U.S. Chemical Safety and Hazard Investigation Board

Explosion, Molten Salt Eruption, and Fatal Injury at TS USA Liquid Nitriding Facility

Chattanooga, Tennessee | *Incident Date: May 30, 2024* | **No. 2024-01-I-TN**

Investigation Report

Published: June 2025

SAFETY ISSUES:

- **Safety Management Systems**
  - **Procedures**
  - **Hazard Analyses**
  - **Training**
- **Learning from Past Incidents**
- **Corporate Engagement**
  - **Knowledge Management**
  - **Corporate Engagement**

U.S. Chemical Safety and Hazard Investigation Board

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The May 30, 2024, explosion and molten salt eruption at the TS USA Chattanooga Liquid Nitriding facility fatally injured Brent "Tex" Morgan.

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ABBREVIATIONS

APQP	Advanced Product Quality Plan
CCPS	Center for Chemical Process Safety
CEO	Chief Executive Officer
CFR	Code of Federal Regulations
CSB	U.S. Chemical Safety and Hazard Investigation Board
EPA	Environmental Protection Agency
FMEA	Failure Modes and Effects Analysis
IATF	International Automotive Task Force
ISO	International Organization of Standardization
NFPA	National Fire Protection Association
NIOSH	National Institute of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
PHA	process hazard analysis
PPE	personal protective equipment
PSM	Process Safety Management
RBPS	Risk Based Process Safety
RMP	Risk Management Program
SDS	Safety Data Sheet

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EXECUTIVE SUMMARY

On May 30, 2024, at 8:58 a.m., an explosion occurred while employees were processing rollers with cavities at the TS USA facility in Chattanooga, Tennessee. The explosion caused an eruption of molten salts from the process, fatally injuring one TS USA employee and resulting in fires throughout the facility.

TS USA, a subsidiary of the French company HEF Groupe, treats metal parts in a liquid nitriding process, which involves a reaction to harden the surface of the metal. Leading up the incident, five rollers were submerged in molten salt baths used in the nitriding process. Each roller was a large cylinder that had an empty cavity with drain holes on the top and bottom. When the rollers were submerged in the baths, molten salt entered the cavities through the drain holes. Due to the small size of the drain holes, when the rollers were lifted from the salt bath to drain, the salt was unable to fully drain from one of the rollers and created a thick, solidified plug at the bottom of the roller. All five rollers were submerged in a hot water rinse bath to remove residual salt, but when the rollers were lifted for the water to drain, the salt plug prevented the water from draining from the plugged roller. Although the rollers were allowed to cool for over an hour, the plugged roller with the retained water remained at a temperature too hot to continuously touch.

When troubleshooting the plugged, hot roller, TS USA employees believed the internal cavity to be filled with solidified salt and that there was no water in the cavity. As such, a plan was developed to reintroduce all five rollers back into the salt bath to melt the solidified salt in the plugged roller so that salt could drain from the part. When introduced to the 800°F salt bath, the roller with the retained water began heating up. The water inside the roller began to boil, which rapidly increased the pressure inside the roller's cavity. The increasing pressure resulted in the roller failing and ejecting the bottom press fit end due to an overpressure, releasing steam and water into the molten salt. When the water contacted the high-temperature salt, it rapidly vaporized, resulting in a steam explosion. The steam displaced the hot molten salt, causing it to erupt from the bath and engulf a TS USA line operator, resulting in second- and third-degree chemical and thermal burns over 95 percent of his body. He was transported to a nearby hospital, where he died later that day.

The hot molten salts also ignited multiple fires throughout the facility. TS USA estimated that the eruption released 4,500 pounds of molten salt.

No off-site impacts were reported. The incident resulted in approximately $1.3 million in property damage. The facility was shut down for approximately eight months until it reopened in February 2025.

SAFETY ISSUES

The CSB's investigation identified the safety issues below.

- **Safety Management Systems.** At the time of the incident, although TS USA had *quality* management systems to ensure that parts met the appropriate quality standards, the company did not have an adequate *process safety* management system in place at its Chattanooga facility. As a result, there were insufficient programs at the Chattanooga facility to ensure the safety of the facility's operation. TS USA lacked procedures for reprocessing parts in the oxidizer bath and did not have training on the hazards present in the nitriding line. TS USA also lacked hazard analyses on processing new parts, on the liquid nitriding line, and for reprocessing parts. Due to the lack of these programs, on the day of the incident, TS USA employees were unprotected from and unaware of the hazards presented by the nitriding line, entrapment of materials in the parts, and reprocessing the rollers. (Section 4.1)

- **Learning from Past Incidents.** Before the 2024 fatal eruption in Chattanooga, HEF Groupe had at least three similar incidents involving the processing of parts with accumulation hazards or sealed cavities. TS USA and HEF Groupe did not ensure that these safety incidents were investigated or that lessons learned from events were shared and incorporated across the organization to help prevent future incidents. (Section 4.2)

- **Corporate Engagement.** HEF Groupe developed hazard analyses for the nitriding process. However, the details of these analyses and the safeguards were not communicated to HEF Groupe's subsidiary companies, including TS USA. Additionally, HEF Groupe did not ensure that its subsidiaries were following the company's guidance, such as the risk assessments and safety alert letters, developed at the corporate level to ensure the safety of the operations. Furthermore, HEF Groupe did not ensure that the safety knowledge maintained at the corporate level was communicated to its subsidiary companies to promote the safe operation of the liquid nitriding line. (Section 4.3)

CAUSE

The CSB determined that the cause of the incident was the introduction of water contained in the roller cavity to the 800°F oxidizing salt bath. The hot salt caused the water to expand and boil in the cavity of a roller, which resulted in an overpressure, a steam explosion, and a molten salt eruption.

Contributing to the incident was TS USA's lack of awareness of the accumulation hazards associated with parts containing cavities. These cavities presented accumulation hazards when processed in the nitriding line. Also contributing to the incident were TS USA's and HEF Groupe's insufficient process safety management systems, which did not include adequate procedures, training, hazard analyses, and incident investigations. Also contributing to the incident was HEF Groupe's ineffective corporate governance and safety knowledge management, which did not ensure that critical safety information was communicated and accessible to all TS USA facilities, including details of prior safety incidents and the results of those investigations.

Recommendations

To TS USA

2024-01-I-TN-R1

Implement physical, protective barriers around the molten salt baths that isolate employees from hazardous releases at all locations that perform liquid nitriding.

2024-01-I-TN-R2

Develop a safety management system that incorporates industry guidance and includes, but is not limited to:

a. A hazard analysis program for assessing the nitriding process. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*, the National Fire Protection Association's (NFPA) *Standard for Ovens and Furnaces*, and ASM International's Handbook. The program shall apply to new and existing parts, assess parts for accumulation hazards and sealed cavities, and include non-routine tasks such as reprocessing unsatisfactory parts.

b. Written operating procedures for the nitriding process. The procedures shall be based on the information gathered from the hazard analysis program. The procedures shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Writing Effective Operating and Maintenance Procedures*.

c. A training program, including written materials, for the employees involved in the nitriding process. This program shall be based on the nitriding facility's operating procedures and other relevant information from the hazard analysis program. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*.

d. An incident investigation program. This program shall include requirements for performing causal analysis, producing written reports, and communicating findings and corrective actions throughout the entire TS USA organization. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Investigating Process Safety Incidents*.

2024-01-I-TN-R3

For each TS USA facility, establish a position with specific professional expertise and experience in safety management systems, such as risk-based process safety. This position shall be responsible for TS USA's safety management system, ensuring that HEF Groupe's safety information is incorporated at the site level, and implementing regulatory and industry safety guidance.

To HEF Groupe

2024-01-I-TN-R4

Include physical, protective barriers as part of the standard design for liquid nitriding processes. These protective barriers shall be intended to isolate employees from molten salt releases.

2024-01-I-TN-R5

Develop a safety management system that incorporates industry guidance and includes, but is not limited to:

a. A hazard analysis program for assessing the nitriding process. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*, the National Fire Protection Association's (NFPA) *Standard for Ovens and Furnaces*, and ASM International's Handbook. The program shall apply to new and existing parts, assess parts for accumulation hazards and sealed cavities, and include non-routine tasks such as reprocessing unsatisfactory parts.

b. Written operating procedures for the nitriding process. The procedures shall be based on the information gathered from the hazard analysis program. The procedures shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Writing Effective Operating and Maintenance Procedures*.

c. A training program, including written materials, for the employees involved in the nitriding process. This program shall be based on the nitriding facility's operating procedures and other relevant information from the hazard analysis program. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*.

d. An incident investigation program. This program shall include requirements for performing causal analysis, producing written reports, and communicating findings and corrective actions throughout the entire HEF Groupe organization. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Investigating Process Safety Incidents*.

2024-01-I-TN-R6

Develop and implement an effective and comprehensive Knowledge Management program for sharing knowledge throughout the HEF Groupe organization. Knowledge shall include all information from audits, hazard analyses, and incident investigations, including causal analyses and corrective actions recommended and taken. This program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Process Safety Knowledge Management*.

2024-01-I-TN-R7

Develop and implement a comprehensive and effective Corporate Governance program. This program shall include regular audits of subordinate facilities throughout the organization, with tracking and accountability for implementation of all recommendations and corrective actions identified in the audits. Facility adherence to the safety management system recommended above shall be evaluated during the audits. The program shall require documentation of audit findings, prompt responses to deficiencies, development of corrective actions, and implementation of the corrective actions throughout the organization. This program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Implementing Process Safety Management*.

1 BACKGROUND

1.1 TECHNIQUES SURFACES USA

Techniques Surfaces USA ("TS USA") is headquartered in Springfield, Ohio [1]. TS USA operates metal treatment facilities (**Figure 1**) in Springfield, Ohio; Kearney, Nebraska; Chino Valley, Arizona;[a] Kennebunk, Maine;[b] Benton Harbor, Michigan; and Chattanooga, Tennessee [1]. TS USA is a subsidiary of HEF USA, which also is headquartered in Springfield, Ohio. HEF USA is a subsidiary of HEF Groupe, which is headquartered in Andrézieux-Bouthéon, France [1, 2, 3]. HEF Groupe owns numerous facilities throughout the world, including locations in Mexico, China, India, and Brazil [2].

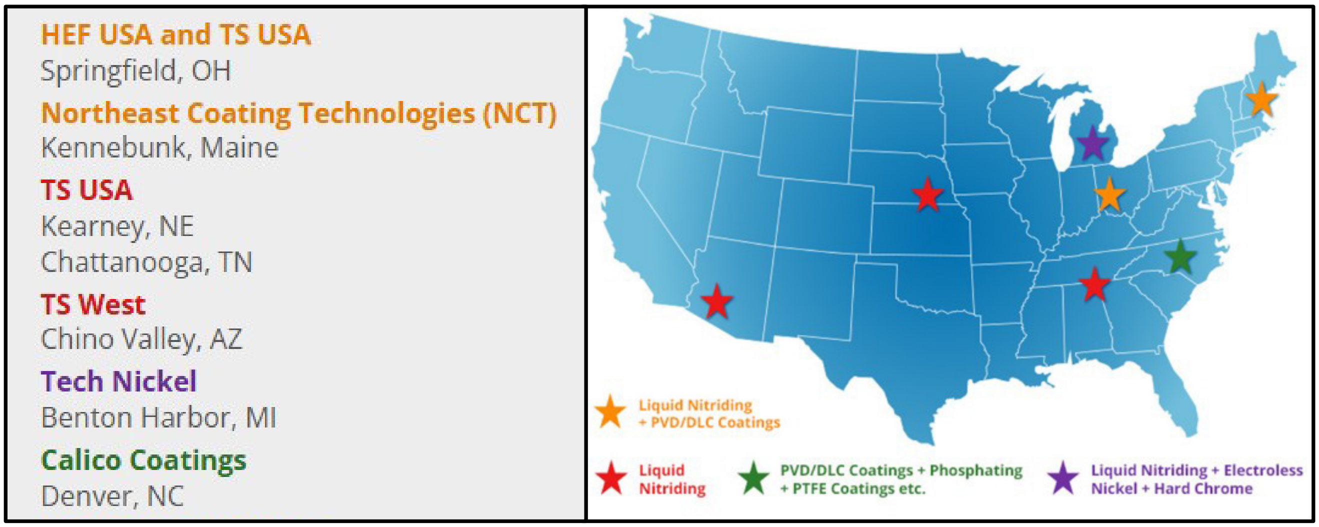


Figure 1. HEF USA and TS USA metal treating locations [4]. (Credit: HEF USA, modified by CSB)

At the time of the May 30, 2024, incident, TS USA employed 15 people at the Chattanooga facility, consisting of the plant manager, one supervisor, one maintenance technician, two administrative staff, eight support workers, and two nitriding line operators. The approximate average tenure of the employees involved in the incident was 2.5 years. No employee involved in the incident had more than five years of experience at the Chattanooga facility.

In day-to-day operations, the TS USA plant managers report to the TS USA operations manager. The TS USA operations manager reports to the TS USA president. The TS USA president reports to the HEF USA chief executive officer (CEO). The HEF USA CEO reports to HEF Groupe.

The only process engineer who supports the TS USA Chattanooga facility is located in southeast Georgia and reports to the HEF USA CEO.

This organizational structure is graphically represented in **Figure 2**.

[a] The Chino Valley, AZ, facility operates under the name TS WEST [1].

[b] The Kennebunk, ME, facility operates as TS Northeast Coatings Technology, a wholly owned subsidiary of HEF Groupe [1].

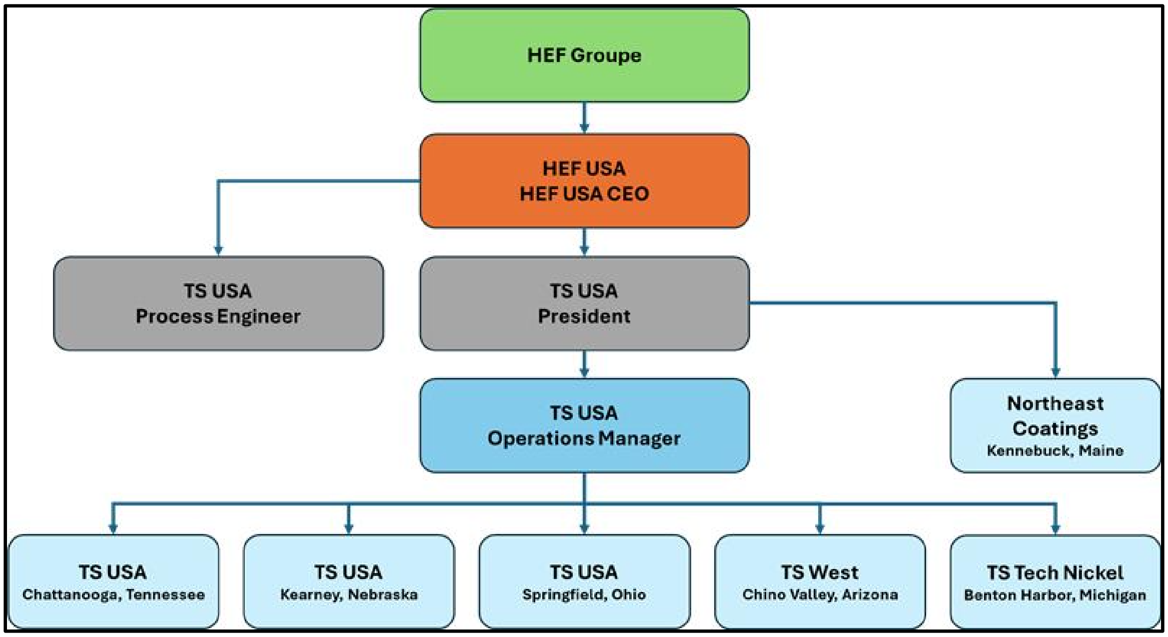


Figure 2. Organizational structure of TS USA and HEF USA. (Credit: CSB)

The TS USA Liquid Nitriding facility in Chattanooga, Tennessee, began operations in September 2017 and was designed for the surface treatment of large and heavy metal parts [5]. The facility operated in two 8-hour shifts.[a] The incident occurred during the first shift. Ten employees were present when the incident occurred.

1.2 Liquid Nitriding

Nitriding is a process that hardens and improves the wear resistance of iron and steel materials by diffusing nitrogen into the surface [6, p. 322, 7, p. 680]. Nitriding can be performed using numerous techniques, one of which is liquid nitriding. Liquid nitriding is a process whereby components are submerged in molten (liquefied) nitrogen-containing sodium and potassium salts[b] to achieve the desired surface enhancement [7, p. 680].[c]

TS USA's liquid nitriding process (**Figure 3**) began with an optional degreasing and water rinsing step, followed by the preheat furnace, where the metal parts were heated to at least 570 degrees Fahrenheit (°F), which removed moisture before surface treatment. Once heated and dried, the metal parts were submerged, via crane, in a nitriding bath containing molten sodium and potassium salts at approximately 1,100°F. Once the nitriding step was completed, a line operator transferred the parts to an oxidizer bath containing a mixture of 800°F molten sodium hydroxide and sodium nitrate [8]. The metal parts were then cooled and washed through a series of water quenching[d] and rinse baths, to remove residual salt from the parts.

[a] The first shift operated from 7:00 a.m. to 3:30 p.m. The second shift operated from 3:00 p.m. to 11:30 p.m., except for the second shift line operator, who worked from 12:00 p.m. to 8:30 p.m.

[b] The nitriding process uses cyanide and cyanate salts to provide the nitrogen for the thermo-chemical reaction to strengthen the metal parts [7, p. 680].

[c] According to HEF USA, liquid nitriding is "not a coating or plating: it is a diffusion process that modifies/transforms the surface of the treated component" [1].

[d] Quenching is the process of cooling a heated metal by sudden immersion in a fluid, such as oil or water [54].

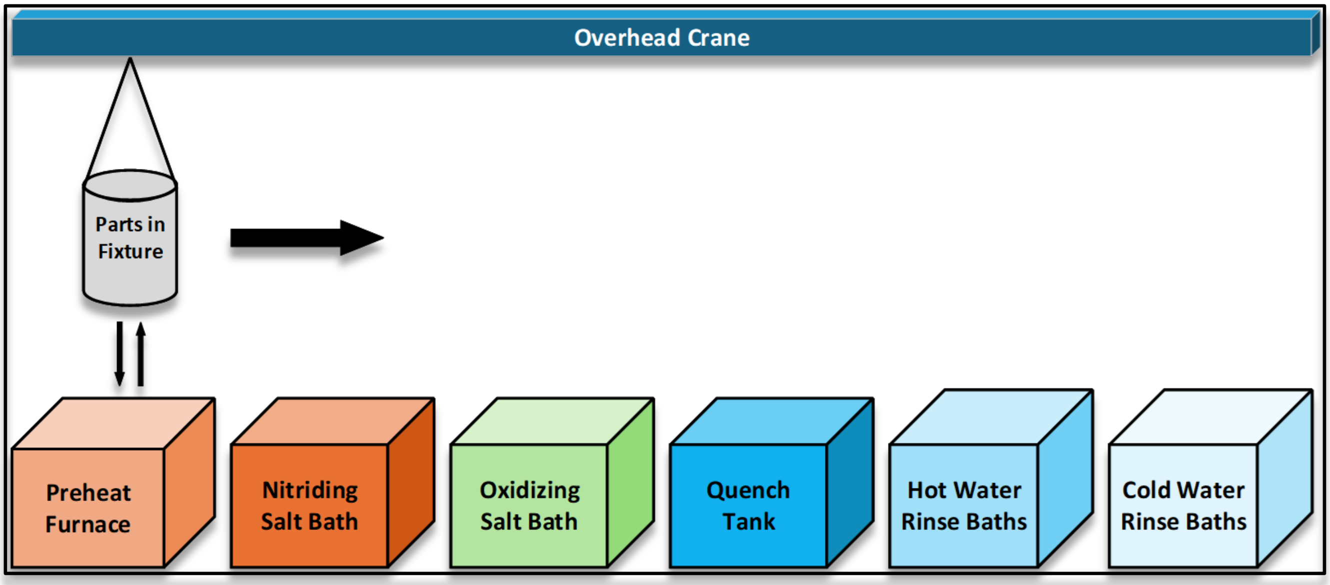


Figure 3. TS USA liquid nitriding line. (Credit: CSB)

After completing the nitriding process, metal parts continue to a surface finishing process, called polishing, and an optional oil impregnation step to increase corrosion resistance. Subsequently, the metal parts are reintroduced into the nitriding line, where the degreasing, water rinsing, preheat furnace, oxidizer bath, water quench, and water rinse bath steps are repeated to increase the parts' corrosion resistance. TS USA refers to this reintroduction process as the "re-oxidation process" [9].

1.3 Sodium Hydroxide and Sodium Nitrate

The incident at TS USA released a mixture of molten sodium hydroxide and sodium nitrate, called oxidizing salts, which are bright green in the molten state.[a] Sodium hydroxide, also known as lye or caustic soda, is a highly corrosive, strong base (high pH) that causes damage when in contact with human tissues, including the eyes, skin, and respiratory system. Sodium hydroxide is a white solid at room temperature and melts at 604°F.[b] Sodium hydroxide is non-combustible [10]. Sodium nitrate is a strong oxidizer that accelerates the burning of combustible materials. It is a white crystalline solid at room temperature and melts at 584°F [11].

1.4 Metal Parts Processed on May 30, 2024

During the incident, TS USA was processing cylindrical metal parts, called rollers. The rollers were constructed of 316 stainless steel and were approximately 7.4 feet (2.3 meters) long. The rollers had an approximately 5-inch (120-millimeter) outer diameter and contained a 4-inch (100-millimeter) cavity through the largest diameter portion, as shown in **Figure 4**. The cavity was enclosed by press fit inserts at each end that contained five blind holes, which are holes that are not drilled entirely through the material [12, p. 95]. The press fit insert also had

[a] At the moment of the release, the molten oxidizing salt mixture was approximately 800˚F.
[b] When cooled below 604˚F, molten sodium hydroxide returns to a solid state.

an approximately 0.2-inch (5-millimeter) diameter hole on either end of the roller that penetrated to the cavity interior, as shown in **Figure 5**. There were no other openings to the interior cavity.

Figure 4. Metal roller containing a cavity that TS USA processed during the incident. The annotated area is approximate. (Credit: CSB)

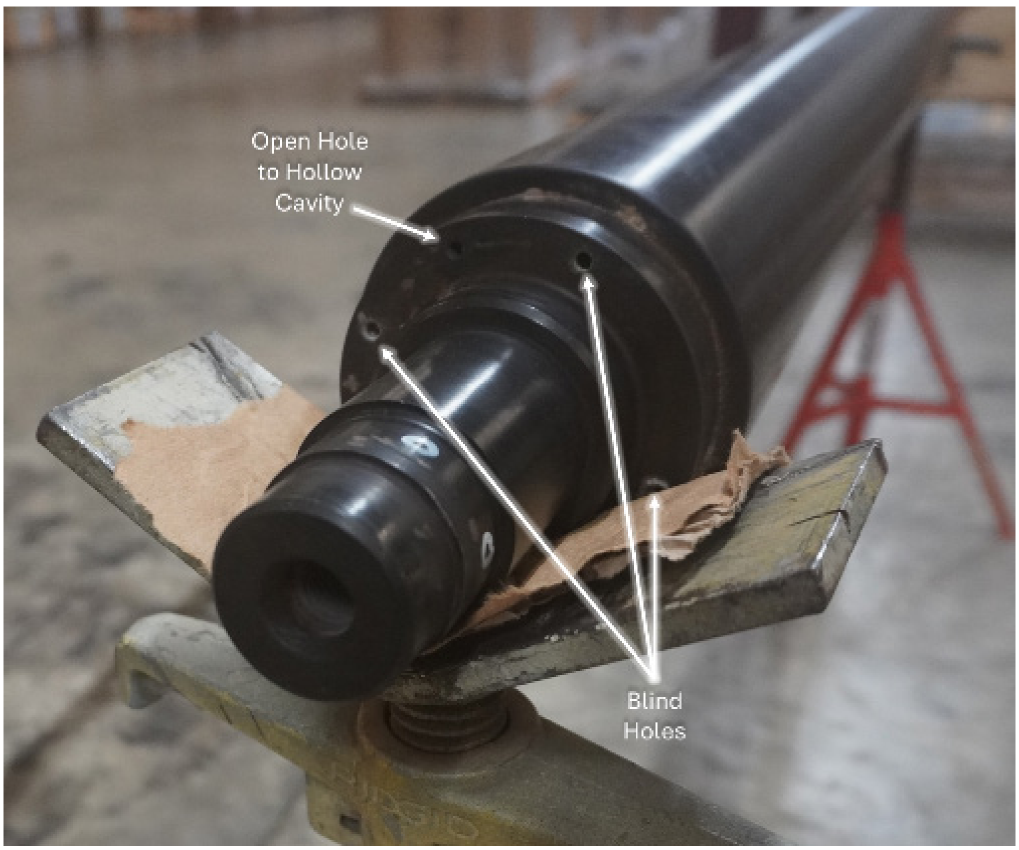


Figure 5. Open hole to the interior cavity on rollers. (Credit: CSB)

1.5 Regulatory Coverage

The Tennessee Occupational Safety and Health Administration (TOSHA) oversees an Occupational Safety and Health Administration (OSHA) approved state program and is responsible for Process Safety Management (PSM) compliance in Tennessee. The TS USA Chattanooga facility did not process or store any materials covered by the OSHA PSM[a] standard or the Environmental Protection Agency's (EPA) Risk Management Program (RMP)[b] rule and, as such, was not subject to the requirements of either the PSM standard or the RMP rule. The nitriding and oxidizing baths were also not covered under OSHA's Dipping and Coating Operations standard, 29 CFR 1910.123, which exempts operations "if your dip-tank operation only uses a molten material (a molten metal, alloy, or salt, for example)."[c]

Due to the sodium hydroxide used in the oxidizer bath, the Chattanooga facility was subject to the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).[d] The facility was also subject to the Hazardous Waste Operations and Emergency Response (HAZWOPER) standard, 29 CFR 1910.120.

1.6 Description of Surrounding Area

Figure 6 shows the TS USA Chattanooga facility and depicts the area within one, three, and five miles of the facility boundary. Summarized demographic data for the approximate one-mile vicinity of the TS USA facility are shown below in **Table 1**. There are more than 9,000 people residing in approximately 6,000 housing units, most of which are multi-unit homes, within one mile of the TS USA facility. Detailed demographic data are included in **Appendix C**.

[a] 29 CFR 1910.119 *Process Safety Management of Highly Hazardous Chemicals*

[b] 40 CFR Part 68 *Chemical Accident Prevention Provisions*

[c] 29 CFR 1910.123(c)

[d] The reportable quantity amount for sodium hydroxide is 1,000 pounds.

Figure 6. Overhead satellite image of the TS USA facility and the surrounding area. (Credit: Google, annotated by CSB)

Table 1. Summarized demographic data for the approximately one-mile vicinity of the TS USA facility. (Credit: CSB using data obtained from Census Reporter)

Population	Race and Ethnicity		Per Capita Income	Percent Poverty	Number of Housing Units	Types of Housing Units	
9,054	White	57%	$51,083[a]	21%	5,933	Single Unit	20%
	Hispanic	2%				Multi-Unit	80%
	Asian	2%				Mobile Home	<1%
	Two+[b]	4%					
	Black	35%					

[a] Census Reporter reports that the per capita income in Chattanooga, Tennessee, was $39,967 [45]. The Census Bureau reports that the overall per capita income for the United States from 2018-2022 was $41,261 [48].

[b] "Two+" refers to "Two or More Races" as defined by Census.gov.

2 Incident Description

2.1 TS USA Received New Parts

On April 5, 2024, TS USA received six rollers for treatment from a customer. Shortly thereafter, the customer requested that TS USA treat one roller as a prototype to verify its properties after undergoing the liquid nitriding process. Before the end of April 2024, TS USA finished the liquid nitriding process for the single roller and informed the customer that the roller took longer to drain than expected.[a] On May 13, 2024, the customer confirmed that the roller met the required specifications and approved TS USA to treat the remaining five rollers.

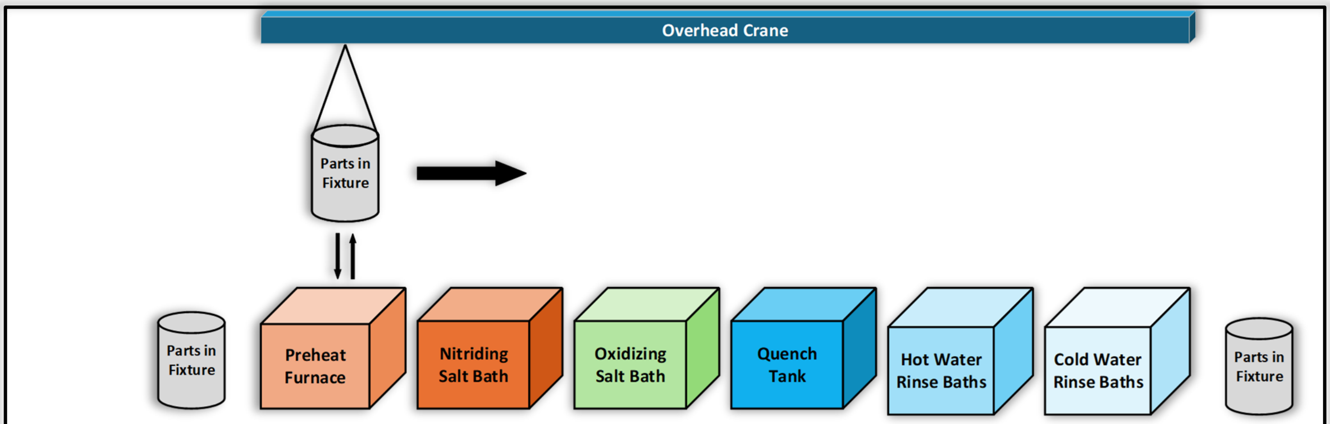
2.2 TS USA Attempted to Treat the Remaining Five Rollers

On May 24, 2024, at approximately 11:36 a.m., the remaining five rollers began the nitriding process. The rollers were placed in a metal cage, called a fixture, to secure the parts as they were moved and submerged in different steps of the nitriding process (**Figure 7**).

Figure 7. Five rollers are placed in the fixture.
(Credit: TS USA, annotated by CSB)

[a] The TS USA employee operating the line told the CSB that it took 20 minutes for the one roller to completely drain.

By the end of the day, the rollers had been processed through the nitriding bath and were placed in the rinse bath. On May 28, 2024, at approximately 9:56 a.m., the rollers were removed from the rinse baths to drain. A timeline of the initial processing steps is shown in **Figure 8**.

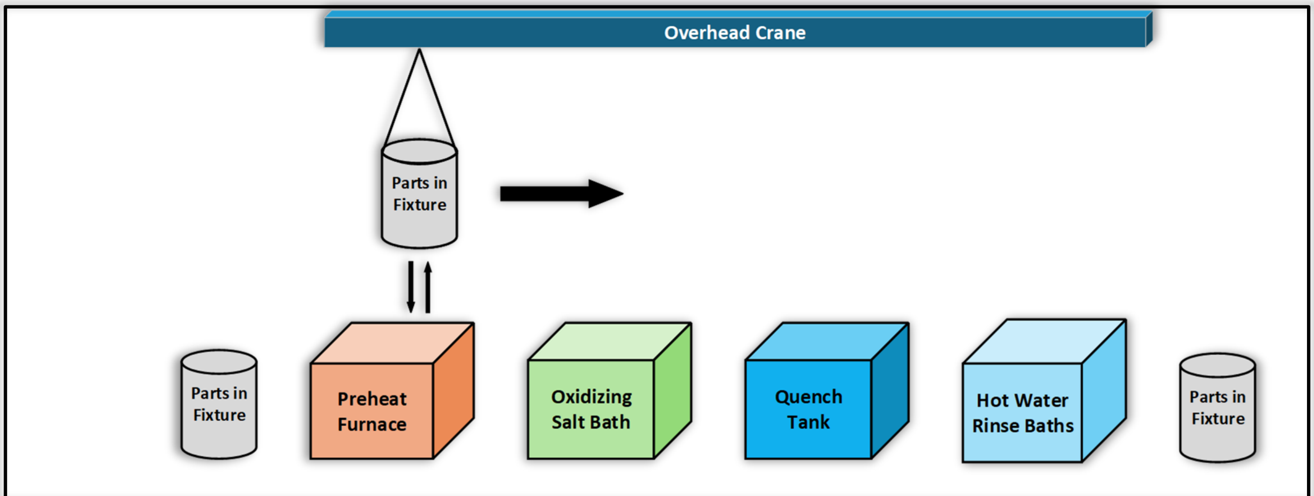


Time when Rollers entered Process Step	5/24/2024	5/24/2024	5/24/2024	5/24/2024	5/24/2024	5/24/2024	5/28/2024	5/28/2024
	1136	1335	1502	1720	1815	1858	0855	0956

Figure 8. Timeline of initial nitriding processing of rollers. (Credit: CSB)

At approximately 10:48 a.m., the remaining five rollers were moved in a single fixture to the polishing area of the Chattanooga facility to be polished. While the rollers were being polished, the polishing operators noted that the rollers retained water and salt in their cavities. To address the accumulation of water and salt, the operators tipped the rollers over to allow water to drain from the cavities. The operators also used compressed air in an attempt to remove any remaining materials, such as water or salt, from the rollers' cavities. The compressed air likely removed the majority of the water from the cavities.

The rollers completed the polishing process on the morning of May 29, 2024, and were ready for further processing. Less than two hours later, at approximately 10 a.m., the TS USA line operator connected the fixture containing the rollers to an overhead crane and began the re-oxidation process as described in **Section 1.2**. A timeline of the process steps is shown in **Figure 9**. By approximately 3:06 p.m., the rollers reached the hot water rinse bath step in the process, where they remained overnight.



Time when Rollers entered Process Step	5/29/2024	5/29/2024	5/29/2024	5/29/2024	5/29/2024	5/30/2024
	0836	1002	1248	1325	1332	0724

Figure 9. Timeline of the roller re-oxidation process. (Credit: CSB)

On May 29, 2024, when the five rollers were submerged in the oxidizer salt bath, the molten salts entered the cavities through the 5-millimeter holes on the top and bottom, shown in **part A of Figure 10** (**Figure 10.A**). After the oxidizing salt bath treatment was completed, the line operator pulled the rollers out and let the molten salt drain out of the holes at the bottom of the rollers (**Figure 10.B**). However, the drain holes were very small—0.03 square inches, or just 0.25 percent of the cross-sectional area of the cavities, which resulted in slow drain times. As a result, the molten salt was unable to fully drain out of one of the rollers before it cooled and solidified, likely as a thick disk or plug (**Figure 10.C**). The solidified salt obstructed the bottom of the roller, blocking the flow path of anything trapped in the cavity of the roller.

The rollers were then fully submerged in the hot water rinse tank to remove residual salt from the parts. The water from the hot water rinse tank entered the rollers' cavities through the five-millimeter drain holes on the top of the roller (**Figure 10.D**). The water was unable to freely flow through the one roller because of the solidified salt plug. The lack of flow significantly decreased the rate at which the salt dissolved, trapping the solidified salt and water inside the cavity of the roller.

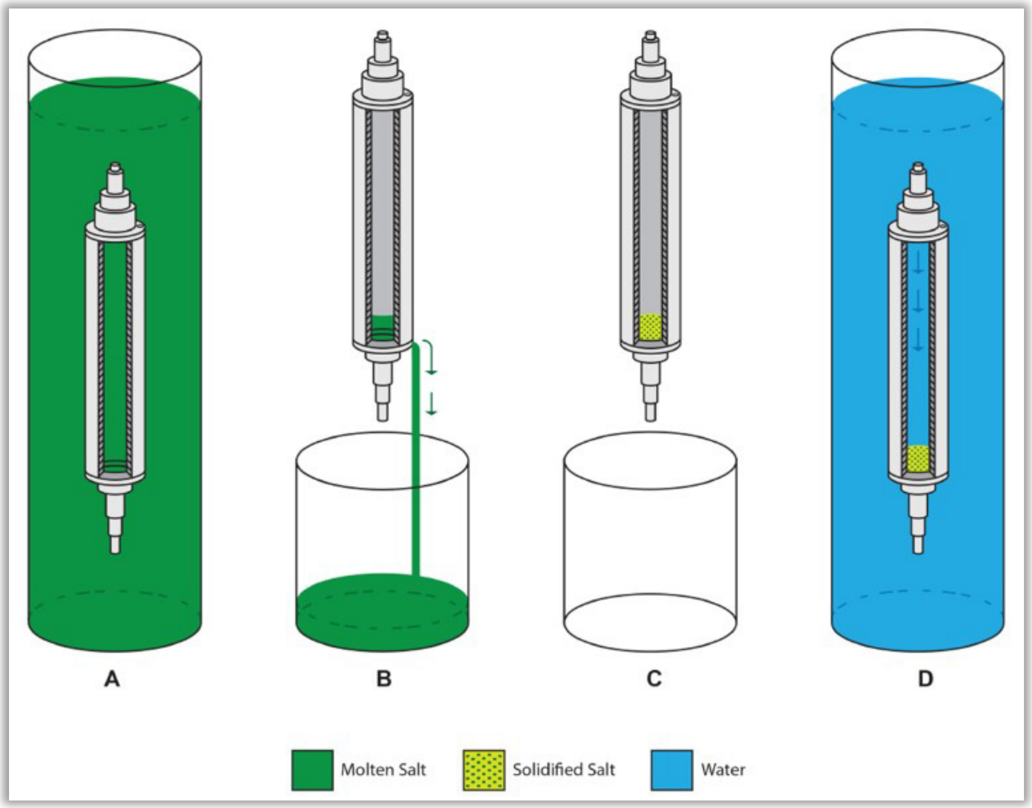


Figure 10. Sequence of events: A) Molten salt enters the roller. B) Molten salt incompletely drains from the roller. C) Molten salt solidifies in the roller. D) Water enters the roller and cannot exit. (Credit: CSB)

At 7:09 a.m., on May 30, 2024, a TS USA line operator removed the rollers from the rinse bath containing 160–180°F water. The rollers were suspended over the rinse tank to allow water to drain from the parts and then moved to the end of the production line to cool down. However, the water was unable to drain out of the one roller with the solidified salt plug blocking its drain hole. The other four rollers were likely able to fully drain. Approximately 15 minutes later, the plant manager moved the rollers to the end of the process line and placed them on the floor to cool down.

After the rollers had cooled for over an hour, the plant manager and supervisor observed that at least one roller was too hot to continuously touch. The one roller that was unable to drain likely remained hot due to the retention of water in its cavity. Since the manager and supervisor were unable to continuously touch the roller (**Section 2.2**), the surface temperature likely exceeded 140°F because metal surfaces greater than 140°F can cause immediate burns [13, pp. 4-5] [14].

Additionally, water was still slowly draining from the one roller that was too hot to touch (**Figure 11**). The drain hole appeared to be clogged, which the plant manager and supervisor believed to be due to oxidizer salt. Before the incident, the plant manager and supervisor attempted to clear the obstruction from the roller using a piece of wire, but they were unsuccessful, which allowed water to remain in the cavity. Although some of the water drained from the roller, it stopped draining before the cavity was empty. Due to the lack of any additional water draining from the parts, the plant manager believed that the part only contained solidified oxidizer salt and no water. No further actions, such as turning the rollers over, were taken to verify that there were no other materials in the roller.

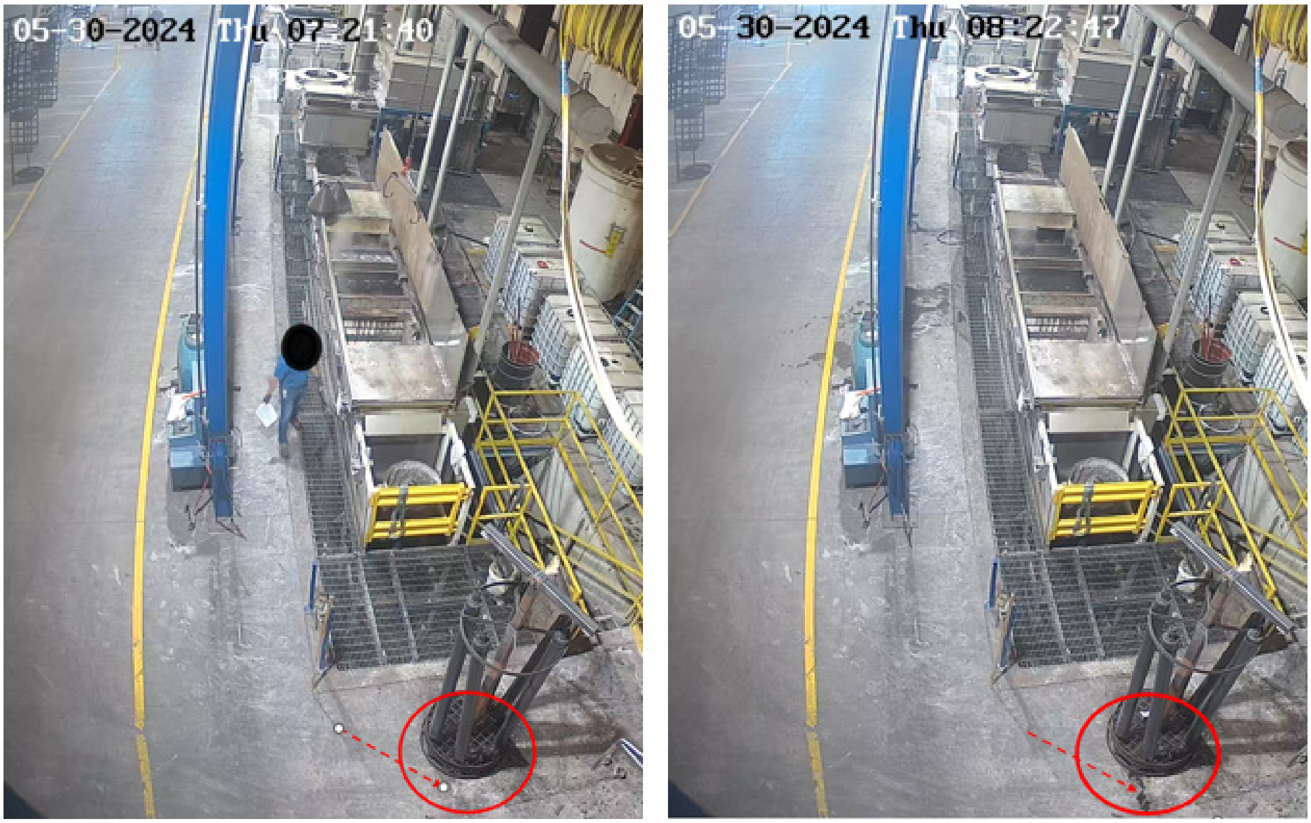


Figure 11. Rollers at the end of the nitriding line. On the left, the rollers are sitting on a concrete floor at the end of the process line with no visible water draining. The photo on the right shows water that had drained from the roller an hour later. (Credit: TS USA, annotated by CSB)

Shortly thereafter, the plant manager contacted the process engineer who was responsible for the Chattanooga facility—but who actually was located in southeast Georgia—for guidance on how to clear the obstruction. The process engineer recommended reintroducing the rollers directly into the oxidizing bath. The preheat furnace was bypassed due to concerns about potential damage to the process equipment from salt coming out of the roller and off the roller surface.

At 8:46 a.m., the plant manager and supervisor instructed the line operator to reintroduce the rollers into the oxidizing bath, as the process engineer had recommended. All five rollers were reintroduced to the oxidizing bath. The line operator was standing behind the protective shielding, less than three feet from the opening of the oxidizer bath, while reintroducing the rollers to the bath.

By 8:54 a.m., the rollers were submerged in the oxidizing tank. Approximately two minutes later, as the rollers began to heat up, steam began to vent from one of the submerged rollers and intensified as the line operator raised the rollers from the oxidizer bath. At 8:58 a.m., the chemical mixture inside the oxidizing tank erupted (**Figure 12**), releasing hot molten salt into the process area and engulfing the line operator, resulting in second- and third-degree chemical and thermal burns over 95 percent of his body. The line operator was treated on-site by Chattanooga Fire Department (CFD) personnel who were called to the facility and then was transported by

Hamilton County Emergency Medical Services (EMS) personnel to a nearby hospital. He died later that day at the hospital. Three other TS USA employees suffered minor burns and were treated on-site.

Because the released hot molten salt likely reached or exceeded the autoignition temperature of combustible materials within the building, it triggered multiple fires in the facility. The fires were extinguished by TS USA employees and CFD personnel.

Figure 12. Molten oxidizing salt erupting from the oxidizing tank. (Credit: TS USA)

Following the incident, the plugged roller (**Figure 13**) was found outside of the oxidizer vessel, indicating that it was propelled from the vessel due to the release of the steam. Damage to the overhead crane indicated that the roller had contacted the equipment approximately 20 feet above.

Figure 13. Roller in its final resting state following the explosion, with a missing press fit end. (Credit: TS USA)

A detailed timeline of events can be found in **Appendix B**.

2.3 Consequences

The TS USA line operator was fatally injured. The incident resulted in $1.3 million in property damage, and the facility was shut down for over eight months. An estimated 4,500 pounds of the molten salt mixture was released from the oxidizer bath. TS USA was investigated by TOSHA, which issued three citations because of the incident and proposed a penalty of $6,600.[a] The citations are summarized in **Appendix D**.

[a] TOSHA Inspection Detail

3 Technical Analysis

3.1 Accumulation Hazards

Before accepting the rollers for processing in the nitriding line, the process engineer had asked the customer whether the main body of the roller had a sealed cavity. The process engineer told the customer that TS USA could not treat parts with sealed cavities due to concerns about pressure buildup. The customer confirmed that the rollers had cavities and through-holes[a] on each end, which were plugged with set screws.[b] At TS USA's request, the set screws were removed by the customer from the through-holes to open the sealed cavity.

With the drain holes opened, TS USA did not consider the rollers to be sealed and, therefore, safe to process in the liquid nitriding line. However, due to the configuration of the cavity and the small size of the drain hole, the rollers still presented an accumulation hazard. This hazard was not recognized by TS USA's management systems and reviewers.

The CSB concludes that the roller's design allowed for the accumulation of molten salt in the roller's interior cavity, which solidified into a salt plug. The CSB also concludes that TS USA did not recognize the accumulation hazard presented by the cavity, which, when the molten salt solidified, blocked the drain hole in the bottom of the roller.

Organizations such as FM Global,[c] ASM International,[d] and the National Fire Protection Association (NFPA) have developed guidance that provides numerous reminders of the importance of not introducing foreign materials into the molten salt baths.

The molten salt baths used in the TS USA facility are classified as Class C furnaces, as described by the NFPA in NFPA 86, *Standard for Ovens and Furnaces*. The NFPA states:

> The potential hazards in the operation of molten salt bath furnaces can result in explosions, fires, or both, either inside the salt bath furnace or outside the furnace. Basic causes can be chemical or physical reactions or a combination.
>
> Because molten salts have high heating potential, low viscosities, and relatively little surface tension, even minor physical disturbances to the molten salt bath can result in spattering or ejection of the molten salt out of the furnace container. This ejection can become violent when liquids (e.g., water, oil) or reactive materials are allowed to penetrate the surface of the salt bath [15].

[a] A through-hole is a hole that goes through the part [52, p. 103].

[b] The diameter of each hole was 5 millimeters.

[c] FM Global is an insurance company that specializes in loss prevention and publishes data sheets detailing guidelines to minimize property loss [55].

[d] ASM International, formerly known as the American Society of Metals, is an organization that provides resources and information about materials and metals [51].

The NFPA also states that, "[a]ll items such as fixtures, tools, baskets, and parts that are to be immersed in a molten salt bath shall be made of solid bar materials and shall be completely dry" [15].

FM Global states that when molten salts contact water, the water will rapidly boil and create large volumes of steam, which can result in an explosion. FM Global also states that water introduced with parts to be treated in the molten salt bath can turn to steam with explosive effect [16, p. 11].

ASM International, in its handbook titled *Steel Heat Treating Fundamentals and Processes*, states that molten oxidizing salts can react with nitriding salts, resulting in a violent reaction and possible explosion [17, p. 6].[a] The handbook further states that entrapped air, when introduced to molten salts, rapidly heats up, which can result in high pressures that can lead to explosions, similar to water entrapment. Based on the ideal gas law,[b] as temperature increases, a gas held at a constant volume increases in pressure proportional to the increase in temperature [18, p. 135].

Cavities, sealed voids, and blind holes all provide mechanisms for materials to accumulate between each process step. Cavities, including those open at both ends, can accumulate materials if the internal orientation of the parts does not allow for adequate drainage. Blind holes can also carry over materials due to inadequate drainage. Sealed cavities can trap air, which can expand and result in an explosion.

The CSB concludes that the rollers were not suitable for processing through the liquid nitriding process. The drain holes were not large enough to ensure the rollers fully drained the molten salts, resulting in the salt plug forming at the bottom of the roller's interior.

3.2 Overpressure of the Roller, Steam Explosion, and Eruption

When the five rollers were reintroduced into the 800°F oxidizer bath, shown in **Figure 14** (**Figure 14.A**), the water in the cavity was heated until it began to boil. The steam generated from the boiling water began to vent from the top hole of one of the rollers (**Figure 14.B**).

As liquid water boils, it expands to approximately 1,600 times its original volume. This expansion of steam rapidly increased the pressure inside the plugged roller that still contained water [19, 20]. Additionally, as described by Gay-Lussac's gas law,[c] in the nearly constant volume of the roller cavity, gases increase in pressure as the temperature increases. As such, as the steam in the one roller's cavity continued to be heated, the internal steam pressure continued to increase [18, p. 135].

Once the force caused by the increased pressure inside the one roller's cavity exceeded the frictional force that held the press fit end in place, the roller experienced an overpressure event where the bottom press fit end dislodged and was ejected, along with any remaining liquid water, into the molten oxidizer salt (**Figure 14.C**). The depressurization of the cavity and the contact of any remaining liquid water with the molten salts resulted in

[a] The nitriding salts, while in a molten state, will react violently with the nitrate salts, such as sodium nitrate, used in the oxidizing bath [17, p. 6].

[b] The ideal gas law describes the ideal relationship between the volume, pressure, temperature, and the amount of gas [18, p. 135, 57, pp. 184-186, 58, pp. 123-125].

[c] Gay-Lussac's Law (Amonton's Law) states that an ideal gas's pressure and absolute temperature are directly proportional in a fixed volume [18, p. 135, 57, pp. 184-186, 58, pp. 123-125].

the rapid vaporization of water, also known as a vapor or steam explosion.[a] The rapid expansion of the steam displaced the molten salt in the oxidizer bath, resulting in molten salt erupting from the vessel (**Figure 14.D**).

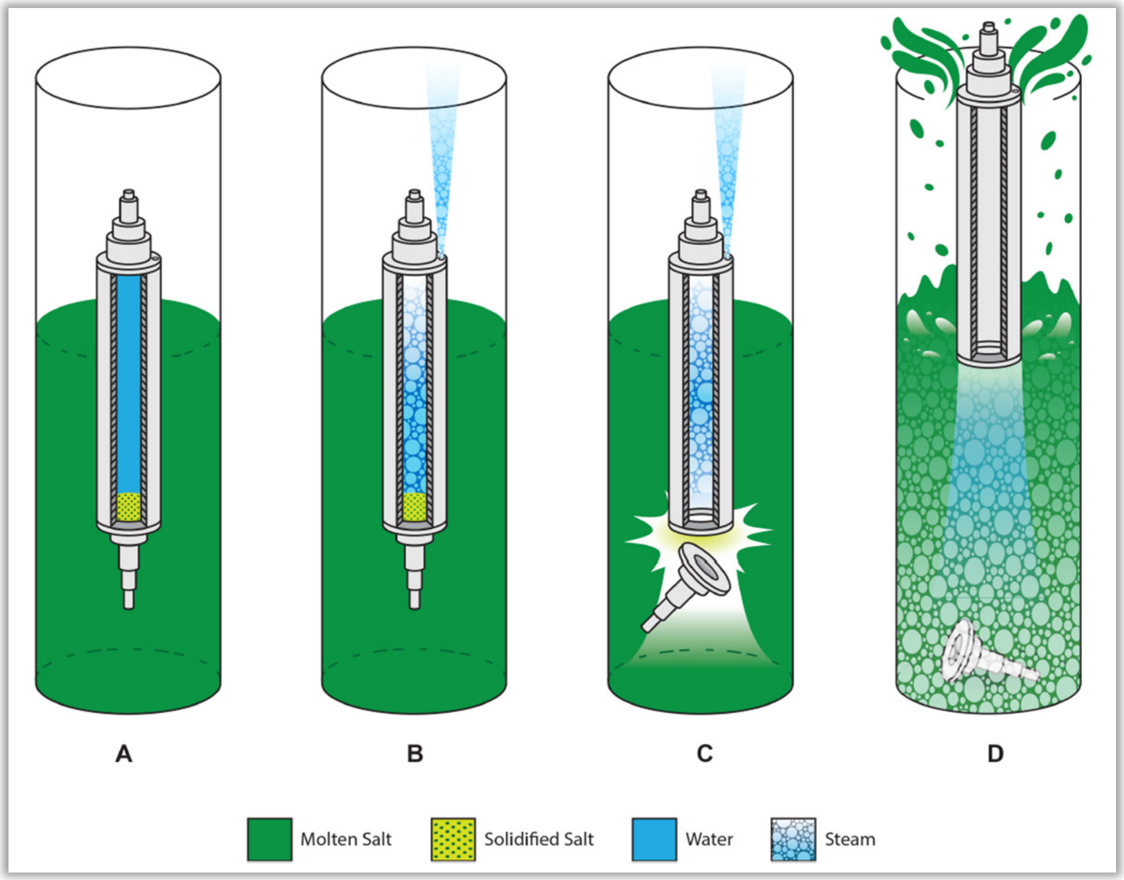


Figure 14. Sequence of events of the overpressure: A) The roller is placed in the molten salt bath. B) Water boiled and vented from the roller. C) Overpressure caused the press fit end to dislodge. D) Rapid expansion of steam and molten salt eruption. (Credit: CSB)

The CSB concludes that the retained water boiled inside the roller's cavity and rapidly expanded as steam. The increased pressure forcefully ejected the roller's press fit end, the salt plug, and the water into the molten salt bath. The water rapidly boiled, creating a violent steam explosion that drove an uncontrolled eruption of molten salt from the vessel.

[a] A vapor explosion can occur on contact between two liquids of differing temperatures if the temperature of the hotter liquid is above the boiling point of the cooler, and the explosion is due to extremely rapid vapor generation (phase transition) of the cooler liquid [53, p. 1392].

4 Safety Issues

The following sections discuss the safety issues contributing to the incident, which include:

- Safety Management Systems
- Learning from Past Incidents
- Corporate Engagement

Appendix A contains the accident map (AcciMap), which provides a graphical analysis of this incident.

4.1 Safety Management Systems

A safety management system is a formalized process that establishes and monitors the responsibilities, procedures, and processes to prevent incidents [21]. Safety management systems can include aspects for protecting workers from injury, known as occupational safety and health, and for managing the integrity of operating systems and processes handling hazardous substances, known as process safety. They also ensure that established policies and procedures are followed [22, 23].

The Center for Chemical Process Safety[a] (CCPS) published guidelines on the implementation of safety management systems in its *Guidelines for Risk Based Process Safety*. The guidelines help organizations design and implement more effective process safety management systems. These guidelines provide methods and ideas on how to:

1) design a process safety management system,
2) correct a deficient process safety management system, or
3) improve process safety management practices [24].

TS USA did not have a sufficient safety management system and lacked adequate processes and procedures to effectively manage the risk that ultimately led to this incident.

The TS USA Chattanooga facility did not store or process any materials that OSHA and the EPA define as highly hazardous chemicals or extremely hazardous substances. Therefore, neither OSHA's PSM standard nor the EPA's RMP rule applied to the liquid nitriding line. Because of this, no specific regulation required TS USA to implement process safety management[b] practices for its liquid nitriding process. However, nationally and internationally recognized standards and

KEY LESSON

Even in the absence of regulatory requirements, companies should develop safety management systems to ensure the operations are managed and risk is mitigated based on concepts developed by the CCPS's *Guidelines for Risk Based Process Safety* or other industry guidance, including well-written procedures, technically sound hazard analyses, and training on necessary safety topics.

[a] The Center for Chemical Process Safety is a not-for-profit corporate membership organization within AIChE, with over 280 members, that identifies and addresses process safety needs in the chemical, oil, petroleum, energy, food, pharmaceutical, fine chemicals. mining, minerals, metals, pipeline, specialty products, recycling-batteries, software and AI industries [56].

[b] This report distinguishes the terms "process safety management" (lower case) as the practices used to improve process safety and "Process Safety Management (PSM)" to refer to OSHA's PSM standard.

guidelines are available, which provide safety management guidance to companies of all sizes. Although there was no regulatory obligation to implement these systems, TS USA could have implemented a sufficient safety management system but did not do so.

4.1.1 PROCEDURES

The CCPS's *Guidelines for Risk Based Process Safety* states that good procedures describe the process, hazards, tools, protective equipment, and controls with enough detail so that operators can understand the hazards, verify that controls are in place, and confirm that the process responds in an expected manner. Procedures should also provide instructions for troubleshooting when the system does not respond as expected. They should specify when an emergency shutdown should be executed and address special situations, such as temporary operations when specific equipment is out of service. Operating procedures are also normally used to control activities such as periodic cleaning of process equipment, preparing equipment for certain maintenance activities, and other activities routinely performed by operators [25, pp. 245-246].

The CCPS's *Guidelines for Writing Effective Operating and Maintenance Procedures* also states that procedures should identify the hazards presented by the process. Procedures should state precautions necessary to prevent accidental chemical release, exposure, and injury. Process safety information is an important resource in developing procedures. Using this information ensures that known hazards are addressed properly and lessons learned from incidents can be included [26, pp. 5, 9-19].

TS USA's Operating Manual

TS USA had an operating manual for the liquid nitriding line. The operating manual did not provide specific details about how the nitriding line is operated. The manual did include troubleshooting guidance related to the process and information about how the process affects the quality of the parts. Moreover, while the manual discussed the potential for salt residue on parts and how to address external salt residue, it did not discuss how to address salt accumulations inside parts. Additionally, the manual provided some safety guidance regarding the prohibition of parts with blind holes or sealed cavities:

> We wish to emphasize that welded up cavities such as blind holes, closed tubes etc. must not be put into the bath because they can cause the hot liquid salt to be ejected out of the bath. For the same reason only frames and working equipment of solid material are to be used!

Despite this information, the operating manual did not explain why blind holes or closed tubes presented hazards or why they could result in molten salt being ejected from the bath. Furthermore, although the manual stated that wet components could also result in salt ejecting from the bath, it did not discuss the potential for an explosion due to water accumulation in a cavity. The operating manual simply instructed employees to refer to the safety data sheets (SDSs) for additional hazard information:

> Reference is therefore made to the respective Safety data sheets which are […] continuously brought up to date to comply with the latest legislation and sent to our customers automatically. They contain all the information regarding safety and the environment relevant to the individual products and their application.

Although an SDS provides information regarding the hazards associated with a chemical, it does not inform the user of the hazards in the process. In the case of the nitriding and oxidizing salts, the hazards listed in the SDSs are for the salt in its packaged state. The SDSs do not provide information on the hazards when the salt is in its molten state. The SDS provided by TS USA for its oxidizer salt does not list any explosion hazards for the molten salts making contact with water.

The TS USA SDS also does not discuss the chemical properties or physical hazards present in the process. As such, critical safety information, such as the potential interaction of water contacting molten salts, is not included. The operating manual did not include any information about the salts in their molten state, and there is no discussion in it of the potential for rapidly boiling water due to the high temperatures. Furthermore, the operating manual did not discuss the accumulation hazards present in the parts. Additionally, the operating manual did not include any information from previous incidents (**Section 4.2**) to highlight hazards and how to prevent these hazards.

The CSB concludes that the operating manual used by TS USA employees did not provide sufficient information to ensure that employees were aware of the potential hazards in the nitriding operation. The CSB also concludes that TS USA and HEF Groupe relied on the oxidizing salt mixture safety data sheet (SDS) for safety instructions in its operating manual, but the SDS does not provide sufficient information on hazards for materials in the process, which should be incorporated in the operating manual.

Reprocessing Procedures

In some cases, as discussed below in **Section 4.2**, TS USA experienced problems with parts that contained cavities retaining material, some of which resulted in overpressure events. To address residual salt in parts, such as gun barrels, TS USA reintroduced parts to the molten salt baths to melt the salts and allow them to drain out. One TS USA employee described this process, stating:

> The oxidizer, like I said, when it dries and cools, it hardens like concrete. You get stuck in there. And it's not uncommon for us to stick parts like gun barrels or cylinders – granted open-end cylinders – into the oxidizer to dissolve, melt that away, and pull it out slower than normal, to kind of melt all that away, to clear out the clog. It's not uncommon. It's a pretty routine process if something of that nature occurs, as far as a clogged part.

The CSB requested a copy of the procedure and any documentation to support TS USA's practice of reintroducing parts directly to the oxidizer bath. The company could not produce any such written procedures, however, and the process engineer told the CSB that the practice was "…just something they have learned on the job and from experience." This practice, while not documented in any procedures, was performed routinely on other parts at the facility.

Furthermore, TS USA stated that it was not required to have a procedure for reworking the rollers or assessing the hazards of reprocessing parts. TS USA operated and maintained its quality management systems under the International Organization for Standardization (ISO) and International Automotive Task Force (IATF) standards. Therefore, TS USA believed that it did not need specific written procedures for assessing the rework process. However, the ISO 9001 standard states that it does not include requirements specific to other management systems, such as those for occupational health and safety management [27, p. ix]. The IATF standard also states that an "…organization shall have a documented process for rework… to verify compliance with original specifications" [28, p. 46]. The IATF standard for documenting rework does not require assessments of potential hazards introduced during new activities.

On the day of the incident, upon identifying that one of the rollers was too hot to continuously touch, the plant manager believed that the part was still filled with molten salt based on prior experience with parts retaining salts from the oxidizer and nitriding baths. Additionally, the employees at the facility relied on visual inspection of the parts to determine that there was no active drainage. Although some water drained from the roller when the manager tried to clear the obstruction, the lack of continuous drainage led the employees to believe that only salt remained in the cavity, when in reality, the drain hole had become plugged with salts and the roller retained water.

As such, in consultation with the process engineer, the decision was made to reintroduce the rollers to the oxidizer tank based on the facility's past practice of removing salt accumulations from other parts. Furthermore, the decision was made to skip the preheat treatment step. HEF Groupe documents indicate that the preheat treatment step is required for all parts to ensure that the parts are completely dry before they can be introduced into the molten salt baths. Although this step was skipped in the steps leading up to the May 30, 2024, incident, it is possible that the water within the roller could have vaporized and caused a similar explosion while in the preheat furnace. However, molten salt would not have been ejected from the oxidizer bath and would not have fatally injured the line operator.

Since TS USA did not have procedures for reprocessing the parts, there was no standard process, and the hazards presented by these actions were not identified by the company. As such, the TS USA employees did not recognize the potential hazards of reintroducing the rollers to the oxidizer bath.

The CSB concludes that TS USA lacked procedures for reprocessing the rollers on the day of the incident. Had TS USA had procedures for reprocessing operations, it could have ensured that risks were identified and that safeguards were in place to mitigate the hazards presented by the operation. The CSB also concludes that TS USA deviated from its operating manual and HEF Groupe's requirements by reintroducing parts to the oxidizer bath and skipping the required preheating step.

The CSB recommends that TS USA develop written operating procedures for the nitriding process. The procedures shall be based on the information gathered from the hazard analysis program. The procedures shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Writing Effective Operating and Maintenance Procedures*.

The CSB recommends that HEF Groupe develop written operating procedures for the nitriding process. The procedures shall be based on the information gathered from the hazard analysis program. The procedures shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Writing Effective Operating and Maintenance Procedures*.

4.1.2 Hazard Analyses

The CCPS's *Guidelines for Risk Based Process Safety* element *Hazard Identification and Risk Analysis* encompasses all activities involved in identifying hazards and evaluating risk at a facility throughout the facility's life cycle, to ensure that risks to workers, the public, and the environment are consistently controlled. The analysis should assess and ask:

- Hazard – What can go wrong?
- Consequences – How bad could it be?
- Likelihood – How often might it happen [25, p. 210]?

The understanding of risk developed from these exercises helps form the basis for establishing most of the other process safety management activities undertaken by the facility [25, p. 211]. A process hazard analysis (PHA) is typically performed to meet industry guidance for hazard identification and risk analysis [25, p. 210]. Volume 20 of the ASM International Handbook, *Materials Selection and Design*, provides guidance for risk analysis through multiple methodologies, including Failure Modes and Effects Analysis (FMEA) and Fault Tree Analysis [29, pp. 117-125]. PHAs are required by the NFPA for all furnaces covered by NFPA 86, *Standard for Ovens and Furnaces* [15].[a]

The hierarchy of controls should be considered when assessing hazard controls and determining safeguard effectiveness. The hierarchy of controls (**Figure 15**) is a method of describing the effectiveness or preference of safeguard implementation.

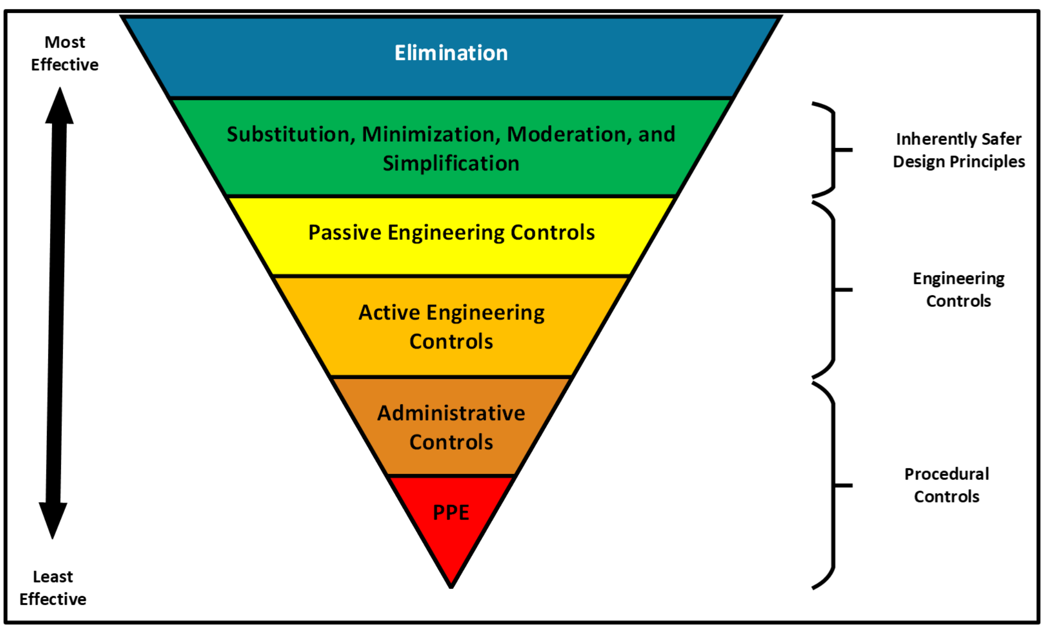


Figure 15. Hierarchy of controls. (Credit: CSB, modified from CCPS [30] and NIOSH [31])

[a] The NFPA defines Class C furnaces as "An oven or furnaces that has a potential hazard due to a flammable or other special atmosphere being used for treatment of material in process" and specifically identifies molten salt baths as this type of furnace. Annex N provides additional details for the frequency and contents of process hazard analyses to be performed as required by NFPA 86, *Standard for Ovens and Furnaces* [15].

With the hierarchy of controls, hazard elimination is the preferred method of risk reduction. Hazard elimination is completed when the hazard no longer exists and has been physically removed [32, 33]. When elimination is not feasible, applying inherently safer design concepts[a] should be considered. Passive engineering[b] controls, such as shielding, can provide additional control of hazards. Additionally, active engineering controls,[c] which activate upon the detection of an upset condition, can be implemented. Finally, administrative controls, such as signage and procedures, and personal protective equipment (PPE) can be used.

At the time of the incident, HEF Groupe had attempted to eliminate the potential for water introduction into a molten salt bath and causing an explosion by prohibiting "hollow parts" from the nitriding process. However, this was not effectively implemented and is more appropriately considered an administrative control, as it was only detailed in the operating manual. As such, TS USA regularly processed parts with internal cavities that presented accumulation hazards (**Section 3.1**).

HEF Groupe had opportunities to assess hazards, use the hierarchy of controls, and implement inherently safer design principles to mitigate risk in the nitriding process. TS USA also had multiple occasions where the rollers involved in this incident could have been reassessed for new hazards. **Figure 16** shows a timeline of the opportunities HEF Groupe and TS USA had to re-evaluate the process and the parts.

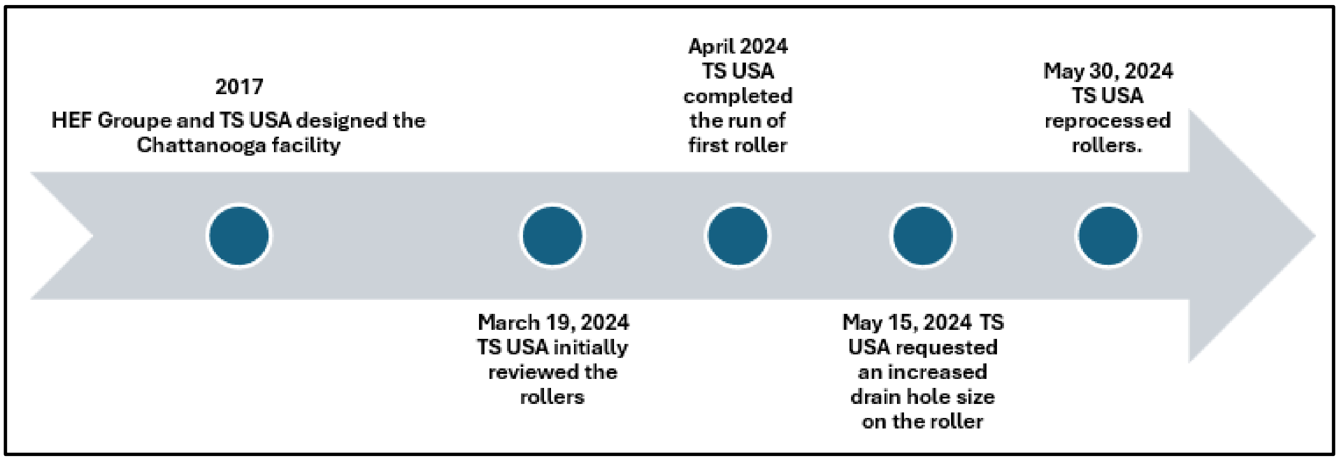


Figure 16. Timeline of opportunities to identify hazards within the process and the rollers. (Credit: CSB)

Hazard Analysis of Nitriding Process

TS USA was familiar with the concept of risk assessments, particularly the FMEA methodology. The FMEA methodology is a hazard analysis methodology in which a multidisciplinary team identifies consequences and risks associated with component failures. TS USA performed an FMEA on the process as required by its quality program. The assessment did not include any considerations for safety or hazards of the process, however. TS USA did not perform an analysis that evaluated how process hazards could affect the safety of workers and equipment, despite having an established framework to evaluate process failures within its established quality management system.

[a] Inherently safer design concepts include substitution, minimization, moderation, and simplification [30, p. 18].

[b] Passive engineering controls mitigate hazards through designs without requiring input to activate control of the hazard [30, p. 126].

[c] Active engineering controls mitigate hazards through designs that detect a hazard and activate a system to respond [30, p. 126].

The CSB concludes that TS USA did not perform any safety-based risk assessments on the liquid nitriding process. Had TS USA applied the methodology used for its quality program for process hazard analyses, it could have identified hazards, such as the risk of accumulations in parts, reactions due to foreign material in the molten salt baths, and the potential for upset conditions, such as overpressure events or explosions.

HEF Groupe developed the liquid nitriding process under the requirements of the European Union directive, Directive 2006/42/CE. The Directive covers machinery and the protection of workers and users of the equipment. Annex I of the Directive covers the essential health and safety requirements relating to the design and construction of machinery. The Annex requires risk assessments to determine the health and safety requirements [34]. This standard requires the development and communication of these hazard analyses with the user. The Directive requires manufacturers to apply the hierarchy of controls in the following order:

1. Eliminate or reduce risks as far as possible using inherently safer design principles;
2. Implement necessary protective measures, such as engineering controls, to mitigate risks that cannot be eliminated; and,
3. Inform users of residual risks that cannot be mitigated and indicate any training required or specify the use of personal protective equipment for employees [35, p. 19].

HEF Groupe used the FMEA methodology to assess process hazards for the nitriding line used in its overall design throughout the company. The analysis identified potential risks of fire, explosion, and burns, as well as other hazards. For each of the recognized hazards, it identified measures to control the risks throughout the process. HEF Groupe relied on administrative controls and did not implement inherently safer design concepts or engineering controls to mitigate the risk of an explosion in the nitriding line. HEF Groupe relied on PPE to mitigate the potential for small releases of molten salt from the salt baths that could contact the line operator.

HEF Groupe could have required all parts to be separated into their individual components before introduction to the nitriding line, simplifying the parts. For example, the press fit ends of the rollers could have been removed (assuming that the customer would have approved of this), which would have eliminated the accumulation hazards in the rollers' cavities. Additionally, HEF Groupe could have implemented a continuous weighing or thermal imaging system to check for accumulated materials in the parts.

KEY LESSON

Companies should incorporate elimination of hazards or inherently safer design concepts, such as simplification, into hazard analyses to ensure that there are effective and reliable controls to protect employees from process hazards.

The nitriding facilities relied on the line operator to visually inspect the parts to ensure that there was no active drainage before introducing the part to another bath. This was how HEF Groupe mitigated the accumulation hazards. The lack of engineering controls or inherently safer design principles is counter to the intent of the hierarchy of controls, where it is preferential to implement those controls to mitigate hazards rather than rely on PPE and administrative controls. The safeguards identified by HEF Groupe were:

- Instructions prohibiting any treatment of hollow parts;
- Process of drying the parts before introduction into the baths; and,
- Evacuation of the area.

Based on HEF Groupe's FMEA, the risk of an explosion was determined to be moderate and that mitigative actions should be considered. However, no action items were identified to lower risk, which demonstrates that HEF Groupe deemed the risk of an explosion to be acceptable with the existing safeguards in place. As shown in this incident and the incidents discussed in **Section 4.2**, the administrative controls were not effective in preventing explosions and the eruptions of molten salt. This risk analysis was not communicated to the TS USA facilities to ensure the employees were aware of the risks while operating the nitriding line.

The CSB concludes that HEF Groupe assessed the potential hazards presented by an explosion and release of molten salts. However, the risk analyses did not incorporate inherently safer design principles or engineering controls. Had HEF Groupe implemented additional controls, it could have prevented the release of the molten salt and the explosion. The CSB also concludes that the risk analyses were not communicated to the TS USA facilities. Had the risk analyses been communicated, the hazard of water introduction into the bath and the requirement for all parts to be fully dried could have been followed, and the cause of the explosion eliminated.

The Chattanooga facility, in addition to other TS USA liquid nitriding facilities, had passive engineering controls in addition to the administrative controls required by HEF Groupe. TS USA installed a protective barrier (**Figure 17**) that was approximately 3 feet wide, 7 feet tall and had an overhang above the barrier. The barrier also had two viewing windows to allow the line operator to watch the process from behind the barrier. This barrier was installed to protect against the recognized splash hazards.

At the time of the incident, the line operator was behind the barrier when the molten salt eruption occurred. The line operator was engulfed in the molten salt as it erupted from the oxidizer bath. The barrier did not protect the line operator from the eruption. Furthermore, the viewing window melted due to exposure to the molten salts.

Figure 17. Protective barrier at the oxidizer bath, pre-incident (left) and post-incident (right). (Credit: TS USA)

The CSB concludes that the additional passive engineering controls in place at the Chattanooga facility were insufficient to protect the line operator due to the severity of the eruption of molten salt, which was more significant than the installed barrier was designed to withstand and protect against.

Following the incident at Chattanooga, TS USA constructed an enclosure (**Figure 18**) around the nitriding and oxidizer baths. This enclosure is intended to limit access to the molten salt baths and protect against loss of containment or an eruption of the molten salts. This enclosure, which has only been installed at the Chattanooga facility, provides a barrier from the molten salt while parts are in the nitriding and oxidizer baths. The enclosure is fully encapsulated and could prevent an eruption of molten salt from contacting any employees outside of the barrier.

Figure 18. Enclosure installed at the TS USA Chattanooga facility after the incident. (Credit: TS USA)

The CSB recommends that TS USA implement physical, protective barriers around the molten salt baths that isolate the employees from hazardous releases at all TS USA locations that perform liquid nitriding.

The CSB recommends that HEF Groupe include physical, protective barriers as part of the standard design for liquid nitriding processes. These protective barriers shall be intended to isolate employees from molten salt releases.

Hazard Analysis for the Rollers

TS USA used an Advanced Product Quality Plan (APQP) document to review and accept new parts for the liquid nitriding process. APQP is an automotive industry methodology that:

> [I]ncludes a series of steps and tools, such as risk assessment, design and process FMEAs (Failure Mode and Effects Analysis), control plans, and production trials, to ensure that all necessary planning and preparations are made before mass production. The goal of APQP is to prevent quality problems, improve overall customer satisfaction, and drive continuous improvement [36].

The APQP process further describes the use of FMEAs as "a tool used to identify and address failure modes in products and processes" [37]. TS USA employees described the process as a review performed by the plant manager and the process engineer. The plant manager stated that their review was focused on the ability to handle the parts and whether the parts could be processed through the facility. The process engineer was responsible for reviewing new parts for performance requirements, processing development, and safety hazards.

PROCESS - Salt bath / Liquid Nitriding ARCOR® + POLISH (QP) - Salt bath / Liquid Nitriding ARCOR® + POLISH + REOX (QPQ) ☐ AMS 2753 (current version) compliant* *POST-NITRIDING STEPS* - Post-Nitriding Rust Preventative ☐ Other Post-Nitriding comments: Click here to enter text.	**POLISHING PROCESS, IF REQUIRED** - OD Honing - Manual, Buffing **FIXTURES** ☐ Bulk Handling Fixtures ☒ Current Fixtures ☐ Special Fixtures required ☐ One-time fixture contribution & set-up charges: Click here to enter text.
CUSTOMER NITRIDING RELATED REQUIREMENTS, IF ANY: ☒ Nitriding Temperature: [redacted] ☐ Post-nitriding Surface Finish: ☒ Case Depth: [redacted] ☐ Case Hardness: ☐ Surface Hardness Prior Surface hardening, e.g., case carburizing etc. Click here to enter text. CORE HARDNESS: Click here to enter text. MATERIAL:316 SS ☐ Cosmetic factors Click here to enter text.	**FIXTURING COMMENTS** Time frame to manufacture special fixtures: Click here to enter text. Batch Size: **10** Projected Fixturing time for non-bulk, Level III projects: minutes
☐ Nitriding Recipe (to be completed when job received) ☐ Re-oxidation Recipe (to be completed when job received) Click here to enter text. ☒ Nitriding Temp, different than 1075° F. SPECIFY [redacted] ☒ Nitriding time: [redacted] minutes ☐ Oxidation time, if different than standard. SPECIFY Click here to enter text. minutes ☒ Air cool time, if different than standard. SPECIFY [redacted] minutes ☐ Re -Oxidation time, if different than standard. SPECIFY Click here to enter text. minutes ☐ Any polishing after Re-OX ☐ COROLAC L ☐ COROLAC D ☒ OTHER OILS	☐ OTHER CONSIDERATIONS ☐ Customer Specific Requirements / Supplier Manual Review. Quality____________________ Secondary Review____________________

Figure 19. Excerpt of the APQP document for the rollers. (Credit: TS USA, redactions by CSB)

The APQP documentation (**Figure 19**) used by TS USA did not identify potential safety considerations; rather, the form only focused on the processing and quality requirements of the parts. It did not incorporate industry guidance for operating molten salt baths. As previously stated, guidance from the NFPA, ASM International, and FM Global (**Section 3.1**) requires parts to be completely dried and solid, and that foreign materials must not be introduced into the molten salt baths. At the time of the incident, TS USA introduced the rollers into the molten salt bath and did not ensure that the parts were completely dried. Additionally, the parts were able to retain water because they were not solid.

TS USA received a request to process the rollers through the liquid nitriding process on March 19, 2024. TS USA reviewed and approved the processing of the parts through the liquid nitriding line, but modifications to the rollers were required before accepting the work (**Section 3.1**). The process engineer identified that the roller had a sealed cavity, which could present a hazard, stating that pressure could build in the sealed hollow cavity when treating the part. The safety concerns were alleviated by removing two set screws to ensure the rollers had a drain hole on each end.

TS USA was unable to provide documentation for the hazard assessment or the FMEA performed on the rollers that were described in the APQP process. Although the potential hazards of the sealed cavity were identified, there was no assessment or analysis of the hazards introduced by the new drainage holes or their adequacy to fully drain the salt and water from the rollers.

The CSB concludes that TS USA viewed the rollers as safe to process once the sealed cavity was opened and did not recognize the accumulation hazard in the newly opened cavity. Had TS USA recognized the risk of accumulations in the cavity, it could have requested that the customer take additional actions, such as removing the press fit ends, to eliminate the hazard.

Once the customer modified the roller by removing the set screws to open the cavity, the hazard of the sealed cavity had been eliminated. However, the rollers still presented an accumulation hazard (**Section 3.1**). By adding through-holes to the parts, new hazards were introduced to the process. TS USA did not assess the potential hazards of introducing the modified rollers to the nitriding process. Although this modification could have been assessed through a management of change program or the preexisting part review process at the Chattanooga facility, it was not, and the accumulation hazard went undetected.

Because of the holes in the rollers, molten salts and water entered the cavity of one roller and solidified, causing the 2024 explosion. The solidified molten salts prevented water from draining from the bottom of one of the rollers, which allowed the water to generate pressure when it boiled while in the molten salt bath. The process engineer did not foresee that the new drainage holes could present an accumulation hazard in the cavity of the roller. Furthermore, there were no discussions about the alternative methods to mitigate the hazard, such as the potential to remove the press fit ends to open the roller up and allow better drainage.

The CSB concludes that the review process for new parts used by TS USA and HEF USA did not adequately assess the potential accumulation hazards or hazards due to modifications to new parts. The review process did not include corporate and industry guidance, such as the prohibition of processing sealed parts or parts that had not been dried, which could have mitigated or prevented the incident. Had TS USA's review included the guidance to prohibit the processing of parts that could accumulate materials, it could have decided that the rollers were not suitable for the nitriding operation.

The CSB also concludes that adding drainage holes to parts with sealed cavities directly contributed to the fatal May 2024 eruption at the Chattanooga facility. Had the practice of adding through-holes been thoroughly assessed before it was implemented, the new hazards, such as the accumulation in the roller cavity, could have been identified and mitigated.

Following the initial trial of a single roller in April 2024, TS USA identified that the roller accumulated salt and water during the nitriding process. The accumulations required increased time to drain the roller at each step. This issue was raised to the plant management and the process engineer and was communicated to the customer on May 15, 2024. TS USA requested an increase in the size of the holes, which could have reduced the drain time in between steps of the nitriding line. TS USA did not follow up on the request, however, and processed the five rollers through the nitriding process, as it viewed this as an operational efficiency concern and not a safety concern. Ultimately, the customer did not reply to the request until May 30, 2024, approximately three hours after the incident occurred, and stated it would determine whether a larger hole could be drilled into the ends of the rollers. TS USA did not reassess the hazards of the rollers when it identified the need to increase the drainage hole size.

The CSB concludes that TS USA did not perform an additional hazard analysis following the initial trial run and failed to recognize the accumulation hazard in the rollers. Had TS USA performed a hazard analysis, TS USA could have taken additional steps, such as removing the press fit ends, which could have improved drainage, eliminated the accumulation hazard, and provided access to the internal cavity.

Hazard Analysis for Reprocessing Rollers

As discussed in **Section 4.1.1**, TS USA lacked procedures to troubleshoot material accumulations inside parts, such as the rollers, on the day of the incident. TS USA also lacked procedures for reprocessing parts through the oxidizer bath to remove accumulations of salt from inside the rollers. While developing the plan for addressing the accumulated salt inside the roller, TS USA did not perform a hazard analysis that could have identified the potential for water accumulation inside the parts or alternate approaches to address the salt buildup.

The reprocessing of the parts deviated from the normal process and constituted a change, but TS USA stated that it does not assess changes to the process. When asked about management of change, a manager told the CSB, “We don’t do that. Usually, what it’s like is very expensive and very time-consuming…. So we don’t do that very often.” As such, in addition to not having a process to assess hazards while reprocessing the rollers, TS USA did not have a management of change process to assess the changes that were introduced when the rollers were placed back into the oxidizer bath. TS USA also stated that the risks of reprocessing the rollers should be captured by the APQP process and the FMEA that was performed as part of the quality process. However, the rollers were not fully established in the APQP program due to their status as a prototype. The engineer stated, “…this was our first run through, and this was a prototype… we were still developing a process.”

Furthermore, the IATF standard states that organizations shall utilize risk analysis, such as the FMEA methodology, to assess the risks of the rework process before the decision to rework a product [28, p. 46]. TS USA was unable to provide any documentation in accordance with the IATF standard that shows a risk analysis was performed on the reprocessing of the parts in the oxidizer bath.

The CSB concludes that TS USA did not perform a hazard analysis on the non-routine task for reworking the rollers. Had TS USA performed a hazard analysis, it could have identified that the rollers were filled with water, and that reintroducing the rollers to the oxidizer bath could be a hazard.

The CSB recommends that TS USA develop a hazard analysis program for assessing the nitriding process. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety’s (CCPS)

Guidelines for Risk-Based Process Safety, the National Fire Protection Association's (NFPA) *Standard for Ovens and Furnaces*, and ASM International's Handbook. The program shall apply to new and existing parts, assess parts for accumulation hazards and sealed cavities, and include non-routine tasks such as reprocessing unsatisfactory parts.

The CSB recommends that HEF Groupe develop a hazard analysis program for assessing the nitriding process. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*, the National Fire Protection Association's (NFPA) *Standard for Ovens and Furnaces*, and ASM International's Handbook. The program shall apply to new and existing parts, assess parts for accumulation hazards and sealed cavities, and include non-routine tasks such as reprocessing unsatisfactory parts.

4.1.3 Training

Training workers and ensuring their reliable performance of critical tasks is an important element in managing risk. Training is practical instruction in job and task requirements and methods. Training provides employees with the ability to recognize hazards and mitigate risk. TS USA maintained a training program that focused on occupational safety and health requirements for general industry. TS USA's training program included information on occupational safety hazards, such as PPE, hearing conservation, and ergonomics.

As discussed in **Section 3.1** and **Section 4.1.2**, the molten oxidizer salt can cause rapid boiling or an explosion when contact with water occurs. However, this hazard was not addressed in any of the training materials. The nitriding line operator and plant management told the CSB that they were aware that when water contacts the salt baths, it makes what they described as making a "popping" sound. TS USA did not provide specific training on the hazards presented by the molten nitriding salt baths. Rather, TS USA simply relied on on-the-job training to instruct the line operators on how to use the equipment and for occupational health hazard awareness.

The CSB concludes that TS USA's training program did not provide information or guidance on the process hazards. Had TS USA provided training on the hazards of the process and the potential for explosions, the risk of water accumulation and the potential for an explosion could have been identified, the operation stopped, and the incident prevented.

Furthermore, TS USA did not have any training materials that were specific to the managers or process engineers. Although TS USA relied on its plant managers to perform safety activities at the facilities, no specific training was provided to ensure that the managers were informed of the hazards present in the facility and how to recognize potential risks when processing parts in the nitriding line. Additionally, TS USA did not have any specific training for the review and identification of hazards with new parts. The plant managers told the CSB that they were unaware of any specific training on hazard awareness or hazard identification. As such, the reviewers were not trained to assess parts for accumulation hazards, especially in parts that previously had sealed cavities.

The CSB concludes that TS USA did not have a training program on how to identify hazards in the process or when evaluating new parts. Had TS USA developed and trained its reviewers on potential hazards when evaluating new parts, the reviewers could have identified the accumulation risks present in the rollers.

The CSB recommends that TS USA develop a training program, including written materials, for the employees involved in the nitriding process. This program shall be based on the nitriding facility's operating procedures and other relevant information from the hazard analysis program. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*.

The CSB recommends that HEF Groupe develop a training program, including written materials, for the employees involved in the nitriding process. This program shall be based on the nitriding facility's operating procedures and other relevant information from the hazard analysis program. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*.

4.2 Learning from Past Incidents

In his 1993 book *Lessons From Disaster: How Organizations Have No Memory and Accidents Recur*, process safety expert Trevor Kletz stated:

> It might seem to an outsider that industrial accidents occur because we do not know how to prevent them. In fact, they occur because we do not use the knowledge that is available [38, p. 1].

Incident investigations are used to determine the cause(s) of an incident and develop corrective actions to reduce the frequency and consequences of industrial accidents, ideally preventing similar incidents [25, pp. 552-554, 39, p. 65]. To effectively learn from incidents and the resulting investigations, the CCPS provides several techniques that companies should utilize. Two of these are:

- Investigating incidents that occur at the facility to identify and address root causes [25, p. 549]
- Applying lessons from incidents that occur at other facilities within the company and within the industry [25, p. 549]

In *Guidelines for Risk Based Process Safety* and *Guidelines for Investigating Process Safety Incidents*, the CCPS recommends that companies broadly communicate investigative findings internally and externally [25, pp. 561-562, 40, p. 345]. Communicating investigation results within the company where the incident occurred allows all involved parties to be aware of the causes and lessons learned; additionally, internal communication allows a company to track corrective actions to determine whether they led to improvements [25, p. 562]. Sharing the results between different facilities within the same company allows the causes and successful corrective actions to be communicated to facilities that perform similar or identical processes; external communication helps prevent similar incidents at different facilities [25, p. 562].

The CSB identified three incidents that occurred at TS facilities. TS USA did not effectively learn from these incidents, however, because it did not investigate incidents at its facilities and did not apply any lessons from previous incidents. None of these three incidents were effectively communicated to other facilities within HEF Groupe.

KEY LESSON

Companies should have an incident investigation program that generates formal reports, performs causal analysis, and reviews corrective actions. The findings of the investigations should be communicated, including translation, throughout the site and to other facilities within the company.

4.2.1 2018 Event in Mexico

On January 25, 2018, an explosion occurred at a TS ETSA facility in Aguascalientes, Mexico, that injured three workers and caused serious damage at the facility. TS ETSA was hired to treat an 8-foot (2.3-meter) long cylindrical roller with an 18-inch (450-millimeter) outer diameter, and an internal coil that spiraled through the center (**Figure 20**). This roller was designed so that a fluid could cool the roller while it was operating.

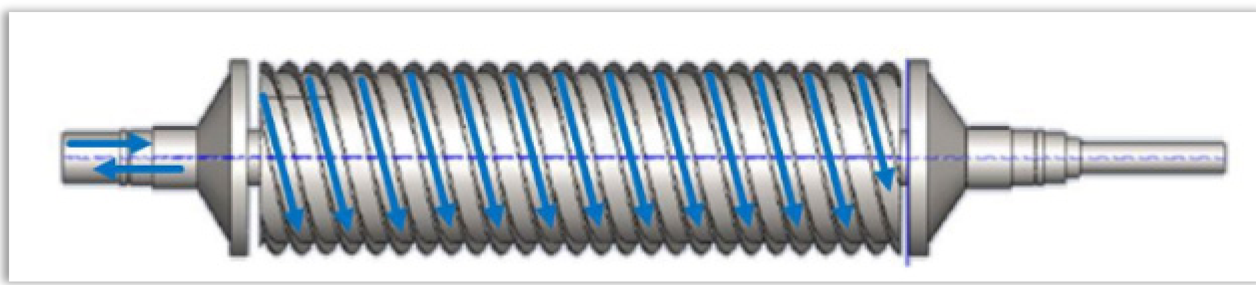


Figure 20. A diagram of the roller involved in the Mexico explosion. (Credit: TS ETSA)

On the day of the incident, a cap was placed over the end where the fluid could enter and leave; however, TS ETSA's investigation found that the cap was not correctly placed over the opening. TS ETSA positioned the roller so that the capped end was facing downward when it was hooked up to the crane. The roller was then processed through the degreasing, cleaning, and rinse baths; water likely entered the roller during the rinsing step. The roller was then sent to the preheating step. TS ETSA measured that the roller reached a temperature of approximately 400°F during preheating.

After preheating, the roller was introduced to the nitriding salt bath, which was approximately 1,040°F. Shortly after the introduction to the nitriding salt bath, the roller exploded. The high temperature caused the water to expand and rapidly increased the pressure until the cap was no longer able to contain it. The cap was forcefully ejected from the roller, relieving the built-up pressure in an overpressure explosion, similar to the conditions discussed in **Section 3.2**.

The explosion ejected molten salt from the bath and launched the roller across the facility, where it impacted several areas, destroyed the nitriding salt bath's furnace, cracked a wall at the facility, deformed the crane's support structure, destroyed the crane's hoist, and tore a hole in the roof. In addition to the damages caused by the launched roller, the ejected salts damaged the electrical control boards at the facility and sprayed onto the building's roof and onto the roofs of neighboring buildings. The ejected salt contacted three employees, causing first- and second-degree burns and eye damage.

Figure 21. The visual aid created by TS ETSA for part inspections. (Credit: TS ETSA, translated by the CSB)

TS ETSA investigated the incident and developed a formal report detailing the incident, causal factors, and corrective actions. TS ETSA determined that the cause of the incident was that a part with an accumulation hazard was allowed to be processed in the liquid nitriding line. As part of TS ETSA's corrective actions, a pre-processing inspection is now required at the facility before parts are allowed to be processed, and a visual aid was created to help employees with the inspection (**Figure 21**). The visual aid showed operators specific items to look for during the inspection, such as hollow cavities, welds, or sealed parts.

The investigation report for the 2018 Mexico explosion only existed in Spanish and required translation by the CSB. A significantly less detailed report was created, translated to English, and presented to HEF Groupe, however. The English version of the report omitted many details and is only five pages long, while the Spanish version is 44 pages long. Additionally, no translated version of the visual aid existed, and in order to read it, it required translation by the CSB.

The TS USA plant managers told the CSB that they were not familiar with the incident at the TS ETSA facility in Mexico. One plant manager said that he "learned [about the Mexico explosion] by accident." Another said, "There was just hearsay after the [2024] Chattanooga one that something similar may have happened in Mexico." Despite HEF Groupe being aware that this incident had occurred, neither TS USA plant manager had received any official communication from HEF Groupe regarding the incident, even though one of the plant managers had been in that position at the time of the incident in Mexico. Additionally, none of the TS USA plant managers had seen the visual aid produced from the incident (**Figure 21**).

Although porous welds and permeation were not mentioned in the Spanish or English versions of the TS ETSA investigation report, both the TS USA president of operations and the HEF USA CEO believed that those matters had been discussed in the report. Further, the president of operations also told the CSB that there were no injuries from the Mexico incident, although both the Spanish and English versions of the report plainly say that there were three injuries. Additionally, the HEF USA CEO told the CSB that he was unaware of the Mexico incident before the CSB's investigation and mentioned that he only had access to the Spanish version of the report. These statements indicate the HEF USA CEO and the TS USA president of operations were unaware of the specific details of the Mexico incident. More significantly, these statements demonstrate that HEF Groupe did not adequately communicate the findings, causes, and consequences of the incident to other HEF Groupe facilities.

The CSB concludes that the 2018 explosion in Mexico, the explosion's causal factors, and the corrective actions taken were not communicated from HEF Groupe to the other facilities. Had the corrective actions from the Mexico incident been communicated, TS USA could have identified the accumulation hazard and rejected the rollers during the pre-processing safety review, which could have prevented the 2024 incident.

4.2.2 2020 Event in France

In May 2020, an incident in which molten salt was ejected from a nitriding bath occurred at the TS REW facility in Valentigney, France, although no injuries resulted from the incident. TS REW was treating a part. The part was approximately 14 inches (360 millimeters) tall, 22 inches (550 millimeters) long, and 9 inches (240 millimeters) wide. The part had a welded, sealed cavity that was filled with air (**Figure 22**).

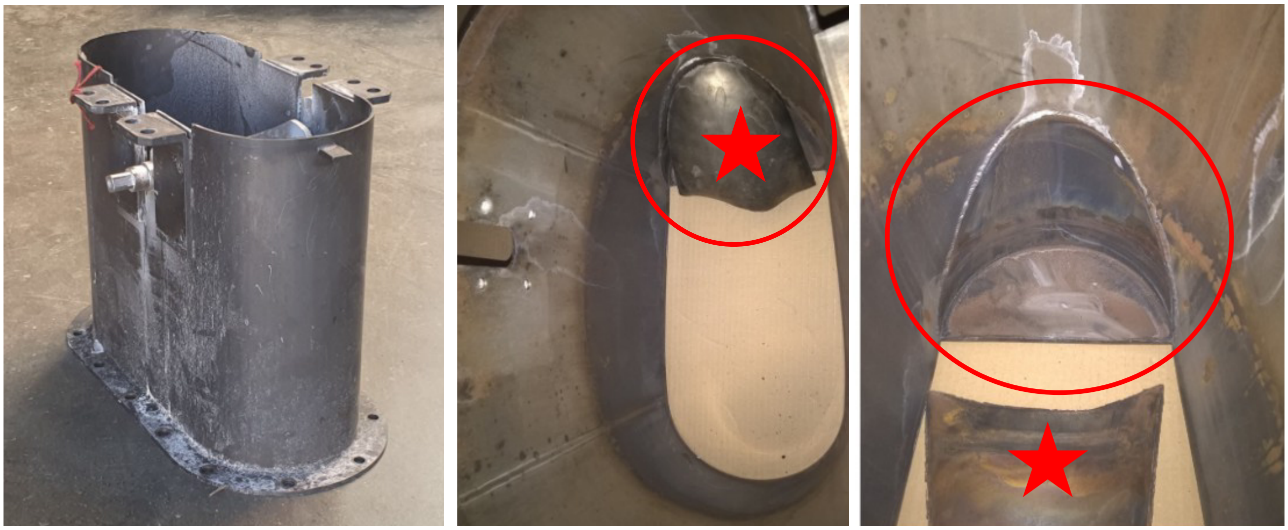


Figure 22. The part with a sealed cavity in the part involved in the 2020 incident at the TS REW facility in France, staged to show the location of the void (circled) and how the explosion separated the cavity (star). (Credit: TS REW, annotated by CSB)

The part went through the preparatory steps and was introduced to the nitriding bath. As the part was entering the bath, the air trapped in the cavity began expanding due to the high temperature. As the trapped air expanded, the pressure increased until the weld failed, and the pressure was relieved in an overpressure explosion (**Section 3.2**). This increase in pressure happened rapidly as the part was only able to be submerged halfway before the explosion occurred. The incident resulted in salt being ejected from the nitriding bath. No one was injured during this incident.

The CSB requested the investigation report for the France incident, but neither TS USA nor HEF Groupe was able to provide either a formal investigation report, a causal analysis, or what, if any, corrective actions were taken. Moreover, in interviews with the CSB, none of the TS USA plant managers stated they were aware that the incident at the TS REW facility in France had occurred.

The CSB concludes that no investigation report or corrective actions were distributed to TS USA or other HEF Groupe facilities following the 2020 explosion in France, and the CSB cannot confirm whether a formal investigation was performed, or a written investigation report produced after the incident. The lack of documentation prevented the communication of the incident, its causal factors, corrective actions (if any), and lessons learned to other facilities within HEF Groupe.

4.2.3 2023 Event in Chattanooga

Less than a year before the 2024 incident, another incident involving the liquid nitriding process had occurred at the TS USA facility in Chattanooga, Tennessee, on September 18, 2023, although no one was injured during this incident. TS USA was putting several hydraulic cylinders through the liquid nitriding process. The cylinders ranged from about 4- to 5-feet (1.2- to 1.5-meters) in length with an approximate outer diameter of 4 inches (100 millimeters) (**Figure 23**). The cylinders had a large cavity at one end (bottom) that connected two hollow regions running through the body. Due to quality concerns, the customer required the end with the outlets of the two hollow regions (top) to be covered with a cap and not submerged during the nitriding process.

On the day of the incident, a cap was placed over the top of the cylinder. However, there were still holes in the bottom of the cylinder that allowed molten salt to enter the space. The cylinder was passed through the initial rinsing and degreasing steps in the liquid nitriding process. After the initial steps were completed, the cylinder was placed in the nitriding salt bath, which was approximately 1,100°F. The cylinder was then moved to the 800°F oxidizing salt bath. Shortly after, molten salts were ejected from the oxidizing salt bath. Some employees described it as an explosion event, while others stated that the salt just foamed and overflowed out of the oxidizing salt bath. No one was injured during this incident.

Figure 23. The hydraulic cylinders involved in the 2023 explosion in Chattanooga, Tennessee. (Credit: TS USA)

The 2023 Chattanooga incident was likely caused by a rapid increase in pressure within the cavity of the hydraulic cylinder. The hydraulic cylinders likely accumulated nitriding salts in their cavities when introduced to the nitriding bath. Once the cylinders were submerged in the oxidizing salt, the salts reacted, generating pressure and causing the salts to overflow from the oxidizer salt bath.

The CSB's investigation found that HEF Groupe had created a risk matrix in French showing the potential for an explosion when processing parts that could accumulate materials, discussed in **Section 4.1.2.** The matrix had been prepared before the 2023 Chattanooga incident occurred. The Chattanooga facility, with the assistance of other TS facilities and HEF Groupe, was unable to produce an English translation of the document, however, indicating that one did not exist at the time of either the 2023 or 2024 Chattanooga incidents. Additionally, TS USA plant managers told the CSB that they had not seen the document.

The CSB requested a formal, written investigation report for the 2023 Chattanooga incident, but TS USA was unable to provide one. The only documents produced by TS USA relating in any way to the incident were emails to the customer who hired TS USA to process the part. These emails provided a brief description of the incident and requested that the customer modify the parts to include drain holes. Similarly, neither the TS USA operations manager nor the president of operations for TS USA had any knowledge of the 2023 Chattanooga incident. Additionally, the other TS USA plant managers were unaware of this incident.

Had the Chattanooga facility investigated the 2023 incident, the potential for accumulation hazards could have been identified. The employees could have known that transferring materials from one bath to another has the potential to cause an explosion, and the facility could have developed corrective actions to prevent accumulations. The learnings could have been applied to reintroducing the rollers involved in the 2024 incident into the bath. TS USA could have ensured that there was no water in the roller's cavity, and the 2024 incident could have been prevented.

The CSB concludes that the 2023 Chattanooga incident and its causal factors were not formally or robustly investigated, and any corrective actions taken were not communicated to other TS USA facilities. Had the 2023 Chattanooga incident been formally investigated and findings communicated, the safety personnel at HEF Groupe could have investigated the incident and communicated HEF Groupe's policy not to process parts that could accumulate materials. Had TS USA been aware of the safety concerns associated with processing parts that accumulate materials, the fatal 2024 incident could have been prevented.

The CSB concludes that TS USA, HEF Groupe, and other TS facilities have repeatedly had reason to understand that parts with accumulation hazards and sealed cavities are not suitable for the liquid nitriding process. All three incidents discussed above—2018 in Mexico, 2020 in France, and 2023 in Chattanooga—show that these parts are susceptible to trapping materials in their cavities, which leads to overpressure explosions when the parts are introduced to the salt baths, making them unsafe to process. The CSB further concludes that TS USA's and HEF Groupe's failure to learn from these previous incidents led to missed opportunities to identify the conditions that contributed to the 2024 explosion.

The CSB recommends that TS USA develop an incident investigation program. This program shall include requirements for performing causal analysis, producing written reports, and communicating findings and corrective actions throughout the entire TS USA organization. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Investigating Process Safety Incidents*.

The CSB also recommends that HEF Groupe develop an incident investigation program. This program shall include requirements for performing causal analysis, producing written reports, and communicating findings and corrective actions throughout the entire HEF Groupe organization. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Investigating Process Safety Incidents*.

4.3 Corporate Engagement

The American Society of Safety Professionals' (ASSP) *Safety Professional Handbook* states that a critical step in managing safety and health is to secure the commitment and engagement of leadership in the organization for such practices. Leadership engagement means business leaders actively promote and support workplace safety and health at all levels of the organization, including proactively designating roles, responsibilities, and authority for assuring a safe and healthy workplace in all operations [41, p. 1152].

Two ways that corporate leadership can engage with subsidiary locations are through knowledge management and governance. HEF Groupe did not actively engage with any of its facilities, including the TS USA facility in Chattanooga, to ensure that safety knowledge was communicated and risks were mitigated. The lack of active engagement by HEF Groupe allowed for deviations from the guidance published by the corporation that led to hazards that contributed to the incident.

4.3.1 Knowledge Management

In his 1993 book *Lessons From Disaster: How Organizations Have No Memory and Accidents Recur*, process safety expert Trevor Kletz stated:

> How can we persuade people to use the knowledge that is already available? The knowledge may not be known to us but it is known to other people [38, p. 1].

The CCPS defines process safety knowledge management as, "A system for capturing, organizing, maintaining, and providing the right process safety knowledge to the right people at the right time to improve process safety in an organization" [42, p. 1]. Knowledge management is critical to understanding hazards and risks because it provides the written body of technical information upon which other risk-based process safety elements are derived. This is critical for the development of hazard identification, hazard assessments, operating procedures, training, incident investigations, and other safety management systems [25, pp. 265-266].

As indicated by multiple TS USA and HEF USA managers, the design decisions and safety documentation were developed by HEF Groupe in France. HEF Groupe developed and published operating manuals that defined the process protocols, which were distributed to its various facilities. Although HEF Groupe developed the operating manual for the nitriding line, it included only limited safety information about the hazards of the process and the safeguards that were in place to protect the employees. For example, the operating manual indicates that "hollow" parts with closed cavities or blind holes must not be processed. The operating manual does not discuss why "hollow" parts with closed cavities or blind holes can present a hazard. This information was not included in the hazard assessment process for new parts, as discussed in **Section 4.1.2**, which could have prevented the 2024 incident in Chattanooga.

TS USA and HEF USA management stated that hazard analyses, safety assessments, and reviews of process hazards were generated by HEF Groupe. TS USA and HEF USA management were unaware of the hazard analyses performed by HEF Groupe. As discussed in **Section 4.1.2**, HEF Groupe had developed risk assessments and identified safeguards for potential water introduction into a molten salt bath (**Figure 24**) before the 2024 incident, but this information was never communicated to the Chattanooga facility.

Work Unit : ARCOR3	Description of Risk			Control Methods in Place
Operation	Risk family	Dangerous situation / defect / danger	Possible damage(s)	Organizational, technical, human
Work on the line	Risk(s) of explosion/implosion	Risk of explosion if water is present in the baths which may be on or in the parts	Projection(s), burn(s), contusion(s), wound(s), death	Instructions prohibiting any treatment of hollow parts Parts are dried before being introduced into the baths Area evacuated during the breakdown stage

Figure 24. Excerpt of HEF Groupe risk analysis. (Credit: HEF Groupe, annotated/translated by CSB)

The HEF Groupe risk analyses were maintained at the HEF Groupe corporate level and were not written in English or even available in English. At the time of the 2024 incident, the risk analyses were only available in French. Further, these risk analyses and safeguards were not communicated to the TS USA facilities. The HEF USA CEO stated to the CSB:

> I don't think there's anything which is done formally. You know, any risk analysis. That's an interesting concept, actually, now that you mention it. That might be worth looking into. But I don't think it has been ever done formally, not in our system.

HEF Groupe did not incorporate safety knowledge from its risk analyses into its training or procedures, preventing employees throughout the entire HEF Group organization (including TS USA) from even knowing that the information was available. HEF Groupe's lack of communication and knowledge management of the necessary safeguards to mitigate the process risks left the employees at the Chattanooga facility completely unaware of this information and unable to take the necessary precautions to prevent the 2024 incident.

The CSB concludes that HEF Groupe did not communicate the risk assessments performed by HEF Groupe on the nitriding process. Had HEF Groupe communicated the risk assessments and the controls for the identified hazards, TS USA could have ensured that the necessary safeguards were in place when processing parts through the nitriding line, and the 2024 incident likely could have been prevented.

Furthermore, HEF Groupe's prohibition on processing hollow parts in order to prevent explosions in the nitriding line was not communicated to any of its subsidiaries. In its FMEA, HEF Groupe highlighted the risk of water present in or on a part, which could result in an explosion. HEF Groupe apparently was well aware of the potential accumulation hazards where parts could introduce water into a molten salt bath. The CSB asked HEF Groupe and TS USA for the definition of the term "hollow" as it was used in the HEF Groupe guidance, but neither HEF Groupe nor TS USA were able to provide a specific definition of the term or any clarification of the intent of the prohibition of hollow parts.

At the time of the roller assessment by TS USA employees in Chattanooga, the concern was the sealed cavity. TS USA considered the rollers safe to process because they were open on both ends. Due to the orientation of the rollers and configuration of the cavity, the rollers still presented an accumulation hazard. The potential accumulation hazard was not identified during the review. Therefore, TS USA understood "hollow" to mean the sealed cavities in parts and not the other aspects of the rollers that could present the potential to accumulate materials.

HEF Groupe did not ensure that the corporation's subsidiary facilities were aware of the prohibition on processing hollow parts, what parts could be considered "hollow" (and therefore prohibited), and why the prohibition on processing these parts exists in the nitriding process. TS USA was unaware of HEF Groupe's prohibition on processing parts with the potential to accumulate materials. Had HEF Groupe memorialized the intent of prohibiting parts that present an accumulation hazard and communicated the prohibition and its intent to its subsidiary facilities, the part reviewers at the Chattanooga facility could have identified the hazards of the cavity in the rollers, and the 2024 incident could have been prevented. HEF Groupe failed to institutionalize the requirements of the corporation's prohibition on processing "hollow" parts and did not disseminate critical safety information to ensure that all facilities in HEF Groupe's organization understood the risks and what was intended by the prohibition.

The CSB concludes that HEF Groupe did not sufficiently share critical process safety knowledge with its subsidiaries, particularly by not communicating and explaining the hazards of accumulations in parts with cavities. Had HEF Groupe provided TS USA with the knowledge to assess the potential hazards presented by the rollers with the information in the risk analysis, TS USA could have recognized the accumulation hazard.

TS USA and HEF Groupe experienced multiple explosions, as discussed in **Section 4.2**, but poor communications (and the glaring lack of communication) between and among HEF Groupe and its subsidiaries, which resulted in a critical lack of knowledge and awareness of these explosions throughout the organization. HEF Groupe was unaware of the 2023 explosion that occurred in Chattanooga, although it was aware of the 2018 incident in Mexico and developed training slides after the 2018 incident. Similarly, HEF Groupe was aware of the 2020 explosion and sent out a safety alert letter following the incident. In contrast, at the time of the 2024 incident, the Chattanooga employees were unaware of the previous explosions that had occurred at the TS ETSA facility in Mexico in 2018 and the TS REW facility in France in 2020. HEF Groupe and TS USA lacked effective lines of communication to ensure that critical safety information was reported fully throughout the HEF Groupe corporation and its subsidiaries.

Exemplifying this communications dysfunction, HEF Groupe provided training about the Mexico explosion to its managers during HEF Groupe's 2018 annual meeting. However, this training was not provided to any other employees in the HEF Groupe organization.

Additionally, HEF Groupe did not perform any subsequent training or institutionalize the lessons learned from the 2018 explosion in Mexico or the 2020 explosion in France. The lack of training meant that new employees, such as all the employees at the Chattanooga facility, were unaware of the previous incidents, the consequences of water entrapment in parts, and the potential for an explosion to occur during the nitriding process.

Although HEF Groupe published a safety alert following the 2020 explosion in France, the alert focused only on PPE that should be worn. The alert did not discuss any details about the explosion or any corrective actions resulting from the incident. Moreover, no additional actions were taken by HEF Groupe to ensure that all the facilities throughout its corporate organization were aware of the hazards presented by the types of parts involved in the incidents in Mexico and France or that the facilities were following established safety guidelines.

Furthermore, HEF Groupe did not ensure that the lessons from these incidents were institutionalized by managing the safety information learned from them. HEF Groupe's poor knowledge management resulted in the repeated introduction of parts into molten salt baths at HEF Groupe facilities that presented an accumulation hazard, which deviated from the company's expected operations of the nitriding process. HEF Groupe did not provide sufficient information regarding the incidents in Mexico and France to its employees, which resulted in a serious knowledge gap among the employees at Chattanooga, including the Chattanooga employees being completely unaware of the prior incidents, their causes, and the unintended consequences of material accumulations in parts.

The CSB concludes that HEF Groupe did not manage safety knowledge throughout the company. HEF Groupe did not ensure that its subsidiary companies were provided with all the safety information that had been developed or that safety knowledge had been transferred and managed at

KEY LESSON

Companies should ensure that critical safety information is communicated to all employees and that safety knowledge is managed and institutionalized throughout the company. Safety knowledge management ensures that previous incidents and lessons learned are institutionalized at all levels of the organization.

its facilities. Had HEF Groupe managed its safety knowledge appropriately and ensured that safety information was incorporated into the operations of each of HEF Groupe's facilities, TS USA could have been aware of the hazards, mitigated the risk of fatally injuring an employee, and likely prevented the fatal 2024 incident in Chattanooga.

The CSB recommends that HEF Groupe develop and implement an effective and comprehensive Knowledge Management program for sharing knowledge throughout the HEF Groupe organization. Knowledge shall include all information from audits, hazard analyses, and incident investigations, including causal analyses and corrective actions recommended and taken. This program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Process Safety Knowledge Management*.

4.3.2 Corporate Governance

Corporate governance is described as the systems or processes by which companies are controlled and operated [43]. Regarding safety, governance can be described as the processes or systems by which a company manages the policies, practices, and procedures in place to ensure safe operations. The HEF Groupe corporate values and commitments are listed as "Employee Shareholding, Innovation, Internationally, and Environment."

Following the CSB's investigation of the 2010 Macondo Blowout and Explosion,[a] the CSB issued guidance[b] for corporate boards of directors and executives to prevent major accidents in the oil and gas industry, including the following actions:

- Ensure that a robust safety management system is in place that integrates internal safety requirements with regulatory requirements to control major accident hazards and that identifies, prevents, and mitigates identified process safety deficiencies.
- Communicate process safety policies and their importance as well as the crucial role of workers in risk identification and management.
- Ensure the following items are in place:
    - Consistent corporate policies
    - Procedures for hazard identification, risk assessment, and controls
    - Clear management structure with established responsibilities
    - Established operating procedures, document control measures, and performance indicators
    - Investigations of process safety incidents and near misses, and documentation of findings and corrective actions

Although the CSB's guidance focused on the executive boards in the oil and gas industry, the recommended actions can be applied to many industries or companies, including HEF Groupe.

The CCPS recommends that companies assign responsibilities at the corporate, business, and facility levels for coordinating and executing the aspects of process safety management systems. Additionally, the CCPS

[a] Macondo Blowout and Explosion

[b] CSB Best Practice Guidance for Corporate Boards of Directors and Executives in the Offshore Oil and Gas Industry for Major Accident Prevention

recommends that companies and leadership establish risk criteria and ensure controls are implemented and maintained [44, p. 13].

HEF Groupe did not set up systems within its subsidiary companies to ensure that the corporation's safety requirements were implemented at each of its facilities. Neither TS USA nor HEF USA employed any safety professionals at the individual facilities to ensure the corporate safety guidance was implemented at the facilities. Rather, HEF Groupe relied on regional and plant management to ensure all regulatory and corporate safety requirements were implemented at each location. However, as stated by multiple employees, TS USA relied on the safety guidance from HEF Groupe. Furthermore, TS USA and HEF USA dictated that the line operator was responsible for the shift's quality, safety, and productivity. The lack of resources at HEF Groupe and its subsidiaries specifically devoted to safety resulted in the failure to ensure that safeguards were enforced at the plant level and contributed to the fatal 2024 incident at the Chattanooga facility.

The CSB concludes that HEF Groupe did not provide the resources necessary to ensure that safety requirements and management systems were in place at its facilities. Had HEF Groupe and TS USA leadership assigned safety resources and responsibilities to dedicated roles, the safeguards and barriers identified to mitigate explosions could have been maintained and their implementation verified at the facilities, including the Chattanooga facility.

KEY LESSON

Companies should ensure that critical safety tasks are assessed to ensure that policies and procedures are in place and that the expectations of the organization are being followed at all levels. Companies should adopt guidance, such as that developed by the CSB following the CSB's investigation of the 2010 Macondo incident for the oil and gas industry, to govern safety activities in day-to-day operations. This guidance can be scaled based on the size and nature of the company and organization to provide the appropriate level of oversight.

The CSB recommends that for each TS USA facility, establish a position with specific professional expertise and experience in safety management systems, such as risk-based process safety. This position shall be responsible for TS USA's safety management system, ensuring that HEF Groupe's safety information is incorporated at the site level and implementing regulatory and industry safety guidance.

The CSB recommends that HEF Groupe develop and implement a comprehensive and effective Corporate Governance program. This program shall include regular audits of subordinate facilities throughout the organization, with tracking and accountability for implementation of all recommendations and corrective actions identified in the audits. Facility adherence to the safety management system recommended above shall be evaluated during the audits. The program shall require documentation of audit findings, prompt responses to deficiencies, development of corrective actions, and implementation of the corrective actions throughout the organization. This program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Implementing Process Safety Management*.

5 CONCLUSIONS

5.1 FINDINGS

Technical Analysis

1. The roller's design allowed for the accumulation of molten salt in the roller's interior cavity, which solidified into a salt plug.

2. TS USA did not recognize the accumulation hazard presented by the cavity, which, when the molten salt solidified, blocked the drain hole in the bottom of the roller.

3. The rollers were not suitable for processing through the liquid nitriding process. The drain holes were not large enough to ensure the rollers fully drained the molten salts, resulting in the salt plug forming at the bottom of the roller's interior.

4. The retained water boiled inside the roller's cavity and rapidly expanded as steam. The increased pressure forcefully ejected the roller's press fit end, the salt plug, and the water into the molten salt bath. The water rapidly boiled, creating a violent steam explosion that drove an uncontrolled eruption of molten salt from the vessel.

Safety Management Systems

1. The operating manual used by TS USA employees did not provide sufficient information to ensure that employees were aware of the potential hazards in the nitriding operation.

2. TS USA and HEF Groupe relied on the oxidizing salt mixture safety data sheet (SDS) for safety instructions in its operating manual, but the SDS does not provide sufficient information on hazards for materials in the process, which should be incorporated in the operating manual.

3. TS USA lacked procedures for reprocessing the rollers on the day of the incident. Had TS USA had procedures for reprocessing operations, it could have ensured that risks were identified and that safeguards were in place to mitigate the hazards presented by the operation.

4. TS USA deviated from its operating manual and HEF Groupe's requirements by reintroducing parts to the oxidizer bath and skipping the required preheating step.

5. TS USA did not perform any safety-based risk assessments on the liquid nitriding process. Had TS USA applied the methodology used for its quality program for process hazard analyses, it could have identified hazards, such as the risk of accumulations in parts, reactions due to foreign material in the molten salt baths, and the potential for upset conditions, such as overpressure events or explosions.

6. HEF Groupe assessed the potential hazards presented by an explosion and release of molten salts. However, the risk analyses did not incorporate inherently safer design principles or engineering controls. Had HEF Groupe implemented additional controls, it could have prevented the release of the molten salt and the explosion.

7. The risk analyses were not communicated to the TS USA facilities. Had the risk analyses been communicated, the hazard of water introduction into the bath and the requirement for all parts to be fully dried could have been followed, and the cause of the explosion eliminated.

8. The additional passive engineering controls in place at the Chattanooga facility were insufficient to protect the line operator due to the severity of the eruption of molten salt, which was more significant than the installed barrier was designed to withstand and protect against.

9. TS USA viewed the rollers as safe to process once the sealed cavity was opened and did not recognize the accumulation hazard in the newly opened cavity. Had TS USA recognized the risk of accumulations in the cavity, it could have requested that the customer take additional actions, such as removing the press fit ends, to eliminate the hazard.

10. The review process for new parts used by TS USA and HEF USA did not adequately assess the potential accumulation hazards or hazards due to modifications to new parts. The review process did not include corporate and industry guidance, such as the prohibition of processing sealed parts or parts that had not been dried, which could have mitigated or prevented the incident. Had TS USA's review included the guidance to prohibit the processing of parts that could accumulate materials, it could have decided that the rollers were not suitable for the nitriding operation.

11. Adding drainage holes to parts with sealed cavities directly contributed to the fatal May 2024 eruption at the Chattanooga facility. Had the practice of adding through-holes been thoroughly assessed before it was implemented, the new hazards, such as the accumulation in the roller cavity, could have been identified and mitigated.

12. TS USA did not perform an additional hazard analysis following the initial trial run and failed to recognize the accumulation hazard in the rollers. Had TS USA performed a hazard analysis, TS USA could have taken additional steps, such as removing the press fit ends, improving drainage, eliminating the accumulation hazard, and providing access to the internal cavity.

13. TS USA did not perform a hazard analysis on the non-routine task for reworking the rollers. Had TS USA performed a hazard analysis, it could have identified that the rollers were filled with water, and that reintroducing the rollers to the oxidizer bath could be a hazard.

14. TS USA's training program did not provide information or guidance on the process hazards. Had TS USA provided training on the hazards of the process and the potential for explosions, the risk of water accumulation and the potential for an explosion could have been identified, the operation stopped, and the incident prevented.

15. TS USA did not have a training program on how to identify hazards in the process or when evaluating new parts. Had TS USA developed and trained its reviewers on potential hazards when evaluating new parts, the reviewers could have identified the accumulation risks present in the rollers.

Learning from Past Incidents

1. The 2018 explosion in Mexico, the explosion's causal factors, and the corrective actions taken were not communicated from HEF Groupe to the other facilities. Had the corrective actions from the Mexico incident been communicated, TS USA could have identified the accumulation hazard and rejected the rollers during the pre-processing safety review, which could have prevented the 2024 incident.

2. No investigation report or corrective actions were distributed to TS USA or other HEF Groupe facilities following the 2020 explosion in France, and the CSB cannot confirm whether a formal investigation was performed or a written investigation report produced after the incident. The lack of documentation prevented the communication of the incident, its causal factors, corrective actions (if any), and lessons learned to other facilities within HEF Groupe.

3. The 2023 Chattanooga incident and its causal factors were not formally or robustly investigated, and any corrective actions taken were not communicated to other TS USA facilities. Had the 2023 Chattanooga incident been formally investigated and findings communicated, the safety personnel at HEF Groupe could have investigated the incident and communicated HEF Groupe's policy not to process parts that could accumulate materials. Had TS USA been aware of the safety concerns associated with processing parts that accumulate materials, the fatal 2024 incident could have been prevented.

4. TS USA, HEF Groupe, and other TS facilities have repeatedly had reason to understand that parts with accumulation hazards and sealed cavities are not suitable for the liquid nitriding process. All three incidents discussed above—2018 in Mexico, 2020 in France, and 2023 in Chattanooga—show that these parts are susceptible to trapping materials in their cavities, which leads to overpressure explosions when the parts are introduced to the salt baths, making them unsafe to process.

5. TS USA's and HEF Groupe's failure to learn from these previous incidents led to missed opportunities to identify the conditions that contributed to the 2024 explosion.

Corporate Engagement

1. HEF Groupe did not communicate the risk assessments performed by HEF Groupe on the nitriding process. Had HEF Groupe communicated the risk assessments and the controls for the identified hazards, TS USA could have ensured that the necessary safeguards were in place when processing parts through the nitriding line, and the 2024 incident likely could have been prevented.

2. HEF Groupe did not sufficiently share critical process safety knowledge with its subsidiaries, particularly by not communicating and explaining the hazards of accumulations in parts with cavities. Had HEF Groupe provided TS USA with the knowledge to assess the potential hazards presented by the rollers with the information in the risk analysis, TS USA could have recognized the accumulation hazard.

3. HEF Groupe did not manage safety knowledge throughout the company. HEF Groupe did not ensure that its subsidiary companies were provided with all the safety information that had been developed or that safety knowledge had been transferred and managed at its facilities. Had HEF Groupe managed its safety knowledge appropriately and ensured that safety information was incorporated into the operations

of each of HEF Groupe's facilities, TS USA could have been aware of the hazards, mitigated the risk of fatally injuring an employee, and likely prevented the fatal 2024 incident in Chattanooga.

4. HEF Groupe did not provide the resources necessary to ensure that safety requirements and management systems were in place at its facilities. Had HEF Groupe and TS USA leadership assigned safety resources and responsibilities to dedicated roles, the safeguards and barriers identified to mitigate explosions could have been maintained and their implementation verified at the facilities, including the Chattanooga facility.

5.2 Cause

The CSB determined that the cause of the incident was the introduction of water contained in the roller cavity to the 800°F oxidizing salt bath. The hot salt caused the water to expand and boil in the cavity of a roller, which resulted in an overpressure, a steam explosion, and a molten salt eruption.

Contributing to the incident was TS USA's lack of awareness of the accumulation hazards associated with parts containing cavities. These cavities presented accumulation hazards when processed in the nitriding line. Also contributing to the incident were TS USA's and HEF Groupe's insufficient process safety management systems, which did not include adequate procedures, training, hazard analyses, and incident investigations. Also contributing to the incident was HEF Groupe's ineffective corporate governance and safety knowledge management, which did not ensure that critical safety information was communicated and accessible to all TS USA facilities, including details of prior safety incidents and the results of those investigations.

6 RECOMMENDATIONS

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB makes the following safety recommendations:

6.1 TS USA

2024-01-I-TN-R1

Implement physical, protective barriers around the molten salt baths that isolate employees from hazardous releases at all locations that perform liquid nitriding.

2024-01-I-TN-R2

Develop a safety management system that incorporates industry guidance and includes, but is not limited to:

a. A hazard analysis program for assessing the nitriding process. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*, the National Fire Protection Association's (NFPA) *Standard for Ovens and Furnaces*, and ASM International's Handbook. The program shall apply to new and existing parts, assess parts for accumulation hazards and sealed cavities, and include non-routine tasks such as reprocessing unsatisfactory parts.
b. Written operating procedures for the nitriding process. The procedures shall be based on the information gathered from the hazard analysis program. The procedures shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Writing Effective Operating and Maintenance Procedures*.
c. A training program, including written materials, for the employees involved in the nitriding process. This program shall be based on the nitriding facility's operating procedures and other relevant information from the hazard analysis program. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*.
d. An incident investigation program. This program shall include requirements for performing causal analysis, producing written reports, and communicating findings and corrective actions throughout the entire TS USA organization. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Investigating Process Safety Incidents*.

2024-01-I-TN-R3

For each TS USA facility, establish a position with specific professional expertise and experience in safety management systems, such as risk-based process safety. This position shall be responsible for TS USA's safety management system, ensuring that HEF Groupe's safety information is incorporated at the site level, and implementing regulatory and industry safety guidance.

6.2 HEF GROUPE

2024-01-I-TN-R4

Include physical, protective barriers as part of the standard design for liquid nitriding processes. These protective barriers shall be intended to isolate employees from molten salt releases.

2024-01-I-TN-R5

Develop a safety management system that incorporates industry guidance and includes, but is not limited to:

a. A hazard analysis program for assessing the nitriding process. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*, the National Fire Protection Association's (NFPA) *Standard for Ovens and Furnaces*, and ASM International's Handbook. The program shall apply to new and existing parts, assess parts for accumulation hazards and sealed cavities, and include non-routine tasks such as reprocessing unsatisfactory parts.

b. Written operating procedures for the nitriding process. The procedures shall be based on the information gathered from the hazard analysis program. The procedures shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Writing Effective Operating and Maintenance Procedures*.

c. A training program, including written materials, for the employees involved in the nitriding process. This program shall be based on the nitriding facility's operating procedures and other relevant information from the hazard analysis program. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety*.

d. An incident investigation program. This program shall include requirements for performing causal analysis, producing written reports, and communicating findings and corrective actions throughout the entire HEF Groupe organization. The program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Risk-Based Process Safety* and the CCPS's *Guidelines for Investigating Process Safety Incidents*.

2024-01-I-TN-R6

Develop and implement an effective and comprehensive Knowledge Management program for sharing knowledge throughout the HEF Groupe organization. Knowledge shall include all information from audits, hazard analyses, and incident investigations, including causal analyses and corrective actions recommended and taken. This program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Process Safety Knowledge Management*.

2024-01-I-TN-R7

Develop and implement a comprehensive and effective Corporate Governance program. This program shall include regular audits of subordinate facilities throughout the organization, with tracking and accountability for implementation of all recommendations and corrective actions identified in the audits. Facility adherence to the safety management system recommended above shall be evaluated during the audits. The program shall require documentation of audit findings, prompt responses to deficiencies, development of corrective actions, and implementation of the corrective actions throughout the organization. This program shall incorporate industry guidance, such as the Center for Chemical Process Safety's (CCPS) *Guidelines for Implementing Process Safety Management*.

KEY LESSONS FOR THE INDUSTRY

To prevent future chemical incidents, and in the interest of driving chemical safety excellence to protect communities, workers, and the environment, the CSB urges companies to review these key lessons:

1. Even in the absence of regulatory requirements, companies should develop safety management systems to ensure the operations are managed and risk is mitigated based on concepts developed by the CCPS's *Guidelines for Risk Based Process Safety* or other industry guidance, including well-written procedures, technically sound hazard analyses, and training on necessary safety topics.

2. Companies should incorporate elimination of hazards or inherently safer design concepts, such as simplification, into hazard analyses to ensure that there are effective and reliable controls to protect employees from process hazards.

3. Companies should have an incident investigation program that generates formal reports, performs causal analysis, and reviews corrective actions. The findings of the investigations should be communicated, including translation, throughout the site and to other facilities within the company.

4. Companies should ensure that critical safety information is communicated to all employees and that safety knowledge is managed and institutionalized throughout the company. Safety knowledge management ensures that previous incidents and lessons learned are institutionalized at all levels of the organization.

5. Companies should ensure that critical safety tasks are assessed to ensure that policies and procedures are in place and that the expectations of the organization are being followed at all levels. Companies should adopt guidance, such as that developed by the CSB following the CSB's investigation of the 2010 Macondo incident for the oil and gas industry, to govern safety activities in day-to-day operations. This guidance can be scaled based on the size and nature of the company and organization to provide the appropriate level of oversight.

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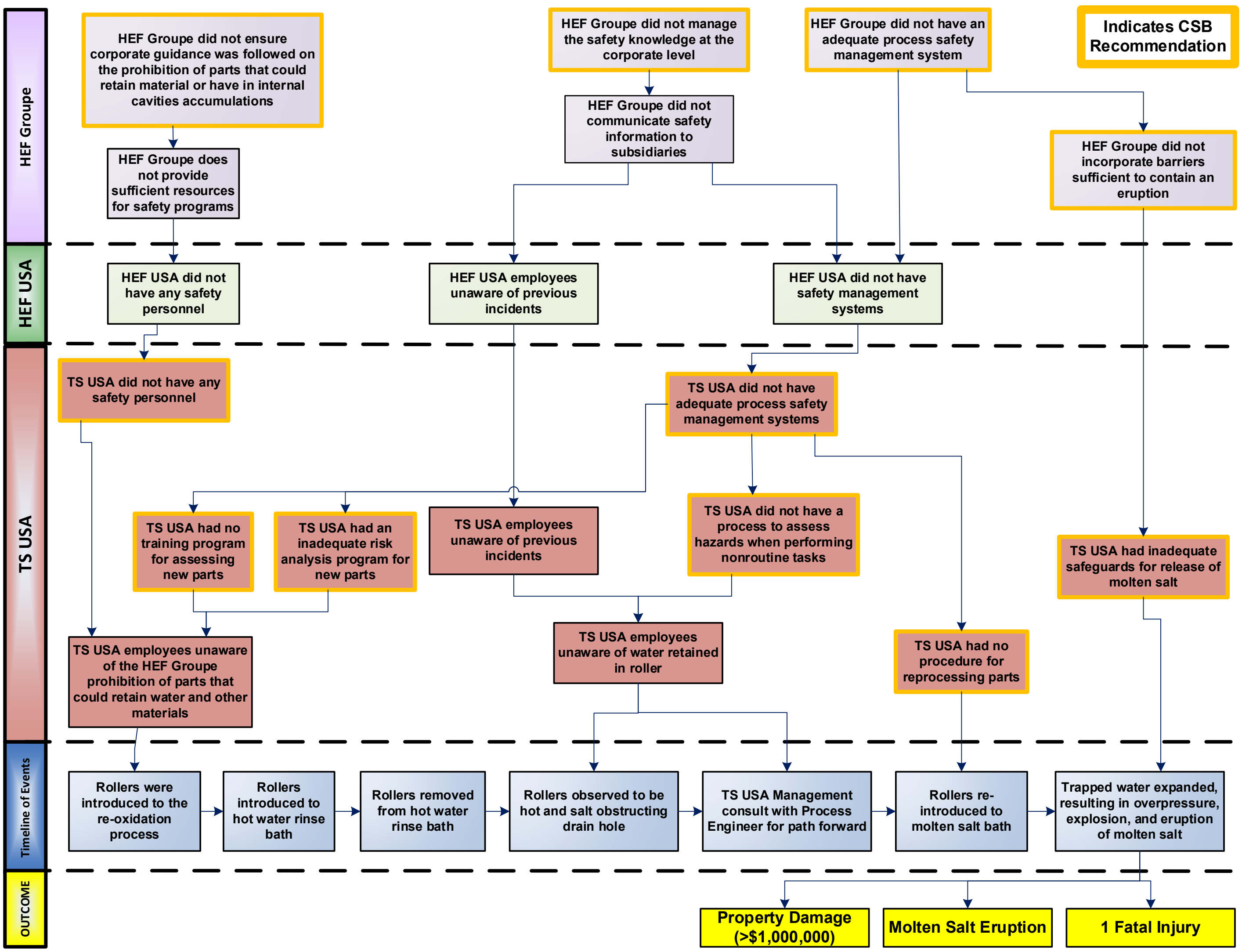
APPENDIX A—SIMPLIFIED CAUSAL ANALYSIS (ACCIMAP)



APPENDIX B—DETAILED TIMELINE

Date	Time (Military)	Description
March 19, 2024		Customer contacts TS USA for the potential to liquid nitride the rollers.
March 20, 2024		TS USA process engineer notifies the customer of the concern about the sealed cavity.
March 21, 2024		Customer identifies that the set screws can be removed to open the cavity.
March 22, 2024		Customer request accepted by TS USA.
April 10, 2024		Prototype roller processed through the nitriding process.
May 13, 2024		Prototype roller approved by the customer.
May 15, 2024	0854	TS USA process engineer contacted the customer to request an increase in the size of the drainage holes.
May 23, 2024	1244	First roller uncrated.
	1257	Rollers unloaded from crates and placed in fixtures.
May 24, 2024	1136	Rollers placed on the weighing scale.
	1355	Rollers moved to the preheat furnace.
	1500	Rollers removed from the preheat furnace.
	1502	Rollers placed into the nitriding bath.
	1708	Rollers removed from the nitriding bath.
	1720	Rollers moved to the oxidizer bath.
	1722	Rollers fully submerged in the oxidizer bath.
	1805	Rollers removed from the oxidizer bath.
	1814	Rollers stopped draining.
	1815	Rollers placed in the quench bath.
	1858	Rollers removed from the quench bath.
	1858	Rollers placed in the first rinse bath.
May 27, 2024	0827	Rollers moved from the first rinse bath to the second rinse bath.
May 28, 2024	0855	Rollers moved from the second rinse bath to the third rinse bath.
	0954	Rollers removed from the third water rinse bath.

Date	Time (Military)	Description
	0956	Rollers placed at the end of the line to drain.
	1046	Rollers moved from the end of the line to the polishing station.
	1048	Rollers placed at the polishing station.
	1118	The first roller removed from the fixture for polishing.
	1120	The first roller placed on a polishing stand.
	1238	The first roller was moved from the polishing station, with water observed at the end of the polishing station
	1326	The second roller moved away from the polishing station.
	1441	Water drained from the roller after polishing.
	1443	Water continued to drain from the roller.
	1445	Water stops draining from the roller.
	1503-1600	Pressurized air used on the rollers to remove water and salt from the cavity.
May 29, 2024	0707	Operators begin working on rollers in the polishing station.
	0713	Water begins emptying onto the ground at the polishing station.
	0831	Rollers completed at the polishing station.
	0836	Rollers placed on the scale for weighing.
	1002	Rollers placed into the preheat furnace.
	1237	Rollers removed from the preheat furnace.
	1248	Rollers placed in the oxidizer tank.
	1321	Rollers removed from the oxidizer tank.
	1325	Rollers placed in the quench tank.
	1331	Rollers removed from the quench tank.
	1332	Rollers placed in the first rinse bath.
	1348	Rollers placed in the second rinse bath.
	1506	Rollers placed back in the hot water rinse bath.
May 30, 2024	0709	Rollers removed from the hot water rinse bath.
	0724	The plant manager moves the parts to the end of the line.

Date	Time (Military)	Description
	0835	The plant manager, with the supervisor present, attempted to clear the salt obstruction.
	0836	The plant manager and supervisor identified that one of the rollers is too hot to touch.
	0839	The plant manager contacted the process engineer.
	0846	The plant manager instructed the line operator of plan to reprocess the rollers.
	0854	Rollers submerged in the oxidizer vessel.
	0858	Explosion and eruption of oxidizer salts occurred.
	0907	Hamilton County Emergency Medical Services arrived and began initial evaluation and care of the line operator.
	0917	EMS departed from the facility to transport the line operator to the hospital.
	0924	EMS arrived at the hospital.
		The line operator succumbed to his injuries.

APPENDIX C—DESCRIPTION OF SURROUNDING AREA

Figure 25 shows the census blocks immediately surrounding the TS USA Chattanooga facility. The census information for the blocks is presented in **Table 2** [45].

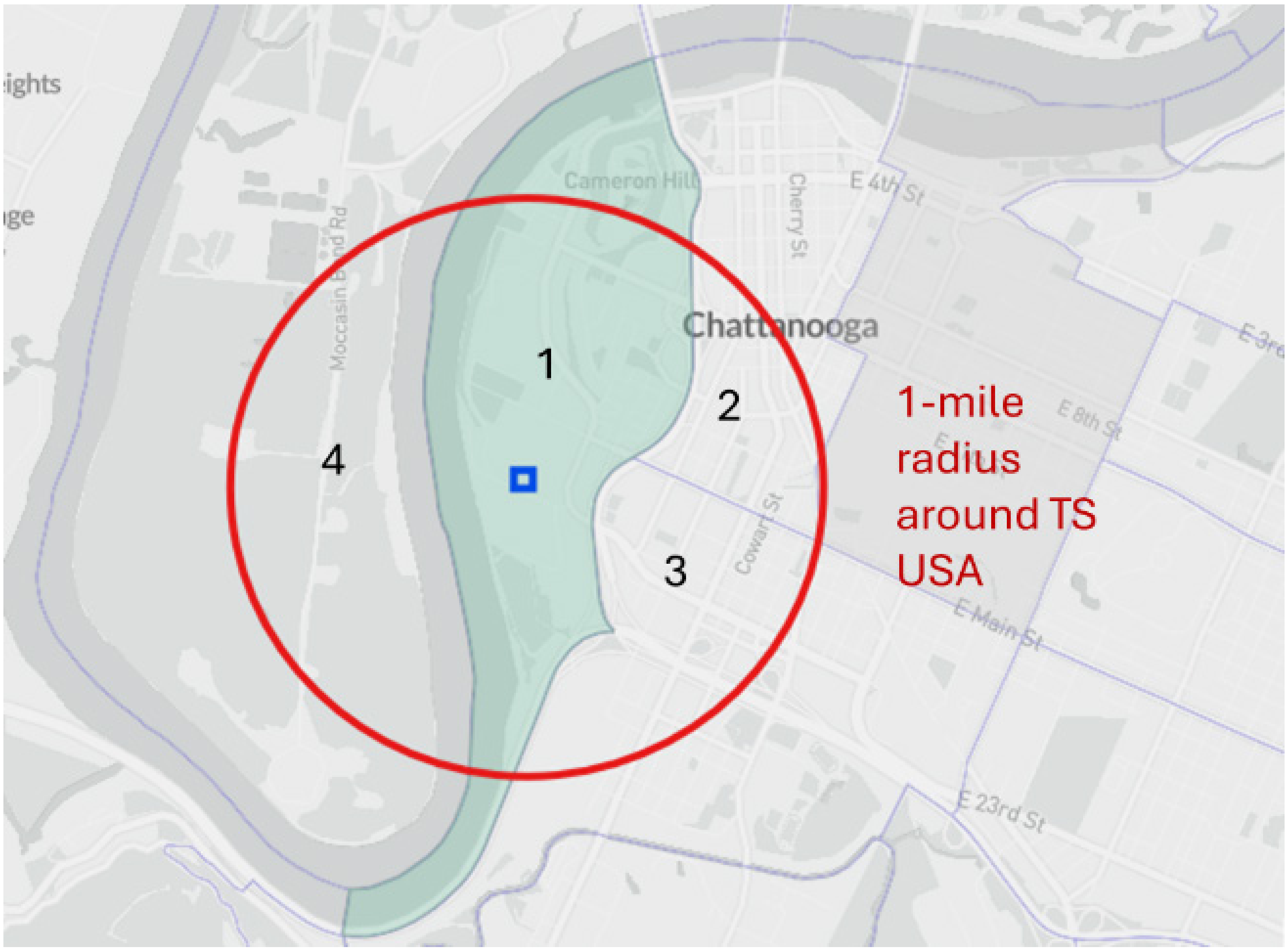


Figure 25. Census blocks within a one-mile distance from the TS USA facility [45]. (Credit: Census Reporter, annotated by CSB)

Table 2. Tabulation of demographic data for the populations within the census blocks shown in **Figure 25**.

Tract Number	Population	Median Age	Race and Ethnicity		Per Capita Income	% Persons Below Poverty Line	Number of Housing Units	Types of Structures	
1	2,714	51.7	23.0%	White	$30,424	38.6%	2,134	9%	Single Unit
			70.0%	Black				91%	Multi-Unit
				Native					Mobile Home
				Asian					Boat, RV, van, etc.
				Islander					
				Other					
			5.0%	Two+					
			2.0%	Hispanic					
2	1,944	33.7	78.0%	White	$66,209	16.0%	1,370	9%	Single Unit
			15.0%	Black				91%	Multi-Unit
				Native					Mobile Home
			2.0%	Asian					Boat, RV, van, etc.
				Islander					
			1.0%	Other					
			2.0%	Two+					
			3.0%	Hispanic					
3	2,066	33.4	55%	White	$65,414	12.9%	1,158	47%	Single Unit
			38%	Black				53%	Multi-Unit
				Native					Mobile Home
			3%	Asian					Boat, RV, van, etc.
				Islander					
				Other					
			1%	Two+					
			3%	Hispanic					
4	2,330	28.9	80%	White	$49,818	10.6%	1,271	24%	Single Unit
			8%	Black				75%	Multi-Unit
				Native				1%	Mobile Home
			4%	Asian					Boat, RV, van, etc.
				Islander					
				Other					
			6%	Two+					
			1%	Hispanic					

APPENDIX D—TENNESSEE OSHA CITATIONS

Citation Number	Standard Cited	Standard Language
Citation 1 Item 1	TCA 50-3-105(1)	Each employer shall furnish to each of its employees conditions of employment and a place of employment free from recognized hazards that are causing or are likely to cause death or serious injury or harm to its employees.
Citation 2 Item 1	Tennessee Department of Labor and Workforce Development Rule 800-01-03-.05(2)(A)	Basic requirement. When an authorized government representative asks for the records you keep under this rule, you must provide copies of the records within four (4) business hours.
Citation 2 Item 2	29 C.F.R. § 1910.1200(e)(1)	Employers shall develop, implement, and maintain at each workplace, a written hazard communication program which at least describes how the criteria specified in paragraphs (f), (g), and (h) of this section for labels and other forms of warning, safety data sheets, and employee information and training will be met.

U.S. Chemical Safety and Hazard Investigation Board

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