Risk Management Analysis

Transportation Risk Assessment for Shipping Rocket Motors from Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP)

Site: BGCA/BGCAPP	Study Number: RM-20-010
This study assesses the risk related to offsite shipment, via a commercial hazardous waste carrier, of non-agent-contaminated rocket motors from the Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) site in Richmond, Kentucky. The results indicate that the transportation risk is *Low.*	

Final, Rev. 2

September 2021

Prepared for
Program Executive Office, Assembled Chemical Weapons Alternatives

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Controlled Unclassified Information has been redacted from this document.

Revision Log

Rev. #	Date	Summary
Draft	December 2020	Initial submittal
Second Draft	March 2021	Incorporated government comments
Final Draft	May 2021	Incorporated government comments
Final	June 2021	Incorporated government comments
Final, Rev. 1	August 2021	Incorporated government comments
Final, Rev. 2	September 2021	Incorporated Bechtel Parsons Blue Grass comments

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1 INTRODUCTION

1.1 Objective

The objective of this study is to assess the risk related to offsite shipment, via a commercial hazardous waste carrier, of non-agent-contaminated M67 rocket motors (hereinafter rocket motors) from the Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) site in Richmond, Kentucky, to the Anniston Army Depot (ANAD) in Anniston, Alabama. A potential option—transport from ANAD to Aberdeen Proving Ground in Edgewood, Maryland—is addressed in Appendix C.

1.2 Background

During processing of M55 rockets (hereinafter rockets) at BGCAPP, the rocket is cut to separate the warhead and motor sections. The rocket motors were originally intended to be disposed onsite in energetic batch hydrolyzers. Due to concerns and risks associated with the processing of sarin (GB) rockets and O-ethyl S-(2-diisopropylaminoethyl) methylphosphonothioate (VX) rockets at BGCAPP, alternatives were evaluated to improve the safety margin, mitigate risks, and increase confidence associated with completing the destruction of the stockpile by 31 December 2023 as mandated by Public Law 114-82. This evaluation influenced decisions regarding the rocket processing strategy, including changes to eliminate neutralization of energetics and to process drained rocket warheads in a Static Detonation Chamber (SDC).

Non-contaminated rocket motors will be processed in the Anniston SDC, existing BGCAPP SDC 1200, and/or the new SDC 2000. This transportation risk assessment (TRA) evaluates the conditions under which the rocket motors may be shipped off-site and determines the risk to the public due to an accident with ensuing fire during transportation. This is accomplished using the Army's standard risk assessment methods coupled with conservative (pessimistic) assumptions regarding the likelihood of the accident and the severity of the resulting hazard. It is likely that these methods greatly overestimate the public risk due to offsite shipment.

This TRA did not consider risk from potential accidents during handling, loading, or unloading the rocket motors at BGCAPP or at ANAD. Documents that address hazards during these activities, such as job hazard analyses or monitoring plans, will be developed independently from this TRA. In addition, this TRA is just one element of the Army's program to ensure protection of the public, workers, and the environment during shipment operations. Other documents will be prepared to cover (1) monitoring and characterization of the waste, (2) packaging and segregation of the waste, (3) loading and unloading operations, (4) transportation planning and procedures, and (5) emergency response planning and procedures.

1.3 Process Description

The rocket inventory at Blue Grass Army Depot consists of GB rockets and VX rockets (BPBG 2004). Each rocket is packed in a fiberglass shipping and firing tube (SFT). The processing steps that involve the rocket motors are as follows (NRC 2012; PEO ACWA 2020):

- The SFT is cut into two pieces. The forward piece of SFT covering the warhead is removed, conveyed to the Motor Packing Room, and placed in a crate. The rear portion of the SFT remains with the rocket motor.
- A second cut is made at the threaded connection between the warhead and the rocket motor. The separated warhead containing the chemical agent, burster, and fuze, continues through processing at the Main Plant and the Static Detonation Chambers.
- The separated rear section of the rocket (the rocket motor) containing the M28 rocket propellant, M62 igniter, rocket nozzle, fins, and other components is conveyed to the Motor Packing Room and loaded, cut side up, into a plywood shipping box designed to hold 30 rocket motors.
- The rocket motors and the SFTs (from the warhead section) are collected in their respective crates in the Motor Packing Room and transferred to the airlock for monitoring of chemical agent to the vapor screening level (VSL).
    - If agent is detected above the VSL, the rocket motors are manually monitored individually. After contaminated rocket motors are removed, the empty spaces in the crate are refilled and the headspace is monitored again to ensure the crate meets the exit criteria.
    - If the monitoring does not detect agent above the VSL, the box is released to the Motor Shipping Room.
- In the Motor Shipping Room, the SFT crates are emptied into roll off containers for shipment and the motor crates are passed on to the Box Transfer Room.
- In the Box Transfer Room, air monitoring is conducted again in the headspace of the rocket motors at the Worker Population Level (WPL) (5 parts per trillion for GB and 0.09 parts per trillion for VX). An alert or action level is established as low as reasonably practicable based on the operating environment (0.5 WPL would be typical). The crates are sealed to be shipped off-site for disposal.

This TRA addresses only rocket motors that have been monitored and cleared for disposal off-site.

In January 2020, a representative from the Program Executive Office, Assembled Chemical Weapons Alternatives (PEO ACWA) visited Redstone Arsenal and observed a demonstration of a machine intended to trim the threaded portion of the assembly in the event a small metal ring of the warhead remained behind. Observations indicated that this metal ring remained in about 10 percent of the rocket motors. A Redstone Arsenal subject matter expert stated that the ring—when threaded into the rocket motor—could confine exhaust gases from burning propellant and result in a transition to detonation.

The rocket motors used in the demonstration were actually ACWA test equipment (ATE) rockets processed in a horizontal orientation through the rocket cutting machine. In April 2021, the PEO ACWA representative learned that in comparison to stockpile rockets, the warhead assembly in ATE rockets extends about 2 inches further into the motor assembly. This is the primary reason for the metal rings observed at Redstone Arsenal.

In addition, the old rocket cutting machine (now replaced) chose where to cut based on measurement from the end cap of the SFT. The new vertical rocket cutting machine chooses where to cut based on measurement from the fuze tip of the rocket itself. This removes a significant amount of variability from the cut location. Based on testing and commissioning, subject matter experts stated they do not expect a metal ring to remain in any rocket motor. Recent ATE testing confirmed no residual warhead threads on the rocket motor (Anderson 2021).

2 DESCRIPTION OF WASTE TO BE SHIPPED

The rocket motor section contains propellant, an igniter, and a fin/nozzle assembly. The propellant is a solid, double-based propellant grain containing two energetic materials—nitroglycerine (NG) and nitrocellulose (NC)—and additional components. The stabilizer, 2-nitrodiphenylamine (NDPA), is added to adsorb the degradation products of the nitrocellulose. The grain is manufactured as a tri-lobe core providing a large, central burning area that allows exhaust gases to exit through nozzles located at the rocket motor aft.

Table 1 lists the composition of the rocket motor (propellant).

Rocket motors are considered a listed hazardous waste in Kentucky, with the following Kentucky waste codes:

- N101 – Uncontaminated M67 rocket motor assembly, propellant component of the rocket motor, SFTs, and end-caps associated with GB munitions.
- N102 – Uncontaminated M67 rocket motor assembly, propellant component of the rocket motor, SFTs, and end-caps associated with VX munitions.

In addition, the following Resource Conservation and Recovery Act (RCRA) characteristic hazardous waste codes may apply:

- D003 (Reactive)
- D008 (Lead)

Table 1. Composition of Propellant Grain

Component	Weight Percent	Purpose
Nitrocellulose (NC)	60	Energy source
Nitroglycerin (NG)	23.8	Energetic plasticizer
Triacetin (TA)	9.9	Casting solvent
Dimethylphthalate (DMP)	2.6	Plasticizer
Lead stearate	2.0	Burn-rate modifier
2-nitrodiphenylamine (NDPA)	1.7	Stabilizer

Source: National Research Council. *Disposal Options for the Rocket Motors From Nerve Agent Rockets Stored at Blue Grass Army Depot*. Washington, DC: The National Academies Press. 2012. https://doi.org/10.17226/13439.

The rocket motors are also a Department of Transportation (DOT) hazardous material (hazmat) belonging to Class 1, Division 1.2C (explosives that have a projection hazard but not a mass explosion hazard, Compatibility Group C), per a Department of the Army memo (DA 2021).

3 PROPELLANT HAZARD REVIEW

3.1 Potential Hazards

Several studies, tests, and reviews have been conducted over the past decades to determine or investigate the hazards constituted by the rocket motors during storage, handling, and transport. The principal hazards are the following:

- Propellant fire
- Propellant fire transitioning to a detonation

3.2 Causes and Findings

Based on a review of the studies, Appendix D identifies some of the causes leading to the propellant hazards identified in Section 3.1. Appendix D addresses only causes relevant to handling and transportation. Based on the findings of the studies, the most plausible cause of a propellant fire would be from an external fire caused by an accident with a fuel spill/fire.

4 PACKAGING AND TRANSPORTATION REQUIREMENTS

Commercial transporters and operators are subject to DOT regulations. Applicable codes, standards, and regulations for packaging and transport are summarized in the following paragraphs.

4.1 DOT Regulations

49 Code of Federal Regulations (CFR) 172 prescribes the requirements for shipping papers, package marking, labeling, and transport vehicle placarding applicable to the shipment and transportation of each class of hazmat. In addition, it prescribes requirements for emergency response, training, and safety and security plans.

49 CFR 173 prescribes requirements for preparing the hazmats for shipment, including packaging requirements and quantity limitations. 49 CFR 173.50 prescribes requirements for packaging of Class 1 hazmats.

49 CFR 177 prescribes requirements for transportation via public highway by motor vehicle, including inspections, driver training, segregation and separation, and loading and unloading requirements for each class of hazmat.

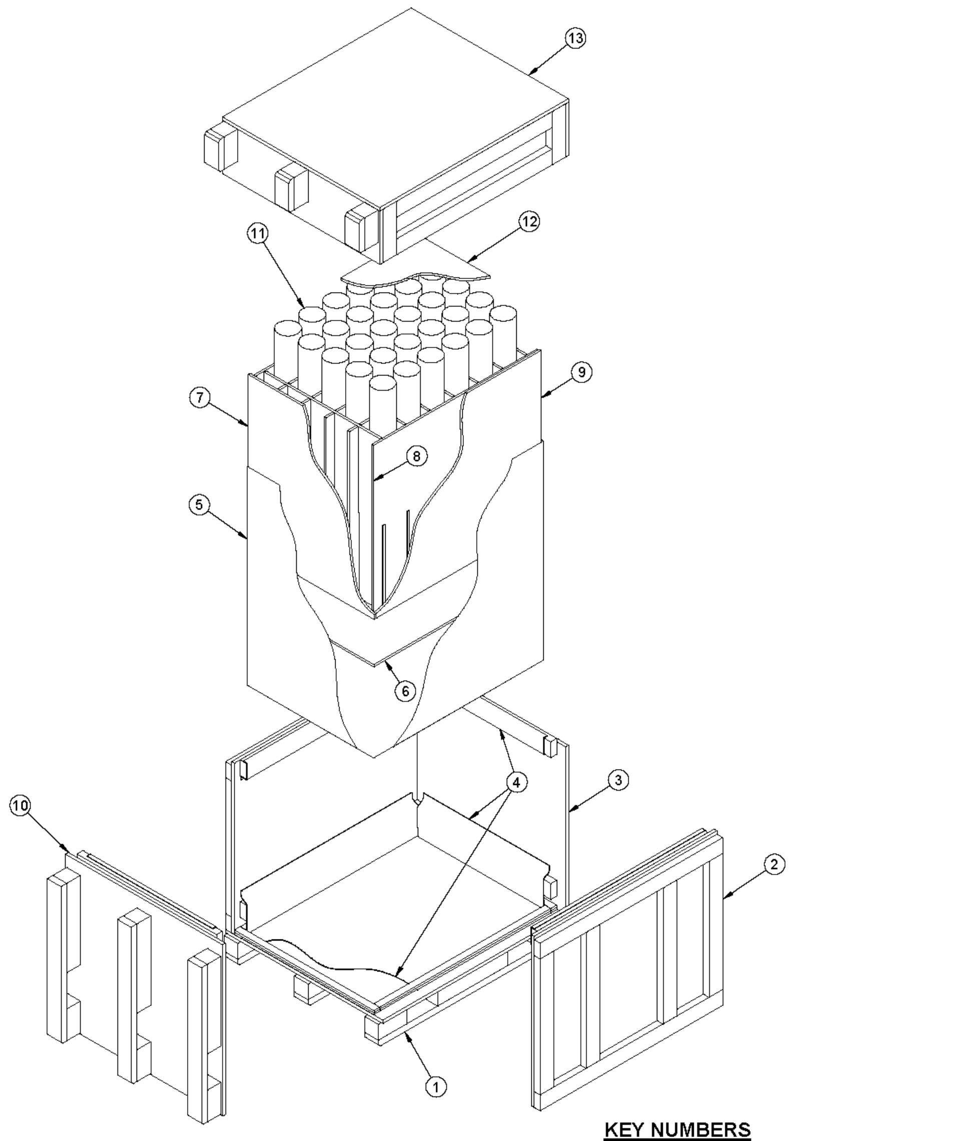
49 CFR 178 prescribes testing requirements for packaging and containers used for transportation of hazmats.

4.2 Waste Packaging

The rocket motor packaging must allow for safe storage, loading, and transportation of the contents to their final destination. The packaging must meet the applicable codes, standards, and regulations for the shipment and handling of DOT hazard Class 1 explosives and hazmats.

The rocket motors will be placed in MIL-PRF-81705E Type I Class I electrostatic barrier bags (DA 2015) for protection from radio frequency and electrostatic discharge environments.

The wooden box crate for unitization of the rocket motors is approximately 53x40x55 inches (AMC 2018) (see Figure 1). Vertical spacers inside the crate accommodate 30 rocket motors in a vertical orientation. Figure 2 provides a photograph of the assembled crate. The crate is turned on its side during storage and transport. A truck load is assumed to hold 18 crates (540 motors). This results in an estimated total of 129 shipments based on the number of rocket motors to be shipped.



KEY NUMBERS

7 END HONEYCOMB PAD, 32" X 38" X 1/2" THICK HONEYCOMB FILLER (2 REQD). CUT-TO-FIT AND PLACE INSIDE THE BARRIER BAG NEXT TO THE ENDWALL ASSEMBLIES.

8 SPACER ASSEMBLY (1 REQD). SEE DETAIL ON PAGE 7. PLACE ON TOP OF 1/2" THICK HONEYCOMB PAD.

9 SIDE HONEYCOMB PAD, 38" X 41-3/4" X 1/2" THICK HONEYCOMB FILLER (2 REQD). CUT-TO-FIT AND PLACE BESIDE THE SPACER ASSEMBLY, BETWEEN THE SPACER ASSEMBLY AND THE BARRIER BAG.

10 BOTTOM ENDWALL ASSEMBLY (1 REQD). SEE DETAIL ON PAGE 5. NAIL TO THE SIDEWALL ASSEMBLIES W/6-10d NAILS AT EACH END.

11 ROCKET MOTOR (30 SHOWN). SEE GENERAL NOTE "B" ON PAGE 2.

12 TOP HONEYCOMB PAD, 32" X 43" X 1/2" THICK HONEYCOMB FILLER (1 REQD). CUT-TO-FIT AND PLACE ON TOP OF ROCKET MOTORS INSIDE BARRIER MATERIAL.

13 TOP LID ASSEMBLY (1 REQD). SEE DETAIL ON PAGE 6. PLACE ON TOP OF PALLET BOX.

1 BOTTOM ASSEMBLY (1 REQD). SEE DETAIL ON PAGE 4. NAIL TO THE SIDEWALL ASSEMBLIES W/6-10d NAILS AT EACH JOINT. PLACE THE TOP ENDWALL ASSEMBLY ON THE GROUND AND USE AS A GUIDE TO NAIL THE SIDEWALL ASSEMBLIES TO THE BOTTOM ASSEMBLY.

2 SIDEWALL ASSEMBLY (2 REQD). SEE DETAIL ON PAGE 4.

3 TOP ENDWALL ASSEMBLY (1 REQD). SEE DETAIL ON PAGE 5. NAIL TO THE SIDEWALL ASSEMBLIES W/6-10d NAILS AT EACH END.

4 POLYETHYLENE WRAP, 1/8" THICK ANTI-STATIC POLYETHYLENE FOAM. PLACE IN THE INTERIOR OF BOX (INCLUDING INTERIOR OF LID) AT LOCATIONS WHERE BARRIER MATERIAL WILL COME IN CONTACT WITH THE BOX.

5 BARRIER MATERIAL. CUT TO FIT THE INSIDE DIMENSIONS OF PALLET BOX AND SEAL EDGES TO CREATE A BOUNDARY AROUND ROCKET MOTORS, SPACER ASSEMBLY, AND HONEYCOMB PAD. SEAL CLOSED ONCE KEY NUMBERS 1 THROUGH 12 ARE INSTALLED.

6 BOTTOM HONEYCOMB PAD, 32" X 43" X 1/2" THICK HONEYCOMB FILLER (1 REQD). CUT-TO-FIT AND PLACE ON TOP OF THE BOTTOM ASSEMBLY AND BARRIER MATERIAL. CENTER USING THE IMMOBILZING PIECES.

(Source: AMC 2018)

Figure 1. Rocket Motor Crate Sections

(Source: DAC 2018)

Figure 2. Assembled Rocket Motor Crate

4.3 Description of Transport Procedures

Transport requirements for hazmats are governed by DOT regulations, as described in Section 4.1. General provisions applicable during the transportation phase include the following:

- Transport without unnecessary delay, from and including the time of commencement of the loading of the hazmat until its final unloading at destination
- Availability of records, equipment, packaging, and containers under the control of a motor carrier, insofar as they affect safety in transportation of hazmats
- Compliance with safe clearance requirements for highway-rail grade crossings in 49 CFR 392.12
- Prohibition of texting and use of handheld telephones while driving, in accordance with 49 CFR 392.80 and 392.82
- Compliance with requirements of hazmat transport restrictions in vehicular tunnels

- Driver training in accordance with 49 CFR 177.800 and 49 CFR 390 through 397, including:
  - Pre-trip safety inspection
  - Use of vehicle controls and equipment, including operation of emergency equipment
  - Operation of vehicle, including turning, backing, braking, parking, handling, and vehicle stability
  - Procedures for maneuvering tunnels, bridges, and railroad crossings
  - Requirements pertaining to attendance of vehicles, parking, smoking, routing, and incident reporting
  - Loading and unloading of materials, including compatibility, segregation, package handling, and load securement.
- Availability of shipping papers to authorities in the event of accident or inspection
- Marking and placarding a transport vehicle containing a hazardous waste in accordance with 49 CFR 172
- Prohibition on moving a transport vehicle containing a hazardous waste during an emergency unless:
  - The vehicle is escorted by a representative of a state or local government
  - The carrier has permission from the DOT
  - Movement of the vehicle is necessary to protect life or property.

Specific provisions for transportation of DOT Class 1 materials include the following:

- Loading or unloading with the engine running is prohibited.
- Use of bale hooks or other metal tools for loading or unloading is prohibited.
- Throwing or dropping packages during loading or unloading is prohibited.
- Tarpaulins (if used) must be secured by means of rope, wire, or other tie downs.

- Class 1 materials must not be loaded into or carried on any vehicle or a combination of vehicles if:
  - More than two vehicles are in the combination (e.g., a tractor truck with a semi-trailer or a tractor truck with a full trailer is a combination of two vehicles)
  - Any full trailer in the combination has a wheel base of less than 184 inches
  - The other vehicle in the combination contains any Division 1.1A (explosive) material
- Sharp projections (bolts, screws, nails) inside vehicle bodies are prohibited.
- No detonator assembly or booster with detonator may be transported on the same vehicle with Division 1.1, 1.2, or 1.3 material, unless:
  - It is packed in a Specification MC 201 (49 CFR 173.318) container, or
  - The package conforms with 49 CFR 173.62.
- No Division 1.1, 1.2, or 1.3 material may be transferred from one container to another, or from one motor vehicle to another vehicle, except in the case of emergency.
- Division 1.1, 1.2, or 1.3 materials that are stored during transportation in commerce must be attended and afforded surveillance in accordance with 49 CFR 397.5.

Additional local or state requirements for truck transport (e.g., safe following distance of 250 or 300 feet between trucks; platooning [using an automated connection, such as an automated braking system, between vehicles to allow for closer following distances and fuel savings], if utilized) will apply. The transporter will ensure compliance with these requirements.

5 RISK ASSESSMENT METHODOLOGY

5.1 Overview of Methodology

Department of the Army Pamphlet (DA PAM) 385-61 (DA 2018) is the basis for the Army risk management program for chemical-agent related hazards. DA PAM 385-61 requires that risk management be executed in accordance with DA PAM 385-30. However, DA PAM 385-30 (DA 2014) does not contain quantitative criteria for defining the probability of a risk. It references the Army Acquisition Community risk assessment and acceptance processes, which are contained in Army Regulation 70-1, Military Standard (MIL-STD)-882. MIL-STD-882E (DoD 2012) provides qualitative definitions of the risk probabilities, but Appendix A of the standard contains quantitative example probability levels. These probability levels (Table 2) can then be used in conjunction with the specified quantitative hazard severity levels (Table 3) to determine the risk assessment code (Figure 3).

Table 2. Example Probability Categories per MIL-STD-822E

Probability Levels				
Description	**Level**	**Individual Item**	**Fleet/Inventory***	**Quantitative**
Frequent	**A**	Likely to occur often in the life of an item	Continuously experienced.	Probability of occurrence greater than or equal to 10^{-1}.
Probable	**B**	Will occur several times in the life of an item	Will occur frequently.	Probability of occurrence less than 10^{-1} but greater than or equal to 10^{-2}.
Occasional	**C**	Likely to occur sometime in the life of an item	Will occur several times.	Probability of occurrence less than 10^{-2} but greater than or equal to 10^{-3}.
Remote	**D**	Unlikely, but possible to occur in the life of an item	Unlikely but can reasonably be expected to occur.	Probability of occurrence less than 10^{-3} but greater than or equal to 10^{-6}.
Improbable	**E**	So unlikely, it can be assumed occurrence may not be experienced in the life of an item	Unlikely to occur, but possible.	Probability of occurrence less than 10^{-6}.
Eliminated	**F**	Incapable of occurrence within the life of an item. This category is used when potential hazards are identified and later eliminated.		

* The size of the fleet or inventory should be defined.

Table 3. Hazard Severity Descriptions per MIL-STD-882E

SEVERITY CATEGORIES		
Description	**Severity Category**	**Mishap Result Criteria**
Catastrophic	1	Could result in one or more of the following: death, permanent total disability, irreversible significant environmental impact, or monetary loss equal to or exceeding $10M.
Critical	2	Could result in one or more of the following: permanent partial disability,injuries or occupational illness that may result in hospitalization of at least three personnel, reversible significant environmental impact, or monetary loss equal to or exceeding $1M but less than $10M.
Marginal	3	Could result in one or more of the following: injury or occupational illness resulting in one or more lost work day(s), reversible moderate environmental impact, or monetary loss equal to or exceeding $100K but less than $1M.
Negligible	4	Could result in one or more of the following: injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K.

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Figure 3. Risk Assessment Matrix (per MIL-STD-822E)

5.2 Technical Approach

Section 5.1 presents a brief discussion of the methodology for this TRA. This technical approach describes the specific steps taken to complete this assessment and identifies key assumptions made in the analysis for a fire scenario. Section 6 details the analysis approach.

The following steps were completed to determine the transportation risks during shipment:

- Develop the transportation accident scenario to be assessed.
- Determine the hazard probability by estimating the probability of a truck accident that results in a fire, using available data for hazmat transportation accidents.
- Characterize the hazard consequences.
- Determine if the calculated risk is within the acceptable risk range, based on the hazard probability and consequences, using Figure 3.

6 RISK ASSESSMENT

6.1 Transportation Routing

Different transportation routes could be used to ship the rocket motors from BGCAPP to ANAD in Anniston, Alabama. The transporter selects a shipment route in accordance with the National Hazardous Materials Route Registry (80 Federal Register [FR] 23859). The selected route considers several factors, such as avoiding major population centers/sensitive land areas and ensuring adequate emergency response capabilities, and may not be the shortest route available. Using Google Maps, potential route options were examined; the routes ranged between 361 and 381 miles. For the purposes of this TRA, the route distance of 381 miles was selected.

6.2 Truck Accident Probability Estimation

A baseline probability for truck accidents was obtained from a Battelle study of hazmat truck shipments (Battelle 2001, Table 24). The accident rate from the 2001 Battelle study for transportation of Division 1.1, 1.2, and 1.3 materials is 6.15×10^{-7} accidents/mile.

When an accident occurs, the packaged rocket motor skids could be released onto the roadway. This release by itself is not evaluated in this study because the material can be readily removed from the roadway, repackaged, and secured onto the truck, and there is likely no impact to the public. Impacts, if any, are from a fuel spill/fire that potentially could ignite the rocket propellant.

The potential accident scenarios are depicted in the event tree shown in Figure 4. After the initiating event (accident) occurs, there are two possibilities (fire or no fire). The conditional probability for a fire to occur (0.09) was obtained from a Battelle study of hazmat truck shipments (Battelle 2001, Table 6). If a fire occurs, it is assumed that subsequent ignition of the propellant will occur within 12 to 16 minutes (see Appendix D). The basis for the probability determinations is summarized in Table 4.

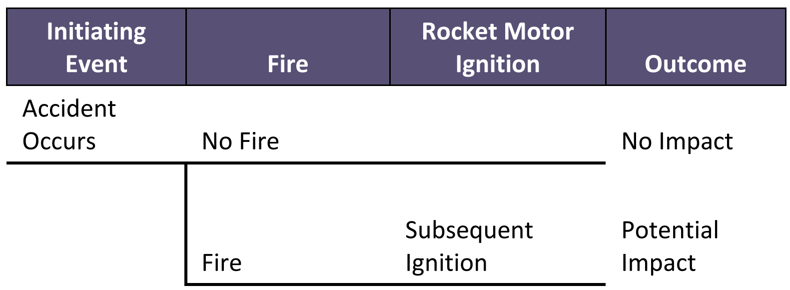


Figure 4. Event Tree

Table 4. Basis for Probability Determination

Parameter	Reference	Value
Hazmat Transporters for Class 1, Division 1.1, 1.2, 1.3 Materials	Battelle 2001	6.15×10^{-7} accidents/mile
Conditional [a] Probability of Fire Following Accident	Battelle 2001	0.09
Miles per Shipment	Google Maps	381 miles

Notes:

a Conditional probability is the probability of an event given that a prior event (or events) has occurred.

Based on Table 4, the probability of an accident is 6.15×10^{-7} accidents per mile. The conditional probability of a fire following an accident is 0.09. Therefore, the probability of an accident with fire per shipment of a distance of 381 miles is equal to $(6.15 \times 10^{-7}) \times 0.09 \times 381 = 2.11 \times 10^{-5}$. Table 5 shows the fire frequency per shipment from BGCAPP to ANAD. Only single-vehicle accidents are considered in this study because state-specific safe following distance requirements (250 to 300 feet) and/or safety measures for platooning (if utilized) make it unlikely for multiple trucks in a convoy carrying Class 1 materials to be involved in an accident.

Table 5. Calculated Frequency of Fire per Shipment from BGCAPP to ANAD

Event	Accident with Fire
Single-Vehicle Accident	2.11×10^{-5}

An accident that results in a fire is the primary concern for this TRA. Various factors that influence the fire include fuel tank involvement, amount of fuel available, type of accident or collision, and availability of firefighting equipment. Fires usually develop slowly so there should be sufficient time to evacuate to a safe distance. However, as stated in Appendix D, it is assumed that the rockets are immediately involved in the fire and propellant ignition occurs 12 minutes (for flat-bed trucks) or 16 minutes (for box cars) after the start of the fire. This provides sufficient time for an evacuation.

6.3 Hazard Consequence Assessment

Based on a 2006 study by Mitretek, rocket ignition has relatively minor consequences. The Mitretek study documented prior assessments involving the intentional ignition of the rocket motors in palletized configurations. Those assessments indicated that the rocket motors burn but do not explode. The Mitretek study, which focused on worker operations in a chemical demilitarization facility, noted that a worker exposed to exhaust gases potentially could be severely burned. However, in a transportation situation, there would be no “workers” present in the vicinity of the rocket motors. The drivers are trained to immediately begin evacuation at the start of a fire. Considering that ignition of the propellant could start 12 to 16 minutes after the fire, it is highly unlikely that the drivers or any members of the public would be present in the vicinity of the truck if and when the motor ignites.

Testing of propellant processing at the Anniston Static Detonation Chamber (WDC 2016) demonstrated that rocket motors, when rapidly heated, did not detonate. In addition, it was observed that the fore closure ejected, which would prevent rocket propulsion. In the event of propellant ignition, the exhaust gases would escape from both ends of the motor, thus preventing any forward propulsion.

Based on the analyses (Mitretek 2006, WDC 2016), it is concluded that the hazard consequence meets the *Negligible* severity category (Table 3), which is described as “Could result in one of more of the following: injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K.”

6.4 Risk Evaluation

The fire frequency given in Table 5 is on a per-shipment basis. To determine the total frequency, the per-shipment frequency is multiplied by the total number of planned shipments ($2.11 \times 10^{-5} \times 129 = 2.72 \times 10^{-3}$). Table 6 summarizes the frequency and consequence severity.

Table 6. Frequency and Consequence Severity as Function of Number of Shipments

Total Number of Shipments	Accident with Fire Leading to Propellant Ignition		
	Frequency	Injury	Fatality
129	2.72×10^{-3}	Injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K (No injury expected)	None likely

This frequency would place the scenario in the *Occasional* probability category based on the definitions in Table 2. As noted in Section 6.3, the consequence severity meets the severity category of *Negligible* based on the definitions in Table 3.

Table 7 summarizes the information from Table 6 in qualitative terms, in accordance with the risk assessment matrix (Figure 3).

Table 7. Risk Levels as Function of Number of Shipments

Scenario	Number of Shipments	Probability Category	Severity Category	Risk Level
Accident with Fire Leading to Propellant Ignition	129	Occasional	Negligible	Low

7 RISK MITIGATION

The authority for acceptance of the risk lies with the BGCAPP Site Project Manager, and any risk mitigation efforts or required actions will be determined by the BGCAPP Site Project Manager.

8 SUMMARY AND CONCLUSIONS

An evaluation of the risk of transporting non-agent-contaminated energetic materials from BGCAPP was conducted. The codes, standards, and regulations for hazmat classification, storage, handling, packaging, and transport were reviewed for safe transport of the energetics. A TRA was conducted for BGCAPP rocket motors using the Army approach by determining accident frequency and event consequences for an accident with a fire followed by an ignition of the rocket motor. The results indicate that the transportation risk is *Low.* Any risk mitigation efforts or required actions will be determined by the BGCAPP Site Project Manager.

APPENDIX A. ABBREVIATIONS

ANAD	Anniston Army Depot
APG	Aberdeen Proving Ground
ATE	ACWA test equipment
BGCAPP	Blue Grass Chemical Agent-Destruction Pilot Plant
CFR	Code of Federal Regulations
DA PAM	Department of the Army Pamphlet
DOT	Department of Transportation
FR	Federal Register
GB	nerve agent, sarin
NC	nitrocellulose
NDPA	2-nitrodiphenylamine
NG	nitroglycerine
PEO ACWA	Program Executive Office, Assembled Chemical Weapons Alternatives
RCRA	Resource Conservation and Recovery Act
SFT	shipping and firing tube
TRA	transportation risk assessment
VSL	vapor screening level
VX	nerve agent, O-ethyl S-(2-diisopropylaminoethyl) methylphosphonothioate

APPENDIX B. REFERENCES

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APPENDIX C. OPTION TO SHIP FROM ANNISTON ARMY DEPOT TO ABERDEEN PROVING GROUND

This appendix addresses a potential option to ship the rocket motors from Anniston Army Depot (ANAD) in Anniston, Alabama, to Aberdeen Proving Ground (APG) in Edgewood, Maryland, as part of development and testing of emerging demilitarization technologies at APG. The shipping distance, per Google Maps, is 800 miles (longer of two routes), versus 381 miles from Blue Grass Chemical Agent-Destruction Pilot Plant (BGCAPP) to ANAD, which was evaluated in the main report. This difference is reflected in revisions to Tables 5 and 6 in terms of the calculated fire frequencies and consequences. However, Table 7 remains unchanged as the resulting risk characteristics did not change.

Revised Table 5. Calculated Frequency of Fire per Shipment from ANAD to APG

Event	Accident with Fire
Single-Vehicle Accident	4.43×10^{-5}

Revised Table 6. Frequency and Consequence Severity as Function of Number of Shipments

Total Number of Shipments	Accident with Fire Leading to Propellant Ignition		
	Frequency	Injury	Fatality
129	5.72×10^{-3}	Injury or occupational illness not resulting in a lost work day, minimal environmental impact, or monetary loss less than $100K (No injury expected)	None likely

Table 7. Risk Levels as Function of Number of Shipments

Scenario	Number of Shipments	Probability Category	Severity Category	Risk Level
Accident with Fire Leading to Propellant Ignition	129	Occasional	Negligible	Low

APPENDIX D. CAUSES OF PROPELLANT HAZARDS RELATING TO HANDLING AND TRANSPORTATION

The content of this appendix has not been approved for public release and has been redacted.