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Technical Report ARWEC-CR-98016

TEMPERATURE CONCERNS IN M795 CONTROLLED COOLING PROCESS HAZARD ANALYSIS

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ARMAMENT RDE CENTER

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13. ABSTRACT

A hazards analysis for using 260°F water in the Iowa Army Ammunition Plant M795 controlled cooling process was performed. The effort consisted of a failure modes and effects analyses. The report documents recommendations to eliminate/control potential process hazards. The analysis did not identify any unacceptable initiation hazards for the use of 260°F water in the thermal panels of the pilot and full scale controlled cooling process for the M795.

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CONTENTS

SUMMARY

Objectives

Identify potential hazards associated with the use of 260°F water in the thermal panels of the M795 controlled cooling process. Specific goals of this process hazards analysis include:

- Identify failure modes that may result in TNT exposure to temperatures >260°F
- Evaluate each of the identified failure modes for credibility, potential effect, and design safety
- Recommend design or procedural changes that minimize or eliminate the identified failure modes.

Scope

This report addresses thermal concerns associated with using 260°F water to heat thermal panels in the pilot and full-scale M795 controlled cooling process located in lines 3 and 3A of the Iowa Army Ammunition Plant (IAAP).

PROCESS DESCRIPTION

Iowa Army Ammunition Plant currently has a pilot-scale controlled unit in operation in line 3 and is constructing a full-scale process in line 3A. The process consists of loading the M795 projectiles with molten TNT, placing the projectiles in an insulated oven that is designed to heat the funnel and neck of the projectile with thermal panels, and circulating temperature conditioned water around the body of the projectiles.

HAZARDS ANALYSIS

Information Sources

This hazards analysis is based on on-site review of equipment, design drawings, discussions with Mason & Hanger personnel, previous reports, and historical information.

Hazards Analysis Methodology

A tailored Alliant Techsystems/Global Environmental Solutions (ATK/GES) process hazards analysis (PHA) methodology was used to analyze the M795 controlled cooling process. This approach was adopted from the Alliant Techsystems Hazards Evaluation and Rish Control (HERC®) methodology. The approach used in this analysis consisted of an on-site visit, review of operating procedures, discussions with facility personnel, and review of drawings. A failure modes and effects analysis (FMEA) was generated. Each of the identified failure modes was evaluated for consequences to the process and for design safety which mitigated the failure mode.

A qualitative assessment of risk was assigned to each failure cause identified in the FMEA. The risk assessment category contains both a severity and frequency, per MIL-STD-882C, which was used for ranking each of the failure causes (fig. 1) and are assigned to each line item in the FMEA. The FMEA for the controlled cooling process is presented in table 1.

Where engineering or administrative controls (safeguards) were missing or inadequate to control process hazards, a recommendation was issued. These recommendations were compiled in a recommendation summary table (table 2). Definitions for column headings which appear in table 2 and FMEAs are presented in figures 2 and 3, respectively.

DISCUSSION AND SIGNIFICANT ANALYSIS FINDINGS

The controlled cooling units for the M795 projectiles are designed to provide a uniform fill and solidification of the TNT fill. This is accomplished by cooling the base of the projectile with water, while heating the neck and fill funnel with thermal panels. As the TNT solidifies and contracts in the base of the projectile, molten TNT from the funnel flows into the projectile and maintains the fill level above the neck.

The maximum temperature to which the thermal panels normally are heated is 250°F. This is the maximum process temperature which can be used to heat or process explosives per AMCR 385-100 (ref. 1). The initial development studies (ref. 2) of the controlled cooling process were conducted by the U.S. Army Armament Research and Development Command (ARDC) in Dover, New Jersey using thermal panels and water heated 257 to 260°F. In order to prove-out and operate the controlled cooling process at IAAP, it may be necessary to operate in the same temperature range used in the initial development studies (ref. 2). The purpose of this report is to document the hazards analysis required by AMCR 385-100 to show that the thermal panels can be safely operated at temperatures up to 260°F for M795 TNT projectiles.

Significant Analysis Findings

Several safety concerns were identified and reviewed in this hazards analysis (table 1). These concerns include initiation of TNT from exposure to temperatures ≥260°F, funnel to thermal panel contact, formation of long TNT crystals during cooling, and direct steam/hot water contact.

Initiation of TNT due to exposure to excessive temperatures is not considered to be credible for the controlled cooling system design. The cooling units are heated with water provided by a heat transfer package. This eliminates safety concerns of superheated steam and provides more even heating to the ovens. A PLC will be used to monitor the supply and return thermal panel water temperatures, and will be programmed to alarm if temperatures are outside operating parameters. Also, the thermal panels are only heated for 3 hrs. Pressure relief valves are present in the thermal panel water circulation system to relieve and vent if the water pressure exceeds 60 psig (274°F). The heat transfer package steam supply is regulated to 50 psig and also has a pressure relief valve specified to relieve at 60 psig. Therefore, the maximum temperature which may be achieved with multiple component and control system failures is 274°F.

TNT has been heated at 284°F for 40 hrs (refs. 3 and 4) with no noticeable decomposition. TNT heated to 392°F (200°C) will auto-ignite after approximately 38 hrs (ref. 4). Review of previous TNT melt-pour thermal studies (ref. 5) determined that the critical temperature of TNT in a continuous melter was 338°F for an in-process confinement of 6-in. The molten material in the M795 projectile funnels has a smaller diameter, and under normal operations will have a maximum temperature of 200°F (ref. 2). Based on review of the controlled cooling system design and safeguards, no credible failure scenario was identified that would result in thermal initiation of TNT in the M795 projectiles.

During insertion of the projectile carts into the cooling ovens, it is possible for the projectile funnel to contact the thermal panels. This would result in the TNT being directly exposed to 260°F temperatures by contact. Normally, the maximum temperature of the TNT in the funnel is anticipated to be 200°F or lower (ref. 2). Direct contact heating of the TNT in the funnel may result in quality problems and in melting of all the (seed) flake TNT and subsequent formation of long crystals, discussed later. Recommendation CC-01 was issued to assure that the fill funnels are not in direct contact with thermal panels after the projectile carts have been inserted into the ovens.

Mason and Hanger (ref. 6) personnel identified a potential concern that all of the flake TNT mixed into the molten TNT may be melted. These small flakes of TNT act as seed crystals to start TNT crystalization (solidification) as the TNT cools. If there are no seed crystals and the TNT is cooled slowly, then long TNT crystals can be formed (ref. 7). At the time of this analysis, there were no known safety concerns involving long crystals in the M795). These long crystals are being formed under current operating conditions using 250°F water in the thermal panels. Recommendation CC-02 was issued to determine if long crystals of TNT present safety hazards or quality concerns for M795 projectile manufacture and handling.

Another concern is direct TNT contact with steam or hot water. This can only occur if there is a leak or mechanical failure in the thermal panels or piping systems. If hot water/steam were sprayed into the funnel(s) of molten TNT, the TNT would likely be splashed onto the insides of the cooling ovens and into the projectile cart. This would present increased operator exposure, excessive cooling water contamination, and the potential for mechanical initiation during clean up operations. The thermal panels were pressure tested to 300 psig by the manufacturer, and the water system will be operated at 50 psig (260°F) with a pressure relief valve set at 60 psig. To minimize the potential for leaks or mechanical failure, it is suggested that the thermal panels be included in the facilities mechanical integrity program (CC-03).

While on-site, Mason & Hanger personnel requested that the small scale or pilot controlled cooling unit located in Building 3 be included in this assessment. Currently, this buildings steam supply is regulated to 15 psig. Increasing the pilot scale temperature to 260°F would require modifications to the steam supply system. The heat transfer package on the pilot oven has a temperature controller that maintains the water temperature by controlling steam flow with a pneumatic flow control valve. As in the full scale unit, the thermal panel water system has a pressure relief valve. However, this valve is set to relieve at 100 psig (316°F). This does not present a TNT thermal initiation concern, but is higher than necessary. CC-04 recommends that the thermal panel water system relief valve on the pilot oven be replaced with a relief valve having a 60 psig (274°F) relief pressure.

CONCLUSIONS

A hazards analysis for using 260°F water in the Iowa Army Ammunition Plant controlled cooling process was completed. The analysis is documented in the failure modes and effects analysis located in table 1. Recommendations were issued to eliminate or control potential process hazards identified in the hazard analysis. Safety issues that were addressed as part of this analysis are potential hazards related to TNT exposure to temperatures ≥260°F.

This analysis did not identify any unacceptable initiation hazards for the use of 260°F water, heated with steam at pressures > 15 psig, in the thermal panels of the pilot and full scale controlled cooling process for the M795 projectile. Under planned operating conditions, the maximum temperature that the TNT is anticipated to reach is 200°F. Safety concerns involving the process and the design of the controlled cooling process were identified and recommendations issued to eliminate these concerns.

RECOMMENDATIONS

Recommendations issued in the analysis are summarized in table 2. Implementation of the recommendations will minimize risk associated with a given failure mode.

HAZARD RISK ASSESSMENT MATRIX
(MIL-STD-882C, page A-5)

Frequency of Occurrence	Hazard Category			
	(1) Catastrophic	(2) Critical	(3) Marginal	(4) Negligible
(A) Frequent	1A	2A	3A	4A
(B) Probable	1B	2B	3B	4B
(C) Occasional	1C	2C	3C	4C
(D) Remote	1D	2D	3D	4D
(E) Improbable	1E	2E	3E	4E

HAZARD SEVERITY CATEGORY DEFINITIONS
(MIL-STD-882C, page 11)

	Category	Definition
Catastrophic	1	Death, system loss, or severe environmental damage.
Critical	2	Severe injury, severe occupational illness, major system or environmental damage.
Marginal	3	Minor injury, minor occupational illness, or minor system or environmental damage.
Negligible	4	Less than minor injury, occupational illness, or less than minor system or environmental damage.

HAZARD FREQUENCY DEFINITIONS
(MIL-STD-882C, page 11)

	Frequency	Definition
Frequent	A	Likely to occur frequently.
Probable	B	Will occur several times in the life of an item.
Occasional	C	Likely to occur sometime in the life of an item.
Remote	D	Unlikely, but possible to occur in the life of an item.
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced.

The Hazard and Frequency categories defined above are used by GES as a tool to rank potential hazards identified in the FMEA line items, and are assigned to all recommendations issued. Implementation of recommendations is the responsibility of the client. Also, the client is responsible for defining the level of risk to facilities and personnel which the client is willing to accept. GES will act in an advisory capacity only in matters concerning acceptance of risk and recommendation implementation.

Figure 1
FMEA frequency and risk category explanation sheet

1)	NO.:	A sequential recommendation number.
2)	OPERATION/ITEM:	Operation or process equipment.
3)	RECOMMENDATIONS:	Recommendations help achieve an acceptable level of risk and enhance safety.
4)	POTENTIAL HAZARD:	Consequences to the process if the recommendation is implemented (safety benefit) or if it is not implemented (potential hazard).
5)	HAZARD RISK INDEX:	Hazard classification ranking (refer to Appendix B)
6)	REFERENCE DOCUMENTS:	Report, note, drawing or regulation that applies to the recommendation. (Deleted from this table)
7)	(FMEA #) LINE NO.:	The Line Number from the FMEA Table.
8)	CORRECTIVE ACTION REFERENCE:	Reference to document that notified the customer of the recommendation (e.g. SAR #).
9)	STATUS:	
	I–IMPLEMENTED:	Recommendation is accepted and is incorporated.
	IP–IN PROCESS:	Recommendation is accepted but will be implemented at a later date.
	O–OPEN:	Recommendation is being considered, but no decision has been made.
	C–CANCELED:	Recommendation will not be implemented as stated.

Figure 2
Recommendation table heading description

1)	LINE NO.:	Consists of an "Item" number and a single letter identifying the "Failure Cause" (e.g., 1A, 1B, 2A ...).
2)	ITEM:	The item of concern in the scenario.
3)	FAILURE MODE:	The potential problem.
4)	FAILURE CAUSE:	Events which cause the failure mode.
5)	POTENTIAL EFFECTS:	Potential effects of the problem in the system or subsystem. The Potential Effects column lists the consequences of the Failure Mode.
6)	DESIGN SAFETY:	Those features of a system which will prevent the Failure Mode from occurring. Any deficiencies in Design Safety will be reflected in the Recommendation column.
7)	HAZARD CATEGORY:	Hazard classification ranking (refer to Appendix B).
8)	RECOMMENDATIONS:	Recommended corrective actions. Deficiencies in the Design Safety are corrected by implementing the recommendations in the Recommendation column.

Figure 3
FMEA table heading description

Table 1
Failure modes and effects analysis of M795 controlled cooling unit thermal concerns

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LINE NO.	ITEM	FAILURE MODE	FAILURE CAUSE	CONSEQUENCES	DESIGN SAFETY	HAZARD RISK INDEX	RECOMMENDATIONS
1	Full Scale Controlled Cooling Process						
2	TNT Exposed to Temperatures > 260°F	Process water exceeds 260°F.	PLC failure.	Initiation of TNT from exposure to temperatures above 260°F.	1. Thermal panel water system pressure relief valve will relieve at 60 psig. Therefore maximum anticipated temperature is 274°F (134°C) which is well below thermal onset for TNT, 482°F (250°C).[4] 2. Cooling cabinet heating time is 3 hrs. TNT has been held at 284°F (140°C) for 40 hours with no noticeable decomposition.[3,4]	1E	Initiation is not Credible. Adequate safeguards exist to prevent this event from occurring.
3	TNT Exposed to Temperatures = 260°F.	Funnel in Direct contact with Thermal Panel.	Misalignment of projectile, funnel and cart. (Possible due to multiple design tolerances of units.)	TNT would be directly exposed to 260°F. Initiation is not anticipated. This could result in projectile quality problems.	1. This temperature is well below thermal onset for TNT, 482°F (250°C). 2. TNT has been held at 284°F (140°C) for 40 hours with no noticeable decomposition.	3C	Recommendation CC-01: Assure that funnels are not in contact with thermal panels. Suggestions: 1. Modify Operating Instructions to require inspection of funnels inside of controlled cooling cabinets. Require rolling cart to be repositioned if any funnel is contacting a thermal panel. or 2. Make design modifications to prevent funnel to thermal panel contact with cart in final position.

Table 1
(cont'd)

LINE NO.	ITEM	FAILURE MODE	FAILURE CAUSE	CONSEQUENCES	DESIGN SAFETY	HAZARD RISK INDEX	RECOMMENDATIONS
4		Formation of Long Crystals in Projectile	Operating at temperatures where all TNT flakes are melted. (i.e. TNT temperature exceeds 176°F)	Potential Quality and Safety Concerns	Temperatures of TNT in the funnel have been monitored. After 3 hrs with 250°F water in the thermal panels TNT temperature was 188°F. (On-site Inspection) Previous studies of this process the maximum temperature recorded in the funnel was 200°F with thermal panel temperatures from 257-260°F.		Insufficient information to assign a complete hazard category to the formation of long crystals. Recommendation CC-02: Determine if the formation of long crystals present safety and quality concerns for projectile manufacture and handling. Note: Previous Studies did not identify any safety concerns from operating the thermal panels at 260°F.
5		Thermal Panel/Piping leaks.	Mechanical Failure	260°F water/steam is sprayed into molten TNT. TNT could be splashed onto inside of controlled cooling oven surfaces and into cart. Initiation due to exposure to 260°F water is not anticipated.	1. Thermal panels have been in use since 1950's and have a history of being mechanically sound. (Mason&Hanger Personnel) 2. New thermal panels have been tested at 300 psig by manufacturer. (Mason & Hanger Personnel) 3. Maximum planned water pressure will be 50 psig. (i.e. 260°F)	2D	Recommendation CC-03: Include the thermal panels in the PSM Mechanical Integrity program.
6	Pilot Scale Controlled Cooling Unit						
7	TNT Exposed to Temperatures > 260°F	Process water exceeds 260°F.	Temperature Controller or Steam Flow Control Valve Failure and Building SteamPressure Reducing Valve Failure	Initiation of TNT from exposure to temperatures above 260°F.	1. Thermal panel water system pressure relief valve will relieve at 100 psig. Therefore, maximum possible temperature is 316°F (158°C), which is well below thermal onset for TNT 482°F (250°C) [4] 2. Cooling cabinet heating time is 3 hrs. TNT autoignition occurs after about 36 hrs at 200°C. [4]	1E	Initiation is not Credible. Adequate safeguards exist to prevent this event from occurring. Recommendation CC-04: Replace the existing 100 psig thermal panel relief valve with a relief valve having a relief pressure of 60 psig.

Table 1
(cont'd)

LINE NO.	ITEM	FAILURE MODE	FAILURE CAUSE	CONSEQUENCES	DESIGN SAFETY	HAZARD RISK INDEX	RECOMMENDATIONS
8	TNT Exposed to Temperatures = 260°F.	Funnel in Direct contact with Thermal Panel.	Misalignment of projectile, funnel and cart. (Possible due to multiple design tolerances of units.)	TNT directly exposed to 260°F. Initiation is not anticipated. This could result in projectile quality problems.	1. This temperature is well below thermal onset for TNT, 482°F (250°C)[4]. 2. TNT has been held at 284°F (140°C) for 40 hours with no noticeable decomposition[3,4].	3C	Recommendation CC-01: Assure that funnels are not in contact with thermal panels. Suggestions: 1. Modify Operating Instructions to require inspection of funnels inside of controlled cooling cabinets. Require rolling cart to be repositioned if any funnel is contacting a thermal panel. or 2. Make design modifications to prevent funnel to thermal panel contact with cart in final position.
9		Formation of Long Crystals in Projectile	Operating at temperatures where all TNT flakes are melted. (i.e. TNT temperature exceeds 176°F)	Potential Quality and Safety Concerns	Temperatures of TNT in the funnel have been monitored. After 3 hrs with 250°F water in the thermal panels TNT Temperature was 188°F. (On-site Inspection) During previous Studies of this process the maximum temperature recorded in the funnel was 200°F with thermal panel temperatures from 257-260°F.		Insufficient information to assign a complete hazard category to the formation of long crystals. Recommendation CC-02: Determine if the formation of long crystals present safety and quality concerns for projectile manufacture and handling. Note: Previous Studies did not identify any safety concerns from operating the thermal panels at 260°F.
10	TNT exposed to heating medium.	Thermal Panel/Piping leaks.	Mechanical Failure	260°F water/steam is sprayed into molten TNT. TNT could be splashed onto inside of controlled cooling oven surfaces and into cart. Initiation due to exposure to 260°F water is not anticipated. (See FMEA Line 2)	Thermal panels have been in use since 1950's and have a history of being mechanically sound. (Mason&Hanger Personnel)	2D	Recommendation CC-03: Suggest that the thermal panels be included in the PSM Mechanical integrity program.

Table 2
Recommendations for M795 controlled cooling process

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No.	OPERATION/ITEM	RECOMMENDATIONS	POTENTIAL HAZARD	HAZARD RISK INDEX**	REFERENCE	IMPLEMENTATION		
					TABLE No. & FMEA LINE No.	CORRECTIVE ACTION	CORRECTIVE ACTION REFERENCE	STATUS
CC-01	Controlled Cooling Oven/ Funnels	Assure that funnels are not in contact with thermal panels. Suggestions: 1. Modify Operating Instructions to require inspection of funnels inside of controlled cooling cabinets. Require rolling cart to be repositioned if any funnel is contacting a thermal panel. or 2. Make design modifications to prevent funnel to thermal panel contact with cart in final position.	Heating of explosives to 260°F by direct contact.	3C	T2-3, 8	1) If the temperature level is raised to 260 degrees F., M&H will modify the procedures to inspect for funnel contact with the panels. 2) If the temperature level is raised to 260 degrees F. M&H will adjust the cart guides to prevent the thermal panels from contacting the funnels.	Email from M.Patriarca dated 2/18/97.	Open
CC-02	Controlled Cooling Oven/ Funnels	Determine if the formation of long crystals present safety and quality concerns for projectile manufacture and handling.	Long crystals may present a safety hazard to the manufacture and handling of M795 projectiles.	See Note:	T2-4,9	M&H has contacted Mr. Holmberg and confirmed that the crystals present a quality problem not a safety hazard.	Email from M.Patriarca dated 2/18/97	Closed
CC-03	Controlled Cooling Oven/ Thermal Panels	Suggest that the thermal panels be included in the PSM Mechanical Integrity program.	Heating of explosives to 260°F by direct contact. Spillage of explosives in the process.	2D	T2-5,10	M&H prefers not to establish a PM program for this characteristic as a leak will immediately be detected by the water flashing to steam.	Email from M.Patriarca dated 2/18/97	Closed
CC-04	Pilot Controlled Cooling Oven/ Thermal Panel Water System	Replace the existing 100 psig thermal panel relief valve with a relief valve having a relief pressure of 60 psig.	TNT exposure to higher than necessary temperatures in the event of multi-component failures.	1E	T2-7	M&H will replace the existing 100 psig relief valve if the panel temperature is raised to 260 degrees F.	Email from M.Patriarca dated 2/18/97	Open

Note: No known safety hazards were identified concerning the formation of long TNT crystals at the time of this analysis. An appropriate Hazard Risk Index cannot be assigned.
Status Definitions
Open: Recommendation has not been implemented.
Closed: Recommendation has been implemented or a satisfactory resolution developed.

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