U.S. Chemical Safety and Hazard Investigation Board

AL Solutions, Inc., New Cumberland, WV
Metal Dust Explosion and Fire

December 9, 2010

Three Killed, One Injured

No. 2011-3-I-WV

KEY ISSUES

- Federal Combustible Dust Oversight
- Hazard Recognition and Training
- Learning from Previous Incidents

INSIDE

This case study examines a metal dust explosion and fire at the AL Solutions facility in New Cumberland, West Virginia. The incident resulted in three employee fatalities and one contractor injury. The explosion and ensuing fire damaged the production building and ultimately caused the shutdown of the plant.

DEDICATION

This case study is dedicated to the three men who lost their lives as a result of the AL Solutions incident on December 9, 2010.

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1.0 INTRODUCTION

1.1 AL SOLUTIONS, INC.

AL Solutions processes titanium and zirconium scrap metal into pressed compacts[1] that aluminum producers use as alloy additives. AL Solutions obtains scrap from titanium and zirconium manufacturers, and the end user adds the pressed compacts to furnaces or molten metal to increase the strength of aluminum alloys.

In 2006, AL Solutions purchased Jamegy, Inc., a metal producer based in New Cumberland, West Virginia. Jamegy founded the New Cumberland facility and operated it before AL Solutions.

At the time of the incident, AL Solutions owned and operated two processing facilities. The primary office and production facility was located in New Cumberland, West Virginia. AL Solutions also has a facility for milling in Washington, Missouri. In 2010, AL Solutions employed 23 workers at the New Cumberland facility and two at the Washington facility. After the 2010 incident, AL Solutions constructed a new manufacturing facility in western Pennsylvania, projected to be fully operational by 2015.

1.2 FACILITY DESCRIPTION

The New Cumberland facility (shown in Figure 1) lies on the east bank of the Ohio River in the Northern Panhandle of West Virginia, approximately 40 miles west of Pittsburgh, Pennsylvania. The New Cumberland site contains a main production facility (now idle), warehouse, outside storage area, laboratory, and office area.[2]

FIGURE 1

Overhead View of AL Solutions New Cumberland Facility Before the 2010 Incident (photograph courtesy of Google Earth)

[1] AL Solutions compacts are densely compressed titanium and zirconium pucks (or disks) measuring approximately 3 inches in diameter and 1 to 2 inches in thickness. The compacts vary in size and weight, depending on customer specifications.

[2] As of the publication date of this case study, production at the New Cumberland facility remains idle as a result of the 2010 incident. Warehousing and office activities still take place at the facility.

The New Cumberland production facility operated 24 hours a day, 7 days a week, and contained processing equipment for metal milling, blending, pressing, and water treatment. Separated from the warehouse and office area by an access road, the production building was the site of the December 2010 explosion.

2.0 PROCESS DISCUSSION

A variety of suppliers shipped scrap titanium and zirconium to AL Solutions in 55-gallon drums (Figure 2). The metal typically arrived packed in water, but it also was packaged with salt or an inerting agent, such as argon gas, to reduce the risk of explosion during transit.

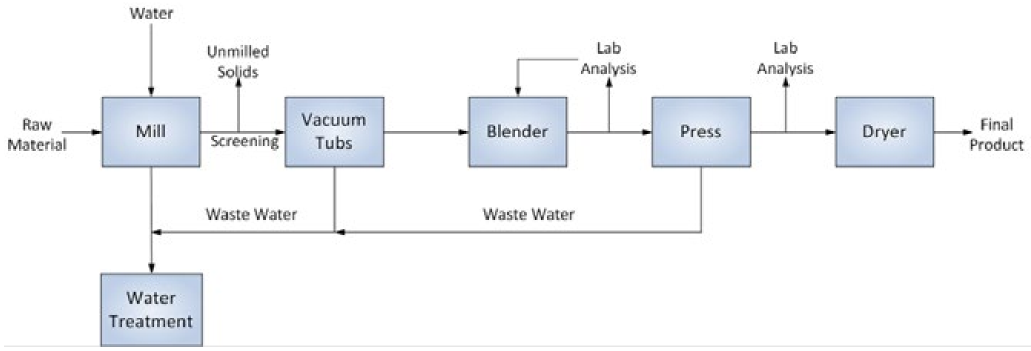
FIGURE 2

Sample of Titanium Raw Material

AL Solutions took the raw material from the drums and milled it for several hours in a batch (or lot) while submerging it under water. During milling, a blade reduced the metal particle size and removed the oxide surface layer of the raw material. When milling was completed, operators decanted[3] the water and some fine metal particulates (known as fines) and then sent the water to treatment tanks (Figure 3).

FIGURE 3

Simplified Process Flow Diagram of Press Operations at the New Cumberland Facility



The milled metal was transferred from the milling tank and screened to remove any large solids. These solids were either returned to the mill for further size reduction or discarded. Operators placed the milled and screened metal in tubs and then vacuumed excess water into water treatment tanks. Next, operators blended the metal to ensure uniform composition in the lot.

Once the material met the laboratory specifications, it proceeded to the hydraulic presses. The blended material was pressed into 3-inch-diameter compacts (Figure 4). At the time of the incident, one press was used to press zirconium compacts, and two presses were used for titanium compacts. An oven dried the compacts to remove any remaining water. The laboratory analyzed the density and percent moisture of two compacts from each dryer lot before the compacts were wrapped in aluminum foil and sent to the customer.

[3] Decanting is a process that removes a liquid or solution from a vessel while leaving any solids undisturbed.

FIGURE 4

Samples of Zirconium Compacts

On a typical shift, four operators worked in the production building: two press operators, one blender operator, and the shift supervisor. The shift supervisor was in charge of the mill and water treatment. Another operator worked in the warehouse to dry and wrap the compacts. During the day, the plant manager and an engineer responsible for operations were onsite to assist with any operational issues. During the day shift, two laboratory workers analyzed the blended samples and created recipes for the blenders.

2.1 TITANIUM

Titanium (symbol Ti) is a widely used metal with unique flammability characteristics. Fine titanium particulates are easily ignited in air and can ignite spontaneously at elevated oxygen concentrations or high pressures.[4] According to the Hazardous Materials Identification System (HMIS),[5] titanium fines and powders have a flammability hazard rating of 3 or 4 (on a scale of 0 to 4, with 4 the highest hazard).[6] The AL Solutions titanium swarf[7] materials safety data sheet (MSDS) states that titanium particles dispersed in a cloud can explode.[8] The MSDS recommends having procedures in place to keep the powder away from static discharges, sparking equipment, and other ignition sources. Class D sodium chloride extinguishers are intended for use on combustible metal fires involving titanium and zirconium. The MSDS also states that large quantities of water can be used to quench small titanium fires but water should not be used on large fires because water can react with the burning metal at high temperatures to produce explosive hydrogen gas.

Titanium powder has low toxicity, but excessive inhalation can cause respiratory irritation or acute respiratory distress. The primary route of exposure is inhalation and ingestion, especially during processes that produce metal particulates.

2.2 ZIRCONIUM

The metal zirconium (symbol Zr) also carries a significant flammability hazard. Zirconium particulates have an HMIS flammability hazard rating of 3 or 4 (on the scale of 0 to 4), and small particle-sized material (with less than 2% moisture)[9] can autoignite in air at room temperature. According to the AL Solutions zirconium MSDS, dust clouds with very small concentrations of zirconium (less than 100 g/m^3) are explosible. The MSDS recommends

[4] *DOE Handbook: Primer on Spontaneous Heating and Pyrophoricity*; DOE-HDBK-1081-94; U.S. Department of Energy: Washington, DC, December 1994.

[5] HMIS is a hazardous materials rating system developed by the American Coatings Association to identify health, flammability, and physical hazards associated with chemicals. The hazard ratings are similar, but not identical, to National Fire Protection Association (NFPA) ratings.

[6] Under the HMIS rating system, a flammability hazard rating of 3 is assigned to materials capable of ignition under almost all normal temperature conditions.

[7] Swarf is a waste product of machining titanium and consists of fine ribbons and particles of titanium in a steel wool–like form. Pape, Ronald; Schmidt, Fredick. Fires and Explosions: Combustibility Analysis of Metals. *Advanced Materials and Processes* 2009, 167 (11/12), 41.

[8] Titanium metal can be explosive if the particles can pass through a 100-mesh sieve (that is, less than 150 microns) and are suspended at a concentration greater than or equal to approximately 43 g/m3. *Titanium*; MSDS AL Solutions: New Cumberland, WV.

[9] Zirconium particulate ignition data are available in several sources. (1) Cooper, *Review of Zirconium-Zircaloy Pyrophoricity*; Rockwell International Report; Rockwell International:1984. (2) Matsuda,Yashima, *Ignition Characteristics of Zirconium Dust*; Japanese National Institute for Industrial Safety Report; Japanese National Institute for Industrial Safety: Japan, 2000. (3) *NFPA 484: Standard for Combustible Metals*; National Fire Protection Association (NFPA): Quincy, MA, 2012 and references therein.

keeping the powder wet to avoid explosion hazards. If zirconium metal particulates ignite, the MSDS advises letting the material burn out and not fighting the fire; the MSDS also notes that fires in wet metal zirconium fines can result in an explosion. The MSDS recommends keeping zirconium fines either extremely dry (less than 5 percent water) or extremely wet (more than 25 percent water). Spontaneous explosions of moist, finely divided zirconium scrap have occurred during handling.[10] Zirconium powder can cause respiratory and digestive irritation if inhaled or ingested.

3.0 INCIDENT DISCUSSION

3.1 OPERATIONS AT THE TIME OF THE INCIDENT

Around noon on the day of the incident, the day shift operators returned to work from lunch. Two operators were running the three presses making titanium and zirconium compacts, and another operator was at the blender, mixing a batch of zirconium. The shift supervisor was changing the mill blade in the adjacent milling room.

Three electrical contractors were also onsite, running conduit in a hydraulic room adjacent to the blending and press room. These contractors were performing preparatory work for a maintenance outage planned for the next day.

3.2 INCIDENT DESCRIPTION

At about 1:20 p.m., immediately before the explosion, an electrical contractor located about 6 feet outside a partially open door heard a loud noise that he characterized to U.S. Chemical Safety and Hazard Investigation Board (CSB) investigators as a "metallic failure … like something popped … or fell." He then heard a "woof ... just how you'd light your gas grill" and "a big boom." The shift supervisor in the mill room heard a loud bang and seconds later noticed an orange glow or flame coming from the blending and press room. At about the same time, a second electrical contractor working in the hydraulic room heard an explosion in the neighboring blending and press room and then saw a fireball moving rapidly into the hydraulic room through the blending and press room door. The fireball burned his head, neck, arms, and hand as he exited the production building. The third electrical contractor was in the restroom, where he heard "an angry noise," felt a strong wind enter through a door, and then saw orange sparking flame at the ceiling.

The shift supervisor told CSB investigators that he noticed the "air was sparking" after the explosion. He had previously experienced this phenomenon at AL Solutions and knew that it signified airborne metal was burning. After the explosion, the supervisor ran outside and around the production building. At about this time, employees in the main office building, who heard the explosion, called 911 to request emergency assistance. The plant manager was walking from the warehouse to the production building at the time of the explosion and witnessed the event. Some employees and contractors reported hearing a second explosion minutes after the initial explosion, which might have been caused by a propane tank rupture from a forklift inside the building.

The explosion and fire severely burned the zirconium press operator. The supervisor, an electrical contractor, and the plant manager provided aid to the press operator until emergency personnel arrived. During this time, employees realized that two other operators were missing and presumably in the burning building.

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[10] *DOE Handbook: Primer on Spontaneous Heating and Pyrophoricity*; DOE-HDBK-1081-94; U.S. Department of Energy: Washington, DC, December 1994, p 30.

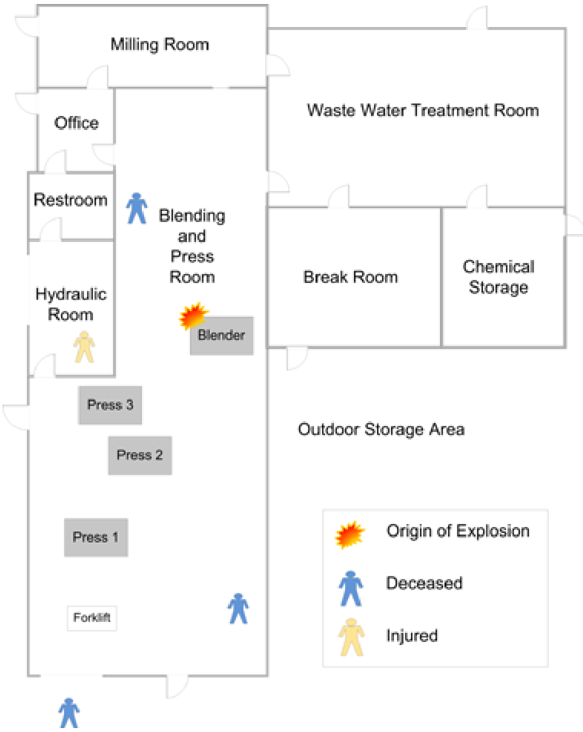
FIGURE 5

Production Building Exterior, with Firefighters on Scene (photograph courtesy of the New Cumberland Police Department).

A nearby volunteer firefighter heard the explosion and immediately proceeded to the scene. The New Cumberland Volunteer Fire Department (VFD) arrived minutes later (as depicted in Figure 5). At approximately 2:30 p.m., an airlift transported the injured contractor to a hospital. By the time the VFD arrived, the building water deluge system had activated. The firefighters attempted to access the building through the office, but the fire was too intense, and they could not enter. Upon entering the original explosion area, firefighters discovered two deceased operators at the inside locations indicated in Figure 6.

FIGURE 6

Main Production Building Layout, Likely Initiation Point of the Incident, and Worker Injury and Fatality Sites



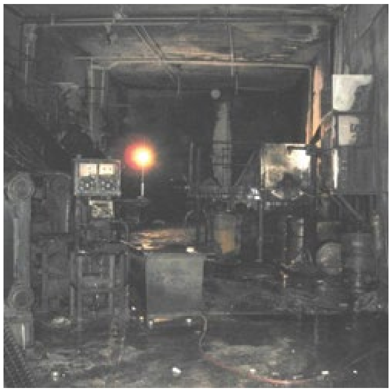
The two operators in the blending and press room died at the scene, and the zirconium press operator died three days following the incident from severe burn injuries. The explosion and subsequent fire caused minor blast damage to doors, walls, and interior windows as well as more substantial thermal damage throughout the production area (illustrated in Figure 7). The explosion caused thermal damage to the wall and overhead ceiling area adjacent to the blender (shown in Figure 8). Equipment damage included a lift truck, the blender, and the press feed conveyor. The explosion propelled papers, desks, and lockers from the office into the parking lot outside of the production building.

FIGURE 7 (LEFT)

North End of Blending and Press Room

FIGURE 8 (RIGHT)

Ceiling in Blending and Press Room



4.0 ANALYSIS

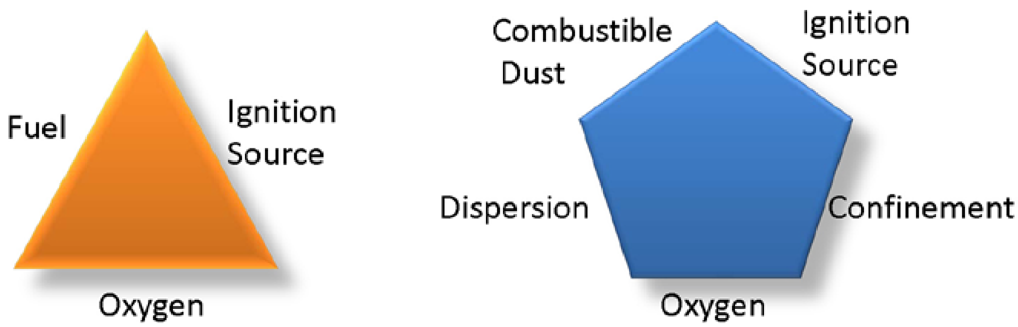
CSB investigators observed and documented the production building after the incident and concluded that the fire damage and deformations caused by the explosion overpressure were consistent with a metal dust explosion. Most solid organic materials (and many metals and some nonmetallic inorganic materials) will burn or explode if finely divided and dispersed in sufficient concentrations. Even seemingly small quantities of accumulated dust can cause catastrophic damage.[11]

Like all fires, a dust fire occurs when fuel (the combustible dust) is exposed to energy (an ignition source) in the presence of oxygen (typically from air). Removing any one of these elements of the classic fire triangle (depicted in Figure 9) eliminates the possibility of a fire.

A dust explosion requires the simultaneous presence of two additional elements: dust dispersion and confinement (as shown in the dust explosion pentagon in Figure 9). Suspended dust burns rapidly, and confinement enables pressure buildup. Removal of either the suspension or the confinement element can prevent an explosion, although a dust fire can still occur.

FIGURE 9

Classic Fire Triangle and the Dust Explosion Pentagon



[11] Combustible Dust Hazard Study; U.S. Chemical Safety and Hazard Investigation Board: Washington, DC, 2006.

4.1 EXPLOSION ORIGIN

Metal particulates or dusts can produce a flash fire or explosion, using metal as the fuel and air as the oxidizer. As metals become finely divided in milling, blending, or crushing operations, freshly exposed surfaces on the fines or dust particles can become highly reactive. Finely divided metals such as titanium and zirconium can become pyrophoric[12] and spontaneously combust in air.[13]

The AL Solutions explosion likely initiated when particulates ignited in the blender that was processing zirconium. Sparks or heat produced by metal-to-metal contact between the blender blades and the blender sidewall ignited the zirconium. Mechanical impacts, such as the blender blades against the sidewall, can produce potential ignition sources where metal-to-metal contact occurs. In rotating machinery, repeated impacts can result in hot spots with temperatures high enough to result in ignition.[14]

The pre-explosion sound of metal failure or popping reported by AL Solutions employees likely originated in the blender, which showed evidence of the most substantial metal deformation after the incident. Both endwalls were deformed inward and had visual indications of the blade scraping or scoring on the wall (Figure 10). Residual burned zirconium was detected in the blender beneath the shaft. Severe burn damage was also seen in the press on the other side of the production room (shown in Figure 11) and there were indications of two adjacent cracks in one of the blender sidewalls. Investigators examined the production building wall and ceiling adjacent to the blender and found visual evidence of a burning dust cloud projected upward toward the ceiling (displayed in Figure 12).

FIGURE 10 (LEFT)

Zirconium Blender Wall Deformation and Scoring (circled)

FIGURE 11 (RIGHT)

Press Blade Damage

FIGURE 12

Blender and the Adjacent Wall and Ceiling

Investigators examined the production building wall and ceiling adjacent to the blender and found visual evidence of a burning dust cloud projected upward toward the ceiling (displayed in Figure 12).

AL Solutions employees noted mechanical problems with the blender in the days before the explosion. Blender paddles were striking the sidewall of the

[12] Pyrophoric materials are substances that ignite instantly when exposed to oxygen. They can also be water-reactive, producing heat and hydrogen.

[13] Pape, Ronald; Schmidt, Fredick. Fires and Explosions: Combustibility Analysis of Metals. *Advanced Materials and Processes* 2009, 167 (11/12), 41.

[14] Eckhoff, Rolf K. *Dust Explosions in the Process Industries*; 3rd Ed.; Elvsevier Science: Burlington, MA, 2003; p 64.

blender and scoring the housing. To address these problems, maintenance personnel adjusted the blender blades to increase clearance from the blender wall, but this action did not permanently address the issue with the metal-to-metal contact. When the problem returned, maintenance personnel decided to replace parts of the blender in an effort to resolve the issue. While the operators were disassembling the blender, they discovered a large groove cut in the shaft and an 8-inch to 12-inch crack in the sidewall of the blender, most likely caused by the paddle blades scraping the sidewall. The maintenance worker welded this crack, and operators continued to use the blender.

On the morning of the incident, an operator requested that maintenance replace a worn paddle in the blender. A maintenance employee retrieved a paddle from an old blender and attached it to the blender in the production building about two hours before the incident. All of the maintenance performed on the blender only temporarily addressed the problems caused by the metal-to-metal contact, such as the scoring on the sidewall and worn paddles. AL Solutions did not repair or replace the blender to avoid exposing combustible metal dusts to sparks or heat produced by the mechanical impact from the paddles.

On the basis of production operations at the time of the incident, the blender likely contained a substantial quantity of zirconium. Indications of burned residue and char on the ceiling above the blender (shown in Figures 7 and 8) and the presence of burning deposits on the wall behind the blender suggest that the burning zirconium particulates lofted from the blender after the initial explosion, engulfing the room in fire. After the incident, the blender lid, intended to be closed during production, was found left in the open position. The scraping of the blender blades against the sidewalls of the blender likely ignited the zirconium powder early in the incident sequence. The cloud of combustible zirconium resulted in a deflagration.[15] Hot gases expanded, producing the "woof" or "wind" observed by two witnesses. The burning zirconium dust cloud also ignited open drums and tubs of titanium and zirconium at several locations in the production building, propagating the fire.

4.1.1 CSB Combustible Dust Testing

The CSB commissioned combustible dust testing of materials from the AL Solutions facility to determine whether the metal powder contributed to the fire and explosion. CSB investigators collected titanium and zirconium particulate samples for testing, both from drums of raw (received) materials and from in-process materials stored in drums. The testing determined that zirconium and titanium samples in use at AL Solutions were combustible and could produce a fire or metal dust deflagration. These results are consistent with other industry tests of small particle titanium explosibility.[16] The samples were first analyzed for metal composition, moisture content, and particle size and shape. The results for metal composition are shown in Figure 13. Other materials were present in the samples, but the results of the metal composition test are as expected based on MSDS information and AL Solutions batch recipes.

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[15] A deflagration is the combustion of a fuel-air mixture that occurs with a flame propagating through the mixture at a speed less than the speed of sound. Most dust explosions and flash fires are deflagrations.

[16] Boilard, S.P., Amyotte, P.R., Khan, F.I., Dastidar, A.G. and Eckhoff, R.K., "Explosibility of Micron- and Nano-Size Titanium Powders", Journal of Loss Prevention in the Process Industries, **26**, 1646-1654 (2013).

FIGURE 13

Sample Metal Composition

	Ti Samples Percent Weight (%)	Zr Samples Percent Weight (%)
Zirconium	0.4	96.0
Titanium	93.5	1.5
Vanadium	4.5	0.2
Iron	0.6	1.0
Other Metal	1.0	1.3

Explosibility testing of the samples collected at AL Solutions showed that some of the titanium and zirconium dusts were combustible (Appendix A).[17] The dust samples listed in Figure 14 were all found to be combustible, and the zirconium sample meets the characteristics of Class II combustibility. Combustible dust is dust that will burn and Class II combustible dusts possess a higher explosion severity ratio.[18] The Occupational Safety and Health Administration (OSHA) requires dust-ignition-proof electrical equipment where Class II combustible dusts are present. The AL Solutions production building equipment had ignition-proof enclosures on motors and electrical wiring to prevent dusts in the production atmosphere from igniting because of electrical arcs and heat produced by moving parts or mechanical impacts. The metal-to-metal contact occurring in the blender posed a similar hazard, and it was open to the production atmosphere, where combustible dusts were present.

FIGURE 14

Dust Combustibility Testing Results

Dust Sample	Classification
Titanium #1	Combustible, but not Class II
Titanium Mixture	Class II Combustible
Zirconium Crush Pellet	Combustible, but not Class II

4.2 AL SOLUTIONS DUST MANAGEMENT PRACTICES

CSB investigators learned through interviews that AL Solutions employees were generally aware that the metal dust was combustible and that a spark on the metal could cause a fire. In 2007, AL Solutions hired a laboratory to conduct burning rate testing[19] on samples of zirconium and titanium scrap, sludge, and fines. The testing indicated that zirconium sludge and titanium scrap would propagate combustion and have a burning rate high enough to be considered "ignitable."[20]

The AL Solutions safety manual listed several requirements for safe storage and handling of titanium and zirconium. However, the CSB found that management did not enforce these requirements. AL Solutions and the previous owner designed and installed production

[17] This result is based on the Class II test for explosion severity: (1) National Materials Advisory Board (NMAB). *Classification of Combustible Dusts in Accordance with the National Electrical Code*; NMAB 353-3-80; NMAB: 1980. (2) ASTM. *Go/No-Go Test for Combustibility*; ASTM E1226; ASTM: West Conschohocken, PA, 2009.

[18] Class II combustible dusts have an explosion severity ratio greater than or equal to 0.5 or ignition sensitivity ratios greater than or equal to 0.2. From NMAB 353-3-80 "Classification of Combustible Dusts in Accordance with the National Electrical Code"

[19] U.S. Environmental Protection Agency (EPA). *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*; EPA-SW-846; U.S. Government Printing Office: Washington, DC; 1996. See Method 1030.

[20] Ignitable solids can create fires under certain conditions and are spontaneously combustible with a flash point less than 60°C (140°F). The term ignitable is typically used to refer to solid hazardous wastes. U.S. Environmental Protection Agency (EPA). *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*; EPA-SW-846; U.S. Government Printing Office: Washington, DC; Third Edition.

equipment with enclosures intended to limit the accumulation of combustible metals on external surfaces. The blender and the press conveyor had metal lids, and the plan was to leave the lids closed whenever possible to isolate the equipment and prevent dispersion of dust. Management did not enforce this practice at the facility, and the blender, conveyor belt lid, and storage drums were regularly left open during operation. In addition, to limit the quantity of flammable metal in the blending area, only metal currently in production was to be allowed in the production area. All other material was to be kept in a separate warehouse or in outside storage. However, AL Solutions employees commonly left barrels of titanium and zirconium in the production building, even if they were not in use (illustrated in Figure 15).

AL Solutions also did not enforce industrial hygiene practices related to handling metal dusts, although this lack of action was not causal to the incident. The AL Solutions titanium and zirconium MSDSs recommended using a high-efficiency particulate respirator when handling the materials, but management did not enforce the requirement.

FIGURE 15

Drums of Titanium and Zirconium Particulates near Blender

4.2.1 Controlling Dust Accumulations

AL Solutions management had procedures in place to remove dust and to control fire and explosion hazards at the facility. Operators used spark-resistant tools and wore 100 percent cotton clothes, which, although not flame resistant, were intended to reduce the risk of sparks from metal-to-metal contact or static electricity. No open flames were allowed in the production building, and all smoking was restricted to an area outside the break room. The electrical equipment in the production building was designed to reduce the chance of an explosion. Motors in the production room were designed to not provide an ignition source for any metal present.

AL Solutions regularly washed down the equipment with water as its primary means to eliminate dust from process equipment and areas. This approach was intended to keep the metal powder damp and to remove any accumulated powder on process surfaces. All process equipment, walls, and floors were intended to be washed at regular intervals with the hoses available in the production building. AL Solutions expected operators to clean their areas and equipment at the end of every shift, whenever any metal accumulated, or when any equipment was changing from handling titanium to processing zirconium. Operators washed metal powder to the floor and then into troughs that ran along the floor of the production building, and they cleaned these troughs weekly. AL Solutions did not use a dust collection system to remove zirconium and titanium dusts generated during processing, as recommended by industry standards for the safe handling of combustible metal dusts and powders (discussed in Section 5.0). AL Solutions instead relied on the use of water as the only method to eliminate dust fires and explosions by keeping dust moist and avoiding dust accumulation on equipment and flat surfaces.

In the event of a metal fire, the AL Solutions safety manual instructed operators to evacuate the building, alert management, and call the fire department. The AL Solutions Emergency Plan recommended that employees avoid fighting metal dust fires with fire extinguishers, but noted that operators could attempt to fight nonmetal incipient fires with a fire extinguisher. The AL Solutions facility was not equipped with Class D fire extinguishers appropriate for fighting metal fires, so the company instructed its personnel to let metal fires burn and wait for the fire department.

4.2.1.1 Water Deluge System

The main production building had a water deluge system that was set to activate upon detection of high temperatures or high concentrations of hydrogen gas. Sensors located in the blender and press feed belt conveyor system would activate the deluge of water if readings reached a designated alarm point (illustrated in Figure 16). Operators also could manually activate the deluge system by turning a valve located in the blending and press room.

FIGURE 16

Hydrogen Sensing Port at the Top of the Press 2 and 3 Conveyor Belt (post incident)

4.2.1.2 Safety Audits

The CSB found that facility safety and insurance audits did not adequately identify and address metal dust hazards at the New Cumberland facility. Jamegy, the previous owner of the facility, engaged a consultant to conduct a risk assessment of the Jamegy titanium process in 1998 and 2006. The purpose of the risk assessments was to identify events that could cause fatalities or major equipment damage at the site. Fires and explosions due to titanium or zirconium dust ranked among the major events considered during these assessments. In both 1998 and 2006, the consultant recommended that Jamegy acquire an automatic fire control system for the blender and press equipment to augment the water deluge system on the ceiling of the production building. Both risk assessments also recommended audits to address the accumulation of metal powder in the press and blender area. Although the risk assessments considered the risk that water pouring onto burning metal could generate an explosion, the consultant made no recommendations to address the presence of the automatic water deluge fire suppression system in the production area.

The AL Solutions property risk insurer conducted insurance audits at the AL Solutions facility in 2008 and 2009. These insurance audits recognized the hazards posed by titanium and zirconium dust. However, the resulting audit reports show that the insurance companies considered the AL Solutions dust control methods of washing down the metal powder to be acceptable. The 2008 audit commended the facility on its “wet process producing no dust.” The 2009 audit declared that incidents are effectively controlled by “good housekeeping,” “established raw material storage practices,” and “water added during manufacturing process to control dust.” The fire protection system is also mentioned as good process control, despite the fact that it is not advisable to use water to fight a titanium or zirconium fire.

The audits reference a 2006 incident (summarized in Section 4.3.3) when metal dust ignited inside a milling tank at the New Cumberland facility. The audits address the changes made to the milling tank after this incident, but they do not mention what (if any) changes were implemented to reduce the risk of metal dust ignition.

Neither of the insurance audits made any recommendations to AL Solutions that it should change its process design or dust management systems. The insurance audits also did not reference industry consensus standards for dust, such as National Fire Protection Association (NFPA) 484, *Standards for Combustible Metals*,[21] the standard for processing and handling titanium and zirconium metal (addressed in Section 5.1). A comprehensive process hazard analysis was not recommended or performed despite the hazardous nature of the process and despite previous incidents.

4.2.2 Hydrogen Explosion

CSB investigators determined that an ignition of zirconium dust likely caused the fatal explosion; however, the presence of flammable hydrogen acting in addition to the metal dust cannot be ruled out. Both titanium and zirconium dusts are water reactive, burn vigorously compared to other metals, and can produce hydrogen gas in the presence of heat (see below equations).[22]

$$metal+water\ \text{+}metal \rightarrow oxide+hydrogen$$

$$Ti(s) + H_2O(l) \rightarrow TiO_2(s) + H_2(g)$$

$$Zr(s) + H_2O(l) \rightarrow ZrO_2(s) + H_2(g)$$

The metal oxide layer formed on the dust particle prevents the reaction but in the case of AL Solutions, the oxide surface layer of the zirconium particles was removed during the milling process. The milling exposed a fresh layer of zirconium and increased the potential for hydrogen formation. The combustible dust expert commissioned by the CSB sampled the vapor space above the titanium and zirconium in the sample containers to measure the hydrogen concentration. Testing revealed small quantities (about 0.08 percent volume) of hydrogen in both the titanium and zirconium samples.[23] The presence of hydrogen in the interstitial spaces between particles in the blender may have had a small contribution to the explosion energy in addition to the combustible zirconium particulate. AL Solutions did not have a ventilation system to control hydrogen concentrations. Natural ventilation was inconsistent in the production building; employees reported closing rollup doors for temperature control during the cold months.

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[21] *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2012.

[22] Davletshina, T.A. Cheremisinoff, N.P. (1998). Fire and Explosion Hazards Handbook of Industrial Chemicals. William Andrew Publishing/Noyes. Online version available at: http://app.knovel.com/hotlink/toc/id:kpFEHHIC03/fire-explosion-hazards

[23] Both jars had hydrogen concentrations of about 2% of the 4 volume % hydrogen lower flammability limit, i.e. about 0.08 vol%. The oxygen readings indicated some oxidation of the dust samples between collection and testing. The titanium sample likely also underwent some reaction due to the high moisture level in the sample. Moisture reaction does produce some hydrogen in the vapor space.

4.3 PREVIOUS FIRES AND EXPLOSIONS

Before the 2010 incident, the New Cumberland facility had experienced two fatal explosions involving the ignition of metal dust. From 1993 until the December 2010 incident, the New Cumberland VFD responded to at least seven fires at AL Solutions. The AL Solutions milling facility in Missouri also had a fire that required a response from the local fire department. The CSB learned that several other fires occurred at the New Cumberland facility that did not result in a fire department response. In fact, almost all employees (with the exception of the newest ones) reported to CSB investigators that they had witnessed one or more fires in the production building. Despite the frequent incidence of fires during operation, AL Solutions continued to use a housekeeping approach as its principle means to minimize dust accumulations rather than adopting more robust engineering controls. The NFPA 484 Standard recommends that affirmative steps of dust control, such as dust collection equipment, should be implemented above housekeeping. The following three sections discuss in further depth the two previous incidents at AL Solutions that resulted in worker fatalities and a previous fire caused by a blender malfunction.

4.3.1 1995 Propane and Titanium Explosion

In August 1995, one employee was killed and another was injured in an explosion and fire at the New Cumberland facility. A leaking propane tank and undetermined ignition source caused the fire. According to a West Virginia Fire Marshal report on the incident, the propane pooled under the tank outside the production building wall, and propane vapor began to accumulate inside the building walls. The propane ignited because of an unknown source, generating a blast wave that lofted titanium dust. This dust ignited and caused a secondary explosion[24] that ignited combustible material within the production building.

OSHA investigated the incident and issued a series of citations to Jamegy. The incident prompted Jamegy to make numerous changes, including isolating the propane rack from buildings and constructing a new production building designed to address the hazards of processing explosible titanium dust.

After the 1995 incident, Jamegy constructed a new production building made of prefabricated concrete that was separated from the warehouse, laboratory, and office. This production building is the site of the 2010 incident. Its design included drains to better facilitate washing powder from equipment and surfaces. A water deluge system was installed for fire suppression. All electrical equipment in the blending and press room was designed to be sealed to prevent a pathway for dust to any electrical sparks or ignition sources. Jamegy did not take the opportunity to install dust collection systems in accordance with the existing NFPA combustible dust codes at that time and instead continued to rely on housekeeping to minimize dust accumulations. The installation of a deluge system to control a metal dust fire was contrary to recognized industry practices and to the titanium and zirconium MSDSs for extinguishing metal dust fires.

4.3.2 1996 Incident

Soon after production operations resumed in the new building, a flash fire occurred in the blender, damaging the blender and the press located under it. An eyewitness stated that the flame appeared to emerge from the sidewall of the blender. A post-fire examination indicated that one of the paddles had broken off, possibly causing friction between the blender and the paddle, which likely initiated the fire. This fire produced no injuries, but

[24] Secondary dust explosions occur when an initial event dislodges more accumulated dust into the air. If ignited, the dispersed dust may cause one or more secondary explosions. These can be more destructive than the initial event due to a greater quantity and concentration of dust.

Jamegy had to construct and install a new blender. The new blender was constructed of stainless steel rather than the carbon steel used in the previous blender, and it was operated at a lower shaft speed to reduce the likelihood of frictional heating leading to ignition.

4.3.3 2006 Incident

In July 2006, a supervisor was fatally injured while cleaning out the inside of the mill tank when residual metal in the mill ignited. The death caused Jamegy to change its mill cleaning procedure. Before the incident, the procedure required an operator to get into the mill and shovel the metal into tubs. As a result of the incident, a valve was placed on the bottom of the mill, enabling operators to hose down the interior of the mill and drain it.

OSHA conducted an investigation as a result of this incident and levied fines on Jamegy for five serious safety violations: lack of proper confined space permits, lack of protective equipment (such as flame retardant clothing in the presence of zirconium), lack of sufficient guard rails on a platform, lack of machine guarding, and lack of adequate lockout/tagout procedures. The citations did not mention industry standards such as NFPA 484 to address a failure to control metal dust hazards.

5.0 INDUSTRY CODES AND STANDARDS

5.1 NFPA 484

NFPA 484, *Standard for Combustible Metals*, is one of several NFPA standards on combustible dust. It applies to facilities, such as the AL Solutions facility, that produce, process, finish, handle, recycle, or store metals and alloys in a form capable of combustion or explosion. Like many other NFPA consensus standards, NFPA 484 serves as a guidance document that is voluntary unless adopted by local or state authorities. NFPA 484 describes the tests and methods for determining metal dust combustibility and provides guidelines for preventing metal dust explosions and flash fires.

The CSB commissioned the dust explosivity testing listed in NFPA 484 to determine the applicability of the standard. The testing, described in Section 4.3.1 of NFPA 484-2009, shows that the AL Solutions metal dust samples are explosible and therefore that NFPA 484 was applicable to processes at the New Cumberland facility.

Chapter 10 of NFPA 484-2009,[25] the version of the standard available at the time of the incident, covers facilities processing titanium, and Chapter 11 addresses facilities processing zirconium. Both chapters include similar provisions for the handling and storage of titanium and zirconium, respectively. The requirements specific to fire prevention and emergency response are retroactive for existing facilities. The practices at AL Solutions did not align with many of the provisions of these chapters. If AL Solutions had voluntarily followed NFPA 484—or if its provisions had been enforced by the West Virginia State Fire Marshal, the authority having jurisdiction (AHJ),[26] or by OSHA—the incident might have been prevented, or its consequences might have been reduced.

NFPA 484 requires the use of flame-resistant clothing to reduce the severity of injuries from flash fires. AL Solutions provided its operators with 100 percent cotton work shirts and pants that were not flame resistant. NFPA 484-2009 stated that personnel handling dry

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[25] Chapter 10, Titanium, in NFPA 484-2009 is Chapter 12 in the 2012 edition of NFPA 484. Zirconium is Chapter 13 in NFPA 484-2012. (1) *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2009. (2) *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2012.

[26] The authority with jurisdiction is the organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

titanium powder must wear non-sparking shoes and noncombustible or flame-retardant clothing without pockets, cuffs, laps, or pleats in which powder can accumulate.[27] A similar requirement was listed for zirconium. The titanium and zirconium chapters also required the installation and use of dust collection systems to control metal dust accumulations near process equipment and dust-producing operations. The AL Solutions production building was not equipped with a dust collection system.

Chapter 13 of NFPA 484-2009[28]—Fire Prevention, Fire Protection, and Emergency Response—included general provisions for preventing metal dust fires and applied to existing facilities.[29] Section 13.2.5, Control of Friction Hazards, stated, "All machinery shall be installed and maintained in such a manner that the possibility of friction sparks is minimized." Employees at AL Solutions reported recurring issues with the blender blade contacting and scratching the sidewall; however, maintenance did not adequately address the metal-to-metal contact that was the likely ignition source for the 2010 explosion.

NFPA 484 declared that "[a]utomatic sprinkler protection shall not be permitted in areas where combustible metals are produced or handled"[30] because water sprayed on a titanium or zirconium fire can lead to burning metal dust or an explosion.[31] Despite warnings in NFPA 484 and despite MSDS discussions of the hazards of using water to fight metal fires, AL Solutions chose a water deluge system as its method to extinguish a metal dust fire. In previous incidents, the VFD also had extinguished fires with water hoses, exposing the firefighters to potential explosion hazards. Section 13.5.2 of NFPA 484-2009 recommended creating a comprehensive emergency preparedness plan—and making it available to emergency responders—because of the unique characteristics of metal dust fires.

Several sections of NFPA 484 include provisions for the proper storage of combustible metals. For example, according to Chapter 13, "Open storage of metal chips and fines are to be isolated and separated from other metal scrap to prevent fire propagation." Chapter 14, Combustible Metal Recycling Facilities,[32] requires that dry storage of more than six drums of dry combustible metals must be separated from other parts of the recycling facility. The AL Solutions safety manual included similar requirements for the separation of titanium and zirconium; however, at the time of the incident, AL Solutions was storing both metals in close proximity in the production building, which fueled the fire and explosion.

AL Solutions acknowledged the hazards of titanium and zirconium powder in its product MSDSs and company safety plan. Several previous incidents also had demonstrated the hazards of these materials. However, management did not enforce company policies to reduce the risk of metal dust explosions and fires, and its dust management practices did not align with industry consensus standards, such as NFPA 484. The CSB determined that the operators, supervisors, and engineers at AL Solutions were not familiar with NFPA 484 and that the process design, construction, and fire prevention practices did not consider the provisions of the NFPA standard.

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[27] NFPA. Section 10.6.3, Personnel Safety Precautions. *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2009.

[28] This is Chapter 15 in the NFPA 484-2012 edition. *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2012.

[29] According to the NFPA general retroactivity clause, the other chapters in NFPA 484 are not applicable to existing facilities unless the AHJ deems that "the existing situation presents an unacceptable degree of risk."

[30] NFPA, Section 13.3.1. *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2009.

[31] Many metals (including titanium and zirconium) burn at such a high temperature and are sufficiently water reactive to produce a violent reaction when water is applied to burning metal. Such a reaction occurred while firefighters were using hose streams on a 2010 fire at a Los Angeles titanium scrap warehouse, injuring at least one firefighter.

[32] This chapter is Chapter 16 in the NFPA 484-2012 edition. *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2012.

5.1.1 Water-Based Cleaning Methods in Combustible Metal Operations

Though engineering controls such as dust collection systems should be used to prevent accumulations, housekeeping operations may be a secondary means of control. In the absence of a dust collection system, the AL Solutions facility relied primarily on water sprays and wash-downs to control and reduce accumulations of fugitive titanium and zirconium powders. As noted previously, water sprays are not recommended for zirconium and titanium fires and are particularly hazardous when in contact with molten or burning titanium because of a reaction that liberates explosive hydrogen gas.

The CSB reviewed the applicable national consensus standard, NFPA 484-2012, and found that Chapter 15, *Fire Prevention, Fire Protection and Emergency Response*, specifies the following important safety requirements for water cleaning operations:

> 15.2.2.4.4 Water Cleaning Requirements - The use of water for cleaning shall not be permitted in manufacturing areas unless the following requirements are met:
>
> 1. Competent technical personnel have determined that the use of water will be the safest method of cleaning in the shortest exposure time.
> 2. Operating management has full knowledge of, and has granted approval of its use.
> 3. Ventilation, either natural or forced, is available to maintain the hydrogen concentration safely below the LFL (lower flammability limit).
> 4. Complete drainage of all water and powder to a remote area is available.[33]

NFPA informed the CSB that these requirements are intended to apply to water cleaning activities in all combustible metal operations, including those involving titanium and zirconium. The CSB, however, noted that the applicability of these requirements to titanium and zirconium operations is not made clear in the current version of NFPA 484, which could result in employers' failing to follow these requirements for operations involving water-reactive combustible dusts. In discussions with CSB investigators, NFPA staff indicated that this issue will be clarified in the 2015 edition of NFPA 484. The water-based cleaning requirements will be moved to a new housekeeping chapter earlier in the code (Chapter 7). This chapter will include general housekeeping requirements for all metals, including water-cleaning operations.

6.0 REGULATORY ANALYSIS

6.1 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA)

6.2 OSHA COMBUSTIBLE DUST STANDARD FOR GENERAL INDUSTRY

Since 2006, the CSB has recommended that OSHA generate a general industry standard for combustible dust based on NFPA standards 654[34] and 484. Despite repeated CSB recommendations and fatal dust incidents since the issuance of the recommendation, OSHA has not issued a final combustible dust standard. OSHA has recognized the need and importance of a combustible dust standard and in the past have made steps towards promulgating a standard, but it has been delayed. After the CSB recommendation in 2006, OSHA launched a Combustible Dust National Emphasis Program (NEP), but this program is

[33] NFPA. Section 15.2.2.4.4.2 *NFPA 484: Standard for Combustible Metals*; NFPA: Quincy, MA, 2012.

[34] *NFPA 654: Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids.* NFPA: Quincy, MA, 2012.

limited in scope and application and did not have the wide reaching impact that would be achieved by a combustible dust standard.[35] In 2008, the CSB issued a report on the Imperial Sugar explosion that recommended OSHA "proceed expeditiously" in creating a combustible dust standard. After this recommendation OSHA announced that they would start rulemaking for a standard. In 2009 and 2010, OSHA made progress on developing a standard by holding stakeholder meetings around the country. After these stakeholder meetings OSHA postponed the next step in the rulemaking process multiple times. The table in Appendix B gives a full account of CSB investigations and recommendations as well as OSHA actions taken toward developing a combustible dust standard. In this Case Study the CSB is reiterating a recommendation made in 2006 for OSHA to "Issue a standard designed to prevent combustible dust fires and explosions in general industry…" which eight years after the initial recommendation, OSHA still has not fulfilled.

However, OSHA has been involved in several activities since 2005 to increase awareness of combustible dust, for both compliance officers and industry. In addition to working toward enacting a final combustible dust rule, OSHA has developed non-regulatory guidance for combustible dust, including a safety and health information bulletin[36], a combustible dust hazard communication guide[37], and precautions and training information for firefighter fighters[38]. Additionally, OSHA sent out 30,000 letters to employers that handle combustible dust to raise hazard awareness after the 2008 Imperial Sugar incident.

6.2.1 Combustible Dust National Emphasis Program

In 2006 the CSB recommended OSHA develop and issue a special emphasis program to address combustible dust hazards while the combustible dust standard was under development. In 2007, OSHA issued the Federal OSHA Combustible Dust National Emphasis Program (NEP)[39] in response to this recommendation to focus on industries that generate, store, or handle combustible dusts. The NEP provides guidance to OSHA inspectors on how to inspect and issue citations for workplace conditions involving combustible dust hazards through the Occupational Safety and Health Act General Duty Clause,[40] the OSHA Housekeeping Standard,[41] and other applicable general industry standards. The NEP can be applied to any facility with combustible dust, but the program specifically lists target industries by the North American Industry Classification System (NAICS) code.[42]

Although the NEP addressed combustible dust as temporary measure in the absence of a general industry standard, the program has limitations which OSHA has recognized.[43] The NEP itself

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[35] NEP inspections are based on a randomized selection of facilities, regardless of accident history. They can be useful for industry when conducted as a result of a targeted inspection, complaint, or referral.

[36] Occupational Safety and Health Administration (OSHA). *Combustible Dust in Industry: Preventing and Mitigating the Effects of Fire and Explosions*; Safety and Health Information Bulletin SHIB 07-31-2005; July 2005.

[37] Occupational Safety and Health Administration (OSHA). *Hazard Communication Guidance for Combustible Dusts.* https://www.osha.gov/Publications/3371combustible-dust.html

[38] Occupational Safety and Health Administration (OSHA). *Firefighting Precautions at Facilities with Combustible Dust.* https://www.osha.gov/Publications/OSHA_3644.pdf

[39] Occupational Safety and Health Administration (OSHA). *Combustible Dust National Emphasis Program*; Reissued; OSHA Instruction CPL 03-00-008; March 11, 2008.

[40] Under the Occupational Safety and Health Act of 1970, Section 5(a)(1), known as the General Duty Clause, states, "Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."

[41] 29 CFR 1910.22

[42] The AL Solutions NAICS code for the New Cumberland facility was 331492, Secondary Smelting and Metal Refining of Non-Ferrous Metal (except Copper and Aluminum). This NAICS code was not listed in the Combustible Dust NEP; however, the broader Standard Industrial Classification (SIC) code 3341, Secondary Nonferrous Metals, was listed among the industries with a "more frequent and/or high consequence combustible dust explosions/fires."

[43] https://www.osha.gov/dep/combustible_dust/combustible_dust_nep_rpt_102009.html

does not require action from covered facilities;[44] it provides guidance to OSHA Area Offices (and adopted state plan offices) on how to determine whether an employer, upon inspection, is in violation of currently existing regulations, such as the OSHA Housekeeping Standard. The NEP references NFPA 484, 654 and other NFPA industry consensus standards for dust, and the provisions of these codes are not enforceable requirements but may be consulted by OSHA compliance officers to obtain evidence of hazard recognition or provide means for abatement activities issued as a result of the NEP inspection.

6.2.2 OSHA West Virginia Area Office

The West Virginia Area Office of OSHA conducted an inspection of the AL Solutions facility and issued one willful and 12 serious violations to the company as a result of the 2010 incident. OSHA cited AL Solutions for several serious violations of the General Duty Clause, including an inadequate hydrogen detection system, a lack of explosion venting in the production area, and the improper storage of combustible metals. (OSHA typically issues General Duty Clause citations when it lacks a specific enforceable standard for the hazard or industrial sector involved.) Other serious violations included the lack of training, poor communication about hazards, and failure to provide employees with fire-resistant clothing to reduce the severity of injuries from a flash fire. The willful violation issued to AL Solutions cited the use of water rather than the recommended sand or salt extinguishing agents to suppress a metal dust fire. Since the issuance of the Combustible Dust NEP, the CSB found no documentation of any OSHA NEP-based inspection at AL Solutions before the 2010 explosion.

6.3 ENVIRONMENTAL PROTECTION AGENCY

In December 2013, AL Solutions agreed to implement safeguards at all facilities in a settlement of U.S. Environmental Protection Agency (EPA) Clean Air Act violations. EPA cited AL Solutions for a violation of Section 112(r)(1) of the Clean Air Act, which imposes a general duty on owners and operators of facilities with extremely hazardous chemicals to identify hazards associated with an accidental release, design and maintain a safe facility, and minimize the consequences of any accidental releases.

As part of the settlement, EPA requires that AL Solutions implement several company-wide safeguards, including the following:

- Completion of process hazard analyses, including combustible dust testing and analysis
- Limitations on the acceptance of new metal feedstock and a disposal plan for titanium and zirconium metals at the New Cumberland facility
- Implementation of safety procedures for hydrogen gas detection
- Application of specific chapters and sections of NFPA 484-2012.

As of the publication date of this case study, AL Solutions is working in consultation with EPA to complete several requirements of the consent order. The company also will pay a penalty for Clean Air Act violations based on inspections at the New Cumberland, West Virginia, and Washington, Missouri, facilities following the incident.

[44] http://www.oshrc.gov/decisions/html_2014/11-2969.htm

6.4 WEST VIRGINIA FIRE CODE

The West Virginia Fire Code is intended to support "the safeguarding of life and property from the hazards of fire and explosion." It incorporates the standards and requirements in the 2009 edition of the NFPA National Fire Codes. The West Virginia State Fire Code declares that the National Fire Codes "have the same force and effect as if set out verbatim in this rule." It also states, "The State Fire Marshal shall make use of the standards and requirements within the incorporated publications in all matters coming under his or her jurisdiction." The 2009 edition of NFPA 484, *Standard for Combustible Metals,* is one of the standards referenced in the National Fire Codes, and it is incorporated in the West Virginia Fire Code and is enforceable by the AHJ.

The State Fire Marshal holds the authority to dictate which repairs or changes are necessary to mitigate any fire hazard in a facility. The State Fire Marshal can exercise this authority when "any building or structure has been constructed, altered, or repaired in a manner violating the State Fire Code" and when "any building or structure is being maintained or used in such a way as to endanger life or property from the hazards of fire or explosion."

NFPA 484-2009 states, "A documented risk evaluation acceptable to the AHJ shall be conducted to determine the level of explosion protection to be provided for a dust collection system." The State Fire Marshal is the AHJ for West Virginia. However, the State Fire Marshal's Office does not regularly inspect buildings to ensure compliance with the State Fire Code.

In West Virginia, the State Fire Marshal's Office has a variety of roles. It certifies fire departments, investigates fires and explosions, enforces the fire code, and conducts fire inspections. Neither the State Fire Marshal nor the New Cumberland VFD inspected the AL Solutions facility to ensure compliance with the State Fire Code or with NFPA 484. After the 2006 incident, the State Fire Marshal performed an investigation but issued no recommendations and did not require the facility to follow NFPA 484.

Approximately 17 inspectors in the West Virginia State Fire Marshal's Office are tasked with inspecting facilities throughout the state and ensuring compliance with the State Fire Code. A company can request an inspection by filling out a form online and paying $50.

The CSB has previously discussed the issues associated with fire code enforcement by state or local fire marshals. For example, the CSB *Combustible Dust Hazard Study* states the following:

> The CSB found little enforcement of fire codes in industrial facilities. Most jurisdictions focus on life-safety issues; as such, most enforcement resources of local code authorities are dedicated to means of egress, fire extinguishers, etc. in schools, hotels, nursing homes, hospitals, night clubs, and other such facilities, as opposed to industrial fire and explosion hazards including combustible dust hazards or hazardous materials' use and storage. Another problem is that inspections are often conducted by local fire departments, whose members likely have limited knowledge of industrial processes and hazards.[45]

This conclusion further demonstrates the need for an OSHA combustible dust standard. The NFPA 484 requirements incorporated into state fire codes might be enforceable, but they will not be effective if local fire departments do not have the knowledge and resources necessary to inspect facilities and enforce those requirements. The issuance of a combustible dust regulation would provide companies with specific and enforceable requirements for the prevention of combustible dust fires and explosions.

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[45] *Combustible Dust Hazard Study*; U.S. Chemical Safety and Hazard Investigation Board: Washington, DC, 2006.

7.0 RECOMMENDATIONS

The CSB has addressed the issue of combustible dusts in several previous investigations (Appendix B). In 2006, the CSB issued the *Combustible Dust Hazard Study*. The CSB initiated this study after investigating three combustible dust incidents in 2003 that resulted in 14 deaths. One of the three incidents involved combustible metal dust at the Hayes Lammerz Plant in Indiana in 2003. A powdered aluminum explosion and fire killed one worker and injured six other workers.

The 2006 CSB study identified 281 combustible dust incidents between 1980 and 2005, which resulted in the deaths of 119 people and injured 718 other people. In this study, 20 percent of the combustible dust incidents involved metal dusts.

Many of the issues in the *Combustible Dust Hazard Study* apply to the AL Solutions incident. For example, the study includes a discussion of the lack of sufficient oversight and notes the following:

> Consensus standards developed by the National Fire Protection Association (NFPA) that provide detailed guidance for preventing and mitigating dust fires and explosions are widely considered to be effective; however, ... among jurisdictions that have adopted the fire codes, enforcement in industrial facilities is inconsistent, and, in the states the CSB surveyed, fire code officials rarely inspect industrial facilities.

The *Combustible Dust Hazard Study* also considers state oversight priorities:

> The states have mainly focused fire code enforcement on fire hazards in occupied structures such as schools, hospitals, and office buildings, but not in industrial facilities, and not on dust explosion control requirements, which are only a small portion of the broader code requirements.

In the Combustible Dust Hazard Study, the CSB made a recommendation to OSHA that it should issue a general industry standard for the prevention of combustible dust fires and explosions, based on the current NFPA dust standards (including NFPA 654[46] and NFPA 484).

In February 2008, a combustible dust explosion at the Imperial Sugar Refinery in Georgia killed 14 employees and contractors and injured 36 others. The CSB found that the explosion was caused by an ignition of granulated sugar dust in a recently enclosed conveyor belt system under the sugar silos.[47] At the time the CSB report on Imperial Sugar was published, OSHA still had not issued a proposed rule for combustible dust. After the Imperial Sugar Refinery incident, in March 2008, OSHA revised the Combustible Dust NEP to increase enforcement, expanding required NEP inspections to four per area office per fiscal year, instead of one. In 2009, OSHA announced its intention to initiate rulemaking on a combustible dust standard. In its investigation report on the Imperial Sugar Refinery explosion, the CSB made several recommendations to OSHA, including the following:

> Proceed expeditiously, consistent with the Chemical Safety Board's November 2006 recommendation and OSHA's announced intention to conduct rulemaking, to promulgate a comprehensive standard to reduce or eliminate hazards from fire and explosion from combustible powders and dust.[48]

The CSB also produced a case study report on three iron dust fires and a hydrogen explosion involving that occurred in 2011 at the Hoeganaes Corporation iron powder facility in Gallatin,

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[46] *NFPA 654: Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids*; NFPA: Quincy, MA, 2013.

[47] *Imperial Sugar Investigation Report*; U.S. Chemical Safety and Hazard Investigation Board: Washington, DC, 2009.

[48] *Imperial Sugar Investigation Report*; U.S. Chemical Safety and Hazard Investigation Board: Washington, DC, 2009.

Tennessee; these incidents resulted in five worker deaths.[49] At the time of the CSB report, OSHA had twice postponed the next step in the combustible dust rulemaking process, the Small Business Regulatory Enforcement Fairness Act[50] (SBREFA) panel process. The CSB recommended that OSHA ensure that the forthcoming dust standard includes requirements for combustible metals and also recommended the publication of a proposed dust standard within a year after the issuance of the Hoeganaes case study.

The CSB collected and validated data from combustible dust fires and explosions nationwide that resulted in worker injuries or fatalities from 2008 to 2012 (Shown in Appendix C).[51] During that 5-year period, 50 fires or explosions involving combustible dusts resulted in 29 fatalities and 161 injuries.

In October 2012, the CSB investigated an explosion and flash fire at the U.S. Ink manufacturing facility in East Rutherford, New Jersey. This incident resulted in seven employee injuries and was likely caused by an ignition of combustible powders used in the production of ink.

In July 2013, the CSB board voted and declared that OSHA's response to previous combustible dust recommendations was "unacceptable" because OSHA had yet to develop even a proposed rule on combustible dust hazards, more than 4 years after it committed to start rulemaking. The need for an OSHA combustible dust standard became the first item in the CSB Most Wanted Chemical Safety Improvement Program, adopted by the Board at the July 2013 meeting. If OSHA had implemented the first CSB recommendation for a combustible dust standard in 2006, many of the severe combustible dust incidents that followed, including the AL Solutions incident, might have been prevented.

8.0 KEY FINDINGS

As a result of the AL Solutions investigation, the CSB makes the following findings:

1. The explosion in the production building was caused by combustible titanium and zirconium dusts that were processed at the facility.
2. The explosion likely originated in a blender containing milled zirconium particulates and ignited by frictional heating or spark ignition of the zirconium arising from defective blender equipment.
3. The hydrogen gas produced by the reaction of molten titanium or zirconium metal and water, possibly from wash-down operations or the water deluge system, may have also contributed to the explosion.
4. Testing conducted after the incident determined that zirconium and titanium samples collected from the AL Solutions facility were combustible and were capable of causing an explosion when lofted near heat or an ignition source.
5. AL Solutions did not mitigate the hazards of metal dust explosions through engineering controls, such as a dust collection system. Specifically, AL Solutions did not adhere to the practices recommended in NFPA 484 for controlling combustible metal dust hazards.

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[49] *Hoeganaes Corporation Investigation Case Study*; U.S. Chemical Safety and Hazard Investigation Board: Washington, DC, 2011.

[50] When an OSHA proposal is expected to have a significant impact on a substantial number of small entities, the agency must notify the U.S. Small Business Administration (SBA) Office of Advocacy. OSHA convenes an SBREFA panel to hear comments from small entity representatives and to review the draft proposed rule and related analyses prepared by OSHA.

[51] Data collected in support of H.R. 691: Worker Protection against Combustible Dust Explosions and Fires Act of 2013 introduced on February 14, 2013 and referred to the Committee on Education and the Workforce. H.R. 691 is a bill to require the Secretary of Labor to issue an interim occupational safety and health standard regarding worker exposure to combustible dust, and for other purposes.

6. The West Virginia Area Office of OSHA did not conduct a Combustible Dust NEP inspection at AL Solutions before the 2010 incident, despite the company's history of metal dust incidents. The Combustible Dust NEP inspections are based on a randomized selection of facilities regardless of previous incidents, unless initiated by a complaint or referral.
7. Combustible dust incidents continue to occur throughout susceptible industries, but the next steps of the OSHA rulemaking process for promulgating a general industry combustible dust standard have been delayed.

9.0 REITERATED RECOMMENDATIONS

OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

The absence of a general industry safety standard for combustible dust remains an important safety issue as catastrophic dust incidents continue to occur throughout industry. Therefore, the CSB reiterates the following recommendation, originally issued to OSHA in the 2006 Combustible Dust Hazard Investigation:

2006-1-H-1 Issue a standard designed to prevent combustible dust fires and explosions in general industry. Base the standard on current National Fire Protection Association (NFPA) dust explosion standards (including NFPA 654 and NFPA 484), and include at least - hazard assessment, - engineering controls, - housekeeping, - building design, - explosion protection, - operating procedures, and - worker training.

10.0 RECOMMENDATIONS

As a result of its investigation of this accident, the CSB makes the following safety recommendations:

TO AL SOLUTIONS, INC.:

2011-3-I-WV R1 For all new and existing equipment and operations at AL Solutions facilities that process combustible metal dusts or powders, apply the following chapters of NFPA 484-2012, *Standard for Combustible Metals*:

- Chapter 12, Titanium
- Chapter 13, Zirconium
- Chapter 15, Fire Prevention, Fire Protection, and Emergency Response
- Chapter 16, Combustible Metal Recycling Facilities

2011-3-I-WV R2 Develop training materials that address combustible dust hazards and plant-specific metal dust hazards and then train all employees and contractors. Require periodic (e.g., annual) refresher training for all employees and contractors.

TO AL SOLUTIONS, INC., FACILITY IN BURGETTSTOWN, PENNSYLVANIA:

2011-3-I-WV R3 Prohibit the use of sprinkler systems and water deluge systems in all buildings that process or store combustible metals.

2011-3-I-WV R4 Conduct a process hazard analysis as defined in NFPA 484-2012, Section 12.2.5, and submit a copy to the local fire department or the enforcing authority for the fire code.

APPENDIX A

SUMMARY OF DUST EXPLOSIBILITY TEST RESULTS

Material Name	Titanium Inside Press #1	Zirconium Crush Pellet	Titanium Mixture
P_{max}, bar-g[52]	2.8	4.3	6.3
R_{max}, bar/s[53]	n/a	45	277
K_{st} bar-m/s[54]	n/a	12	75
Explosion Severity	n/a	0.08	0.76
Classification*	Combustible[55]	Combustible, but not Class II	Class II Combustible

*Classification of Combustible Dusts: A Class II combustible dust is defined by NFPA 499 *Recommended Practice for the Classification of Combustible Dusts and Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*. A dust is classified as Class II based on its Explosion Severity:

$$\text{Explosion Severity} = \frac{(P_{max} \times R_{max})\ \text{sample}}{(P_{max} \times R_{max})\ \text{reference dust}^{56}}$$

Explosion Severity (ES) Value	Dust Classification
ES < 0.4	Combustible, but not Class II
0.4 < ES < 0.5	Indeterminate. Combustible, but not Class II based on ES criterion alone
ES > 0.5	Class II Combustible
P_{max} < 1 bar	Not Combustible

52 P_{max} is the maximum explosion pressure in the test vessel.

53 R_{max} is the maximum rate or pressure rise in the test vessel.

54 K_{st} is an index computed from R_{max} and the volume of the test vessel. It is used to classify the explosion severity of a material

55 The titanium #1 combustibility determination was based on the Go/No-Go Test for Determination of Dust Cloud Combustibility as described in ASTM Standard Test Method E1226 "*Pressure and Rate of Pressure Rise for Combustible Dusts*" with a focus on establishing whether the sample is capable of propagating a dust cloud deflagration.

56 Pittsburgh Coal Dust

APPENDIX B

CHRONOLOGY OF EVENTS INVOLVING COMBUSTIBLE DUST, 2006 TO PRESENT

November 9, 2006	The U.S. Chemical Safety and Hazard Investigation Board (CSB) votes to approve the *Combustible Dust Hazard Study*, which calls on the Occupational Safety and Health Administration (OSHA) to issue a general industry standard for combustible dust, based on National Fire Protection Association (NFPA) standards 654 and 484.
February 9, 2007	OSHA writes interim response to the CSB, reporting the forthcoming issuance of a dust Special Emphasis Program.
October 18, 2007	OSHA launches Combustible Dust National Emphasis Program (NEP).
February 7, 2008	The CSB investigates a sugar dust fire and explosion at the Imperial Sugar Refinery in Port Wentworth, GA, that killed 14 people and injured 38.
March 11, 2008	OSHA revises and reissues the Combustible Dust NEP to increase enforcement activities and sends a combustible dust safety bulletin to 30,000 workplaces in industries that handle combustible dust.[57]
March 27, 2008	In response to the 2006 CSB recommendation, OSHA submits a second interim response describing efforts to address combustible dust in the NEP. OSHA “continues to consider” the 2006 recommendation for a dust standard.
April 29, 2009	U.S. Department of Labor (DOL) announces that OSHA is initiating a comprehensive rulemaking on combustible dust.[58]
September 24, 2009	The CSB issues its final report on the 2008 Imperial Sugar Refinery explosion and issues recommendation to OSHA to “proceed expeditiously” in promulgating a dust standard consistent with the 2006 recommendation.
October 21, 2009	OSHA publishes an Advance Notice of Proposed Rulemaking (ANPRM) in the Federal Register and requests information from affected stakeholders.[59]
December 14, 2009	OSHA holds stakeholder meetings in Washington, DC, on the combustible dust rule.
January 8, 2010	Because OSHA commenced rulemaking on a combustible dust general industry standard, the CSB votes to designate the recommendation from the 2006 dust study as “Open–Acceptable Response.”
February 17, 2010	OSHA holds a second set of stakeholder meetings on the dust rule, this time in Atlanta, GA.
April 21, 2010	OSHA holds a third set of stakeholder meetings on the dust rule, this time in Chicago, IL.
April 26, 2010	OSHA designates the issuance of a dust standard as a “long-term action” in the Spring Semiannual Regulatory Agenda. OSHA estimates the next step in the rulemaking process, the SBREFA panel, will take place in April 2011.[60]
June 28, 2010	OSHA holds a web chat virtual stakeholder meeting to gather information in developing a combustible dust rule.
December 9, 2010	A dust-related explosion at AL Solutions in New Cumberland, WV, kills three workers and injures one.

[57] Occupational Safety and Health Administration. OSHA Reissues its Combustible Dust National Emphasis Program: Agency Enhances its Enforcement Activities at Facilities Handling Combustible Dusts. Trade News Release, March 12, 2008.

[58] Occupational Safety and Health Administration. U.S. Department of Labor’s OSHA Announces Rulemaking on Combustible Dust Hazards. National Press Release, April 29, 2009. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=17828 (accessed on April, 21, 2014).

[59] Occupational Safety and Health Administration. Combustible Dust: Advanced Notice of Proposed Rulemaking. *Federal Register* **2009**, 74 (202), 54333–347. http://www.gpo.gov/fdsys/pkg/FR-2009-10-21/html/E9-25075.htm (accessed on April 21, 2014).

[60] Occupational Safety and Health Administration. *Federal Register*, 75 (79), 46.

January 31, 2011	An iron dust flash fire fatally injuries two employees at the Hoeganaes facility in Gallatin, TN.
March 29, 2011	A second iron dust flash fire injures one employee at the Hoeganaes facility in Gallatin, TN.
April 30, 2011	OSHA does not convene an SBREFA panel.
May 13, 2011	OSHA holds a Combustible Dust Expert Forum in Washington, DC, to examine all possible approaches to formulating a comprehensive combustible dust standard.
May 27, 2011	A third metal dust–related incident occurs at Hoeganaes in Gallatin, TN. Three workers are killed, and two are injured.
July 7, 2011	The DOL Spring Semiannual Regulatory Agenda estimates an SBREFA panel will take place in December 2011.[61]
December 16, 2011	The CSB votes to approve the Hoeganaes case study, which includes a recommendation to OSHA to issue the proposed rule within 1 year of the issuance of the case study.
December 31, 2011	OSHA does not convene an SBREFA panel.
January 5, 2012	The CSB publically releases the Hoeganaes case study in Gallatin, TN.
January 20, 2012	The DOL Fall Semiannual Regulatory Agenda states that the dust standard is a "long-term action." An estimated date for the next step in the rulemaking "process is undetermined."[62]
June 14, 2012	OSHA responds to the Hoeganaes recommendations, stating that it cannot commit to a date for the proposed rule but that it remains a top OSHA priority.
October 9, 2012	Seven workers are injured in a dust-related flash fire at the U.S. Ink facility in East Rutherford, NJ.
December 16, 2012	This date marked the first anniversary of the issuance of the Hoeganaes case study and the 1-year deadline of the CSB recommendation for OSHA to issue a proposed rule.
July 2013	The DOL Semiannual Regulatory Agenda estimates that the SBREFA panel will be held in November 2013.[63]
July 25, 2013	The CSB votes to designate all four previous recommendations issued to OSHA concerning the issuance of a dust standard with the status "Open–Unacceptable Response."
November 26, 2013	The DOL Fall 2013 Semiannual Regulatory Agenda estimates that the SBREFA panel will be held in April 2014.[64] The SBREFA did not convene in November 2013.
January 29, 2014	This date marked the eleventh anniversary of the polyethylene dust explosion at West Pharmaceuticals in Kinston, NC, which killed six workers and injured 38.
January 31, 2014	This date marked the third anniversary of the first iron dust flash fire at the Hoeganaes facility in Gallatin, TN that killed two workers.

[61] Office of Information and Regulatory Affairs Office of Management and Budget http://www.reginfo.gov/public/do/eAgendaViewRule?pubId=201104&RIN=1218-AC41 (accessed on April 21, 2014).

[62] Office of Information and Regulatory Affairs Office of Management and Budget http://www.reginfo.gov/public/do/eAgendaViewRule?pubId=201110&RIN=1218-AC41 (accessed on April 21, 2014).

[63] Office of Information and Regulatory Affairs Office of Management and Budget http://www.reginfo.gov/public/do/eAgendaViewRule?pubId=201304&RIN=1218-AC41 (accessed on April 21, 2014).

[64] Office of Information and Regulatory Affairs Office of Management and Budget http://www.reginfo.gov/public/do/eAgendaViewRule?pubId=201310&RIN=1218-AC41 (accessed on April 21, 2014).

February 7, 2014	This date marked the sixth anniversary of the sugar dust explosion at the Imperial Sugar Refinery that killed 14 workers and injured 38.
February 15, 2014	This date marked the eleventh anniversary of the phenolic resin dust explosion at CTA Acoustics in Corbin, KY, that killed seven workers and injured 37.
March 29, 2014	This date marked the third anniversary of the second iron dust flash fire at the Hoeganaes facility in Gallatin, TN, which injured one worker.
May 27, 2014	This date marked the third anniversary of the third metal dust–related incident at the Hoeganaes facility in Gallatin, TN, which killed three workers and injured two.
October 9, 2014	This date will mark the second anniversary of the dust-related flash fire at the U.S. Ink facility in East Rutherford, NJ, which injured seven workers.
October 29, 2014	This date will mark the eleventh anniversary of the aluminum dust explosions and fires at the Hayes Lemmerz facility in Huntingdon, IN, which killed one worker and injured two.
November 6, 2014	This date will make the eighth anniversary of the release of the CSB *Combustible Dust Hazard Study* and the initial CSB recommendation that OSHA issue a combustible dust rule.
December 9, 2014	This date will mark the fourth anniversary of the dust explosion and fire at the AL Solutions plant in New Cumberland, WV, that killed three workers and injured another.

APPENDIX C

HIGH CONSEQUENCE INCIDENTS INVOLVING COMBUSTIBLE DUST FROM 2008 TO 2012

No.	Incident Date	City	State	Fatalities	Injuries	Explosion	Fire
1	2/7/2008	Port Wentworth	GA	14	38	Yes	Yes
2	3/24/2008	Muskegon	MS	0	14	No	Yes
3	5/21/2008	Springdale	AR	0	1	Yes	Yes
4	6/19/2008	Monett	MO	0	2	No	Yes
5	7/21/2008	Hunt Valley	MD	0	1	No	Yes
6	8/10/2008	Jaffrey	NH	0	2	No	Yes
7	8/19/2008	Smithton	IL	0	1	Yes	No
8	9/2/2008	Stockton	CA	0	6	Yes	No
9	1/9/2009	Jasper	IN	0	8	No	Yes
10	2/3/2009	Oak Creek	WI	0	4	Yes	Yes
12	3/31/2009	Monrovia	CA	0	1	No	Yes
13	4/22/2009	Rockledge	FL	0	1	No	Yes
14	7/22/2009	Lima	OH	0	1	Yes	No
15	8/28/2009	Oakland	CA	0	1	No	Yes
16	9/29/2009	South Bend	IN	0	1	Yes	No
17	10/5/2009	Panama City	FL	0	5	Yes	Yes
18	10/7/2009	Nebraska City	NE	0	2	Yes	No
19	12/15/2009	Cedar Rapids	IA	0	3	Yes	No
20	12/29/2009	Elkhart Lake	WI	1	9	Yes	Yes
21	2/12/2010	Dillard	OR	0	1	Yes	No
22	9/24/2010	Burnside	KY	1	3	Yes	Yes
23	12/9/2010	New Cumberland	WV	3	1	Yes	Yes
24	12/10/2010	Dearborn	MI	0	3	Yes	Yes
25	12/21/2010	Pendergrass	GA	0	2	Yes	No
26	12/31/2010	Blacksburg	VA	0	4	Yes	No
27	1/31/2011	Gallatin	TN	2	0	No	Yes
28	3/4/2011	Salem	VA	0	1	No	Yes
29	3/15/2011	Wilmington	NC	1	0	Yes	No
30	3/29/2011	Gallatin	TN	0	1	No	No
31	4/26/2011	Santa Rosa	CA	0	1	Yes	Yes
32	5/9/2011	Louisville	KY	0	2	Yes	No
33	5/27/2011	Gallatin	TN	3	2	No	No

34	6/23/2011	Louisville	KY	0	2	Yes	Yes
35	7/27/2011	Harrisonburg	VA	0	1	No	Yes
36	8/12/2011	Biron	WI	0	3	No	Yes
37	8/16/2011	Gaston	OR	0	3	Yes	Yes
38	8/18/2011	Clinton	IA	0	1	Yes	Yes
39	9/9/2011	Niagara Falls	NY	0	1	No	Yes
40	9/15/2011	Britton	SD	2	0	Yes	Yes
41	9/15/2011	London	KY	0	1	Yes	No
42	10/6/2011	Steeleville	IL	0	2	Yes	No
43	12/7/2011	Henderson	KY	1	3	Yes	No
44	1/12/2012	Edmond	OK	0	4	Yes	No
45	3/20/2012	Ronda	NC	0	4	Yes	No
46	5/23/2012	Monroe	OH	0	3	Yes	Yes
47	8/28/2012	Simi Valley	CA	0	1	No	Yes
48	9/10/2012	Phoenix	AZ	0	2	Yes	Yes
49	10/9/2012	East Rutherford	NJ	0	7	Yes	Yes
50	12/28/2012	Cincinnati	OH	1	1	Yes	Yes
			TOTAL	29	161		

CSB Investigation Reports are formal detailed reports on significant chemical accidents and include key findings, root causes, and safety recommendations. CSB Hazard Investigations are broader studies of significant chemical hazards. CSB Safety Bulletins are short general interest publications that provide new or noteworthy information on preventing chemical accidents. CSB Case Studies are short reports on specific accidents and include a discussion of relevant prevention practices. All reports may contain safety recommendations if appropriate. CSB Investigation Digests are plain-language summaries of Investigation Reports.

The U.S. Chemical Safety and Hazard Investigation Board (CSB) is an independent Federal agency whose mission is to ensure the safety of workers, the public, and the environment by investigating and preventing chemical incidents. The CSB is a scientific investigative organization; it is not an enforcement or regulatory body. Established by the Clean Air Act Amendments of 1990, the CSB is responsible for determining the root and contributing causes of accidents, issuing safety recommendations, studying chemical safety issues, and evaluating the effectiveness of other government agencies involved in chemical safety.

 The CSB makes public its actions and decisions through investigation reports, summary reports, safety bulletins, safety recommendations, case studies, incident digests, special technical publications, and statistical reviews. More information about the CSB is available at www.csb.gov.

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