allow for safer transport of the ammunition. The risk of muscular injury to personnel is reduced through safe lifting and carrying techniques as well as adhering to the HSE requirements for maximum load on solo lifting without MHE. While there is no legally defined maximum weight that a person can safely lift, the Manual Handling Operations Regulations 1992 (MHOR) require employers to avoid hazardous manual handling where reasonably practicable, assess any operations that cannot be avoided, and reduce the risk of injury so far as is reasonably practicable. The HSE provides basic guideline figures for lifting and lowering, with the National Institute for Occupational Safety and Health (NIOSH) establishing a load constant of 23 kg (about 51 pounds) as a load that, under ideal conditions, is safe for 75% of females and 90% of males. Ammunition marking diagrams displaying the location of centre of gravity are standard practice, with ammunition marking requirements specifying that the location of centre of gravity of loaded projectiles must be stencilled on the projectile itself. This ensures personnel can identify the balance point of the munition, reducing the risk of unexpected shifts during lifting and carrying. Additionally, markings denoting the present hazards of the munitions provide critical safety information to handlers, including explosive filler type, lot number, and applicable fuse information. These controls align with best practice for ammunition handling, which mandates that personnel must evaluate the object and required task to determine if they can handle the object safely before lifting, and that if there is any doubt, additional manual or mechanical help should be obtained. The use of proper lifting and carrying techniques, combined with adherence to weight limits and clear hazard marking, ensures the risk of manual handling injury and unintended initiation during transport is reduced to a level that is As Low as Reasonably Practicable.

3.1.4 IM Threats

The Insensitive Munitions threat encompasses a range of credible hazards to which the 115mm ammunition may be exposed during its lifecycle. In accordance with UK MOD policy and NATO STANAG 4439, these threats include fast and slow cook-off, bullet impact, fragment impact, shaped charge jet impact, and sympathetic reaction. The adoption of LOVA/IM compliant igniter and propellant materials is the primary engineering control, as these materials exhibit higher ignition temperatures and reduced sensitivity to unplanned stimuli compared to conventional formulations. The requirement to determine the IM signature of the munition aligns with the assessment methodology set out in AOP-39, which mandates a whole body of evidence approach to evaluate munition response to each threat. The design incorporates preventative barriers such as the spiral-wrap cartridge case design or venting blow-off panels that have been proven to provide controlled venting capability, converting aggressive propulsive deflagration responses to a milder burning response and thereby preventing catastrophic overpressure. This is complemented by the fire suppression system, which serves as both a control and mitigation, with testing demonstrating that adequate water application is effective in controlling cook-off propagation and maintaining ordnance temperature below critical thresholds. Appropriate storage arrangements to reduce sympathetic risk and limiting system exposure to operational threats through stowage and armour protection further minimise the likelihood of IM threat exposure. The implementation of physical barriers between involved personnel and others, along with limiting access to range areas and personnel conducting the task, provides additional procedural controls that reduce both the number of personnel exposed and the potential for unintended threat stimuli.

The implementation of further risk reduction measures has been considered but rejected on grounds of cost, feasibility, and operational impact. Full IM compliance across all six threat categories would require

fundamental redesign of the munition's energetic components, as it is well known that common explosives such as TNT-based melt casts of RDX and HMX exhibit widely varying responses to hazard stimuli, and achieving reproducible compliance requires significant investment in insensitive explosive development. The introduction of additional passive hardening measures, such as enhanced thermal insulation or fragment barriers, would add substantial weight to the munition, reducing vehicle stowage capacity and affecting Human Factors Integration requirements for manual handling, as well as requiring a new design of munition breach to accommodate such modifications. Active mitigation systems, such as enhanced sprinkler protection with improved sensor response characteristics, while shown to be effective, represent significant cost and integration challenges for existing platforms, and their marginal safety benefit against already improbable threat scenarios is judged disproportionate. The shaped charge jet threat is particularly challenging, as most munitions fail SCJ attack, and endorsement is not required if a munition fails this test but meets the remaining IM requirements, reflecting the current technical limitations in addressing this threat.

3.1.5 EMR/HERO

A shielded design for the munition, along with grounding and limiting EMI within the range area, reduces the risks associated with HERO and static charges. This approach aligns with MIL-STD-464C, which mandates electromagnetic environmental effects requirements including ordnance HERO safety certification, and MIL-STD-1901A, which establishes design safety criteria for munition ignition systems including electromagnetic environments, fail-safe features, electronic logic functions, and maximum no-fire stimulus requirements. The shielded design provides a physical barrier against external electromagnetic fields by enclosing all Electro-Explosive Devices and their firing circuits within a continuous electromagnetic interference shield. This requires that the integrity of the RF shield be maintained throughout the life cycle of the system, ensuring that EM energy cannot couple into the shielded enclosure. Grounding ensures a low-impedance path for any induced currents or static charges, safely dissipating them away from sensitive energetic materials. Limiting EMI within the area reduces the overall electromagnetic threat environment, ensuring that potential emitters such as radios, radars, and other transmitting equipment are controlled or excluded during munition handling and firing operations, with safe separation distances calculated based on transmitter power and frequency. Together, these controls create multiple layers of protection, ensuring that the electromagnetic stimuli experienced by the munition remain safely below the established no-fire thresholds. The use of exclusion zones within the range area as well as maintaining access control acts as both control and mitigation by reducing the number of personnel present as well as EMI emitters, with HERO EMC on plans prescribing through advance planning the easiest and most efficient method of managing the conflict between the EME created by transmitting equipment and electrically initiated ordnance.

The implementation of further risk reduction measures has been considered but rejected on grounds of cost, feasibility, and operational impact. Secondary containment for the munitions to provide additional shielding has been considered but rejected due to cost, weight and the requirement for a new design of munition breach to handle such a munition. The financial implications of developing and fielding secondary containment would be substantial, requiring new manufacturing tooling, materials, and extensive testing to validate performance without compromising safety. The added weight would also reduce the systems maximum capacity as well as worsen logistics which affects its operational effectiveness, as heavier munitions reduce the number that can be stowed, increase the burden on handling personnel, and complicate resupply operations in the field. Furthermore, the requirement for a new breach design introduces significant technical risk, development timelines, and integration challenges, as the entire weapon system would need to be requalified with the modified munition. The marginal safety benefit of secondary containment against already improbable electromagnetic threats is therefore judged to be disproportionate to the costs and operational penalties incurred.

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