U.S. CHEMICAL SAFETY AND HAZARD INVESTIGATION BOARD

INVESTIGATION REPORT

COMBUSTIBLE DUST FIRE AND EXPLOSIONS

(7 Killed, 37 Injured)

CTA ACOUSTICS, INC.

CORBIN, KENTUCKY

FEBRUARY 20, 2003

KEY ISSUES:

- COMBUSTIBLE DUST HAZARD AWARENESS
- WORK PRACTICES
- BUILDING DESIGN
- PRODUCT STEWARDSHIP

REPORT NO. 2003-09-I-KY

FEBRUARY 2005

Contents

Figures

Tables

Acronyms and Abbreviations

ACC	American Chemistry Council
ANSI	American National Standards Institute
ASTM	American Society for Testing and Materials
ATF	Bureau of Alcohol, Tobacco, Firearms and Explosives
CAS	Chemical Abstracts Service
CSB	U.S. Chemical Safety and Hazard Investigation Board
CTA	CTA Acoustics, Inc.
DSC	Differential Scanning Calorimetry
EPA	U.S. Environmental Protection Agency
ºF	Degrees Fahrenheit
FM Global	Factory Mutual Insurance Company
g/m^3	Gram per cubic meter
HazCom	Hazard Communication (OSHA)
HMIS	Hazardous Materials Identification System (NPCA)
IC	Incident commander
IBC	International Building Code
ICC	International Code Council
IFC	International Fire Code
K_{st}	Explosion Severity
LEL	Lower Explosive Limit
MEC	Minimum explosible concentration
MIE	Minimum ignition energy
MSDS	Material Safety Data Sheet
NBC	National Building Code (American Insurance Association)

NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFC	National Fire Code (NFPA)
NFPA	National Fire Protection Association
NPCA	National Paint and Coatings Association
NSC	National Safety Council
OSH	Kentucky Office of Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
oz/ft^3	Ounce per cubic foot
PBD	Propagating Brush Discharge
psi	Pound per square inch
SCE	Safety Consulting Engineers, Inc.
SPI	Society of Plastics Industry

Executive Summary

A February 20, 2003, dust explosion at the CTA Acoustics, Inc. (CTA) facility in Corbin, Kentucky, killed seven and injured 37 workers. This incident caused extensive damage to the production area of the 302,000-square-foot plant. Nearby homes and an elementary school were evacuated, and a 12-mile section of Interstate 75 was closed. The largest CTA customer, Ford Motor Company, temporarily suspended operations at four automobile assembly plants because CTA had produced acoustic insulation products for those plants, as well as for other industrial and automotive clients.

In investigating this incident, the U.S. Chemical Safety and Hazard Investigation Board (CSB) determined that combustible phenolic resin dust that had accumulated throughout the facility fueled the explosion.

The investigation identified the following root causes for the February 20 incident:

- CTA management did not implement effective measures to prevent combustible dust explosions.
- The CTA cleaning and maintenance procedures for production lines did not prevent the accumulation of unsafe levels of combustible dust on elevated flat surfaces.
- The CTA incident investigation program did not ensure that all oven fires were investigated and that underlying causes were identified and resolved.
- The Borden Chemical product stewardship program did not explicitly convey to CTA the explosive hazards of phenolic resins.
- The original building design and subsequent building modifications did not effectively address the fire and explosion hazards associated with combustible dusts.

This CSB report makes recommendations to CTA, CertainTeed Corporation, and to Borden Chemical, Inc., manufacturer of the phenolic resin used at the Corbin plant. CSB also makes recommendations to the Kentucky Office of Occupational Safety and Health; Kentucky Office of Housing, Buildings, and Construction, Division of Building Codes Enforcement; Factory Mutual Insurance Company; American Chemistry Council; National Fire Protection Association; International Code Council; and The Society of the Plastics Industry, Phenolic Division.

1.0 Introduction

At approximately 7:30 am on Thursday, February 20, 2003, a fire and series of explosions occurred at an acoustic insulation manufacturing plant owned and operated by CTA Acoustics, Inc. (CTA), in Corbin, Kentucky. Seven workers died, and 37 were injured. Nearby homes and an elementary school were evacuated, and a 12-mile section of Interstate 75 was shut down as a precautionary measure. The largest CTA customer, Ford Motor Company, temporarily closed four automobile assembly plants because they relied on parts CTA had supplied.

Because of the catastrophic nature of this incident, the U.S. Chemical Safety and Hazard Investigation Board (CSB) conducted an investigation to determine the root and contributing causes and to make recommendations to prevent similar occurrences. CSB investigators arrived at the site on the morning of February 21. CSB coordinated investigation activity with other responding agencies, including the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATF); Kentucky Office of Occupational Safety and Health (OSH); Office of Kentucky State Fire Marshal; and Laurel County Division of Public Safety. ATF completed an origin and cause investigation and determined that the incident did not involve criminal activity.

CSB photographed and examined the incident scene, conducted nearly 80 interviews, and examined documents CTA and other parties provided. Forty-two samples of dust-containing materials were collected and tested in a laboratory; selected plant production equipment was tested; and relevant safety codes, standards, and guidelines were analyzed. On July 8, 2003, CSB held a public meeting in Corbin to present its preliminary findings and to solicit comments from employees and the public.

The CTA incident is the second in a series of three dust explosions investigated by CSB; CSB also investigated West Pharmaceutical Services (January 29, 2003) and Hayes Lemmerz (October 29, 2003).

As a result of these investigations and industry-wide concerns, CSB has initiated a study of dust explosion hazards that will examine, among other topics, the adequacy of safety regulations and guidelines.

2.0 Key Findings

1. Combustible phenolic resin dust fueled the fire and explosions.

2. Line 405 was operated with the oven doors open due to a malfunction of temperature control equipment. Combustible material in the oven likely caught on fire, and the flames then ignited a combustible dust cloud outside the oven.

3. Lack of effective firewalls and blast-resistant physical barriers allowed the fire and explosions to spread to nonproduction areas of the facility.

4. Borden Chemical did not explicitly communicate the explosive hazard of phenolic resins to CTA.

5. Borden Chemical did not communicate to CTA the safety lessons from the 1999 Jahn Foundry dust explosions that involved a similar Borden phenolic resin.

6. CTA management was aware of the explosive potential of combustible dust, but did not implement effective measures to prevent explosions or communicate the explosion hazard to the general work force.

7. Inefficient baghouse operations and improper production line cleaning activities dispersed combustible dust and deposited it on elevated flat surfaces, where it accumulated.

8. Lack of housekeeping on elevated flat surfaces allowed combustible dust to build up to unsafe levels.

9. The Kentucky Office of Occupational Safety and Health conducted comprehensive inspections of the facility in previous years but did not issue citations regarding combustible dust hazards.

10. The Kentucky State Fire Marshal’s office had not inspected the facility since it was constructed in 1972.

11. Despite frequent inspections, none of CTA’s insurers identified phenolic resin dust as an explosion hazard after 1995.

3.0 Facility Description

3.1 CTA Acoustics Corbin Facility

The 302,000-square-foot CTA facility is located just outside the Corbin city limits in Laurel County, Kentucky. The facility employed 561 full-time personnel at the time of the incident. Operations employees worked rotating 12-hour shifts, while the mechanical department and administrative support staff worked 5-day, 8-hour shifts.

CTA is a privately held company, with a technical and sales office in Madison Heights, Michigan. The Corbin facility is its only manufacturing plant. At the time of the incident, CTA had annual sales of $80 to $90 million.

3.2 Surrounding Community

The neighborhood surrounding the CTA facility is part of an unincorporated community consisting of houses, apartments, and trailer homes. A nursing home, medical clinic, and elementary school are located within one mile of the plant. On the day of the incident, a number of people living or working in the area were evacuated, but no injuries to the public were reported. As a precaution, officials shut down 12 miles of Interstate 75, located approximately 0.5 mile west of the facility.

3.3 History of the Plant

CertainTeed Corporation—a manufacturer of insulation, roofing, siding, windows, and related products—built the Corbin plant in 1972 and operated it for 20 years. Headquartered in Valley Forge, Pennsylvania, CertainTeed employs 7,000 people at 40 manufacturing facilities throughout the United States. In 1988, CertainTeed became a wholly owned subsidiary of Saint-Gobain. Saint-Gobain employs approximately 26,000 people in North America and more than 170,000 people in 46 countries worldwide. Saint-

Gobain's North American companies operate in industries such as industrial ceramics, containers, reinforcements, flat glass, abrasives, and building materials.

In 1992, CertainTeed sold the automotive portion of the facility (production lines 403 and 405) to CTA, while retaining ownership of the overall facility and industrial lines 401, 402, and 416. Those lines produced acoustic duct liner for various industries. In 1997, CertainTeed sold the entire facility to CTA but retained ownership of lines 401, 402, and 416, which were leased to CTA. CTA operated and maintained those three lines. In 1998, CTA became a wholly owned subsidiary of American Rockwool Operating Corporation. American Rockwool then merged into Hercules Fiber II in October of 2001.

3.4 Plant Construction and Layout

Most of the explosion and fire damage occurred in and around the production area of the CTA plant. The following descriptions are based on visual observations and review of plant engineering drawings, in addition to videotapes and photographs taken after the explosion.

3.4.1 Plant Construction

The CTA plant was designed and built in 1972 as a Type II (noncombustible) industrial structure according to classifications developed by the Model Codes Standardization Council.[1] A structural steel skeleton frame, consisting of vertical columns and horizontal beams, supported the building. Exterior curtain walls—constructed of nonload-bearing, prefabricated metal panels—were supported by and attached to the structural frame. The flat building roof was constructed of metal panels covered with weatherproof matting and supported by open-web steel joists, which were attached to the horizontal

---

[1] Formed in 1959, the Model Codes Standardization Council was created to seek greater uniformity among model building codes used in the U.S. Its members included the model building code organizations; national associations, such as American Society for Testing and Materials; and several federal agencies. In 2000, these model building codes were consolidated into the International Building Code developed by the International Code Council.

beams. Nonload-bearing masonry block walls with a 2-hour fire resistance rating partially segregated functional areas of the plant.

3.4.2 Plant Layout

Four production lines—401, 402, 403, and 405—were located in the center portion of the southern half of the plant. Production line 416 was located near the west wall (Figure 1). The production lines included material feeders, separating and mixing machines, curing ovens, and trimming equipment connected by conveyors. Lines 401, 402, and 403 were adjacent to each other; line 405 was approximately 80 feet east of line 403. The open area between lines 403 and 405 was used to store racks of semi-cured acoustical insulation, referred to as “pelts.” The molding department, where hydraulic molding presses and water jet cutters were used to shape and size the automotive insulation products, was located in the northeast quadrant of the plant.

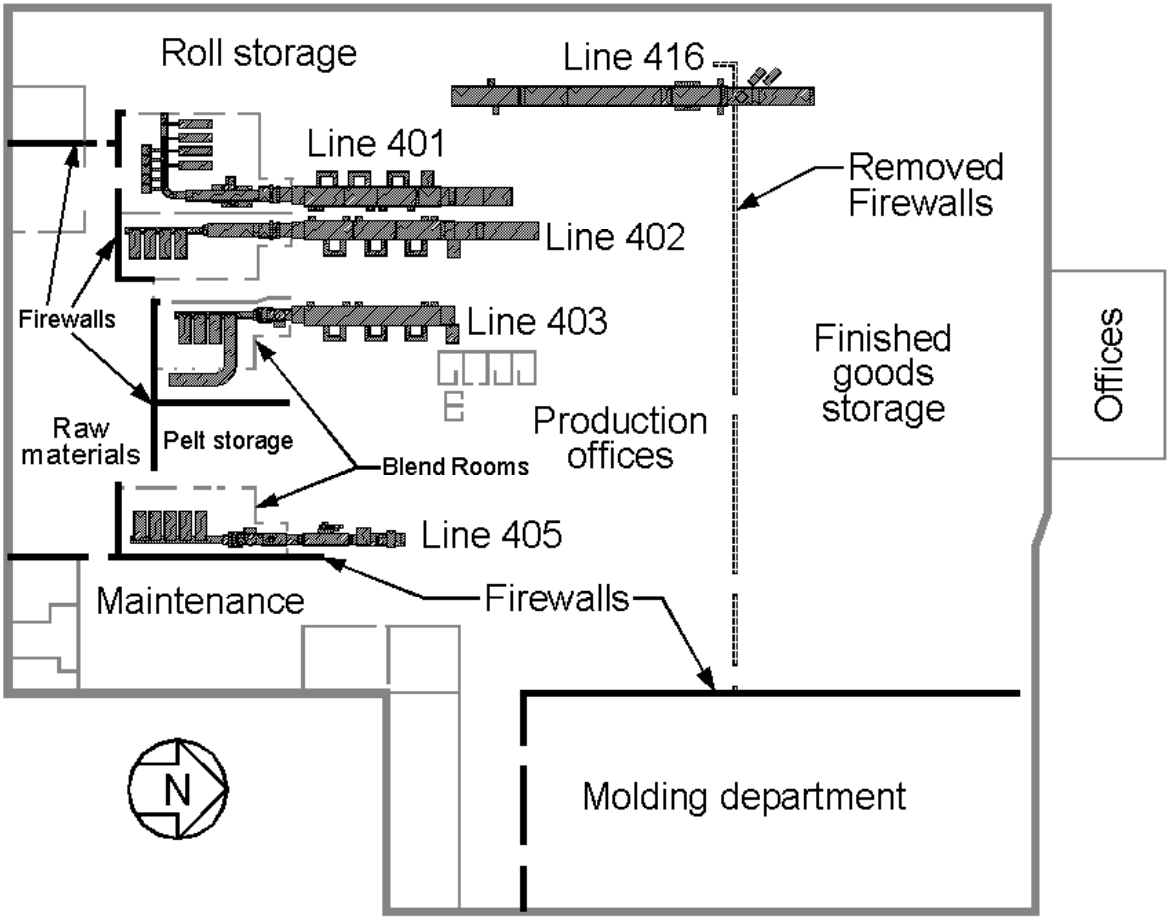


Figure 1. Simplified layout of CTA facility.

Firewalls to the south segregated the production lines from raw materials storage. A firewall also segregated the southeast portion of line 405 from the maintenance shop. This configuration created a 5- to 8-foot-wide aisle between the firewall and the east side of line 405. Another firewall, which ran from south to north in the open area between lines 403 and 405, partially segregated these lines. There was no firewall on the west side of the production area. In late 2002, CTA removed firewalls on the north side of the production area that segregated that area from the finished goods storage area. The Kentucky Department of Housing, Buildings, and Construction (which became the Kentucky Office of Housing, Buildings, and Construction in 2004) approved removal of these firewalls.

Thirteen-foot-high freestanding enclosures, called “blend rooms,” covered processing equipment on the south end of four production lines. Figure 2 shows the location of the blend room in a side view of line 405. Blend room ceilings were constructed of metal panels with recessed fluorescent light fixtures. The areas between the roofs of the blend rooms and the plant roof were generally open on two or three sides.

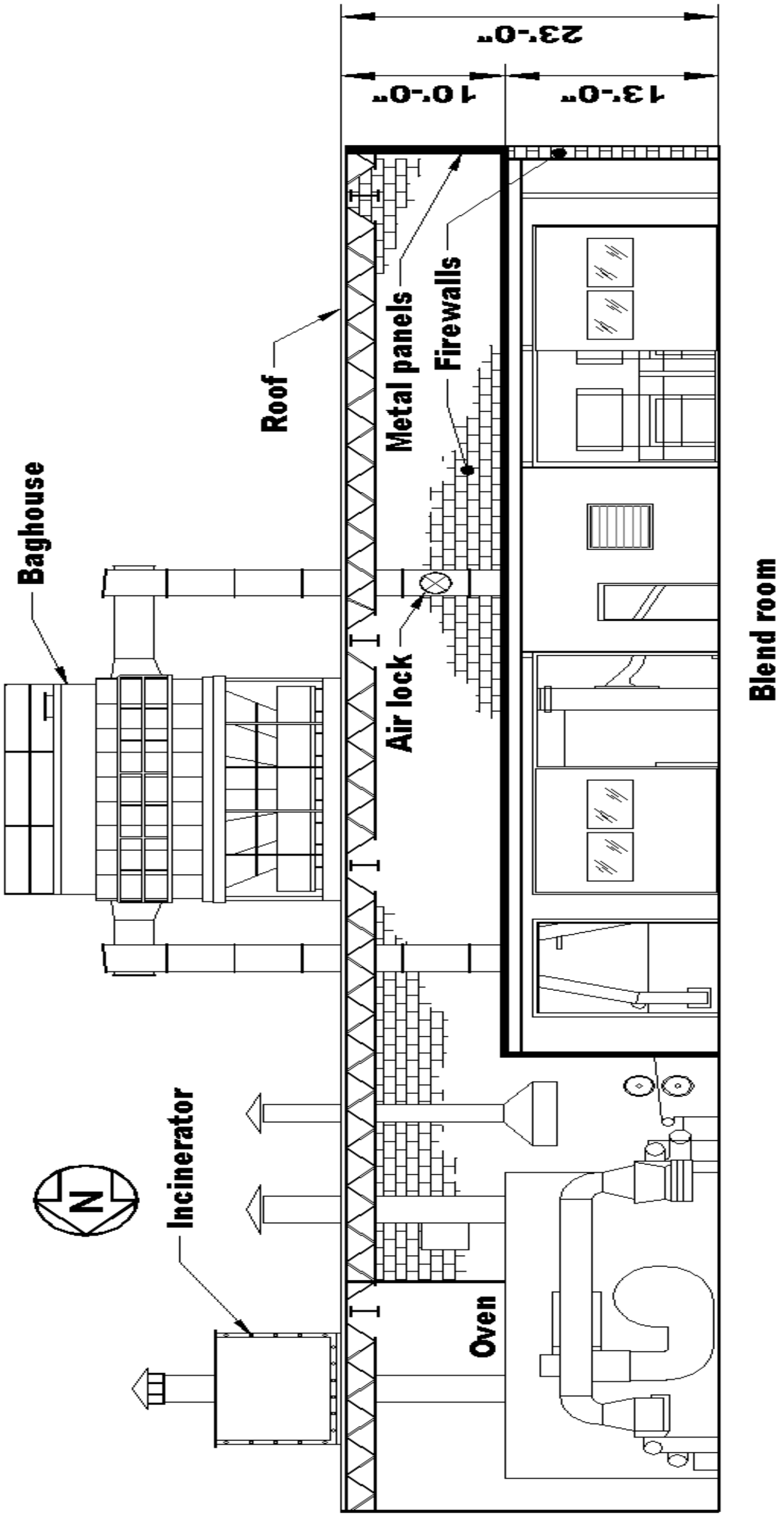


Figure 2. Side view showing location of line 405 blend room.

4.0 Process Description

The production lines in Corbin used a process technology initially patented by the Gustin-Bacon Company.[2] Originally, the process used shoddy[3] cotton and phenolic resin for the manufacture of acoustical and thermal insulation. In the 1990s, fiberglass began replacing the shoddy cotton in CTA insulation products, a changeover that was essentially complete by 2001.

4.1 Line 405

Lines 401, 402, and 403 generally operated in a manner similar to 405 (Figure 3). However, the process at line 405 is significant because CSB determined that it most likely was the origin of the initial ignition and explosion (Section 7.1.1.1). Line 416 only applied additional coatings to the industrial insulation products produced in Lines 401 and 402 and used no powdered phenolic resins.

4.1.1 Raw Materials and Feeders

Three raw materials—fiberglass, phenolic resin powder, and facing—were used to manufacture the industrial and automotive acoustical insulation products at CTA. Various types of fiberglass were fed into the line at the south end by blend line feeders.[4] A picker then chopped, mixed, and spread the fiberglass to create a web, which was moved via another conveyor to the binder-feeder. A manually

---

[2] In April of 1949, the Gustin-Bacon manufacturing company applied for and received a patent number 2,467,291 from the United States Patent Office for a mat process to manufacture Felted Fibrous Insulating Material.

[3] Shoddy is the name given to special types of fabric made from remanufactured materials (i.e., materials which have already been spun into yarn or woven into cloth, but have been torn up or ground up into a fibrous mass, respun, and rewoven).

[4] Fiberglass arrived at the CTA facility in wire-bound bales and was loaded onto conveyors attached to the feeders.

actuated water sprinkler was positioned over this area to extinguish fires. The binder-feeder deposited phenolic resin powder onto the fiberglass web,[5] which then entered the mat-former on a forming chain.[6]

CTA purchased and used two types of phenolic resin powder. The powders—referred to as "natural" and "black"—have similar chemical compositions and properties (Section 8.1). The natural resin, Borden Chemical Durite SD-110A, was used on lines 401 and 402 to make duct liner; while the black resin, Borden Chemical Durite SD-52SS, was used on lines 403 and 405 to make automotive acoustic insulation products. The black resin contained approximately 2 percent carbon black to produce the desired color. Substantial quantities of phenolic resins, often several hundred thousand pounds per month, were used. The quantity of black resin greatly exceeded the quantity of natural resin used in the plant's production lines.

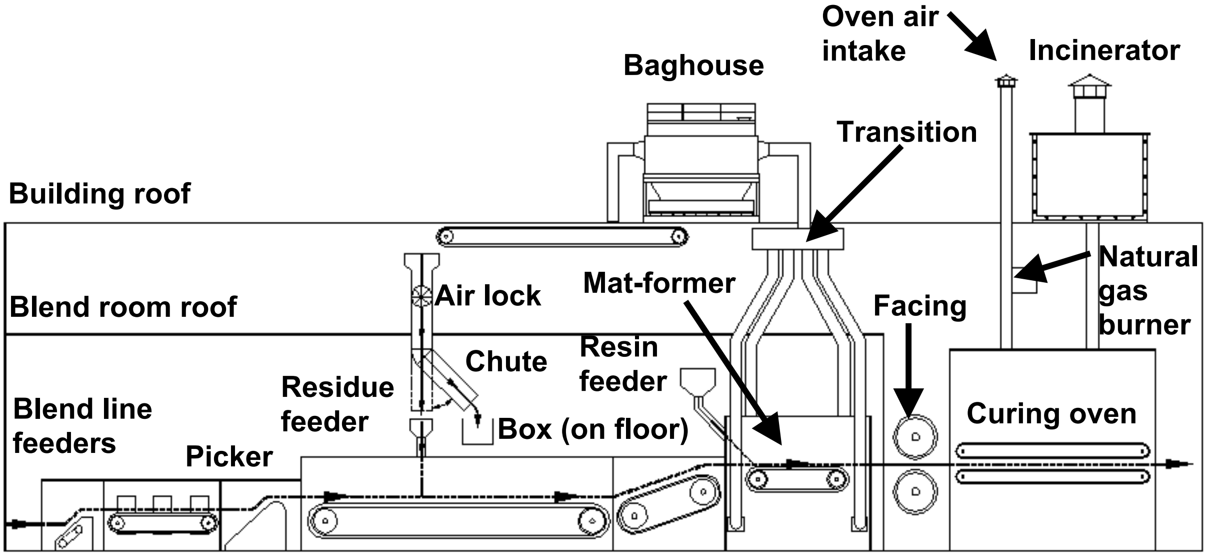


Figure 3. Line 405 process flow.

---

[5] Phenolic resin powder arrived at the CTA facility in 2,000-pound super sacks. A screw conveyor attached to the bottom of the feed hopper transported the powder to the binder-feeder.

[6] The forming chain was basically an open mesh conveyor line.

4.1.2 Mat-former and Baghouse

In the mat-former, air-suction dispersed the phenolic resin powder throughout the web to create a resin-impregnated fiberglass mat. The suction air—along with excess resin powder and smaller fiberglass fibers—traveled from the mat-former via four vertical air ducts to a baghouse, which was located on the plant's roof. Fire dampers and manually actuated water sprinklers were located in the vertical ducts.

The pulse-jet baghouse, designed with a capacity of 40,000 cubic feet per minute, was a large rectangular metal box with a series of long cloth bags hung inside. This baghouse was fitted with an explosion vent. In addition to providing suction for the mat-former, it also served as a pollution control device. The baghouse was designed to remove small fiberglass fibers and phenolic resin powder with 99 percent efficiency. Particulate-laden air entered on one side of the baghouse and passed through the bags, which acted like filters to remove fibers and resin dust. During this process, a dust cake formed on the exterior of the bags.

The difference in pressure between the dirty and clean sides of the baghouse determined the amount of suction generated in the mat-former. A gauge mounted in the blend room measured the pressure in inches of water. [7] Written procedures required that the line be shut down and the baghouse cleaned if the pressure gauge reading was above 6 inches, an amount recommended by the manufacturer. The pressure drop across the baghouse was recorded in a log twice a day to meet a requirement of the plant's air quality permit.

Operators reported that when the bags clogged, an excessive amount of dust blew out of the base of the mat-former and into the plant. To keep the baghouse functioning efficiently, CTA used two methods to periodically clean the bags.

---

[7] An "inch of water" is a unit of pressure equal to the pressure exerted by a column of liquid water 1 inch high at a standard temperature. One inch of water equals 0.0361 pound per square inch (psi).

One method used blasts of high-pressure air. This cleaning process, known as "shaking the bags," was initiated by pushing a button on a control panel in the blend room; however, this could be done only when the mat-former was not processing material. The blast of high-pressure air dislodged the dust from the bags, and it settled in the bottom of the baghouse.

The second method, performed daily during shift line cleaning (Section 4.2), required CTA employees to manually strike the bags with a stick to remove the dust cake. This cleaning procedure was covered in a written Job Safety Analysis, which provided instruction on the hazards associated with cleaning the baghouse, including the risk of explosion.

The residue that collected in the bottom of the baghouse could be either automatically recycled to the process or manually removed as waste during shift cleaning. If the material was recycled, it was returned to the processing line via a conveyor and then dropped through a vertical pipe containing a rotary airlock[8] before being deposited into the residue feeder. In December 2002, the use of the residue feeder on line 405 was discontinued because of a process change, and the baghouse residue was manually removed by dropping it through a chute. The residue fell into a cardboard box placed under the chute on the blend room floor.

4.1.3 Curing Oven

The mat exited the mat-former on a conveyor. Facing[9] was applied above and below the mat just prior to it entering the curing oven. Chain-driven oven flights sandwiched the mat and guided it through the oven. To reduce friction, a pneumatic pump dispensed oil rated for high-temperature use to lubricate the chains and sprockets.

---

[8] A rotary airlock is a valve that contains a set of rotating pockets that mechanically pass solids while preventing excessive return flow of air or gases. This device was necessary for the baghouse to maintain its suction.

[9] Facing is thin plastic nylon sheeting, which arrived at the facility on a spindle. One roll of facing was positioned above and another underneath the discharge conveyor of the mat-former.

Circulating fans and dampers directed heated air (260 to 290 degrees Fahrenheit (°F)) above and below the mat as it passed through the curing oven. The heat semi-cured the mat by melting the phenolic resin powder, which caused the resin to evenly bind with the fiberglass and the facing to form a firm fiber pad. As the resin was semi-cured, waste gases and vapors—such as phenol, formaldehyde, and ammonia—were liberated and released into the oven air exhausts. The exhaust traveled to a roof-mounted incinerator, where the vapors and gases were combusted. The speed of the mat as it passed through the 26-foot-long oven varied depending on mat thickness and end use of the product.

As the mat traveled through the curing oven, small pieces sometimes stuck to the flights and the chain or fell to the oven floor. This combustible material accumulated in the bottom of the oven. Four doors, measuring 4- by 4-feet and located at floor level, provided access to the oven for cleaning. Each door was hinged on its right side and was held shut by a latch and pin near the top of its left side.

A single natural-gas burner was mounted on the air inlet duct at line 405 several feet above the top of the curing oven. The burner incorporated combustion safeguards and interlocks to prevent fuel explosions.[10] A thermocouple measured oven temperature. The thermocouple sent an electronic signal to a digital process controller, which had programmable set points and alarms for temperature settings. The controller altered the airflow to the burner, and the natural gas ratio was automatically maintained by a ratio proportioning valve that controlled natural gas/air mixture. A fuel-gas manifold—which included pressure regulators; shutoff, safety relief, and control valves; and high-/low-pressure switches—supplied natural gas to the burner.

---

[10] These safeguards required that a reliable ignition source be established before fuel reached the main burner; a limited time was then allowed for flame ignition. The fuel automatically shut off in the event of flame failure. The ovens also incorporated an automatic purge of fuel vapors and combustible gases that may have accumulated during shutdown.

4.1.4 Molding Department

After exiting the curing oven, the edges of the pad were trimmed and then the mat was cut into pieces of desired length. These pieces, called “pelts,” were manually hung on storage racks as they left the production line. Later, the pelts were moved into the molding department. There, hydraulic presses were used to fully cure the pelts and form them into their final shapes. The fully cured automotive acoustical insulation parts were then trimmed by water-jet cutters and manually packaged for shipment to CTA’s customers.

4.2 Production Line Operation and Cleaning

The production lines generally ran continuously during the weekdays. The day shift started at 7:00 am. A crew of five, working 12-hour shifts, normally ran each line. A crew leader directed each crew, adjusted various controls and feeder rates, and completed batch records and production logs. Other crew members typically included an inspector, an oven tender, and two blend line operators. The inspector examined the finished product as it came off the production line to determine if the product met quality specifications. The oven tender operated the curing oven and stacked pelts onto racks. Blend line operators ensured that fiberglass and resin feeders were supplied with raw materials.

The crew also cleaned the lines, typically at the beginning of each shift. Daily production line cleaning usually required about 1 hour and included tasks such as:

- Using compressed air to blow out the area under the forming chain in the mat-former.
- Using a chimney sweep[11] or compressed air to clean the vertical pipes leading to the baghouse.

---

[11] A chimney sweep is an instrument used to clean soot or dust off surfaces inside a chimney, duct, or pipe.

- Manually striking baghouse bags with sticks, removing the waste from the baghouse, and dropping it via the pipe chute into the blend room.

These line-cleaning activities suspended the combustible dust and allowed it to settle on flat surfaces.

The oven was not normally shut down during line cleaning because it took a long time to reheat. Material cleaned out of the processing line was typically dumped onto the plant floor and then swept up with brooms and deposited in a dumpster. Wall-mounted and portable pedestal fans were used to blow dust away from the operators as they cleaned around the lines. The fans increased the dispersion of combustible dust in the production area, which resulted in dust settling on overhead flat surfaces.

4.3 Periodic Line Maintenance

Line 405—including the oven—was shut down for maintenance periodically. According to maintenance logs, in 2002, periodic maintenance on line 405 was performed at intervals ranging from 6 to 9 weeks. In 2003, line 405 was first scheduled for periodic maintenance on February 13 (8 weeks from the last maintenance), but the maintenance was postponed twice, and eventually rescheduled for February 21 (9 weeks from the last maintenance).

During normal maintenance, accumulations of phenolic resin powder and fiberglass that collected inside the oven were sandblasted off walls and the oven flights. Material in the bottom of the oven was scraped out, the bags inside the baghouse were replaced, and the rotary airlock was cleaned out. The material removed from the airlock was typically dumped on the roof of the blend room. Over time, a pile of combustible dust—about the size of a 5-gallon bucket—built up on the blend room roof.

4.4 Plant Shutdowns

Twice a year—typically in July and December—the entire CTA facility was shut down for cleaning and/or maintenance. During the cleaning, all plant equipment was shut down except for exhaust fans and lights. Employees used compressed air to blow accumulated dust off equipment and building surfaces. The settled dust was then swept off the floor and removed from the plant.

5.0 Incident Description

5.1 Pre-Incident Events

5.1.1 Ventilation Study

In February 2002, CTA contracted with a heating, ventilating, and air conditioning engineering firm to investigate ventilation improvements in the production and molding areas of the plant. One area of concern was release of dust from the production lines; however, the investigation did not specifically examine combustible dust hazards.

The engineering contractor concluded that the general flow of air inside the building was from south to northeast. The contractor also found that airflow rates at the capture hoods were less than the design intent. Filters had been placed over ventilation hoods but were not regularly cleaned, resulting in poor collection of dust. The contractor also noted that the blend rooms were more dust laden than the rest of the processing lines.

The contractor found that on line 405, the actual volume of air exhausted by the baghouse was only 35 percent of design capacity. The contractor attributed the diminished airflow to the poor condition of the fans, overloading of the baghouse, and possible plugging of the ductwork. The contractor's report also noted that the area around the line 405 mat-former released large quantities of dust. Based on this information, CSB concluded that phenolic resin dust and small fibers migrated from the blend rooms through door and wall openings and settled onto flat surfaces throughout the facility.

To balance the plant airflow, the contractor recommended replacing the baghouses on lines 403 and 405, modifying ventilation hoods on the processing lines to increase capture velocities, and installing four air-handling units on the roof to provide additional makeup air to the plant.

On February 20, 2003—the day of the explosion—CTA was scheduled to begin installing new makeup air units on lines 403 and 405.

5.1.2 Line 405 Oven Temperature Controller

Interviews with operators on line 405 and maintenance personnel, and a review of shift production logs revealed problems with the temperature controller for the curing oven as far back as December 20, 2002; the oven was running too hot. Production log entries noted that maintenance personnel had attempted to fix the controller on five occasions since December 2002.

Four days prior to the explosion, the temperature controller was no longer regulating the oven temperature so controls were switched to manual by the line operators. The oven temperature was then controlled by opening and closing the access doors on the east and west sides of the oven. Since there was no spare controller available in the maintenance shop, an order for a new controller was placed with a supplier.

5.1.3 Line 405 Baghouse

CTA initially planned to replace the line 405 baghouse in 1996-97. Minutes from a December 1996 staff meeting indicate that two baghouse manufacturers were prepared to bid on the project. However, CTA management opted not to fund the replacement of the baghouse at that time. A new cylindrical dust collector was erected in 2002 on a free-standing structure along the south wall of the facility to replace both the line 403 and 405 baghouses, but at the time of the explosion, it was not operational because new piping still needed to be connected.

A few days prior to the explosion, line 405 operators were having problems with clogged bags in the baghouse. Operator statements and notations on shift production logs show that the baghouse was running at a high differential pressure, which indicated the bags were clogged. To unclog them, the bags had to be shaken repeatedly each shift. Operators also manually beat the bags with sticks during the line cleaning to remove the dust. They attributed the clogging problem to two causes:

- The line was one week past due for periodic maintenance, at which time the bags in the baghouse would be changed (Section 4.3).

- Moisture had entered the baghouse and mixed with the phenolic resin dust and small fiberglass fibers. As this mixture dried, it formed a paste that adhered to the bags and was difficult to dislodge. The moisture came from holes in the baghouse structure that let in rain and snow, and a water line break inside the baghouse on January 29, 2003.

5.1.4 Line 405 Oven Fires

Fire was not normally present in the oven where the mats were semi-cured. The burner for the oven was located in a duct several feet above the oven (Section 4.1.3). Line 405 oven temperature was maintained between 260 to 290ºF.

However, small fires sometimes started in the oven when accumulated phenolic resin/fiberglass materials ignited. The operators extinguished those fires with water via a garden hose or with dry chemical fire extinguishers. Production logs, fire reports, and work orders showed that at least seven fires occurred on line 405 in the 6 months prior to the explosion; one in July 2002, three in November, one in December, and one in January 2003. These reports indicated that five of the seven fires originated inside the line 405 oven. Sparks from the oven flight chain were listed as the most frequent source of ignition.

5.2 The Incident

5.2.1 Line 405 Cleaning Activity

The day shift began on February 20, 2003 at 7:00 am. Operators were performing a routine cleaning of the 405 production line. The oven continued operating during the cleaning, which was expected to take 1 hour. The previous shift had stopped the line in the middle of the night to shake the clogged bags in the baghouse. The night shift operators had reported that the poor functioning of the baghouse and resulting lack of suction in the mat-former caused excessive release of dust from the production line.

The baghouse was turned off for cleaning. During the cleaning, a day-shift operator discovered that the transition[12] leading to the baghouse was plugged. Some of the crew went to the roof to unplug it. Those operators used a compressed air lance to blow the remaining material out of the transition. That material fell back through a chute into the production area. Interviews revealed that these activities and other line-cleaning tasks—such as blowing out pipes with compressed air and dry sweeping floors—generated a cloud of combustible dust around line 405.

5.2.2 Initial Explosion at Line 405

Two operators on the roof stated that moments after the baghouse was turned back on at 7:30 am, flames shot up through the inlet ducts, into and out of the baghouse (Figure 4). Both operators were burned—one received minor facial burns; the other received second-degree burns to his hands and face, which required a lengthy hospital stay. Inside the plant, personnel located about 80 feet northwest of line 405 observed smoke coming from the line prior to the initial explosion. Once the explosion occurred, personnel both heard it, and saw a fireball emerge from the south end of the oven.

The initial explosion created a pressure wave that knocked down portions of the firewall on the east side of line 405. Three operators were standing on the west side of the line at the time. One operator suffered third-degree burns and died in the hospital several days later. The force of the explosion knocked the other two operators into the aisle. One received second-degree burns and was hospitalized for several days, while the other received only minor injuries. A fourth employee, who was driving a gas-powered

---

[12] The transition is a junction where the four vertical pipes from the mat-former meet before going into the baghouse (Figure 3).

forklift with a semi-enclosed cab down the aisle west of line 405, was also burned. He was hospitalized but released the same day.

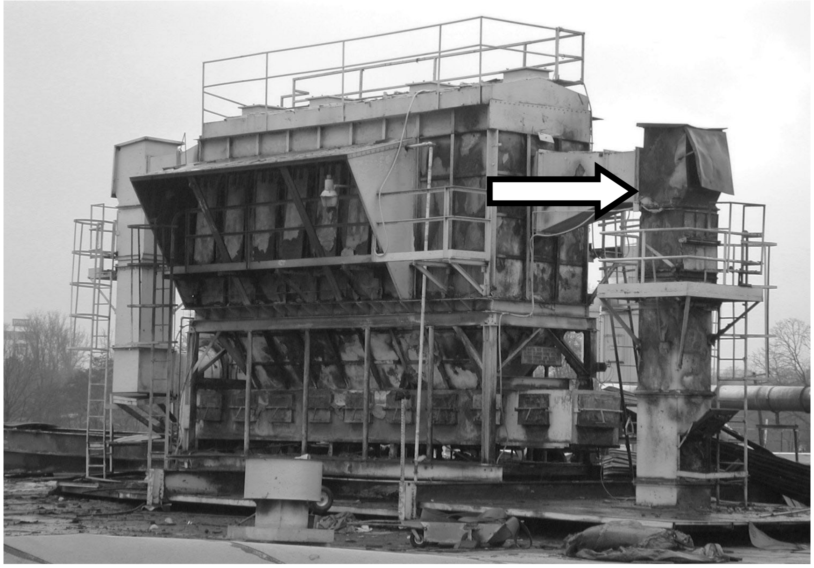


Figure 4. Fire damage to inlet duct of line 405 baghouse.

Figure 5 depicts the sequence of explosions and shows the likely locations of those who were burned in the production area. See Section 5.4 for a description of the extent of injuries to employees.

Eyewitnesses standing northwest of line 405 felt a pressure wave blow dust and other material in their direction. The force shook loose accumulated dust from the overhead roof joists and blew out roof panels. Employees also saw a fireball coming toward them from the south side of the line 405 oven; the fireball dissipated when it reached the molding department. Employees reported that dust fell from above, the lights went out, and the building fire sprinkler system activated.

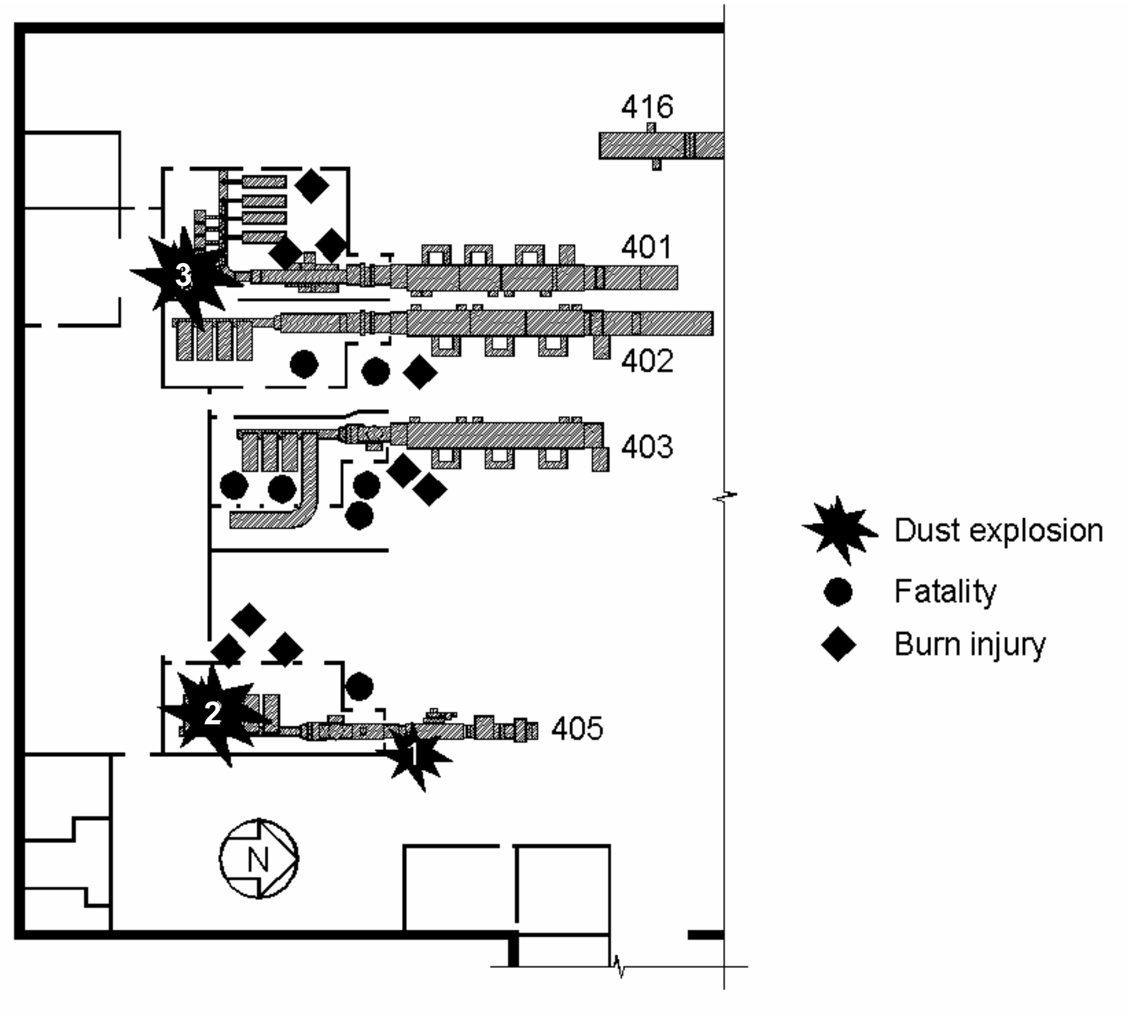


Figure 5. Sequence of dust explosions and likely locations
of those killed and burned in the production area
(Note: All employee injuries not shown in figure).

5.2.3 Secondary Dust Explosion at Line 405

The fireball generated by the initial explosion near the line 405 oven ignited dispersed combustible dust, which caused a secondary explosion in the relatively confined area above the line 405 blend room. The force of this explosion damaged the firewalls to the east and south and pushed metal wall panels above the blend room roof on the south side out to the south (Figure 6). The explosion also pushed ceiling panels and lights down inside the blend room. The pressure wave vented out of the building, damaging metal wall panels on both the south and east outer walls.

Figure 6. Collapsed firewall and metal panels at south end of line 405 blend room.

5.2.4 Fire and Explosion at Line 403

The pressure wave and fireball produced by the secondary dust explosion above the line 405 blend room propagated west along the ceiling toward line 403. Several plant personnel described a rolling fireball traveling in that direction. Evidence of the path of the pressure wave and fireball included:

- A collapsed firewall between lines 403 and 405 (Figure 7).
- Metal wall panels above the line 403 blend room on the east side that were blown to the west.
- Burnt residue on the building's roof trusses.

The fireball also ignited semi-cured pelts stored in the open area between lines 403 and 405.

Figure 7. Collapsed firewall between lines 403 and 405.

When the fireball reached line 403, it moved into the blend room. Three operators and the shift supervisor received second- and third-degree burns from the fireball and were transported to hospital burn units; they died days later. Two other operators were also burned, one critically.

Operators working on the roof of the plant observed the line 403 baghouse catch on fire. The cleanout doors opened on line 403 equipment may have provided a path for flames to travel to that baghouse.

5.2.5 Fire at Line 402

After the pressure wave from the second dust explosion blew in the metal panels above the line 403 blend room, the fireball following it continued to move west and into line 402. Three operators were burned in the blend room or aisle that separated lines 403 and 402 (Figure 5). They were transported to the hospital; two of these men later died.

5.2.6 Fire and Additional Dust Explosion at Line 401

The fireball continued to move west over the top of the line 402 blend room and into line 401. CSB investigators noted extensive explosion damage at line 401, nearly 300 feet from the initial explosion's point of origin at line 405. Physical evidence revealed that an additional secondary dust explosion occurred in the southeast corner of the line 401 blend room, another confined area. The firewall south of line 401 was partially collapsed, and concrete blocks dislodged from this wall fell to the south. The force of the dust explosion pressure wave likely bent a steel column on the west side of the blend room (Figure 8). Metal panels of the north and west walls were deformed outward. A large hole was blown in the building roof above the southeast corner of the blend room.

Figure 8. Bent support column in line 401 blend room.

Line 416 operators observed a fireball traveling north toward them from the line 401 blend room. They stated that the fireball receded when it reached the end of the line 401 oven. Still, the effects of the pressure wave that accompanied the fireball knocked some of them down. That wave vented out of the building at the northwest corner, where it damaged a loading dock door. It also blew out portions of the plant's metal panel west wall (Figure 9) and damaged the north wall of the chemical room, located near the southwest corner of the plant.

At the time of the secondary dust explosions, line 401 had been running for a few minutes. Three operators at this location were severely burned (Figure 5); they received extended treatment from the hospital. Two other operators received minor injuries.

Figure 9. Explosion damage to exterior plant wall at southwest corner of building.

5.3 Emergency Response

5.3.1 Plant Evacuation

As soon as plant personnel heard the explosion, they began to evacuate the facility. Uninjured employees helped those who were injured and burned—in some cases, carrying them out of the plant. Employees assembled in the parking lot, and a headcount was taken to verify that all personnel had evacuated. Injured workers were isolated and provided with first aid and comfort until they could be evaluated by emergency medical personnel.

5.3.2 Notification

Shortly after 7:30 am on February 20, the local 9-1-1 call center received a report of an explosion at CTA. The West Knox Fire Department responded to the call, and the Laurel County Emergency Management Director was notified. Upon seeing a large plume of black smoke over the plant site, the West Knox Fire Chief—who was nearby—called for assistance from three other fire departments.

5.3.3 Firefighting Activities

5.3.3.1 Initial Fire Attack and Treatment of Injured

The West Knox Fire Department arrived at the CTA facility within 10 minutes. Knox County responders set up triage for the injured, and additional ambulances were called.

The Laurel County Emergency Management Director became the incident commander (IC) and established a command post. One of the first priorities of the IC was to find out what chemicals were involved and release accurate information to the media. CTA provided copies of MSDSs and a floor plan, and answered the IC's questions concerning materials and equipment.

5.3.3.2 Community and Plant Site Evacuations

The IC set an initial evacuation zone around the plant of 660 feet based on the rising smoke plume and local weather conditions. This required only removal of employees from the plant property. Telephone discussions with Borden Chemical—the phenolic resin manufacturer—revealed that trace quantities of hydrogen cyanide, ammonia, formaldehyde, phenol, carbon monoxide, and carbon dioxide could be released as the phenolic resin burned.

The IC then increased the evacuation zone to 0.5 mile, and nearby residents and businesses were ordered to evacuate. Police moved employees away from the plant site; rerouted traffic and blocked off roads; and went door-to-door to evacuate businesses, homes, and apartment complexes. As a precaution, an elementary school outside of the evacuation zone was also evacuated. At the request of the IC, the Federal Aviation Administration restricted airspace around the facility.

Due to a misunderstanding in radio communication between the incident command center and other responding emergency agencies, the evacuation zone was inadvertently extended to 1.5 miles. This prompted the Kentucky State Police to temporarily close a portion of Interstate 75.

Later in the emergency response process, inaccurate information also was provided to the IC that a "cyanide trap" on the roof was on fire and about to explode. This inaccurate information came from a truck driver who falsely identified himself as a CTA hazardous materials responder with knowledge of the hazards and the appropriate response. Firefighters pulled back, and the incident command post was moved. When this information was found to be incorrect, firefighting efforts resumed.

The news media also initially reported that the explosion released a 1.5-mile-wide cyanide cloud over north Corbin. The IC then advised the media that the evacuation zone extended to only a 0.5-mile radius and that no cyanide had been released, and the news media reported that cyanide concerns were unfounded.

5.3.3.3 Fire Scene Operations

The fire was primarily confined to the production area and the baghouses on the roof. While two fire crews fought the fire, another crew removed combustible material from the plant, including 80,000 pounds of powdered phenolic resin binder. The fire was extinguished at approximately 3:00 pm, except for smoldering rolls of duct liner and semi-cured pelts. Nearly 4,000 rolls of the smoldering material were removed from the plant over the next 2 days.

At 3:30 pm on the day of the incident, a U.S. military civil support team from Louisville conducted air monitoring in and around the plant, which revealed no toxic chemical levels. At the same time, the U.S. Environmental Protection Agency (EPA) conducted an air monitoring survey of the surrounding neighborhood. Again, no toxic material levels were found. At 4:30 pm, the evacuation order was lifted, and local residents were permitted to return to their homes.

5.4 Incident Aftermath

The CTA incident was the deadliest workplace accident in Kentucky since 1989, when an explosion at the Union County coal mine killed 10 people. The following bullets describe the injuries and fatalities that occurred at CTA:

- On the days following February 20, 2003, 14 people were transferred from the Corbin medical center to hospitals with advanced burn treatment units—University of Kentucky in Lexington, University of Louisville, and Vanderbilt University in Nashville, Tennessee.
- Eleven of these 14 injured were in critical condition.
- The first of seven fatalities occurred on February 23 and the last on April 11. All seven workers died from second- and third-degree burns or medical complications as a result of burn injuries.
- The other four critically injured workers required surgery or spent many weeks of treatment in burn units.
- Of the 30 employees who suffered minor injuries, including burns, cuts, bruises, and smoke inhalation, three had injuries serious enough to be sent to burn treatment units.

Due to the physical damage to the facility, CTA built a new facility in the Corbin area at a reported cost of $56 million. CTA stated that the new facility was designed in accordance with National Fire Protection Association (NFPA) 654 (Appendix D.1), but CSB has not verified this new design. The new plant began operation in 2004—but with about 300 fewer employees, a result of business lost following the incident.

CertainTeed, which received product from CTA prior to the incident, renovated a facility in Sherman, Texas for the production of fiberglass textile duct liner for heating and air conditioning systems. The plant began operation in 2004, and reported relocation and renovation costs were $16 million.

6.0 Understanding Combustible Dust Hazards

6.1 Introduction

Most organic materials and many metals—and even some nonmetallic inorganic materials, if finely divided and dispersed in suitable concentrations—will burn or explode if they contact a sufficient ignition source.[13] Not all small particles burn, however. For example, salt and baking soda, no matter how finely powdered, will not burn because they contain no combustible material. Coffee creamer, on the other hand, will burn because it contains fat (organic material). Materials that are capable of burning in air are called combustible materials.

Combustible dusts can be generated when solid combustible materials are handled or processed due to gradual reductions in the particle sizes and/or segregation of the particles. They are defined by NFPA 654 (2000) (Table 1, see page 48) as any finely divided solid material 420 microns or less in diameter that presents a fire or explosion hazard when dispersed and ignited in air. The combustibility of dust is established through materials testing (FM Global, 2004). Awareness of combustible dust hazards is important to ensure employee safety, to ensure proper facility design, and to develop adequate operations and maintenance procedures.

6.2 Dust Fire and Explosion Hazard Characteristics

Like all other fires, a dust fire occurs when fuel (the combustible dust) comes in contact with heat (an ignition source) in the presence of oxygen (air). Removing any one of these elements of the fire triangle eliminates the possibility of a fire. A dust explosion requires the simultaneous presence of two additional

---

[13] Ignitability and Explosibility of Dusts, Table A.1, Appendix A.2 (Eckhoff, 2003).

elements—dust suspension and confinement.[14] Suspended dust burns more rapidly, and confinement allows for pressure buildup.

Fuel, ignition, oxygen, suspension, and confinement form the five sides of the dust explosion pentagon (Figure 10). Removing either the suspension or confinement elements prevents an explosion, though a fire may still occur.

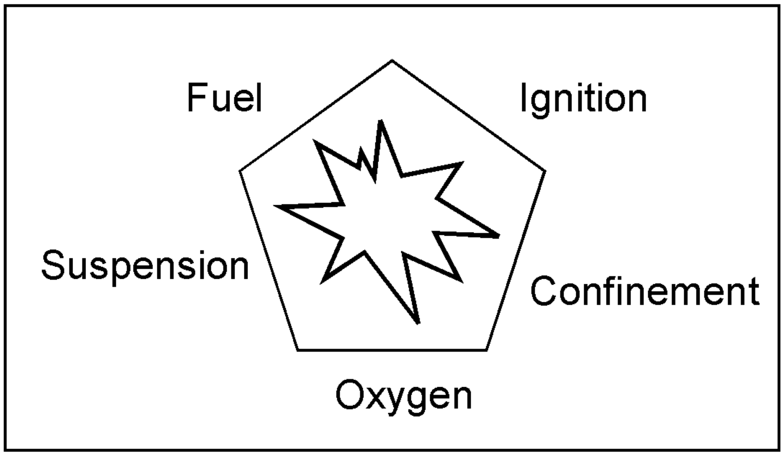


Figure 10. Dust explosion pentagon.

6.3 Significance of Particle Size

The ease of ignition and severity of combustible dust explosions are primarily influenced by particle size or specific surface area.[15] Finely divided particles have a large surface area, which allows them to rapidly react with oxygen when dispersed in air and ignited. The larger the surface area, the faster the reaction, and the larger the explosion.

---

[14] Confinement keeps dust particles in proximity after suspension—which allows for sufficiently rapid heat transfer to allow continued propagation. Without confinement, a propagating explosion is not possible, though a large and very dangerous fireball may occur.

[15] Specific surface area is the total surface area per unit volume or unit mass of dust.

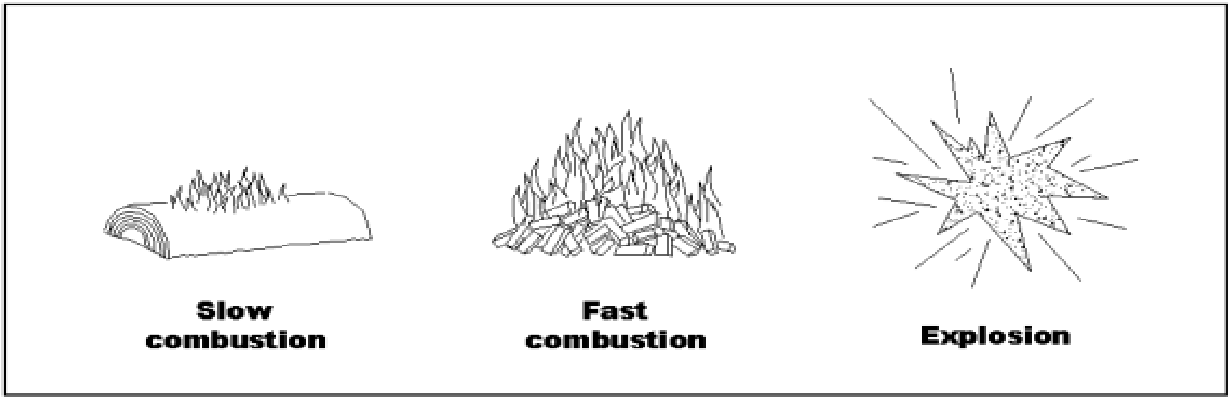


Figure 11. Burning increases with increasing surface area.

As depicted in Figure 11 (Eckhoff, 2003):

- A large piece of wood burns slowly, releasing heat over a long period of time.
- When the wood is cut into smaller pieces, ignition is easier and the pieces burn faster because the total contact surface area between the wood and air has increased.
- When the wood pieces are further cut, ground into a fine powder, suspended in air as a confined dust cloud, and ignited, the dust burns very rapidly and may explode.

The phenolic resin powders CTA used—which provided fuel for the fire and explosions—are combustible dusts. They have a particle size of 10 to 50 microns in diameter, similar to talcum (baby) powder. Table 1 lists the particle sizes for some commonly known materials.

Table 1

Particle Size of Common Materials

Common Material	Size (microns)
Table salt	100
White granulated sugar	450–600
Sand	50+
Talcum (baby) powder	10
Mold spores	10–30
Human hair	40–300
Flour	1–100

Source: Filtercorp International Ltd.

6.4 Secondary Dust Explosions

Typically, dust explosions occur when a small primary explosion—not necessarily a dust explosion itself—lifts dust deposits from floors, walls, overhead beams, or equipment. As illustrated in Figure 12, the suspended dust is then ignited, causing a secondary dust explosion. The blast wave from the secondary explosion causes accumulated dust in other areas to become suspended in air. This effect, in turn, may generate additional dust explosions. Depending on the extent of the dust deposits, a weak primary explosion may cause very powerful secondary dust explosions. At CTA, the initial explosion occurred at line 405, but secondary dust explosions caused severe destruction as far as 300 feet away, near line 401.

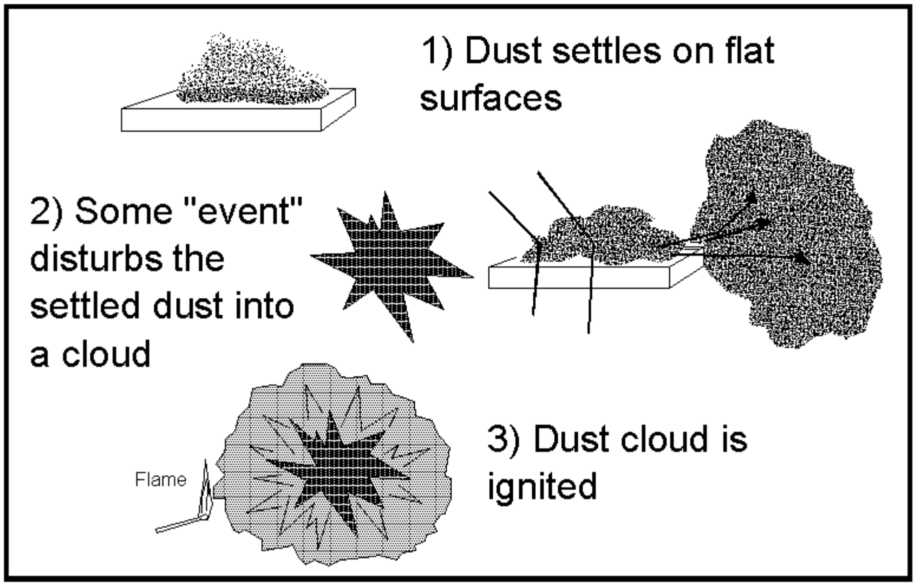


Figure 12. Mechanism for a dust fire or explosion.

6.5 Hazard Evaluation of Combustible Dusts

Dusts with a median particle size smaller than 500 microns are considered explosible unless testing proves otherwise.[16] Dusts with a median particle size greater than 500 microns (which is slightly larger than a staple wire) are assumed to be nonexplosible as long as smaller particles have not been segregated during materials handling (FM Global, 2004). The fire and explosive hazard of a combustible dust should be evaluated based on analytical test data (Eckhoff, 2003). Table 2 links measurable dust properties to each element of the dust explosion pentagon and explains their significance.

---

[16] As an example, activated carbon with a median particle size of 22 microns did not explode when tested. See Ignitability and Explosibility of Dusts, Table A.1, Appendix A.2 (Eckhoff, 2003) for additional exceptions.

Table 2

Dust Properties for Determining Fire and Explosion Hazards **(a)**

Elements	**Properties**	**Significance**
Fuel	Explosion Severity (K_{st}) value	Maximum rate of pressure rise normalized to a 1.0-m^3 volume, which is a relative measurement of energy of the dust explosion. The greater the K_{st} value, the more energetic the explosion.
	Moisture content	Affects ease of ignition and ability to sustain an explosion. Increasing moisture content increases ignition energy (for some dusts, the increase may be exponential) and reduces explosion severity (i.e., water vapor acts as inert heat sink).
Ignition	Minimum ignition energy (MIE)	Provides information on the lowest energy required to ignite the most readily ignitable dust/air mixture at atmospheric pressure and room temperature; a combustible dust with a low MIE is easily ignited. Ignition energies for dust clouds are usually higher than for gases or vapors—typically a fraction of a millijoule for gases and 1–10 millijoules for dust.
Oxygen	Oxygen content	Less oxygen in the air reduces explosion severity by limiting rate of combustion and increases ignition energy.
Suspension/ confinement	Degree of dispersion	Usually dependent on the way dust is dispersed and level of turbulence. An evenly suspended and less turbulent dust cloud is more easily ignited and burns more easily.
	Particle size/shape	Reduction in particle size increases surface area and decreases MIE; the smaller the dust particle, the more easily it is suspended. Particles with high surface area per unit volume exhibit low MIE, low MEC, and high K_{st}.
	Minimum explosive concentration (MEC)	Dusts, like gases and vapors, form explosive clouds only if dust concentration lies between certain limits, known as the lower (LEL) and upper explosive limit. For dusts, LEL is also commonly referred to as MEC.

(a) This table highlights the main characteristics of combustible dusts.

7.0 Reconstructive Analysis

To determine the origin and cause of the fire and explosions, CSB examined and documented the scene. Appendix A provides a detailed listing of the fire and explosion damage. Laboratory testing was conducted to measure the explosibility of the phenolic resins used by CTA (Appendix B), and equipment was tested to determine if it was involved in causing the incident (Appendix C). Through this reconstructive analysis, CSB determined that a combustible phenolic resin dust fueled the fire and explosions. Natural gas was also considered a possible ignition fuel but was ruled out following a detailed investigation.

7.1 Fire and Explosion Scene Investigation

CSB initiated its investigation on the morning of February 21, the day after the incident. The West Knox Fire Department had secured the plant site. ATF, the Kentucky State Fire Marshal, and the Arson Division of the Kentucky State Police Department also conducted investigations during the first few days. These organizations determined that the fire and initial explosion originated near production line 405. They found no evidence of criminal involvement. Kentucky OSH conducted an inspection and issued citations.

7.1.1 Origin and Cause Determination

The purpose of the CSB origin and cause determination was to identify the following:

- First material ignited (the initial fuel).
- Possible source of ignition.
- Event(s) that brought the fuel and energy source together to produce the initiating event.

CSB determined the origin of the fire and explosions by analyzing the following information:

- Physical marks (e.g., fire patterns) left by the fire.

- Physical debris and damage, which indicated the direction and relative force of the explosions.

- Observations reported by persons who witnessed the fire or explosions, or who were aware of conditions at the time.

7.1.1.1 Point of Origin

CSB confirmed the conclusions of ATF and the State Fire Marshal that the fire and initial explosion originated at the line 405 oven. Based on eyewitness accounts and examination of physical evidence, CSB determined that the initial explosion's point of origin was likely in the aisle on the east side of the line 405 oven, near the south end. A number of employees stated that they saw the initial flash at this location.

The partially collapsed concrete block masonry firewall east of the oven also provided evidence of the location of the initial explosion. A metal cabinet along the wall had been knocked over and was found lying against the oven.

In contrast, the west side of the oven received only fire damage rather than explosion damage. Also, burned resin deposits were on the exhaust hood located over the conveyor where the fiber mat enters the oven. Rolls of facing and empty spindles were burned but otherwise intact. The metal ducts that extended above the oven were warped and discolored—signs of extreme heat and external fire, but not explosion damage.

CSB also examined the interior of the oven; virtually all the combustible material that likely had been inside was burned away (Figure 13). In contrast, the interior of the ovens on lines 401, 402, and 403 contained accumulations of resin powder/fiberglass debris. The chain-driven oven flights for 405 were burned clean but otherwise intact and undamaged. Metal discoloration was noted on the interior of the line 405 oven; however, CSB found no evidence of explosion damage inside the oven.

Figure 13. Interior of line 405 oven.

7.1.1.2 Most Probable Initiating Event

CSB concluded that the most probable initiating event was a combustible dust explosion at the line 405 oven. Just prior to the explosion, the line crew cleared a blockage in the transition to the baghouse; this combustible material was dumped down a vertical pipe into a box on the blend room floor. Interviews with the crew revealed that dust was generated as the material landed in the box. A room fan mounted on the west wall of the blend room directed the combustible dust toward the oven. CSB determined that air currents probably transported the dust into the immediate area of the oven, where it likely ignited.

A fire may have developed inside the oven as a result of a buildup of combustible material (Section 5.1.4). The oven had a history of small fires that were typically detected and put out by the line crew. In this case, the crew did not detect the fire because they were cleaning the line elsewhere. Flames may have escaped through an open oven door (Section 5.1.2), or the dust cloud may have entered the oven and ignited.

7.1.1.3 Other Possible Ignition Sources

CSB considered other potential sources of ignition at the point of origin, as noted below, but concluded that they were unlikely:

- ***Electrical equipment***: Several electrical boxes containing switches and relays were located in the area of origin and might have produced electrical sparks. The boxes were not dust-tight, and such sparks would have been capable of igniting a combustible dust cloud. CSB contractors examined the electrical boxes and concluded that—though they were fire-damaged—there were no indications that the spark-producing electrical equipment inside provided an ignition source (Appendix C).

- ***Lube oil system***: The lube oil system and pump for the oven flights were also examined. The piping for the high-temperature oil had no moving parts and was found to be free of leaks. The oil pump was pneumatically operated.

- ***Static electricity***: CSB also eliminated static electricity as an ignition source. Interviews with line crews revealed that electrostatic discharges occurred frequently when the mat-former was cleaned of phenolic resin. However, no one interviewed could recall an instance when the phenolic resin ignited. Tests conducted by a CSB contractor confirmed that the static energy in a propagating brush discharge[17] (PBD) was incapable of igniting the resin because it did not produce enough energy (Appendix B).

---

[17] PBDs are lightning-like electrostatic discharges. They are the most energetic of all types of electrostatic discharges, with spark energies approaching 1 joule.

7.1.2 Other Possible Initiating Events

7.1.2.1 Natural Gas Explosion

A natural gas supply line and the piping manifold were located in the area of origin. CSB considered the possibility that the incident resulted from the ignition of leaking natural gas, but determined that scenario unlikely. The natural gas supplied to CTA contained a mercaptan odorant. If there is a leak, the odor of the gas is readily detectable by smell at one-fifth of the LEL of the gas.[18] None of the employees working on line 405 reported smelling natural gas during the night shift or on the morning of the incident. CSB received reports from a few employees who had smelled natural gas in other areas and believed that leaking gas might have provided fuel for the explosions.

The gas company and insurance investigators conducted a natural gas header leak test after the explosion. No significant leaks were detected. Also, a CSB contractor tested the piping and components of the line 405 natural gas fuel manifold (Appendix C). The results of these tests showed no leaks in the natural gas supply or vent piping that would have caused gas to enter the building.

7.1.2.2 Ignition of Flammable Vapors on Line 403

Another possible initiating event considered by CSB was an explosion caused by the ignition of accumulated flammable vapor in the vent line to the roof incinerator on line 403. Overpressure in the line connecting to the oven had caused a flange to separate, and inspection doors on the vent line were partially blown outward. Burn patterns on the incinerator stack indicated that it had been on fire.

---

[18] The MSDS for natural gas supplied by Delta Natural Gas Company, Winchester, Kentucky, dated December 20, 1991, states that the lower explosive limit is approximately 4.5 percent by volume in air.

CSB determined this scenario unlikely because it is premised on the assumption that the explosion occurred inside the vent line while the line 403 oven was being started or that a flameout occurred. However, just as with line 405, the line 403 oven was operating during line cleaning. In addition, numerous employees reported that the initial flash was observed at line 405—not line 403. Employees standing to the north between the two processing lines and looking in the direction of line 403 stated that they turned their heads toward line 405 when they heard the initial explosion.

7.2 Testing of Materials

CSB contracted with a laboratory to test 42 samples of material found in the production area of the facility. Samples of phenolic resin and residual dust were tested to determine their fire and explosive properties. Testing focused on the black resin because it was used on line 405, the probable location of the initial explosion.

7.2.1 Samples From Facility

Micrographic analysis was conducted on all but two of the samples collected in the production area. Analysis showed the presence of small particles or “clumps” of melted fiberglass in the samples. The resin was combined with fiberglass in the normal manufacturing process.

Differential Scanning Calorimetry (DSC) and PBD Ignition tests were conducted on 14 samples. K_{st}, MEC, MIE, and Hot Surface Ignition Temperature of a Dust Layer tests were conducted on 26 samples. Tests were conducted in accordance with standards of the American Society for Testing and Materials (ASTM). Appendix B includes additional test results plus information regarding the test apparatus, sample specimens, and test procedures. Table 3 lists key test results for the resin.

Table 3

Borden Chemical Black Phenolic Resin (Durite SD-52SS) Test Results

Properties	Results
K_{st}	165 bar-meters per second
MIE	3 millijoules
MEC	50 gram per cubic meter (g/m^3)
PBD	No ignition observed (when subjected to discharge of up to 45 kilovolts for 60 seconds)
Moisture content as tested	1.2 weight percent (material was dried at 75ºC for 3 hours)

These tests established that—with confinement and in the presence of a suitable ignition source—dust particles of the phenolic resin will explode when suspended in air in adequate concentrations.

Test data from the resin samples were also compared to the explosion characteristics of other common combustible dusts—namely, Pittsburgh coal dust, polyethylene dust, and cornstarch. Figure 14 shows that the Borden Chemical black phenolic resin used at CTA has a higher K_{st} value than the other dusts.

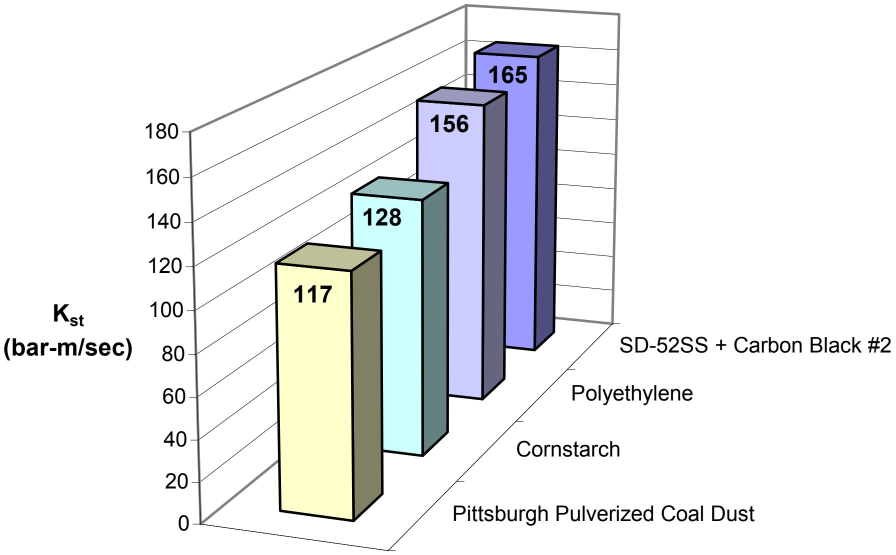


Figure 14. Explosion severity of Durite SD-52SS compared with other common combustible dusts.

7.2.2 Prepared Laboratory Samples

Dust that settled in the CTA production area was typically a mixture of phenolic resin and small fiberglass fibers. Samples of ground fiberglass and phenolic resin were mixed in varying percentages in the CSB contractor's laboratory and tested. The test results show that as the fiberglass content increased, the mixtures remain explosible, but explosion severity decreased (Figure 15).

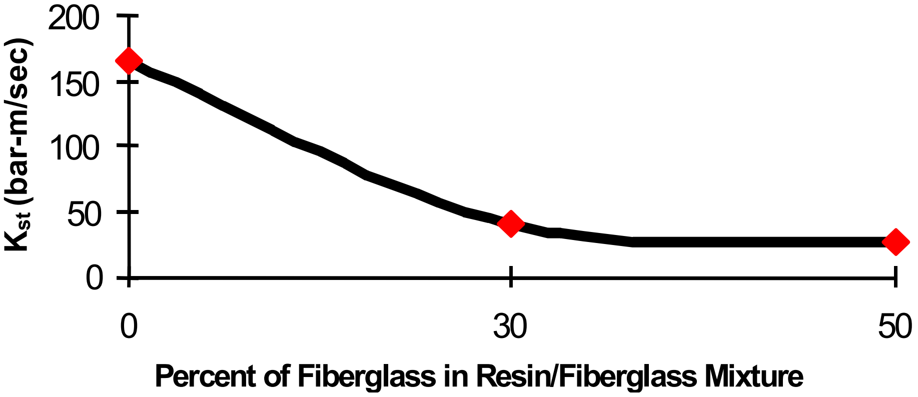


Figure 15. Explosivity testing results for resin/fiberglass mixtures.

7.3 Line 405 Equipment Testing

CSB identified equipment on line 405 that required testing, including:

- Oven temperature controller.
- Gas piping and manifold components.
- Electrical components near the point of origin of the fire.

A CSB contractor tested these components. In some cases, fire and explosion damage prevented CSB from drawing useful conclusions. Results of the testing are presented below and in Appendix C.

Holes for wiring in the burner temperature control box allowed fiberglass, dust, and oily material to enter and accumulate on electrical connections. This debris may have contributed to the failure of the temperature controller. CSB could not determine if this actually impacted the operation of the controller because loss of electric power in the facility and failure of the backup battery erased the controller memory. Therefore, no historical data were available regarding the operating temperatures of the oven prior to or during the incident.

Line 405 distribution gas piping and oven manifold components were tested to determine whether they released natural gas (Section 7.1.2.1 and Appendix C). No leaks were found that would have released gas into the building.

Electrical components near the point of origin of the fire and explosion were tested to see if they were ignition sources. No evidence was found in line 405 electrical boxes or associated wiring from the oven oiling system that indicated they were a source of ignition.

8.0 Incident Analysis

The incident analysis explored reasons why:

- The facility design lacked effective firewalls and blast-resistant construction.
- Inefficient baghouse operations and improper production line cleaning activities dispersed combustible dust and deposited it on elevated flat surfaces, where it accumulated.
- Lack of housekeeping on elevated flat surfaces allowed combustible dust to build up to unsafe levels.
- Borden Chemical did not communicate to CTA the safety lessons from the 1999 Jahn Foundry dust explosions that involved a similar phenolic resin.

CSB investigators constructed a logic tree diagram to assist in the incident analysis (Appendix G). The Board concluded from this analysis that most CTA personnel had a lack of understanding of the explosive hazards posed by combustible dusts. CSB determined that were three reasons for this lack of understanding. First, CTA did not implement effective measures to prevent combustible dust explosions. This was due to the fact that CTA did not obtain and apply NFPA 654 guidelines as recommended by Borden Chemical in its phenolic resin MSDSs. Second, the CTA hazard communication program did not address combustible dusts. And finally, Borden Chemical did not explicitly communicate the explosive hazard of phenolic resins to CTA.

8.1 Explosive Hazards of Phenolic Resins

The Occupational Safety and Health Administration (OSHA) Hazard Communication (HazCom) Standard requires that chemical manufacturers such as Borden Chemical evaluate their products to determine if those products are hazardous. This includes the identification and consideration of scientific evidence concerning their chemicals.

The natural and black phenolic resins[19] CTA used are thermosetting resins.[20] The resin is ground by Borden Chemical to meet CTA specifications—in this case, 270 mesh, which produces particles ranging in size from 10 to 55 microns. Particles of phenolic resin of this size are combustible.

In the early 1960s, the U.S. Bureau of Mines examined the explosibility of dusts used in the plastic industry. It determined that the explosibility of different types of formaldehyde resins—melamine, urea formaldehyde, and phenol formaldehyde—appears to increase as the nitrogen content of the primary ingredient decreases (Jacobson, Nagy, and Cooper, 1962). Phenol-formaldehyde resins contain no nitrogen and, thus, have the greatest explosibility for this class of resin.

The Bureau of Mines test data on the explosibility of plastic dusts are referenced in many standard safety and health textbooks, including *Patty's Industrial Hygiene and Toxicology* (Clayton, 1978), the *Fire Protection Handbook* (NFPA, 1983), and the *NFPA Inspection Manual* (NFPA, 1994). Other standard safety textbooks, such as the *Accident Prevention Manual for Industrial Operations* (National Safety Council [NSC], 1974), also list the explosive properties of phenolic resin dusts.

8.2 Communication of Phenolic Resin Hazards to CTA

This section describes Borden Chemical's efforts to communicate to CTA the fire and explosion hazards associated with phenolic resins. The OSHA HazCom Standard requires that chemical manufacturers describe the physical hazards of a chemical on an MSDS, including the potential for fire, explosion, and reactivity, under normal use and in a foreseeable emergency. OSHA defines a foreseeable emergency

---

[19] A resin is a synthetic polymer or a natural substance of high molecular weight, which becomes moldable under heat, pressure, or chemical treatment.

[20] A thermosetting resin becomes soft and infusible or insoluble when heated; however, if heat is *continually* applied, the material fuses and becomes hard as the resin undergoes a chemical change during the curing process.

in the HazCom Standard as "any potential occurrence such as, but not limited to, equipment failure, rupture of containers, or failure of control equipment which could result in an uncontrolled release of a hazardous chemical into the workplace."

CSB determined that the Borden Chemical phenolic resin MSDSs did not provide adequate warning of the explosion hazard. The MSDSs state that the resin is a combustible dust; however, they only reference NFPA 654, rather than listing specific safety warnings. Also, the information in different sections of the MSDSs was incomplete and inconsistent, and CTA personnel did not have a copy of NFPA 654.

8.2.1 Comparison of Phenolic Resin MSDSs

MSDSs were Borden Chemical's primary means of communicating the hazards of phenolic resins to CTA. The two MSDSs for phenolic resin contained identical information with respect to fire and explosion hazards. The most recent revision of the MSDS for the black phenolic resin, Borden Chemical Durite SD-52SS, was dated January 31, 2003. The most recent revision of the MSDS for the natural (without carbon black) resin, Borden Chemical Durite SD-110A, was dated September 10, 2002.

Borden Chemical personnel responsible for preparing MSDSs stated they followed the OSHA HazCom Standard as well as American National Standards Institute (ANSI) Z400.1, *American National Standard for Hazardous Industrial Chemicals, Material Safety Data Sheets Preparation.* Section 5.1 of ANSI Z400.1 states that qualitative flammable properties and reactivity hazards that enhance the fire and explosion potential of a chemical should be stated in the firefighting measures section of the MSDS. The standard lists several examples of language that can be used on an MSDS; the first example listed is: "Powdered material may form explosive dust-air mixture."

Borden Chemical was aware that phenolic resins could produce dust explosions. In 1988, the predecessor of FM Global—Factory Mutual—provided results of explosibility tests conducted on Borden Chemical Durite AD-6514 phenolic resin powder. (This particular powder was not used at CTA.) The tests showed that the phenolic resin could explode. Following the Jahn Foundry explosion in 1999, which involved a phenolic resin manufactured by Borden Chemical (Section 8.8.1), OSHA requested additional information from Borden on the explosibility of phenolic resins. In response, Borden faxed to OSHA a copy of the 1988 Factory Mutual test results plus the following references, which further demonstrate that Borden was aware of the explosive hazards:

- A copy of a British research report entitled *Explosibility tests for industrial dusts* (Raftery, 1975) that lists the explosion parameters for phenolic resins in its appendix.
- Subchapter 5.5, entitled "Dust Explosions," plus references from the book *Phenolic Resins* (Knop and Pilato, 1985).

CSB compared the hazard warnings on the Borden's phenolic resin MSDSs to hazard warnings on MSDSs from seven other manufacturers of phenolic resins having the same Chemical Abstracts Service (CAS) number. The results of this comparison are presented in Table 4. As CSB was only interested in comparing MSDS hazard warnings for this particular type of phenolic resin, hazards warnings on MSDSs for other types of phenolic resins were not examined. Therefore, the hazard warnings shown in the column entitled "Other Manufacturers" do not necessarily represent hazard warnings found on MSDSs for all types of phenolic resins. Also, CSB limited its comparison to publicly available MSDSs contained in database compilations and/or available on the Internet. CSB did not obtain MSDSs from all manufacturers of this particular type of phenolic resin. Based on an evaluation of the MSDSs collected by CSB, there were notable differences between Borden's hazard warnings and those of other manufacturers.

Table 4

Comparison of Phenolic Resin MSDSs

MSDS Section	**Fire and Explosion Hazard Warnings (a)**	
	Borden Chemical	**Seven Other Manufacturers**
Hazard identification	*CAUTION! Combustible dust when finely divided or suspended in air.*	One manufacturer warns: *CAUTION! Powdered material may form explosive dust/air mixtures*. Another states: *Product may form explosive dust/air mixtures if high concentration of dust is suspended in air*. Two manufacturers state: *Plastic resin is not known or believed to be hazardous*.
Firefighting measures	*Will burn*, with a reference to NFPA 654, if the material is *reduced to or collected as a powder.*	Three manufacturers warn that dusts might form explosive mixtures in air and that ignition sources should be avoided. One manufacturer warns that electrostatic charges might build up during handling and recommends grounding of equipment. Two manufacturers list no hazards.
Unusual fire and explosion hazards	None listed.	One manufacturer warns of the *possibility of a dust explosion at the minimum explosive concentration of 0.025 ounce per cubic foot (oz/ft^3.)* Another warns that dust explosions may occur in air if certain conditions of concentration, humidity, and an ignition source are present.
Explosive limits	*Not applicable.*	Two manufacturers state that the explosive limits are *not determined.* Another lists the resin as *nonflammable*. One manufacturer lists an LEL of 25 g/m^3, while three list 0.030 oz/ft^3.
Stability and reactivity	*In common with most organic materials, this product should be treated as a combustible dust in the finely divided and suspended state.*	One manufacturer warns: *Avoid dust/air mixtures as this condition creates a flammability/explosion risk*. Others list the material as *stable*.
Accidental release measures	*Sweep (scoop) up and remove to a chemical disposal area. Prevent entry into natural bodies of water.*	Six manufacturers advise avoiding generation of dust during cleanup of spills by using wet methods or vacuums with explosion-proof motors and eliminating sources of ignition.
Special hazards	None listed.	One manufacturer specifically advises against using compressed air for cleaning up combustible dust on floors, beams, or equipment.

(a) Italicized words are quoted from the MSDSs.

A 1998 internal Borden Chemical memo from a staff member to the Director of Regulatory Compliance—the person responsible for developing Borden Chemical MSDSs—recommended that wording be added to the firefighting section of the MSDSs for phenolic resins to state that explosive mixtures can be formed in air. The suggested changes recommended in this memo were not adopted.

Information listed in other sections of the MSDSs was inconsistent with information contained in NFPA 654 and warnings listed by other phenolic resin manufacturers. For example, in the firefighting measures section of the Borden Chemical MSDSs, the LELs are marked as “not applicable.” Appendix A.1.5.20 of NFPA 654 explains that the LEL is also known as the MEC. MEC values for phenolic resins have been published by the Bureau of Mines (Section 8.1) and are reported on MSDSs by several other phenolic resin manufacturers (Table 4). The 1998 Borden Chemical internal memo also recommended that the actual MEC for the phenolic resins be listed if test results for these products could be located.

Other sections of the Borden Chemical phenolic resin MSDSs lacked information or listed inappropriate measures for handling combustible dusts. There are no warnings to avoid ignition sources or to avoid cleaning up spills using dry sweeping.

Also, Borden Chemical could have included, in its MSDSs, dust explosibility data found in safety and health textbooks (Section 8.1) as some phenolic resin manufacturers have done.

8.2.2 HMIS Flammability Rating

The Borden Chemical Durite phenolic resin MSDSs contain a Hazardous Materials Identification System (HMIS) rating. The National Paint and Coatings Association (NPCA) developed HMIS as a quick way of identifying the hazards of chemicals (Appendix E). Chemicals are rated in the areas of health, flammability, and reactivity using a numerical scale of “0” to “4,” with “4” being the most hazardous (NPCA, 1976).

Borden Chemical rates the flammability of the Durite phenolic resins as “1” (slight hazard), which according to the NPCA applies to materials that must be preheated for ignition to occur. Borden Chemical personnel stated that this hazard rating was appropriate because they found many examples of combustible solids where the HMIS code for flammability was listed as “1.” However, the *HMIS Implementation Manual* states that “materials that on account of their physical form or environmental conditions can form explosive mixtures with air and that are readily dispersed in air, such as dusts of combustible solids and mists of flammable or combustible liquid droplets” should be rated as “3” (serious hazard; NPCA, 1976).

Of the seven other phenolic resin manufacturers’ MSDSs CSB compared with the Borden Chemical MSDSs, four manufacturers provided HMIS ratings. Three of the four rated flammability as “1,” while the fourth rated it as “2.”

8.2.3 Borden Chemical Product Stewardship

Borden Chemical was a member of the American Chemistry Council (ACC) at the time of the incident—February 2003. As a condition of membership, Borden Chemical participated in the ACC Responsible Care program. Members of ACC agree to develop voluntary practices to address management codes and to submit annual reports of their progress.[21] The codes cover topics such as process safety management, health and safety, and product stewardship. Management practices in the ACC Product Stewardship Code include the following:

- Establish and maintain information on health, safety, and environmental hazards and reasonably foreseeable exposures from new and existing products.

---

[21] The Responsible Care elements referenced herein are those in place in February 2003. ACC has recently added a requirement for independent third-party audits of member company programs.

- Characterize new and existing products with respect to their risks using information about health, safety, and environmental hazards and reasonably foreseeable exposures.

- Provide health, safety, and environmental information to direct product receivers. Commensurate with product risk, collaborate on fostering proper use, handling, recycling, disposal, and transmittal of information to downstream users. When a company identifies improper practices involving a product, work with the product receiver to improve those practices. If, in the company's independent judgment, improvement is not evident, take further measures—up to and including termination of product sale.

Borden Chemical was also a member of the Society of the Plastics Industry (SPI) until 1999. This trade association represents processors, machinery and equipment manufacturers, and raw material suppliers of plastics, including phenolic resins. This association works with technical and regulatory groups to develop standards for product performance and safety.

In March 2004, SPI issued a new product stewardship policy to help plastics manufacturers identify and manage the health, safety, and environmental aspects of their products. SPI has a division dedicated to phenolic resins that keeps its members updated on safety and health issues; however, it has not issued any publications on phenolic resin hazards.

8.2.3.1 Phenolic Resin Product Stewardship Efforts

In 1997, Borden Chemical developed a 2-page fact sheet entitled *Phenolic Resin Powders: Frequently Asked Environmental, Health and Safety Questions*. In answer to: "How finely ground are phenolic resin powders?", the sheet explains that 90 percent of phenolic resin particles are below 40 microns in size. In answer to: "Do phenolic resin dusts pose an explosion hazard?", the fact sheet states:

> Phenolic resin dusts should be regarded as explosible and liable to give rise to a dust explosion hazard provided the concentration in air is very high, i.e., 20 [g/m^3] and the ignition temperature of 450°C is reached.

This fact sheet was provided to Borden Chemical manufacturing, sales, marketing, and research and development personnel. It was not systematically distributed to Borden Chemical customers, and it was not provided to CTA.

In April 2000, Borden Chemical prepared a draft "Dear Customer" letter to discuss the Jahn Foundry explosion, which involved a Borden Chemical Durite phenolic resin (Section 8.8.1). The letter listed the causal factors that led to the explosion, as concluded by a joint OSHA/Massachusetts Department of Fire Services/Springfield Arson and Bomb Squad report. The draft letter recommended that Borden Chemical customers follow good housekeeping practices and the requirements of NFPA 654 to prevent dust explosions. A copy of the joint investigation report was to be attached; however, Borden Chemical did not send the letter or the report. Also, Borden Chemical reviewed the language on its MSDSs and labels for Durite resins, but determined that no changes were needed.

In June of 2004, more than one year after the CTA explosion, Borden Chemical distributed safe handling guidelines (8 pages) to its phenolic resin customers entitled *Phenolic Resin/Powders, Flakes and Pastilles: Dust Hazards and Recommended Control Practices*. These guidelines include: a discussion of the hazardous properties of phenolic resins, including the conditions needed for a dust explosion; typical material characteristics (e.g., K_{st}, MIE, MEC, P_{max}); protective measures; and NFPA 654 excerpts (including information on dust control, inspection, maintenance, and training).

8.2.3.2 Borden Chemical's Product Stewardship Efforts With CTA Acoustics

A Borden Chemical safety engineer stated that in 1995 he sent a letter addressed to CTA to follow up on a telephone conversation with the CTA engineering manager concerning a proposed process change involving Borden Chemical phenolic resins. In the letter, the Borden Chemical safety engineer advised

CTA that phenolic resins, when suspended in air, could cause a dust explosion. The letter recommended precautions such as eliminating ignition sources, and using equipment pressure relief and damage-limiting construction. It also listed a telephone contact number for the FM Global engineer, who was described as “very familiar with the hazards associated with phenolic resin powders and recommended safe handling practices.” CSB could not verify that CTA received the letter. The CTA engineering manager listed as recipient of the letter stated that he had never seen it nor was he aware of its contents.

The Borden Chemical account manager for CTA routinely discussed phenolic resin issues with CTA engineers and operating personnel. Written summaries of these meetings reveal that they primarily covered operational, product quality, and health concerns. In 1998, the Borden Chemical account manager reported having discussions with CTA personnel about two explosions on line 403 while CTA was testing a new formulation of resin.

8.3 CTA Awareness of Combustible Dust Hazards

Examination of CTA documents showed that at certain times, supervisors and managers in the operations, maintenance, quality control, and safety departments; safety committee members; and company fire brigade members discussed the explosive nature of combustible dust. However, this hazard information was not communicated to the general work force. Interviews with plant personnel revealed widespread lack of awareness that phenolic resin powders could explode.

Company memoranda and minutes from safety committee meetings from 1992 through 1995 showed a concern about creating explosive dust hazards when using compressed air during line cleaning. Use of grounded air hoses was required, and CTA explored alternative methods of cleaning. A similar concern was raised prior to a plant cleaning scheduled during a shutdown in July 1995. In this case, special precautions were outlined to eliminate ignition points, remove racks, close fire doors, and cover motor control centers. In addition, a 1997 memo from the CTA safety director to the operations shift managers stated: “If airborne dust concentrations become too high…[it] could create an explosion hazard.” Also, a

CTA maintenance superintendent had detailed knowledge of a catastrophic combustible dust explosion (April 1962) at a company where he previously worked that used a process analogous to CTA's. This superintendent worked at the Corbin facility for over 30 years and retired a month prior to the explosion.

The CTA fire brigade training manual, revised in 1994, warned that a fire *and* an explosion could occur "where accumulations of airborne dust, gas, or other combustible materials are present."

Job safety analyses for cleaning process line dust collectors and ducts, developed in 1997, list explosion as a potential hazard if the cleaning is done with tools capable of producing a spark. In addition, a 1997 job safety analysis on line 405 noted the hazard of using compressed air to clean the baghouse. It warned that using air hoses causes combustible dust to be suspended in air and stated: "At no time is an air hose to be used for cleaning out suction pipes or boxes." Nonetheless, CTA continued to use compressed air to clean the production lines.

8.3.1 Hazard Communication

The OSHA HazCom Standard (29 CFR. 1910.1200) requires employers to train employees on the hazards of chemicals found in the workplace. OSHA does not require employers to evaluate chemicals to determine their hazards. CTA relied on Borden Chemical MSDSs for hazard information. Borden's phenolic resin MSDSs referred CTA to NFPA 654 for safe handling practices, but CTA did not obtain or apply this standard to its operations.

CTA's HazCom training program consisted of an overview, a discussion on how to read an MSDS, a review of hazardous chemicals and materials, a log sheet to identify the locations of materials in the facility, and a video. CTA taught employees about hazard classes listed in the OSHA HazCom Standard (i.e., combustible dusts are not defined in the HazCom standard) by citing examples of chemicals typically used in the facility. This training also covered the HMIS labeling system used at the facility. The plant's safety department conducted this training annually.

CTA department supervisors were responsible for providing employees with information on the physical and health hazards of specific chemicals in each work area. Interviews with supervisors and employees revealed that crew safety meetings did not address the explosive hazards of phenolic resin. CTA did not provide records to CSB documenting the content of supervisor-led training.

8.4 Facility Design and Construction

Lockwood Greene Engineers, Inc. designed and constructed the Corbin facility for CertainTeed in 1972. FM Global (formerly Factory Mutual) was consulted by CertainTeed to review preliminary process design drawings, which the company found to be acceptable.

CertainTeed intended to use plastic resins that were combustible dusts. During design and construction, CertainTeed and Lockwood Greene could have used NFPA 654, *Dust Explosion Prevention in the Plastics Industry* (1970), to minimize potential combustible dust hazards. Although this earlier version of the standard was only applicable to the plastics industry, not to operations like CertainTeed's,[22] it was issued as a guide to eliminate or reduce dust explosion hazards (in this case, those that are inherent in the manufacture, fabrication, molding, and handling of plastics). In 1976, NFPA expanded the scope of the standard to include chemical, dye, and pharmaceutical dusts, but a new edition of the standard was not issued until 1982. The organization revised the standard again in 1997 to include all industries where manufacture, processing, blending, repackaging, and handling of combustible dusts presented a fire or explosion hazard.

The 1970 version of NFPA 654 recommended separate, detached buildings for processing and handling combustible dusts. For processes that could not be detached, NFPA 654 required segregation to minimize

---

[22] CertainTeed did not consider itself a member of the plastics industry based upon its standard industrial classification code.

the possibility of an explosion or fire damaging other portions of the plant. To control dust accumulation, this version of the standard recommended that:

- Horizontal surfaces be minimized by having their tops sharply inclined, or by "boxing" in steel I-beams or similar structural shapes.
- Buildings be equipped with explosion venting.

Combustible dust-handling operations at the Corbin facility were not detached. Two-hour-rated masonry block firewalls—not physical barriers designed to withstand fire and explosion hazards—partially segregated these operations from surrounding storage and maintenance areas. In addition, the facility did not minimize horizontal surfaces, I-beams and open web roof trusses were not boxed, and no explosion venting was provided.

CTA did not follow the more recent editions of NFPA 654 when modifications were made to the blend rooms (1992) or when firewalls were removed separating the production area from the finished goods area (2002). At the time of the incident, the building contained numerous elevated, hard-to-clean horizontal flat surfaces—such as tops of process pipes, sprinkler pipes, electrical conduits, and cable trays. These surfaces allowed the accumulation of substantial combustible dust, which provided fuel for the fire and explosions. Minimization of flat surfaces likely would have prevented accumulation of combustible dust and eliminated it as a source of fuel for the fire and explosions.

Lack of effective firewalls at CTA allowed the fire to spread beyond line 405. Proper placement of firewalls around the production area could have prevented the spread of the fire to the raw material storage and maintenance areas. Some existing firewalls were knocked down in the explosions. Use of blast-resistant physical barriers designed to withstand deflagration and use of deflagration venting to a safe outside location could have minimized the spread of explosive forces (Appendix D.2.3).

8.5 Work Practices

8.5.1 Production Line Cleaning Procedures

Employees reported that production line cleaning routinely created clouds of dust. They used compressed air, brooms, and metal tools—such as rakes, shovels, and chimney sweeps—to clean. Regular line cleaning took place every morning. These cleaning procedures increased the suspension of combustible dust in the production area, particularly around the line 405 oven. Over time, the procedures also contributed to the buildup of dust on flat surfaces—thus increasing the likelihood of a fire and explosion.

Room fans were used to blow dust away from workers when they were cleaning. The fans had the unintended consequence of increasing the dispersion of dust, which settled on elevated flat surfaces. Before the incident, two fans were used on line 405.

NFPA and other safety guidelines warn against the use of compressed air for cleaning combustible dusts and suggest that, whenever possible, vacuuming should be used to minimize the dispersion of dust.

8.5.2 Housekeeping

Inadequate housekeeping allowed unsafe levels of dust buildup on flat surfaces at CTA. NFPA 654 (2000) states: “[D]ust layers 1/32 inch (0.8 mm) thick on the floor can be sufficient to warrant immediate cleaning of an area [1/32 in. (0.8 mm) is about the diameter of a paper clip wire or the thickness of the lead in a mechanical pencil].” NFPA 654 (2000) states that a dust layer of this thickness can create a hazardous condition if it covers more than 5 percent of the building floor area, and gives 1,000 square feet (93 square meters) of dust layer as the upper limit for large facilities. In addition, dust accumulations on other elevated surfaces—such as ducts, pipes, hoods, ledges, and beams, or tops of rooms and equipment—contribute to secondary dust cloud potential and should be considered in estimating dust loading.

Plant personnel reported that the February 20 explosions caused large amounts of dust that had collected on overhead surfaces (e.g., on top of blend rooms, beams, ledges) to descend upon them. CSB found accumulations of combustible dust burned onto flat surfaces in the CTA production area. However, because of the extensive fire and explosion damage, CSB could not determine the thickness of the dust layer on flat surfaces prior to the fire.

Housekeeping involved cleaning floors and plant equipment on a daily basis. In the year prior to the incident, the facility's housekeeping crew for this type of cleaning was reduced in size. The reduced crew was able to clean a limited area within the plant each day. Daily housekeeping on production lines became a job duty of line operators.

The CTA cleaning program focused on production line, floor, and baghouse cleaning. It did not adequately address other flat surfaces such as I-beams, process ducts and pipes, roof trusses, and the top of the blend rooms. Semi-annual cleanings (Section 4.4) during plant shutdowns were supposed to be scheduled; however, CSB did not find evidence that these cleanings occurred. Housekeeping inspections did not detect accumulations of combustible dust that could not be seen at floor level.

Good housekeeping is critical for combustible dust control. NFPA 654 (2000) states: "[R]egular cleaning frequencies shall be established for floors and horizontal surfaces, such as ducts, pipes, hoods, ledges, and beams, to minimize dust accumulations within operating areas of the facility." It further recommends that spaces inaccessible for cleaning be sealed to prevent dust accumulation and that combustible dust inspection programs specifically address housekeeping. A more effective housekeeping program at CTA would have limited the buildup of combustible dust.

8.5.3 Nonroutine Operations

The doors on the line 405 oven were left open because the oven was operating too hot. Personnel viewed the temperature control problem exclusively as a product quality concern, so the safety hazard of operating the oven with the doors open was not evaluated. On the day of the incident, combustible material in the oven probably caught on fire, and flames likely ignited a dust cloud that was created by cleaning activity. NFPA 654 (2000) states: “[W]ritten procedures to manage change to process materials, technology, equipment, procedures, and facilities shall be established and implemented.”

8.6 Maintenance

The production lines were shut down once every 6 to 9 weeks for maintenance and cleaning. Maintenance activity typically included removing accumulated combustible material in the bottom of the ovens, sandblasting oven interiors, and replacing the bags in the baghouses.

The last maintenance shutdown of line 405 took place on December 19, 2002—9 weeks prior to the incident. The next shutdown was initially scheduled for February 13, 2003; postponed until February 20; and then rescheduled a second time for February 21. The incident occurred on February 20.

Employees reported that the delay in replacing bags in the baghouse caused increasing amounts of dust to escape from the production line and into the work area. The differential pressure gauge on the baghouse showed that suction was outside of the manufacturer’s limits. NFPA 654 (2000) recommends pressure drops of 3 to 5 inches of water to maximize baghouse efficiency. According to CSB interviews with line crew employees, the baghouse differential pressure was running above 6 inches on February 19, the day before the incident. Interviews also revealed that line 405 was much dustier than normal.

8.6.1 Oven Operation and Safety

Oven temperature control equipment on line 405 had not been working properly for a few weeks prior to the incident. CSB interviews with line 405 employees revealed that the oven was running too hot. Electricians were unable to fix the problem. Operators compensated by opening two of the oven doors to cool it down. Supervisors and workers did not view the temperature control problem as a safety concern.

The production lines had a history of small fires erupting in the ovens. The ovens were not equipped with internal fire protection such as water sprinklers. Operators routinely put out the fires with garden hoses or with dry chemical fire extinguishers. They reported that waste material from the production process typically accumulated in the bottom of the inside of the line 405 oven. NFPA 86, *Standard for Ovens and Furnaces* (2003), recommends evaluating the need to install automatic water sprinklers in ovens that accumulate appreciable quantities of combustible material (Appendix D.2.1).

8.6.2 Electrical Safety

Employees reported seeing electrical boxes on the production lines catch on fire and blow open on a few occasions. Insurance inspections in 2001 and 2002 warned of the hazard of accumulated dust in electrical boxes. The boxes on the production lines were not designed to seal tightly, and some had holes.

NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* (2004b), recommends that electrical installations be designed and enclosed in a "dust-ignition proof " manner or be pressurized or made intrinsically safe (Appendix D.2.2).

NFPA 70*, The National Electrical Code* (NEC; 2002b), and OSHA regulations (29 CFR 1910.307) classify areas where combustible dusts may be suspended in air as Class II, Division 2. This classification requires dust-tight electrical equipment to prevent combustible dust from entering electrical components. The phenolic resins used by CTA (based on the CAS number) are listed as Class II, Group G,[23] materials in Table 4.5.2 of NFPA 499. CTA did not have the appropriate dust-tight electrical equipment. Although electrical equipment likely was not the ignition source for the February 20 explosions, the use of nondust-tight equipment by CTA was an unsafe practice.

---

[23] NEC (NFPA, 2002b) divides combustible dusts into three groups. Group G combustible dusts include flour, grain, wood, plastic, and chemical dusts.

8.7 Incident Investigations

The incident investigation program at CTA did not ensure that all incidents were investigated or that corrective actions were taken. CTA used a “fire report” for documenting fires. The report was filled out by supervisors and sent to the safety department. In the 7 months prior to the February 20 incident, reports were filed for nine fires on the production lines—three of which involved the line 405 oven. However, CSB interviews with employees revealed that these reports did not account for all fires.

Employees told CSB investigators that numerous small fires took place on the production lines. Most fires occurred in the ovens, which provided radiant heat but did not normally contain flames. Fires erupted when deposits of combustible material built up and ignited. The ovens had permanent openings on each end to allow for the product to move through on a conveyor; therefore, flames from these fires sometimes escaped into the work area.

Employees working on line 405 reported that fires occasionally occurred in the forming hood next to the oven. Some employees described the ignition of dust on the walls adjacent to the line 405 oven. One employee on line 405 remembered an incident where the side of the oven and the floor under the line caught fire. As the layer of dust burned, the fire spread toward the blend room, about 40 feet away. In 1979, another incident occurred on line 403 in a forming hood, severely burning two employees.

Four water hoses and several portable dry chemical extinguishers were mounted near the line 405 oven. This equipment was needed to put out oven fires. CTA safety personnel estimated that oven fires occurred on an average of once a week, based on the frequency of refilling extinguishers. This estimate did not include the fires put out with water.

In the *Accident Prevention Manual for Business and Industry*, NSC (1997) notes that all incidents should be investigated, and that “investigation or analysis must produce factual information leading to corrective actions that prevent or reduce the number of incidents.” However, during the 7 months prior to the incident, production logs documented another four fires on line 405 that were not recorded in fire reports. Of the three fire reports that were recorded from line 405, one contained a recommendation to "clean inside of oven more often." The other two reports did not include any recommendations to prevent recurrence.

The February 20 incident could have been prevented if the CTA investigation program had addressed all fires, identified their underlying causes, and issued and implemented recommendations to prevent recurrence.

8.8 Other Major Dust Explosions

Accumulations of combustible dust within industrial facilities create the potential for severe dust explosions. In the past 5 years, several major dust explosions have occurred in the United States—among them, Ford Motor Company, Rouge River Plant, Michigan (February 1999); Jahn Foundry, Massachusetts (February 1999); Rouse Polymerics International Inc., Mississippi (May 2002); and West Pharmaceutical Services, North Carolina (January 2003). The circumstances of both the Jahn and West incidents are similar to CTA and are discussed below.

8.8.1 Jahn Foundry

On February 25, 1999—4 years prior to the CTA incident—12 employees were badly burned from a dust fire and explosion at the Jahn Foundry in Springfield, Massachusetts (OSHA, 1999). Three of the injured later died. The foundry produced iron castings by pouring molten metal into molds composed of a sand and phenolic resin mixture.

The Jahn and CTA incidents have the following factors in common:

- The same family of phenolic resin powder was involved.
- Borden Chemical manufactured the phenolic resin powders.

- Excessive accumulations of combustible phenolic resin dust on flat surfaces fueled the fire and explosions.
- A malfunctioning oven was involved.
- Housekeeping did not control excessive dust accumulations.
- Multiple secondary dust explosions caused fatalities, numerous burn injuries, and extensive facility damage.

Borden Chemical did not communicate the safety lessons from this incident to CTA (Section 8.2.3.1). CTA employees were not aware of the Jahn incident or the lessons learned from the investigation.

8.8.2 West Pharmaceutical Services

Three weeks prior to the CTA incident—on January 29, 2003—a dust fire and explosion occurred at West Pharmaceutical Services in Kinston, North Carolina. Six workers died; at least 38 others, including two firefighters, were injured. The facility produced rubber drug-delivery components for such items as syringe plungers, septums, and vial seals.

CSB investigated this incident and found that the fuel for the fire and explosion was a combustible polyethylene dust that had accumulated above a suspended ceiling over a manufacturing area. Similar to the CTA incident, an initiating event disturbed the accumulated dust and started a cascade of secondary dust explosions (USCSB, 2004). As a result of the West incident, the North Carolina Department of Labor (2003) published an industry alert, entitled *Combustible Dust Poses a Dangerous, Explosive Threat in the Workplace*.

9.0 Insurance Guidelines and Inspections

Several loss prevention, risk management, and general liability insurance companies provided coverage and inspected the CTA facility. For example, at least twice a year since 1997, FM Global, a large commercial and industrial property insurer, conducted property reviews for CTA, including mechanical and electrical system inspections. Despite frequent inspections, none of CTA's insurers identified phenolic resin dust as an explosion hazard after 1995.

9.1 FM Global Guidelines

FM Global publishes guidelines to reduce or prevent dust fires and explosions. Data Sheets 6-9, *Industrial Ovens and Dryers* (2003), and 7-76, *Prevention and Mitigation of Combustible Dust Explosions and Fire* (2004), apply to operations such as those found at CTA.

FM Global property loss prevention data sheets are engineering guidelines to reduce the likelihood of property loss due to fire, weather conditions, or failure of electrical or mechanical equipment. They incorporate loss experience, research results, and input from consensus standards committees, equipment manufacturers, and others. FM Global usually uses the data sheets during facility inspections. They are also sometimes provided to customers and available to noncustomers for purchase. CTA told CSB that it did not have a copy of either data sheet 6-9 or 7-76.

9.1.1 Industrial Ovens and Dryers

FM Global Data Sheet 6-9 (2003) addresses fire and explosion hazards from process combustibles (e.g., dust, debris), fuel (e.g., natural gas), and flammable materials in industrial ovens and dryers. Sprinkler protection is recommended if "appreciable accumulations of combustible drippings or deposits are present on the interior oven surfaces." Although the process lines at CTA handled combustible material that accumulated in the bottom of the ovens, none of the ovens were equipped with sprinklers.

Data Sheet 6-9 also states:

> Clean ovens and ducts at regular intervals if they are subject to a buildup of flammable deposits of condensed solvent or oil vapors or accumulations of flammable lint, dust or other materials . . . . The method of cleaning varies with the nature of the deposits. Scraping with non-sparking tools is probably the most widely used method for soft or easily removed deposits. Remove lint and dust by vacuum cleaning. Do not blow with compressed air or steam because of the possibility of explosion from a combustible dust cloud.

CTA experienced other fires in ovens due to combustible material buildup, yet compressed air was commonly used to clean out process line equipment.

9.1.2 Prevention and Mitigation of Combustible Dust Explosions and Fire

FM Global Data Sheet 7-76 (2004) provides guidelines to prevent and protect against combustible dust explosions.[24] Like NFPA 654 (2000), Data Sheet 7-76 recommends minimized ledges, smooth interior walls, and sloped horizontal surfaces. Damage-limiting construction—such as explosion vents and physical barriers—is also recommended.

FM Global advises companies to “establish a comprehensive and conscientious housekeeping program to keep dust accumulations to an acceptable minimum.” It also cautions against cleaning accumulated combustible dust with compressed air.

---

[24] FM Global Data Sheet 7-76 was first published in 1976. It has been revised several times since then with the most significant revision taking place in 1995.

Data Sheet 7-76 further states:

> Regardless of the housekeeping methods used, pay particular attention to eliminating accumulations above floor level, such as equipment tops or building structural members. Dust accumulated at higher locations is far more hazardous than dust at floor level, because dust is more likely to become suspended (airborne) and create an explosible cloud if it is disturbed.

9.2 Insurance Company Inspections of CTA

Table 5 lists the dust-related recommendations provided to CTA by its insurance carriers. Despite frequent inspections, none of CTA's insurers identified phenolic resin dust as an explosion hazard after 1995.

Table 5

Insurance Company Dust Issues and Recommendations

Company	Inspection Date	Recommendations and Issues
Royal Insurance	January 1995	The 12/14/94 fire was intensified by accumulation of dust in overhead areas. Installation of fans would prevent phenolic resin dust from accumulating in the overhead and reduce the effects of a fire should one occur. Thoroughly clean all overhead areas before operating fans to avoid creating a large concentration of dust in the atmosphere and possibly explosive concentrations of dust.
CNA Risk Management	February 1997	Improve housekeeping at ovens to prevent fires. "A more frequent and thorough cleaning procedure is needed to eliminate significant buildup."
FM Global	November 1997	Remove dust accumulating on sprinkler heads.
Great American Insurance Companies	July 1999	Reduce the amount of fiberglass and lint dust in the air in the picker and molding areas; check the exhaust system for efficient operation; provide a better holding bin for the resin binder to prevent spills and propagation of binder into the air; and vacuum areas for removal of loose fibers and powder.
FM Global	March 2001	In July 2000, substation no. 1 required full rebuilds of six 600-amp circuit breakers due to heavy accumulations of dust and debris.
FM Global	August 2001	Further concern over dust accumulation on sprinkler heads.
FM Global	September 2001	Concern over manual activation of sprinkler system but due to adequate training and marking of valves, the existing situation—though "not ideal"—is "considered tolerable."
FM Global	June 2002	Removal of firewalls in product storage area would cause more damage and increase length of production shutdown in the event of a fire or explosion (Sections 3.4.2 and 10.2.2).
FM Global	December 2002	Airborne dust contamination posed significant hazards to electrical distribution system; accumulation in switchgear and breakers could cause switchgear failure.

Copies of insurance inspection reports were normally sent to the plant, to the human resources or safety manager, and sometimes to the company president. In some cases, CTA responded to the dust housekeeping concerns by increasing cleaning frequencies. FM Global noted in September 2001 that the cleaning of the sprinklers inside blend rooms had been incorporated into the normal cleaning routine. CTA also replaced worn-out switchgear and installed an air filtering system to prevent dust from accumulating in the electrical substation. The facility began to convert to dust-tight electrical enclosures.

10.0 Regulatory Analysis

CSB reviewed workplace safety regulations and building codes applicable to the CTA facility. These regulations are promulgated and enforced by the Kentucky Department of Labor and the Office of Housing, Buildings, and Construction, which are both part of the Environmental and Public Protection Cabinet (Appendix F).

The regulatory analysis determined that the Kentucky Office of Occupational Safety and Health (OSH) conducted several comprehensive inspections of the facility but did not issue citations regarding combustible dust hazards. Also, the State Fire Marshal's office had not inspected the facility since it was constructed in 1972.

10.1 Federal and Kentucky Workplace Safety

Kentucky regulates workplace safety through a State plan approved by OSHA. Kentucky OSH enforces the state regulations, while the Occupational Safety and Health Standards Board adopts regulations identical to or at least as effective as Federal OSHA regulations.

Kentucky OSH inspectors conducted wall-to-wall planned inspections of the Corbin facility in 1989, 1993, and 2000. No citations related to combustible dust hazards were issued. In December 2002, Kentucky OSH inspectors conducted a limited inspection after receiving a complaint regarding machine guarding and health hazards from resins. CTA was cited for inadequate machine guarding. However, inspectors determined that the health hazard allegation regarding resin was unfounded.

Following the February 20, 2003 incident, Kentucky OSH issued citations to CTA—one of which stated that the company did not provide a place of employment free of recognized hazards likely to cause death or serious harm to employees. This requirement is known as the "general duty clause." The citation further stated that compliance guidance for preventing dust fires and explosions is found in the NFPA standards (Appendix D). Kentucky OSH issued other citations for inadequate ventilation and unapproved electrical equipment in areas where combustible dusts were present.

Following the West Pharmaceutical dust explosion, the North Carolina Department of Labor (2003) issued an industry alert on combustible dust hazards. Kentucky OSH has issued no educational material to alert employers of the dangers of combustible dusts.

Federal OSHA has adopted regulations that address the prevention of dust explosions in certain business sectors, including grain-handling facilities; pulp, paper, and paperboard mills; bakeries; and sawmills. In addition, it has adopted general industry regulations to control certain activities such as the use of electrical equipment and forklifts in environments that may contain combustible dusts.

In 29 CFR 1910.272(j)(3), OSHA requires that grain-handling facilities have a written housekeeping program that sets the frequency and methods for controlling dust on exposed surfaces. These facilities must remove dust whenever it exceeds 0.125 inch in priority areas. In the grain standard, OSHA also warns that using compressed air for cleaning combustible dust can be hazardous if all potential ignition sources are not removed or controlled.

Although both OSHA and the Kentucky Occupational Safety and Health Standards Board have adopted certain NFPA standards, neither has adopted NFPA 654 (2000)—which addresses dusts such as those found at CTA. NFPA 654 lists specific design and work practice precautions (Appendix D).

10.2 Kentucky Office of Housing, Buildings, and Construction

10.2.1 Code History

In 1954, Kentucky Revised Statute Section 227.300 established rules and regulations known as the "Standards of Safety." These standards established requirements for design and construction of various facilities, including combustible dust-handling operations. The State Fire Marshal enforces the standards, including approving new construction permits and conducting inspections.

The Standards of Safety in effect in 1972—when CertainTeed constructed the facility—incorporated the National Building Code (NBC, published by the American Insurance Association), 1967 edition; National Fire Codes (NFC, published by NFPA), 1970-71 edition (all 10 volumes); and NEC, 1968 edition. The CertainTeed process for which the facility was constructed used a phenolic resin that was a combustible dust.

NFC includes dust fire and explosion prevention standards, such as NFPA 654, though they are not specifically referenced in the Standards of Safety. The State Fire Marshal permitted construction of the facility in 1972, even though CertainTeed had not incorporated combustible dust protection into the design.

In 1977, the Beverly Hills Supper Club fire in Southgate, Kentucky, killed 165 people and injured another 70. This incident prompted major changes in State enforcement of building construction and inspection. A team of investigators commissioned by the governor of Kentucky concluded: "During the period of time from December 1970 until May 28, 1977, the fire marshal's office did not implement a proper inspection program which would have revealed code violations."

In the aftermath of the Supper Club fire, Kentucky adopted a State building code (815 Kentucky Administrative Regulation 7:120) and created the Department of Housing, Buildings, and Construction to regulate the construction and use of buildings. The Office of State Fire Marshal became a division of the new department, with responsibility limited to the safety of existing buildings. Another division within the department—Building Codes Enforcement—regulated the Kentucky Building Code as it pertained to the construction of new buildings and alterations, additions, and changes of occupancy to existing buildings. In 2004, the Department was renamed the Office of Housing, Buildings, and Construction.

10.2.2 Division of Building Codes Enforcement

The Division of Building Codes Enforcement is separated into two functions:

- Plan review: Architectural plans are reviewed prior to construction to ensure compliance with the Kentucky Building Code.
- Inspection: Inspections are conducted periodically to ensure that construction is done according to approved plans. Upon final inspection, an occupancy permit is issued and the case file is transferred to the Division of Fire Prevention, Office of State Fire Marshal, for future inspections.

The division has 12 field inspectors for building codes, eight plan reviewers, and three technical advisors. Inspectors use a checklist to document whether construction of the facility meets code requirements. The checklist does not address combustible dusts. No training is provided to building inspectors or plan reviewers on design requirements for combustible dusts. On November 4, 2002, the division allowed the firewalls that separated the combustible dust-handling production area from the finished goods storage area at CTA to be removed (Section 3.4.2).

The Kentucky Building Code incorporates the International Building Code (IBC),[25] which requires buildings that store or handle combustible dusts to comply with applicable provisions of the International Fire Code (IFC) and NFPA 654.[26] The Kentucky Building Code classifies as high hazard (Group H) facilities that handle combustible dusts over a maximum allowable quantity. However, neither the Kentucky Building Code nor IBC specifies maximum allowable combustible dust quantities.

---

[25] The International Code Council (ICC) develops the IBC. The ICC was established in 1994 as a nonprofit organization dedicated to developing a single set of comprehensive and coordinated national model construction codes. The founders of the ICC are Building Officials and Code Administrators International, Inc.; International Conference of Building Officials; and Southern Building Code Congress International, Inc.

[26] The provisions of IFC apply to matters affecting or relating to new construction in buildings only where specifically referenced in the Kentucky Building Code.

10.2.3 Office of State Fire Marshal

After the Kentucky Building Code became effective, enforcement of the Standards of Safety was limited to existing buildings. The State Fire Marshal assumed inspection responsibility for existing facilities. In 1990, the Standards of Safety became the Kentucky Fire Prevention Code. Specific references to the Uniform Fire Code (NFPA 1), NFPA 654, NFPA 86, and NFPA 499 were incorporated into the Kentucky code in October 2002.

The Office of State Fire Marshal has 30 general inspectors and can deputize local fire departments for code enforcement purposes. The office inspects selected, prioritized buildings on an annual basis. High-risk occupancies—such as schools, churches, nightclubs, daycare facilities, and apartments—are on the list. Industrial facilities are usually inspected only upon receipt of a complaint or a request from local officials. The inspectors did not receive training on combustible dust safety standards. The State Fire Marshal's office has not inspected the CTA facility since its construction in 1972. If the State Fire Marshal had a program and sufficient resources to inspect industrial facilities for compliance with state regulations, then the combustible dust hazards at the CTA facility may have been identified, and the explosions and fire could have been prevented.

11.0 Combustible Dust Hazard Study

In three investigations, CSB has identified gaps in the current understanding of dust explosion risks and shortcomings in prevention of dust explosions. As a result, CSB is conducting a study to examine the nature and scope of dust explosion risks in industry and to identify initiatives that may be necessary to more effectively prevent combustible dust fires and explosions. Such initiatives may include regulatory action, voluntary consensus standards, or other measures that could be taken by industry, labor, government, and other parties.

CSB plans to study the effectiveness of hazard communication requirements and programs for combustible dusts, including MSDSs and the HMIS rating system. The study also will examine the effectiveness of national safety standards and guidelines for combustible dusts, including building code requirements and enforcement.

12.0 Root and Contributing Causes

12.1 Root Causes

1. **CTA management did not implement effective measures to prevent combustible dust explosions.**

   - Some managers discussed the explosion hazard of dust in the facility, but this information was not communicated to the general work force.

   - CTA did not obtain and use NFPA 654 as recommended in Borden Chemical's phenolic resin MSDS.

2. **The CTA cleaning and maintenance procedures for production lines did not prevent the accumulation of unsafe levels of combustible dust on elevated flat surfaces.**

   - The use of metal tools, brooms, compressed air, and fans during line cleaning dispersed combustible dust in potentially explosive concentrations and also caused it to settle on elevated flat surfaces throughout the facility.

   - The housekeeping program did not effectively remove combustible dust that accumulated in areas above production lines.

3. **The CTA incident investigation program did not ensure that all oven fires were investigated and that underlying causes were identified and resolved.**

   CTA safety personnel estimated that oven fires occurred on an average of once a week.

4. **The Borden Chemical product stewardship program did not explicitly convey to CTA the explosive hazards of phenolic resins.**

   The Borden Chemical phenolic resin MSDSs noted that the phenolic resins were combustible dusts but did not explicitly warn that they could be explosive. Following the catastrophic explosion at the Jahn Foundry in 1999—which involved one of Borden Chemical's phenolic resins—Borden Chemical did not enhance warnings on its MSDSs nor did it communicate the safety lessons of the Jahn investigation to CTA.

5. **The CertainTeed building design and CTA building modifications did not effectively address the fire and explosion hazards associated with combustible dusts.**

   The NFPA 654 standard on combustible dust safety only applied to the plastics industry in 1972; it did not cover operations such as CertainTeed's. Nonetheless, following the building design principles contained in the standard could have prevented or mitigated the incident at CTA. Those principles include:

   - Minimizing flat surfaces to prevent accumulation of combustible dusts.

   - Installation of adequate firewalls and blast-resistant physical barriers and deflagration venting to prevent the spread of fire and explosive forces beyond the production area.

   CTA also did not use these principles when it made facility modifications.

12.2 Contributing Causes

1. **The line 405 oven lacked fire detection devices and automatic sprinklers.**

   NFPA 86, *Standard for Ovens and Furnaces* (2003), recommends evaluating the need to install automatic water sprinklers in ovens that accumulate appreciable quantities of combustible material.

2. CTA did not have effective procedures for evaluating the hazards associated with nonroutine operating conditions on line 405.

Operating the oven with malfunctioning temperature control equipment and open doors was a nonroutine situation—the hazards of which were not recognized or controlled.

13.0 Recommendations

CSB developed the following recommendations from the findings and conclusions of this investigation. Recommendations are made to parties that can effect change to prevent future incidents. Those parties typically include the facility where the incident occurred, the parent company, trade organizations responsible for developing good practice guidelines, or organizations that have the ability to broadly communicate lessons learned from the incident—such as trade associations and labor unions.

CTA Acoustics, Inc.

1. Develop a combustible dust safety program using good practice guidelines, such as NFPA 654, *Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*. At a minimum:

    - Minimize surfaces where combustible dust could accumulate in the design or modification of the plant. (2003-09-I-KY-R1)
    - Ensure phenolic resin-handling facilities are designed to prevent the spread of fires or explosions involving combustible dust. Options include measures such as the use of firewalls and blast-resistant construction. (2003-09-I-KY-R2)
    - Prevent the unsafe accumulation and dispersion of combustible dust by frequently cleaning process areas, including locations above production lines. (2003-09-I-KY-R3)
    - Minimize the dispersion of combustible dust by using appropriate dust-cleaning methods and tools. (2003-09-I-KY-R4)
    - Address the dangers of combustible dust and the prevention of dust explosions in the hazard communication training program. (2003-09-I-KY-R5)

2. Conduct hazard assessments of ovens to ensure that fire detection and suppression systems are adequate, using good practice guidelines such as NFPA 86, *Standard for Ovens and Furnaces*. (2003-09-I-KY-R6)

3. Develop procedures to maintain safety during nonroutine operating conditions, such as the loss of oven temperature control. (2003-09-I-KY-R7)

4. Revise the incident investigation program to ensure that the underlying causes of incidents such as fires are identified and corrective actions implemented. (2003-09-I-KY-R8)

CertainTeed Corporation

1. Evaluate your facilities that handle combustible dusts and ensure that good practice guidelines such as NFPA 654 are followed. (2003-09-I-KY-R9)

2. Ensure that company design standards—applicable to facilities that handle combustible dusts—incorporate good engineering practices to prevent dust explosions, such as NFPA 654. (2003-09-I-KY-R10)

Borden Chemical, Inc.

1. Ensure MSDSs for phenolic resins include, at a minimum, warnings that dust from these products can be explosive. (2003-09-I-KY-R11)

2. Develop and distribute educational material, in addition to MSDSs, to inform customers of the explosion hazard of phenolic resin dust. (2003-09-I-KY-R12)

3. Communicate the findings and recommendations of this report to your customers that purchase phenolic resin. (2003-09-I-KY-R13)

Kentucky Office of Occupational Safety and Health

1. Develop and distribute an educational bulletin on the prevention of combustible dust explosions. (2003 09-I-KY-R14)

2. Enhance the training program for compliance officers regarding the recognition and prevention of combustible dust explosion hazards. (2003-09-I-KY-R15)

FM Global

Incorporate the findings and recommendations of this report in your training of employees who conduct inspections at facilities that may handle combustible dusts. (2003-09-I-KY-R16)

Kentucky Office of Housing, Buildings, and Construction

1. Incorporate the findings and recommendations of this report in your continuing training of inspectors, plan reviewers, technical advisors, and fire marshal general inspectors who interface with facilities that may handle combustible dusts. (2003-09-I-KY-R17)

2. Identify sites that handle combustible dusts when facilities apply for new or modified construction permits, and use this information to help prioritize establishments that will be inspected by the fire marshal. (2003-09-I-KY-R18)

13.1 Recommendations to Communicate the Findings From the Investigation

In an effort to widely distribute lessons learned from investigations, CSB recommends that organizations communicate relevant findings and recommendations to their memberships. CSB intends for those organizations to use multiple avenues to communicate, such as having presentations at conferences, placing summaries of a report and links to full CSB reports on their websites, developing and holding training sessions that highlight the report findings, and summarizing relevant findings in newsletters or direct mailings to members. CSB encourages the organizations to use all their existing methods of communication and explore new ways to more widely distribute these messages.

American Chemistry Council

Communicate the findings and recommendations of this report to your membership. Emphasize that dusts from phenolic resins can explode. (2003-09-I-KY-R19)

International Code Council

Communicate the findings and recommendations of this report to your membership. (2003-09-I-KY-R20)

National Fire Protection Association

Communicate the findings and recommendations of this report to your membership.
(2003-09-I-KY-R21)

The Society of the Plastics Industry

Communicate the findings and recommendations of this report to your membership.
(2003-09-I-KY-R22)

BY THE

U.S. Chemical Safety and Hazard Investigation Board

Carolyn W. Merritt

Chair

John S. Bresland

Member

Gary L. Visscher

Member

February 15, 2005

14.0 References

American Society for Testing and Materials (ASTM), 2000a. *Standard Test Method for Hot Surface Ignition Temperature of Dust Layers*, ASTM E2021-00.

ASTM, 2000b. *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts*, ASTM E1515-00.

ASTM, 2000c. *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts*, ASTM E1226-00.

ASTM, 1999. *Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air*, ASTM E2019-99.

ASTM, 1997. *Standard Practice for Examining and Testing Items That Are or May Become Involved in Products Liability Litigation*, ASTM E860-97.

Clayton, George and Florence Clayton, eds., 1978. *Patty's Industrial Hygiene and Toxicology*, Third Revised Edition, Volume I – General Principles.

Eckhoff, Rolf K., 2003. *Dust Explosions in the Process Industries*, Gulf Professional.

Factory Mutual Insurance Company (FM Global), 2004. *Prevention and Mitigation of Combustible Dust Explosions and Fire*, Data Sheet 7-76.

FM Global, 2003. *Industrial Ovens and Dryers*, Data Sheet 6-9.

Jacobson M., J. Nagy, and A. Cooper, 1962. *Explosibility of Dusts Used in the Plastics Industry,* Report of Investigations 5971, Bureau of Mines, U.S. Department of Interior.

Knop, A. and L.A. Pilato, 1985. *Phenolic Resins*, Springer-Verlag.

Lawson, Robert G., 1984. *Beverly Hills: the Anatomy of a Nightclub Fire*, UP.

National Fire Protection Association (NFPA), 2004a. *Guide for Fire and Explosion Investigations*, NFPA 921.

NFPA, 2004b. *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, NFPA 499.

NFPA, 2003. *Standard for Ovens and Furnaces*, NFPA 86.

NFPA, 2002a. *Guide for Venting of Deflagrations*, NFPA 68.

NFPA, 2002b. *National Electrical Code*, NFPA 70.

NFPA, 2000. *Standard for the Prevention of Fire and Dust Explosions From the Manufacturing, Processing, and Handling of Combustible Particulate Solids*, NFPA 654.

NFPA, 1994. NFPA Inspection Manual, seventh edition.

National Paint and Coatings Association, 1976. *HMIS Implementation Manual*, second edition.

National Safety Council (NSC), 1997. *Accident Prevention Manual for Business and Industry*.

NSC, 1974. *Accident Prevention Manual for Industrial Operations*, seventh edition.

North Carolina Department of Labor, 2003. *Combustible Dust Poses a Dangerous, Explosive Threat in the Workplace*, Industry Alert.

Occupational Safety and Health Administration–Massachusetts Department of Fire Services–Springfield Arson and Bomb Squad, 1999. *Joint Foundry Explosion Investigation Team Report, Jahn Foundry Corporation, Springfield, Massachusetts, February 25, 1999.*

Raftery, Monica, 1975. *Explosibility Tests for Industrial Dusts*, Fire Research Technical Paper No. 21, Her Majesty's Stationery Office, London, United Kingdom.

U.S. Chemical Safety and Hazard Investigation Board, 2004. *Investigation Report, Dust Explosion, West Pharmaceutical Services, Inc., Kinston, North Carolina, January 29, 2003*, Report No. 2003-07-I-NC, September 2004.

APPENDIX A: Fire and Explosion Damage

Table A-1 lists damage at the CTA facility as a result of the February 20, 2003, fire and dust explosions.

The damage is broken down by specific plant area and likely cause.

Table A-1

Fire and Explosion Damage

Location	Damage	Cause
Line 405	Concrete block masonry firewall on east side partially collapsed and pushed eastward	Explosion overpressure originated in area between oven and wall and in partially enclosed area above blend room and below ceiling
	Metal panels detached at south end of partially enclosed area above blend room deformed in southward direction	Higher explosion overpressure in partially enclosed area above blend room and below ceiling
	Damage to building roof above line	Higher explosion overpressure inside plant in this area
	Ceiling panels and lights pushed downward	Higher explosion overpressure in partially enclosed area above blend room
	Wall and polycarbonate panels of blend room deformed and pushed out in westward direction	Higher explosion overpressure inside blend room
	Combustible material inside curing oven burned away; metal conveyor burned clean and free of debris; no explosion damage observed inside oven	Burning of accumulated phenolic resins and some chain oil inside oven
South of line 405	Concrete block masonry firewalls surrounding room directly south of line and near raw material storage area permanently deformed	Higher explosion overpressure in room south of line
	Fire scorching in area where no masonry walls extend to ceiling; residual burnt resin material attached to open-web steel joists	Path of fire traveled from production area into raw material storage area
Between lines 403 and 405	Concrete block masonry firewall in open bay between lines collapsed	Damage consistent with large rebound movement of wall aided by wrap-around pressure
Line 403	Metal panels above east wall of blend room pushed westward	Higher explosion overpressure east of line
	Oven exhaust line and thermal oxidizer inlet line separated	Higher explosion overpressure inside thermal oxidizer piping

Location	Damage	Cause
Line 402	Metal wall panel separating lines 402 and 403 pushed westward	Higher explosion overpressure in vents through wall panel
Line 401	Metal panels of blend room enclosure, particularly in northeast portion, permanently deformed outward	Higher explosion overpressure inside blend room due to confinement
	Steel columns in blend room permanently bent to west	
	Concrete block masonry firewalls on south end collapsed or severely deformed	
	Building roof above blend room enclosure destroyed	Higher explosion overpressure generated in confined area between blend room roof and ceiling
North wall of chemical room	Sliding door bent and concrete block wall deformed	Higher explosion overpressure from line 401
East wall of plant north of loading dock	Metal curtain wall pushed outward	Higher explosion overpressure from line 405 vented outside building
South wall of plant near new cylindrical dust collector	Metal curtain wall pushed outward	Higher explosion overpressure from line 405 vented outside building
West wall of plant near south wall	Metal curtain wall pushed outward	Higher explosion overpressure from line 401 vented outside building
North wall of plant near west corner	Loading dock door bent	Higher explosion overpressure from line 401 vented outside building
Production area	Charred combustible material adhered to vertical surfaces; horizontal surfaces, covered by combustible material, primarily charred at exposed exterior surfaces	Slow burning of combustible phenolic resin material throughout production area; hot gases freely expanding throughout building prevented large overpressures from developing outside of blend rooms and confined areas above blend room roofs
Baghouses on lines 403 and 405	Bags burned up	Fires inside baghouses
Dust collectors on lines 401 and 402	Access doors on dust collectors blown off	Higher pressure inside dust collectors due to fire or venting of explosion overpressure

APPENDIX B: Laboratory Testing of Phenolic Resin

CSB contracted with Safety Consulting Engineers, Inc. (SCE),[27] for explosibility, ignitability, and reactivity testing of the phenolic resin used at CTA. Samples were taken of Borden Chemical Durite SD-52SS and residual resin dust from production lines 401, 402, 403, and 405. The explosion characteristics of the phenolic resin were then compared with other common combustible dusts, as described in Sections B.1 to B.6.

B.1 Explosion Severity

The explosion severity test determines the deflagration parameters of a combustible dust-air mixture. The parameters measured are maximum pressure (P_{max}) and maximum rate of pressure rise $(dP/dt)_{max}$. Data obtained from this test method provide a relative measure of deflagration characteristics for calculation of the deflagration index, K_{st}. This index is the maximum dP/dt (dP/dt_{max}) normalized to a 1 m^3 volume.

The dust material was first dried and then tested in a U. S. Bureau of Mines 20-liter explosibility test chamber per ASTM E1226-00, *Standard Test Method for Pressure and Rate of Pressure Rise for Combustible Dusts* (2000c).

The 20-liter chamber was equipped with an air nozzle to disperse the material dust and two electrodes for connecting two squib (SOBBE) igniters (2 × 5 kJ = 10 kJ of stored ignition energy) to a voltage source. The chamber was equipped with a pressure transducer to measure the pressure output of an explosion. The data is collected by a high-speed computer-based data acquisition system. The pressure transducer is calibrated (psig/volts) at various pressures using a pressure test gauge.

---

[27] The information in Appendix B is adapted from a report prepared by SCE, Schaumburg, Illinois, on the testing and analysis of phenolic resin used at the CTA facility.

Figures B-1 and B-2 show test overpressures and rates of pressure rise as a function of concentration, respectively. The highest values of each over the entire concentration range determined P_{max} and $(dP/dt)_{max}$. For comparison, Figure 14 (Section 7.2) shows explosion severity data for polyethylene, Pittsburgh coal dust, and cornstarch.

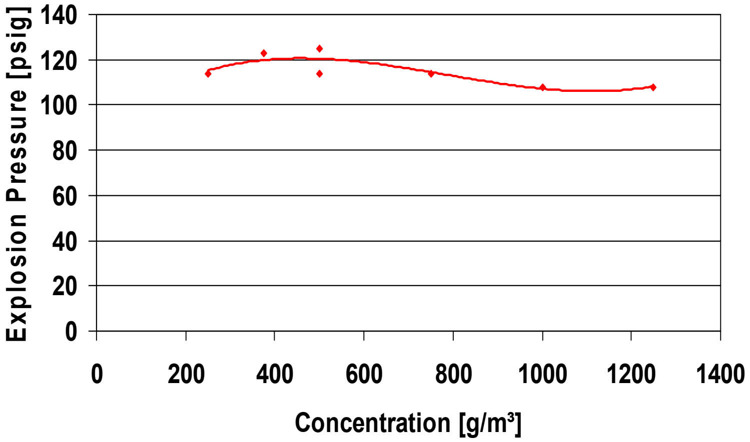


Figure B-1. Durite SD-52SS overpressure versus concentration.

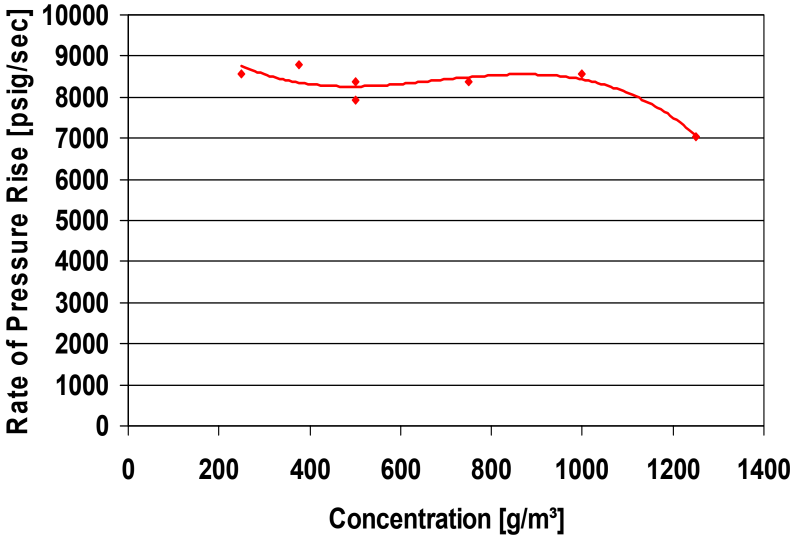


Figure B-2. Durite SD-52SS rate of pressure rise versus concentration.

B.2 Minimum Explosible Concentration

Minimum explosible concentration (MEC) is the minimum concentration of a combustible dust cloud that is capable of propagating a deflagration through a uniform mixture of dust and air under specified conditions. MEC data provide a relative measure of the minimum concentration of a dust cloud necessary for an explosion. The values obtained are specific to the sample (particularly particle size distribution) and test method. MEC values are not to be considered intrinsic material constants. The test was performed per ASTM E1515-00, *Standard Test Method for Minimum Explosible Concentration of Combustible Dusts* (2000b), using the U.S. Bureau of Mines 20-liter explosibility chamber.

Figure B-3 compares MECs for the Borden Chemical SD-52SS phenolic resin, Pittsburgh coal dust, polyethylene dust, and cornstarch.

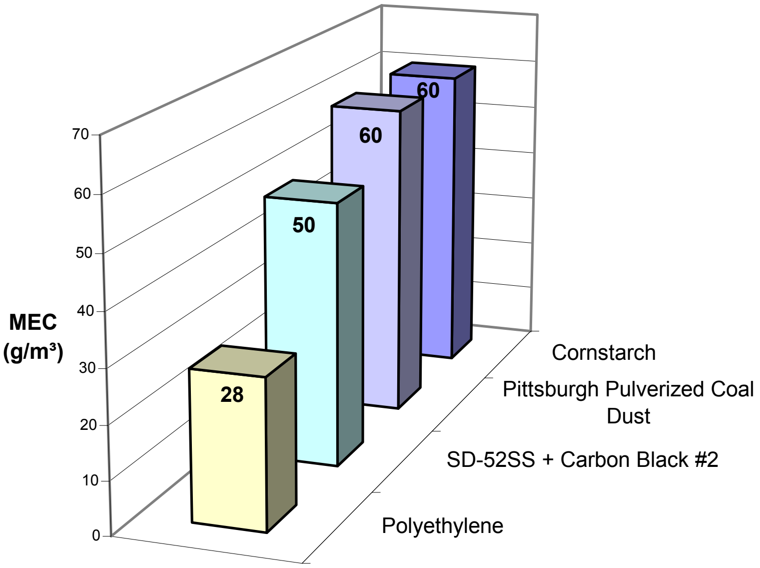


Figure B-3. Minimum explosive concentration of Durite SD-52SS compared with other common combustible dusts.

B.3 Minimum Ignition Energy

The minimum ignition energy (MIE) test is useful to determine whether combustible dust/air mixtures are ignitable by a high-voltage spark. Ignition energies determined by this method can be compared to determine the relative hazard of ignition by sources such as electrostatic discharges, electrical equipment sparks, and friction sparks.

Test results provide a relative measure of the ignition sensitivity of a dust cloud. The values obtained are specific to the sample, test method, and test equipment. MIE values are not to be considered intrinsic material constants. Any change in particle size, shape, or volatility alters MIE results. MIE tests were performed per ASTM E2019-99, *Standard Test Method for Minimum Ignition Energy of a Dust Cloud in Air* (1999), using a 1.2-liter clear plastic Hartmann tube.

Figure B-4 shows MIE test results for a Durite SD-52SS dust cloud in air. Results indicate that the phenolic resin is very easy to ignite, requiring only 3 millijoules (mJ) of energy to initiate an explosion.

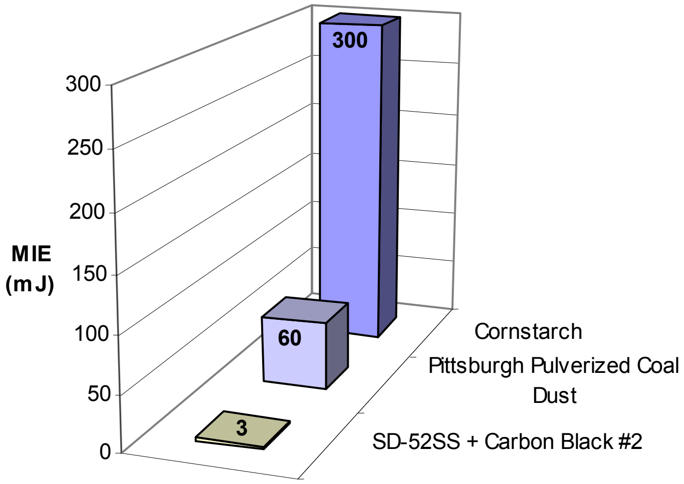


Figure B-4. Minimum ignition energy of Durite SD-52SS compared with other common combustible dusts.

B.4 Propagating Brush Discharge Ignition Test

During the handling of bulk powders, a propagating brush discharge may ignite dust. A sufficient charge built up on the powder surface can break down in the form of a propagating brush discharge. Unlike a spark discharge, which is localized between two conductive points, a propagating brush discharge is a surface phenomenon. Consequently, it poses the potential hazard of being a delocalized multipoint ignition source. The force of the charge breakdown is sufficient to disperse dust deposited on the surface into the air.

B.4.1 Test Setup and Procedure

The test apparatus consisted of a high-voltage power supply (Hipotronics Model 250D) connected to a multipoint corona generator. The base of the apparatus was an 8.5-inch sheet metal disk, which is connected to the ground. An 8.5- by 11-inch plastic sheet, with a thickness of 0.0075 inch, was placed on top of the disk.

A grounded 2-inch-diameter ball electrode was used to initiate the propagating brush discharge. To estimate the energy of the discharge, a Monroe Electronics Model 282 electrostatic fieldmeter was used to measure the change in electrostatic field (i.e., electrical potential of the surface by extension) before and after the discharge.

To produce a charge on the surface of the plastic sheet, 30 to 50 kilovolts were supplied to the multipoint corona generator centered over the sheet metal disk surface at a height of 25.4 millimeters. After a charging time of 60 seconds, the generator was moved away from the surface of the plastic sheet and the power supply was turned off.

The field meter was positioned above the surface of the plastic sheet to measure the electrostatic field. The spherical grounding electrode was then lowered to the plastic surface. A propagating brush discharge was produced as the electrode was lowered but before it touched the surface.

The field meter was repositioned to measure field strength following the electrostatic discharge. The energy of the discharge was calculated by measuring surface potential before and after the discharge.

B.4.2 Dust Ignition Tests

A similar procedure was followed for testing of the powder material to determine its ignitability. However, the material was screened through a 160-mesh sieve and evenly spread over the plastic sheet surface before the multipoint corona generator was energized. As the grounding ball was lowered, observations were made to determine dust flammability. The presence of a flame is the criterion for dust flammability by propagating brush discharge.

For purposes of laboratory testing, the plastic sheet was used to simulate a condition where sufficient powder material existed to form an insulating layer. Depending on the specific process, such a condition may be produced under industrial conditions. RoRo93 (2,26,6-tetramethylpiperdine derivative [a light stabilizer]), a product of Kuhner A.G., was used as a reference dust for testing.

B.4.3 Test Results

Table B-1 shows the results of the propagating brush discharge ignition tests. The RoRo93 material readily ignited, but two samples of the SD-52SS black phenolic resin tested did not. As propagating brush discharges are the most energetic of all types of electrostatic discharges, these tests results show that static electricity was probably not capable of igniting the phenolic resin dust.

Table B-1

Propagating Brush Discharge Test Results

Material	**Corona Charge Voltage (kV)**	**Charge Duration (sec)**	**ES Field Strength Before Discharge (kV/in.)**	**ES Field Strength After Discharge (KV/in.)**	**Observations of Propagating Brush Discharge**
RoRo93	30	60	-30	-4	Ignition of dust, resulting in open flame
Reference	30	60	-26	-6	Ignition of dust, resulting in open flame
SD-52SS	30	60	-30	-10	No ignition of dust
Sample 1	35	60	-28	-10	No ignition of dust
	40	60	-26	-10	No ignition of dust
	45	60	>-40	-10	No ignition of dust
SD-52SS	35	60	-26	-10	No ignition of dust
Sample 2	40	60	-26	-10	No ignition of dust

B.5 Hot Surface Ignition Temperature of Dust Layer

This test determines the hot surface ignition temperature, which is the minimum temperature at which a dust layer will self-heat. The test was conducted per ASTM E2021-00, *Standard Test Method for Hot Surface Ignition Temperature of Dust Layers* (2000a).

No hot surface ignition temperature for the Durite SD-52SS material was observed up to 390°C, the maximum temperature used for this test method (Table B-2). Although the layer temperature did not exceed the hot-plate temperature in either of the two tests, the material did melt and expand in volume. The heated powder layer liberated some fumes; however, they failed to ignite when exposed to a match flame.

Therefore, according to the criteria of ASTM E2021-00, the powder layer does not ignite, though it definitely undergoes some form of reaction under heating.

Table B-2

Hot Surface Ignition Temperature

Material Tested	**Moisture Content** (% wt)	**Particle Size** (mesh)	**Hot Surface Temperature** (°C)	**Observation/ Results**
Durite SD-52SS phenolic resin + carbon black	< 5 (as received)	-200 (sieved prior to testing)	130–390	No ignition
Pittsburgh coal	< 5	~ 80% minus 200 mesh, mass median diameter of ~ 45 µm and 36% volatility	240–250	Ignition (a)

(a) Published calibration values from ASTM E2021-00, *Standard Test Method for Hot Surface Ignition Temperature of Dust Layers* (2000a).

B.6 Dynamic/Isothermal Differential Scanning Calorimeter Test

The Dynamic Differential Scanning Calorimetry (DSC) test measures a material's inclination to absorb or release heat as a function of the environmental temperature to which it is subjected. The samples tested in microgram quantities, SD-52SS + Carbon Black #2, had endothermic peaks near 55°C and multiple exothermic peaks in the 150°C and 350°C – 425°C level. This indicates that the material may undergo a "melting" phase change at low temperatures and take part in multiple energy liberating reactions at high temperatures. In one test, a high-temperature endotherm at 205°C was observed for SD-52SS + Carbon Black. This may be an indication that an endothermic process such as off-gassing or "melting" was occurring.

The Isothermal DSC test measures the time required for a material in microgram quantities to go to reaction at given environmental temperatures. In the series of tests for SD-52SS + Carbon Black #2, environmental temperatures from 90°C to 135°C were used. In all cases, the reaction occurred immediately or within a minute.

APPENDIX C: Equipment Testing

Line 405 piping and equipment were tested:

- To determine if oven-related components released natural gas into the plant.
- To identify equipment failures that may have contributed to causing the oven temperature control problem.

Packer Engineering Technologies conducted the equipment testing on behalf of CSB. The testing began on January 27 and concluded on April 16, 2004. Three phases of testing were conducted at Packer Engineering facilities in Naperville, Illinois, and a fourth phase was carried out in North Hills, California, at Moore Industries, Inc. (an oven temperature controller test facility).

All equipment that required a laboratory environment for testing was removed from the Corbin, Kentucky, storage location and transported to Naperville. The equipment was photographed prior to removal from the storage facility, and the loading process was videotaped. Chain-of-custody documentation and procedures were followed. The equipment tested is being maintained in Packer Engineering secure storage.

Photographic and video documentation was performed on all equipment and components prior to and during testing. Protocols were developed, consistent with the following:

- NFPA 921, *Guide for Fire and Explosion Investigations* (2001).
- ASTM E860-97, *Standard Practice for Examining and Testing Items That Are or May Become Involved in Litigation* (1997).

Sections C.1 and C.2 summarize the findings and conclusions from Packer piping and equipment testing (Phase 1 to 3) and Crane-Powers oven temperature controller testing (phase 4).

C.1 Findings

1. The temperature controller memory was erased due to loss of power in the facility and failure of the backup battery.

2. The natural gas regulator for the oven 405 burner (Eclipse) had a measured output pressure of 11 inches of water column. The burner's fixed gas butterfly valve was set at 80 to 90 percent closed to reduce gas input. Recorded burner flow rates would give a heat rate of approximately 210,000 British thermal units per hour (Btu/hr).

3. All timers in the burner control panel were found at their minimum settings.

4. The audible alarm mounted to the cabinet door of the burner control box was not connected.

5. The high gas pressure cutoff switch was set at 5 psi.

6. The normally open solenoid gas bleed valve had a 0.7 liter per minute (L/min) leak-through rate when energized.

7. The electronics for the oil pump control box were mounted on a plywood base plate. Several knockouts and feed troughs were not adequately covered or strain-relieved. The intended dustproof National Electrical Manufacturers Association (NEMA) ratings of the burner control boxes would not be met under observed conditions.

8. The burner 405 oil pump was found to have no abnormalities beyond damage that can be attributed to excessive external heat.

9. No significant external gas leaks (into the building) were found.

10. All components found on the subject controller were consistent with a Type I-535, manufactured between 1990 and 1998, except the display assembly, which was found to be a design from the Type

II controllers, only manufactured after January 1, 1998. The Type II display assembly was re-fitted into a Type I harness and Type I operator fronts.

C.2 Conclusions

The Crane-Powers temperature controller, tested in phase 4, was reported to have lost all data due to loss of power and backup battery failure. It is not clear why the battery failed. The battery draws down whenever the controller is not powered and is not rechargeable. The Moore Industries controller technician estimated that the average life of the controller's battery was 5 years. If the date code on the controller display harness were consistent with controller and battery installation, then a battery with a life of 5 years likely would have expired prior to 2002.

In general, there are electrical incompatibilities between Type I and Type II assemblies, particularly the option board, the power supply board, and the microcontroller board. By design, these sub-components must be replaced in-kind in order for the controller to operate correctly. However, for the display assembly, electrical designs are compatible, in that the user may cross-populate between types to yield a workable solution. Testing during phase 4 determined that interchangeability between platforms is feasible and that the CTA temperature controller configuration did not present a significant failure mode with respect to controller integrity.

There were indications that the burner control box had been open or not properly sealed during operations and was open at the time of the explosion. Plant debris (i.e., fiberglass, dust, oily material) was present in the interior of the burner control panel and on the inside of the temperature controller, which was intended to be mounted within a NEMA-rated equivalent protected environment. The contamination may have contributed to the reported controller problems; there was some improvement in operation after the internal circuit boards were cleaned during phase 4 testing.

There were indications that the oven 405 burner was operating at a natural gas pressure below the manufacturer's minimum recommended level. The CTA plant was running the burner (Eclipse) at a maximum natural gas pressure of 11 inches of water column—which is below the minimum rate of 14 for this burner model. In addition, the burner's fixed gas butterfly valve was set at 80 to 90 percent closed to reduce gas input. Recorded flow rates indicate that the burner, with a maximum output rating of 5.5 million Btu/hr (at a maximum gas pressure of 2 psi at the proportionator inlet), was being operated at only 210,000 Btu/hr.

All timers on the burner control panel were found at their minimum settings—contradictory to the National Fuel Code, which requires a timed purge cycle prior to burner ignition.

The audible alarm mounted on the cabinet door of the burner control box (presumably for alerting operating personnel of conditions such as flameouts) was not electrically connected. Particulate matter was observed on the electronic components and the cabinet lip, where the door engages the cabinet. The amount of particulate matter indicated that the cabinet was open frequently during operation.

The high gas pressure cutoff switch was set too high to control an over-gas pressure situation. This setting allowed the feeding of excessive amounts of gas into the burner if a high-pressure situation occurred, such as failure of the pressure regulator.

The main gas line primary or safety valve (2-inch flanged, North American) was found with a loose actuator cover and showed debris accumulation on the upper mechanical parts (see Figure C-1). This dust, fiberglass, and oil contributed to the valve's failure to adequately close, thereby creating an internal leak in the gas line. During down time or "burner-off" conditions, the safety valve may have been leaking natural gas through to the gas vent line at the rate of 7.5 L/min.

In the "burner-on" condition with the gas control valves open and the normally open solenoid gas bleed valve closed, there was still a 0.7 L/min leak-through to the vent system from the bleed valve itself.

Therefore, at any given time, it was possible that there was continuous gas leakage through the gas vent lines.

The electronics for the oil pump control box were mounted on a plywood base plate. Several feed-throughs were inadequately sealed. Under observed conditions, the burner control boxes would not meet the intended dust-proof NEMA ratings. Failure to comply with these standards exposes the internal electronics to potentially damaging environmental conditions.

The burner 405 oil pump was found to have no abnormalities beyond the damage attributed to excessive external heat. There is no indication of failure or that the oil pump acted as an ignition or initiation source. If the pump had been operating at the time of the incident, the oil may have acted as an additional fuel source.

No significant external gas leaks into the building were found. All internal gas leaks (i.e., gas control valve, gas bleed valve) would have been directed to the externally piped gas vent line.

CSB reviewed these findings and conclusions and determined that equipment testing results identified no single component failure as the cause of the incident.

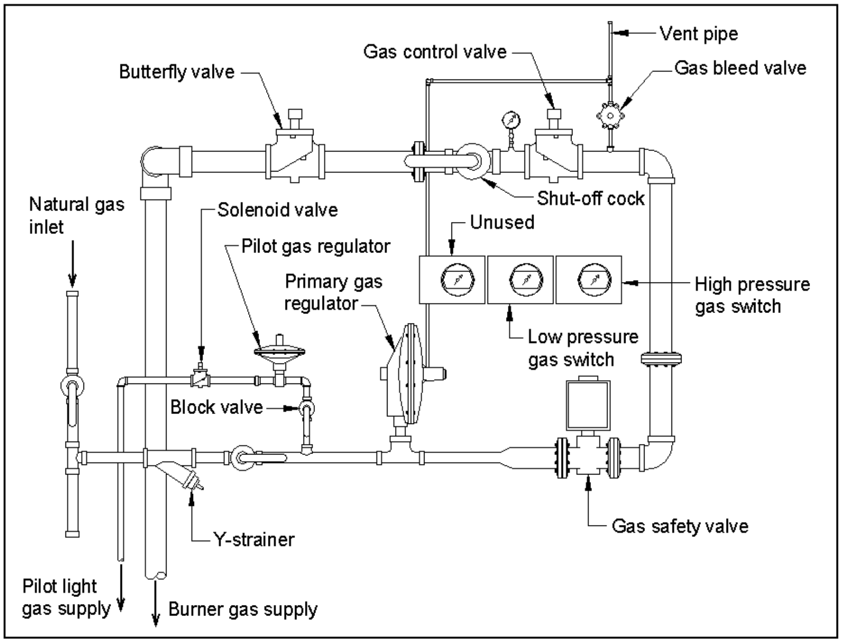


Figure C-1. Oven natural gas piping manifold.

APPENDIX D: NFPA Guidelines

In promoting the science and improving the methods of fire protection and prevention, NFPA develops codes and standards to reduce the loss of life, property, and production. Table D-1 lists NFPA standards relevant to controlling dust explosion hazards.

Although NFPA standards are advisory only, they are widely adopted by regulatory government agencies such as OSHA and state and local public authorities. Upon request, NFPA provides training and ongoing technical support to Federal, state, and local authorities that have adopted its codes and standards.

D.1 NFPA 654

NFPA 654, *Prevention of Fire and Dust Explosions From the Manufacturing, Processing, and Handling of Combustible Particulate Solids* (2000), addresses dust explosion prevention and mitigation for industrial facilities such as CTA. It was developed in 1943 and originally applied only to the prevention of dust explosions in the plastics industry. In 1976, NFPA expanded the scope of the standard to include chemical, dye, and pharmaceutical dusts, but a new edition of the standard was not issued until 1982. The standard was revised again in 1997 to include all industries where manufacture, processing, blending, repackaging, and handling of combustible dusts presented a fire or explosion hazard. NFPA 654 addresses safe design and construction, management of change, and housekeeping for facilities that handle combustible dusts—specifying that "areas in which combustible dusts are produced, processed, handled, or collected shall be detached, segregated, or separated from other occupancies in order to minimize damage from a fire or explosion."[28]

---

[28] NFPA 654 defines segregation as the interposing of a fire- and explosion-resistant barrier between the combustible particulate solid process and other operations. Separation is defined as the interposing of distance between the combustible particulate solid process and other operations in the same room.

Table D-1

NFPA Publications Relevant to Dust Explosion Hazard Control

NFPA Number	Title	Current Version	Original Version
61	*Prevention of Fires and Dust Explosions in Agricultural and Food Products Facilities*	2002	1923
68	*Venting of Deflagrations*	2002	1945
69	*Explosion Protection Systems*	2002	1970
70	*National Electric Code*	2002	1897
77	*Recommended Practice on Static Electricity*	2000	1941
86	*Ovens and Furnaces*	2003	86A–1950 86B–1971
120	*Coal Preparation Plants*	1999	653–1959
484	*Standard for Combustible Metals, Metal Powders, and Metal Dusts*	2002	480–1951 481–1958 482–1959 485–1994 651–1939
499	*Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*	2004	497M–1973 497A–1985
654	*Prevention of Fire and Dust Explosions From the Manufacturing, Processing, and Handling of Combustible Particulate Solids*	2000	1943
655	*Prevention of Sulfur Fires and Explosions*	2001	1939
664	*Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities*	2002	1931

D.2 Other Pertinent NFPA Codes

D.2.1 Oven Safety

The ignition of a dust cloud by a fire that spread from the line 405 oven is the most credible initiating event scenario (Section 7.1.1.2) for the CTA incident. NFPA 86, *Standard for Ovens and Furnaces* (2003), provides guidance for preventing fire and explosion hazards associated with the heat processing of materials in ovens. The standard addresses fire protection; safety equipment and applications; and inspection, testing, and maintenance.

D.2.2 Electrical Safety

NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas* (2004), provides guidance on acceptable protection techniques for electrical equipment or systems in hazardous (classified) locations that could ignite a dust cloud or layer. This standard designates hazardous locations where combustible dusts are present as Class II, Divisions 1 and 2,[29] as adopted from the National Electric Code (NFPA 70). NFPA 499 recommends that electrical installations be designed and enclosed in a "dust-ignition proof"[30] manner or otherwise pressurized or made intrinsically safe.

D.2.3 Explosion Venting and Explosion Suppression Systems

Confinement is one of the requirements for a dust explosion. (Figure 10 [Section 6.2] shows the dust explosion pentagon.) Review of the CTA facility design and assessment of facility damage indicate that the processing area had many confined areas.

---

[29] In Division 1, a combustible material is likely to be present continuously or intermittently under normal conditions of operation, repair, maintenance, or leakage. In Division 2, a combustible material is likely to be present under abnormal operating conditions, such as failure of process equipment or containers.

[30] "Dust-ignition proof" refers to enclosure that excludes dusts; such enclosure prevents arcs, sparks, or heat otherwise generated or liberated inside from igniting exterior accumulations or atmospheric suspensions of a specified dust on or in the vicinity of the enclosure.

“Confined” combustible dust operations can be designed to minimize damage potential or prevent explosions. NFPA 69, *Standard on Explosion Prevention Systems* (1997), and NFPA 68, *Guide for Venting Deflagrations* (2002), describe explosion venting as a means of mitigating or preventing a dust explosion. NFPA 68 states: “[B]y releasing expanding gases through an opening engineered for the purpose, it is possible to maintain a reduced maximum pressure that is below that which would cause unacceptable damage.” CSB investigators did not observe any explosion venting design or explosion prevention systems incorporated into the CTA production process or any of the facility structures.

APPENDIX E: HMIS Rating System

The National Paint and Coatings Association developed the Hazardous Materials Identification System (HMIS) in the early 1970s for use as an in-plant labeling system. The hazard rating system is conveyed in a rectangular-shaped box divided into four areas, each assigned a color and a numerical rating:

- Health hazard (blue)
- Flammability hazard (red)
- Reactivity hazard (yellow)
- Protective equipment (white).

The order of severity of each hazard is indicated by a numerical grading from “4,” indicating severe hazard or extreme danger, to “0,” indicating minimal hazard. HMIS uses a letter code (A to K) to recommend appropriate personal protective equipment to be worn when handling specific chemicals.

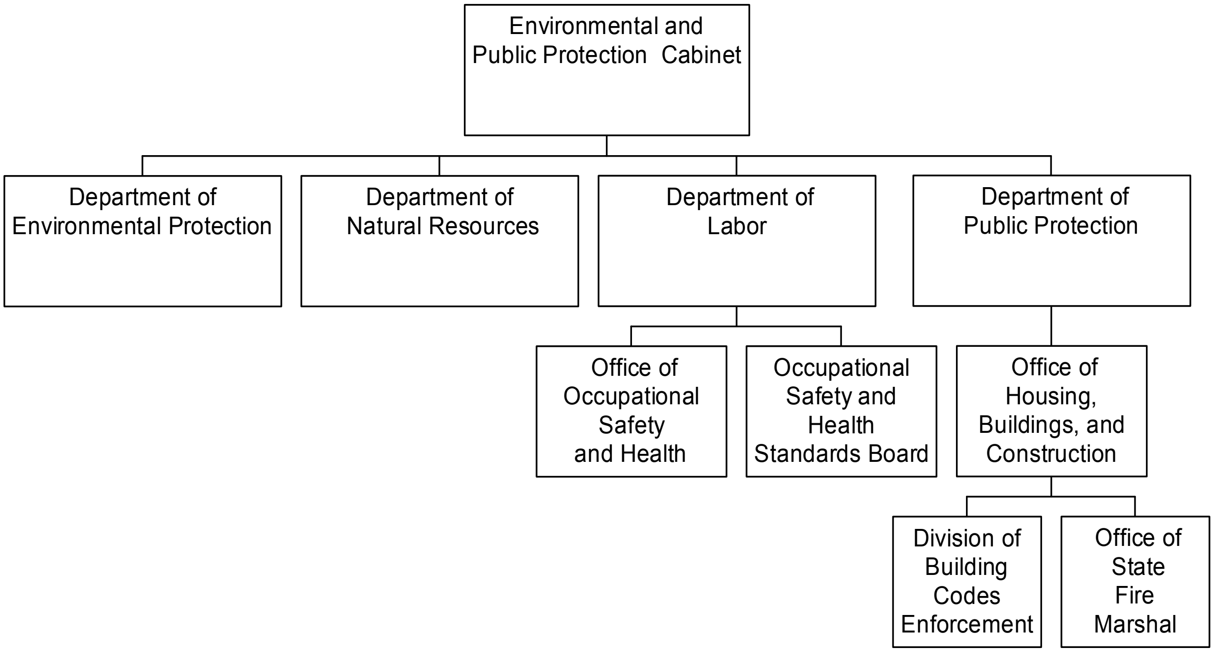
For the CTA investigation, the rating of interest is the flammability rating (Table E-1) assigned by Borden Chemical to its phenolic resins. The flammability rating of a material is based on ease of ignition.

Table E-1

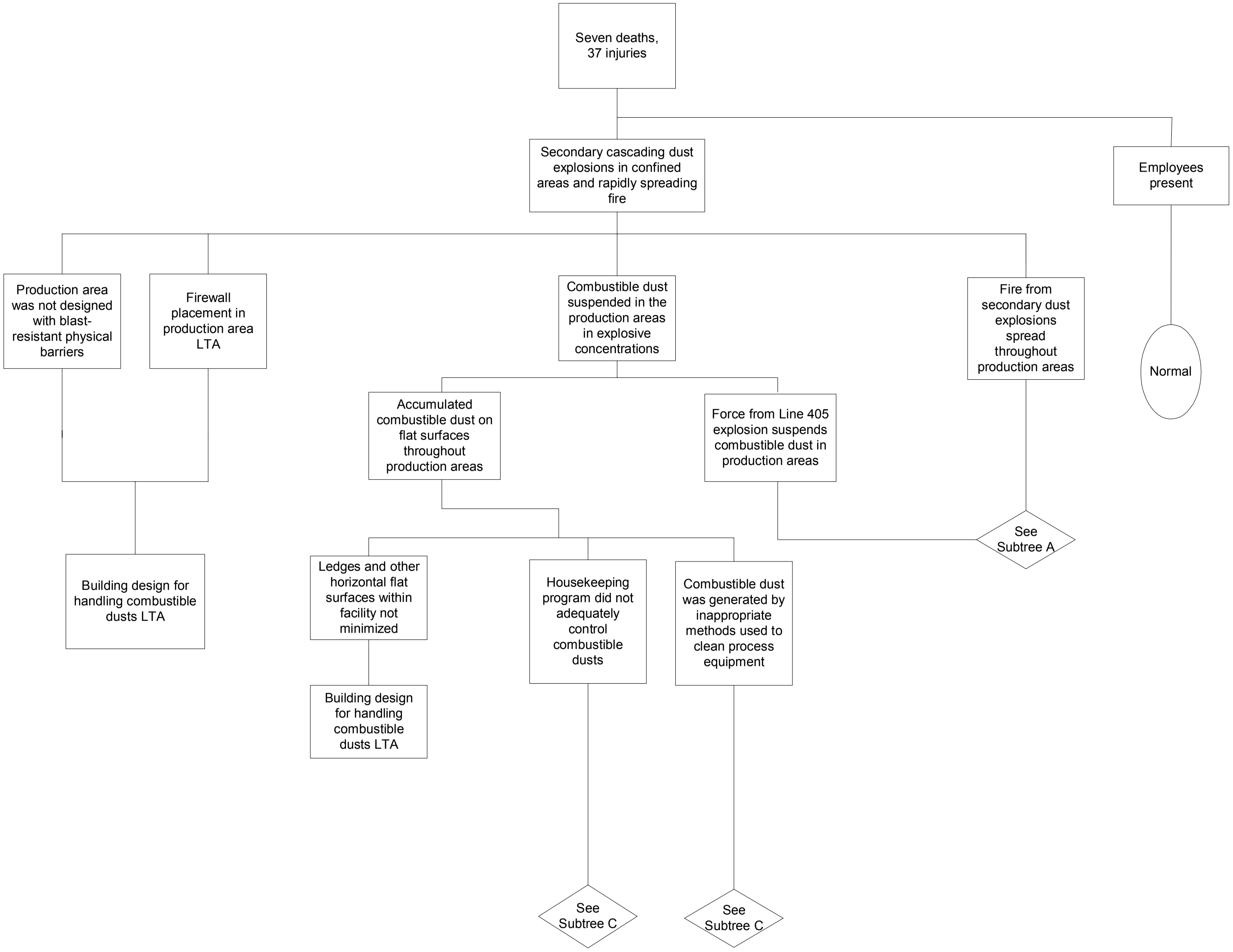
HMIS Defined Degrees of Flammability Hazard

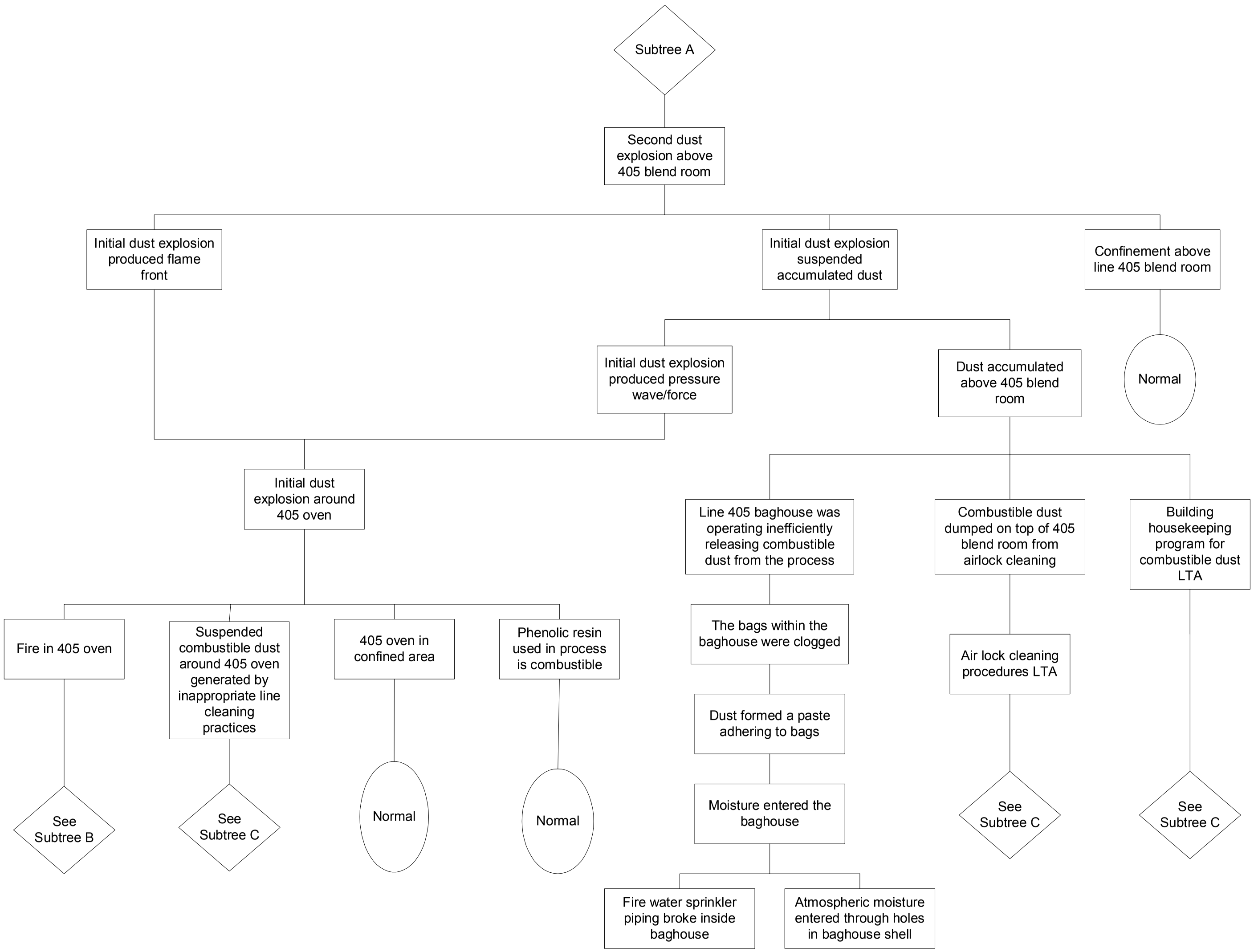
Flammability No.	Stability Criteria	Typically Includes
4 Severe	Materials that rapidly or completely vaporize at atmospheric pressure and normal ambient temperature, or that are readily dispersed in air and readily burn	Flammable gases Flammable cryogenic materials Any liquid or gaseous material that is liquid while under pressure and has a flash point below 73°F and a boiling point below 100°F (NFPA Class IA) Materials that ignite spontaneously in air
3 Serious	Liquids and solids that can be ignited under almost all ambient temperature conditions; materials that produce hazardous atmospheres with air under almost all ambient temperatures—or, unaffected by ambient temperatures, are readily ignited under almost all conditions	Liquids with a flash point below 73°F and a boiling point at or above 100°F (NFPA Class IB); also liquids with a flash point at or above 73°F and a boiling point below 100°F Materials that—because of physical form or environmental conditions—can form explosive mixtures with air and are readily dispersed in air, such as dusts of combustible solids and mists of flammable or combustible liquid droplets Materials that burn with extreme rapidity, usually by reason of self-contained oxygen (e.g., dry nitrocellulose and many organic peroxides)
2 Moderate	Materials that must be moderately heated or exposed to relatively high ambient temperatures before ignition; materials that would not under normal conditions form hazardous atmospheres with air, but under high ambient temperatures or moderate heating may release sufficient quantities of vapor to produce hazardous atmospheres with air	Liquids with a flash point at or above 100°F but not exceeding 200°F (i.e., NFPA Classes II and IIIA) Solid materials in the form of coarse dusts that may burn rapidly but generally do not form explosive atmospheres Solid materials in a fibrous or shredded form that may burn rapidly and create flash fire hazards, such as cotton, sisal, and hemp Solids and semisolids that readily give off flammable vapors
1 Slight hazard	Materials that must be preheated before ignition; materials that require considerable preheating for ignition or combustion under all ambient temperature conditions	Materials that burn in air when exposed to a temperature of 1,500°F for 5 minutes or less Liquids, solids, and semisolids with a flash point above 200°F (NFPA Class IIIB) Most ordinary combustible materials
0 Minimal	Materials that do not burn	Any material that does not burn in air when exposed to a temperature of 1,500°F for 5 minutes

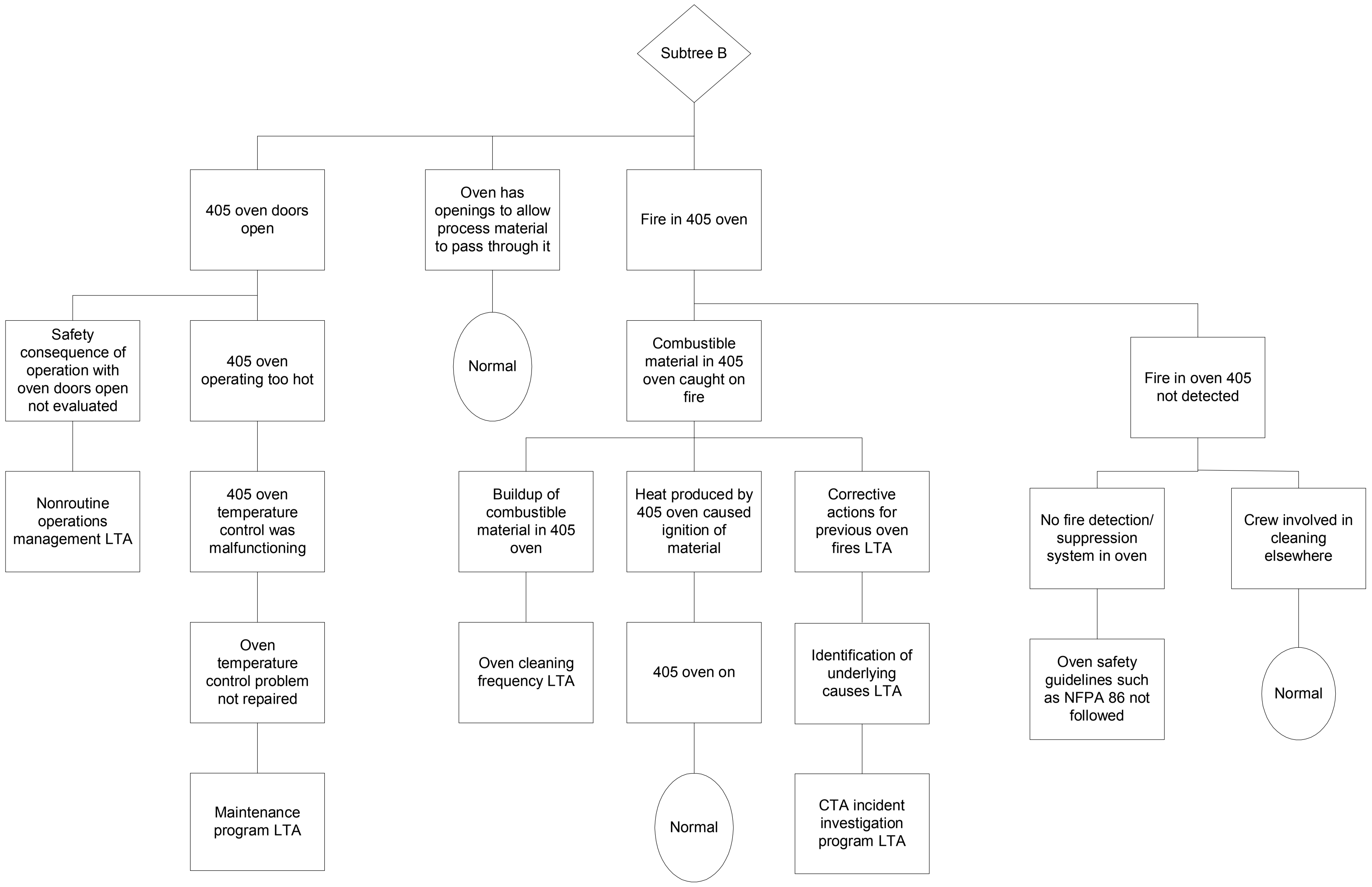
APPENDIX F: Simplified Organization Chart (Kentucky Environmental and Public Protection Cabinet)

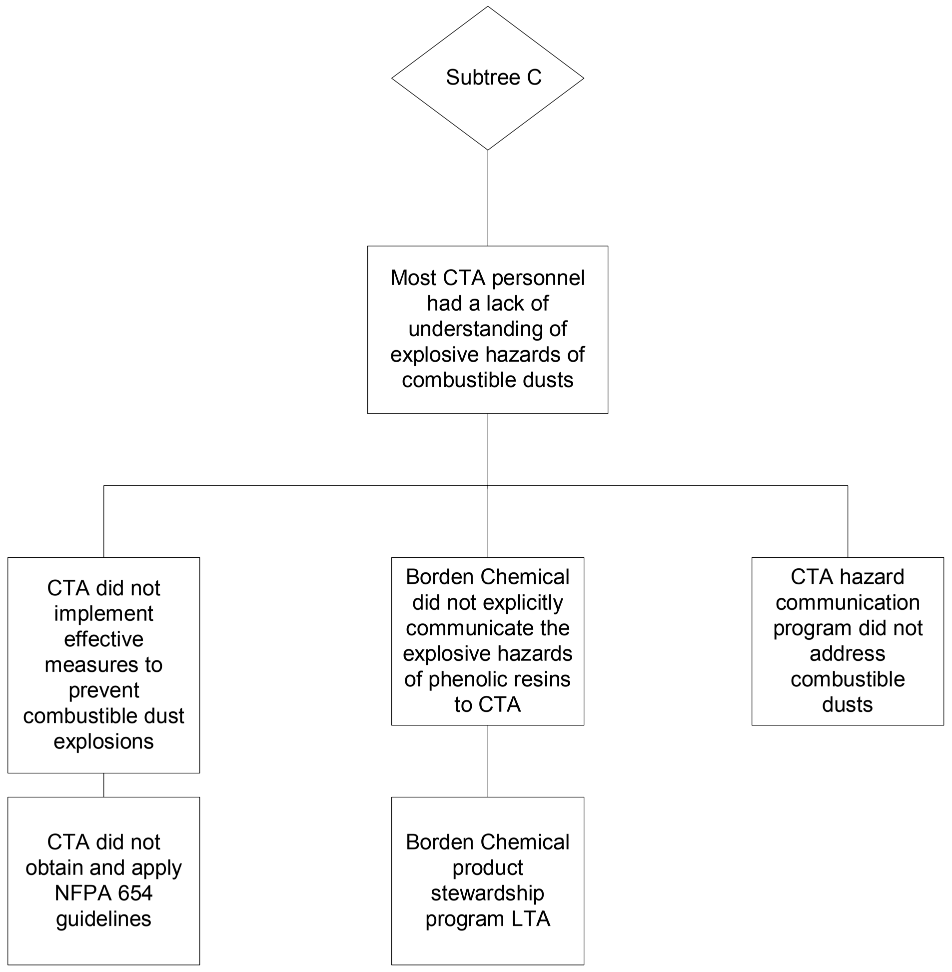


APPENDIX G: Logic Tree Diagram




Subtree A
Second dust explosion above 405 blend room
Initial dust explosion produced flame front
Initial dust explosion suspended accumulated dust
Confinement above line 405 blend room
Initial dust explosion produced pressure wave/force
Dust accumulated above 405 blend room
Normal
Initial dust explosion around 405 oven
Line 405 baghouse was operating inefficiently releasing combustible dust from the process
Combustible dust dumped on top of 405 blend room from airlock cleaning
Building housekeeping program for combustible dust LTA
Fire in 405 oven
Suspended combustible dust around 405 oven generated by inappropriate line cleaning practices
405 oven in confined area
Phenolic resin used in process is combustible
The bags within the baghouse were clogged
Air lock cleaning procedures LTA
Dust formed a paste adhering to bags
Moisture entered the baghouse
See Subtree B
See Subtree C
Normal
Normal
See Subtree C
See Subtree C
Fire water sprinkler piping broke inside baghouse
Atmospheric moisture entered through holes in baghouse shell


Subtree B
405 oven doors open
Oven has openings to allow process material to pass through it
Fire in 405 oven
Safety consequence of operation with oven doors open not evaluated
405 oven operating too hot
Normal
Combustible material in 405 oven caught on fire
Fire in oven 405 not detected
Nonroutine operations management LTA
405 oven temperature control was malfunctioning
Buildup of combustible material in 405 oven
Heat produced by 405 oven caused ignition of material
Corrective actions for previous oven fires LTA
No fire detection/ suppression system in oven
Crew involved in cleaning elsewhere
Oven temperature control problem not repaired
Oven cleaning frequency LTA
405 oven on
Identification of underlying causes LTA
Oven safety guidelines such as NFPA 86 not followed
Normal
Maintenance program LTA
Normal
CTA incident investigation program LTA


Subtree C
Most CTA personnel had a lack of understanding of explosive hazards of combustible dusts
CTA did not implement effective measures to prevent combustible dust explosions
Borden Chemical did not explicitly communicate the explosive hazards of phenolic resins to CTA
CTA hazard communication program did not address combustible dusts
CTA did not obtain and apply NFPA 654 guidelines
Borden Chemical product stewardship program LTA