Housekeeping Solutions

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Abstract

Experience has shown that poor housekeeping is frequently a contributing factor in catastrophic dust explosions. This paper addresses housekeeping challenges faced by facilities processing or generating combustible dusts and describes some relevant industry experience in dealing with these challenges.

Case Histories of Recent Dust Explosions

Dust explosions pose a significant potential for causing injury and damage to plant and equipment. This potential is illustrated by the events described below.[1]

West Pharmaceuticals, Kinston, North Carolina, January 29, 2003.[2] This explosion resulted in six fatalities and injured dozens of additional employees. The facility was extensively damaged and was ultimately razed. An investigation by the U.S. Chemical Safety and Hazards Investigation Board (CSB) determined that significant quantities of combustible polyethylene dust had accumulated above a false ceiling in a manufacturing area. An initiating event suspended this dust in air, where it subsequently contacted an ignition source, resulting in an extremely energetic explosion.

CTA Acoustics, Corbin, Kentucky, February 20, 2003.[3] This explosion injured 44 employees, 12 of whom were flown to hospital burn units; 7 later died. The initial explosion and fire occurred in a production line that was partially shut down for cleaning. A thick cloud of dust, dispersed by the cleaning activities, was ignited by the flames in an oven whose door had been left open. Secondary explosions propagated throughout the facility, as combustible phenol formaldehyde resin dust was dislodged from surfaces, adding to the airborne fuel loading.

Jahn Foundry, Springfield, Massachusetts, February 25, 1999.[4] This explosion in a foundry shell mold fabrication building sent 12 employees to the hospital, with burns covering from 40 to 100% of their bodies. Three of the injured subsequently died. While the cause of the initial explosion could not be conclusively identified, two plausible theories involved (1) the ignition of a natural gas/air mixture in a curing oven or (2) an airborne cloud of combustible phenol formaldehyde resin external to an oven being ignited by the hot oven. The investigation team determined that flames were drawn into an exhaust duct, where significant accumulations of combustible resin dust were ignited. As an explosion propagated through the ductwork, vibrations shook loose resin dust accumulations from the exterior duct surfaces and from adjacent building surfaces, leading to devastating secondary explosions.

Rouse Polymerics International, Inc., Vicksburg, Mississippi, May 16, 2002.[5] An explosion in this rubber recycling plant injured 11 workers (6 critically), 5 of whom later died from severe burns. The plant was reported to be “a total loss.” The process recycled elastomeric materials, producing a very fine powdered rubber product. Investigators believed that sparks from an oven exited an exhaust pipe, landed on the building roof, and started a fire. The fire is believed to have spread to an adjacent piece of equipment, where it caused an initial explosion that prompted a secondary explosion involving accumulations of dust in the building.

Malden Mills Industries, Methuen, Massachusetts, December 11, 1995.[6] This explosion and fire in a textile products manufacturing facility injured more than 20 workers. Fortunately, there were no fatalities. Property damage was estimated at $500 million (at the time, the ninth largest fire loss in U.S. history, based on NFPA data). The explosion originated when employees used high-pressure air hoses to clean flock (short nylon fibers) from the manufacturing equipment.

Ford Motor Company, Rouge Complex, Dearborn, Michigan, February 1, 1999.[7] This powerhouse explosion resulted in the deaths of 6 workers and serious injuries to 14 others. The powerhouse building and related facilities were extensively damaged, with estimated costs exceeding $1 billion, making this one of the most expensive industrial accidents in U.S. history. Investigators determined that the cause of the explosion was a natural gas buildup in a boiler that was being isolated for maintenance. Zalosh, in his review of the incident, suggests that much of the damage in the powerhouse and adjacent buildings was due to secondary coal dust explosions. Inspections after the explosion revealed dust accumulations ranging from light dustings to deposits of up to an inch thick on some surfaces, with dust accumulations in the range of 800 to 3,800 g/m^2 on floors and overhead beams.

Imperial Sugar, Port Wentworth, Georgia, February 7, 2008.[8,9] This explosion in a sugar refinery injured nearly 40 employees and contractors, 14 of whom died from their injuries – some after extended periods in a hospital burn unit. Damage to the refinery was extensive. OSHA's investigation determined that an initial explosion, likely occurring in a bucket elevator, suspended sugar dust accumulations in the processing building leading to secondary explosions. Preliminary results of on an-going CSB investigation indicate that dust accumulations in the sugar refinery were feet deep in some locations. OSHA has proposed citations with fines totally nearly $5.1 million.

Most workers, and many process safety professionals for that matter, will likely go through their career without being personally exposed to the aftermath of a devastating dust explosion. The skeptic might conclude, based upon personal experience, that dust explosions are unlikely and, therefore, low-risk events.

Table 1 shows data from FM Global, listing 166 incidents over the period from 1983 to 2006.[10] This information, which only reflects losses at facilities insured by FM Global, indicates that dust explosions are not limited to any particular industry, but are more prevalent in some industries. Zeeuwen addresses the issue of dust explosion statistics, noting that publically reported incidents may significantly underestimate the true frequency of such events.[11]

The topic of dust explosions has certainly not escaped regulatory and legislative attention. OSHA is currently implementing a national emphasis program (NEP), examining conditions and safety controls in facilities handling combustible dusts. Under this program, state and federal agencies have conducted over 800 inspections since November 2007, resulting in the citation of over 3500 violations. In addition, Congress is considering legislation that would mandate the promulgation of an OSHA combustible dust regulation.

Industry experience has indeed shown that poor housekeeping standards in facilities handling combustible dusts heighten the risks of facility operations – including risks to facility personnel, to business continuity, and to company reputation. Far too many facilities would appear to be, either wittingly or unwittingly, trusting to luck rather than skill in regards to prevention of damaging dust explosions within their facilities.

Control of Dust Explosion Hazards/Sources of Guidance

A significant body of recognized and generally accepted guidance on dust explosion hazard control is provided in the publications of the NFPA. NFPA publications providing such guidance include, but are not limited to:

- NFPA 61 – Prevention of Fires and Dust Explosions in Agricultural and Food Products Facilities
- NFPA 484 – Standard for Combustible Metals
- NFPA 654 – Prevention of Fire and Dust Explosions from the Manufacturing, Processing, and Handling of Combustible Particulate Solids
- NFPA 655 – Prevention of Sulfur Fires and Explosions
- NFPA 664 – Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities

Table 1: Dust Explosion Incidents Reported by FM Global (1983 – 2006)

Industry	Number of Incidents	Percentage of Incidents
Woodworking	64	39
Food	26	16
Metals	18	11
Chemical/ Pharmaceutical	14	8
Pulp/Paper	12	7
Mineral	11	7
Utility	7	4
Plastics	5	3
Rubber	5	3
Printing	1	0.5
Textile	1	0.5
Other	2	1
Total	166	100

NFPA's approach to control of dust explosion hazards focuses first on preventing the combustion event that leads to the explosion, through the elimination of one side of the fire triangle via:

- Controlling the combustible dust concentration. Explosions could be prevented if flammable concentrations of dust were never permitted to exist. Dust explosions differ from explosions of flammable vapors or gases in that some mechanism must be present to suspend the dust in air to form a combustible cloud.
- Controlling the oxidant concentration. By sufficiently lowering the concentration of O_2 in the air, we can prevent the combustion reaction. Addition of inert gases, such as nitrogen, to the process environment is a commonly used method for preventing dust explosions.
- Controlling ignition sources. While NFPA requires efforts to eliminate ignition sources, reliance upon ignition source controls alone is not permitted as a primary means of explosion prevention. Ignition sources are so ubiquitous and hard to identify that the likelihood of eliminating them all is remote.

Alternate, or additional, protection can be provided to mitigate the degree of damage or harm that might occur if combustion cannot prevented. Options provided by NFPA include, but are not limited to: deflagration venting, deflagration suppression, deflagration pressure containment, and isolation of equipment in which the deflagration might occur. Additional guidance on these mitigation measures is provided in NFPA 68[12] and NFPA 69[13].

Learning from the Case Histories

If there is one common learning to be derived from each of the case histories, it is the overarching importance of housekeeping in facilities handling or processing combustible particulate solids. Accumulations of dust throughout a facility extend the effect zone of a dust explosion, potentially increasing the number of personnel exposed to the extreme temperatures of the burning dust/air cloud and the explosion overpressures. Also, the added mass of available fuel can extend the duration of the explosion, increasing the explosion impulse that personnel, structures, and equipment are subject to, and potentially increasing the personnel injuries that are caused directly or indirectly (e.g., due to building collapse) by the blast wave.

The incidents described in this paper reinforce the importance of housekeeping in the safe operation of facilities handling combustible particulate solids. Industry awareness of this issue is reflected in the guidance provided in NFPA publications such as those listed previously. Each of the referenced standards establishes requirements for housekeeping programs to limit the accumulation of combustible dust in facilities.

While the cited standards offer somewhat differing perspectives on the issue of how clean is clean enough, all point out that a surprisingly small amount of dust is sufficient to present a dust explosion hazard. For example, the explanatory material in nonmandatory Appendix A of NFPA 654 points out that a dust layer 1/32 in. (0.8 mm) thick on the floor would, when uniformly suspended, create a dust cloud concentration of 0.35 oz/ft^3 (350 g/m^3) in a room 10 ft (3 m) high – assuming a bulk density of 75 lb/ft^3 (1,200 kg/m^3) for the initial powder layer (Figure 1). The concentration of 0.35 oz/ft^3 is a reasonable value for a "worst-case" organic dust concentration with respect to maximizing the resulting explosion pressure. NFPA 654 points out that, if only as little as half of the dust was suspended, the dust cloud would still likely be at a combustible concentration.

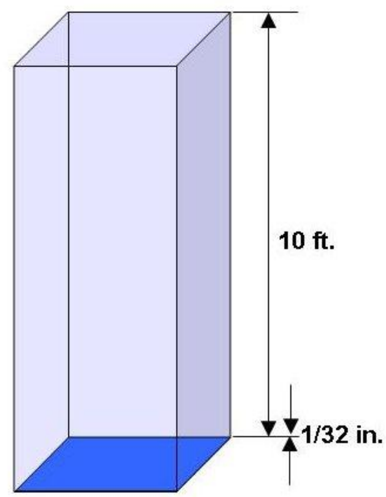

Figure 1 – Dispersion of Dust Layer

NFPA 654 continues this nonmandatory guidance by suggesting the following:

- Dust layers 1/32 in. (0.8 mm) thick can be sufficient to warrant immediate cleaning of the area.
- A dust layer this thick can create a hazardous condition if it covers more than 5% of the building floor area, with 1,000 ft^2 (93 m^2) of dust layer as the upper limit for large facilities.
- Dust accumulations on other surfaces, such as overhead beams and joists, ductwork, conduit and cabling, piping, light fixtures, or tops of equipment, can also contribute significantly to the secondary dust cloud potential, and should be considered in estimating the dust loading in a room.
- Dust adhering to walls and other vertical surfaces should also be considered.

The concept that a dust layer only 1/32 in. thick (about the thickness of the lead in a mechanical pencil) could be hazardous may be a sobering thought for those who have seen process areas with dust layers inches thick on floors and other horizontal surfaces.

How can one simplify and address the housekeeping challenge? NFPA guidance incorporates a number of basic concepts. These basic concepts are described below in preferred order of application.

The easiest/most effective housekeeping is the housekeeping you do not need to do. NFPA emphasizes the importance of designing and maintaining equipment to contain the dust – dust that does not escape containment does not need to be cleaned up. In addition, many of the explosion mitigation options that NFPA describes are more easily applied to dust-containing equipment than dust-containing rooms. It may be easier to provide explosion venting on a piece of equipment than a room, and equipment can often be inerted while occupied rooms cannot. Proper design, maintenance, and operation of equipment to minimize dust emissions should be a priority.

If it is likely that dust will escape from equipment, capture it at the release point. Total containment of dust may be difficult or impractical; e.g., at equipment charging hatches or where product is discharged. Or, total containment of dust-generating equipment may be infeasible, or may introduce other operational safety issues. NFPA provides guidance for the design and safe operation of dust collection systems with pickups local to the point of dust liberation/generation. Such systems, however, must be prudently designed, operated, and maintained to control their own inherent dust explosion hazards.

Limit the extent of dust migration and size of the room that must be cleaned. NFPA 654 permits the use of physical barriers to limit dust migration in order to minimize the extent of the housekeeping zone, but requires (as might be expected) that all penetrations of floors, walls, ceilings, and partitions defining such barriers be dust tight.

Design facilities for easy effective cleaning. NFPA 654 requires that all surfaces where dust might accumulate be designed and constructed to minimize dust accumulations and to facilitate cleaning (e.g., interior window ledges can be sloped, beams can be boxed in, and concrete walls can be painted to limit dust adherence). The standard also requires sealing of spaces that may be inaccessible for cleaning.

Establish and enforce housekeeping schedules. Housekeeping is not effective when it is not done. Experience will dictate how frequently housekeeping must be conducted to prevent the accumulation of hazardous inventories of dust (note that NFPA 654 is currently being revised to provide additional guidance for defining what constitutes a hazardous dust inventory). Responsibilities for housekeeping duties and prescribed schedules for frequency of housekeeping should be established and reinforced. Jahn Foundry had deferred an annual cleaning, which increased the combustible dust loading in the facility.

Ensure that housekeeping programs comprehensively address all areas where combustible dust may accumulate. The housekeeping program at West Pharmaceuticals rigorously addressed the personnel-occupied areas of the facility, but overlooked the area above the false ceiling

Ensure that housekeeping is safely conducted. Several of the case studies described explosions that resulted from housekeeping efforts; housekeeping in dusty areas introduces the potential for the formation of combustible dust clouds. It is important that housekeeping activities be adequately planned and safely executed. Strive to limit the production of dust clouds during housekeeping, after first deenergizing or removing all ignition sources. Recall that the dust cloud generated during cleaning operations at CTA Acoustics was ignited at the open door of a hot oven

NFPA 654 also establishes requirements for the safe conduct of housekeeping operations. The standard cautions against vigorous sweeping or the use of steam or compressed air to blow down equipment. NFPA 654 only permits the use of steam or compressed air when:

- the area and equipment have been vacuumed prior to blowdown,
- electrical power and other sources of ignition have been shut down or removed,
- the steam or air pressure is limited to 15 psig, and

- there are no hot surfaces in the area capable of igniting a dust cloud or layer.

If vacuuming is intended as part of the housekeeping program, NFPA 654 requires either the use of a fixed-pipe ("house") system with a remotely located exhauster and dust collector (properly protected against explosions), or a portable vacuum cleaner listed for use in Class II hazardous locations. Such portable vacuum cleaners are commercially available.

Other commodity-specific NFPA standards generally parallel the requirements in NFPA 654. More restrictive requirements, however, may be established for certain commodities. For example, NFPA 484 recognizes the ease with which aluminum and other metal dusts can be ignited and establishes particularly stringent controls for housekeeping methods. In general, specific characteristics of the dust involved (e.g., MIE, conductivity, chemical incompatibilities) must be considered in planning safe housekeeping procedures.

Written procedures outlining the means used for housekeeping, PPE requirements, and safety precautions are advisable. An uncontrolled hazard should not be introduced in the attempt to abate another hazard (e.g., consider the precautions required in the use of a scissor lift to access elevated locations for cleaning).

The balance of this paper briefly outlines some industry experience in controlling combustible dust hazards.

Development of a House Keeping Program for Control of Fugitive Dust in a Tissue Converting Plant (Mark Holcomb, Kimberly-Clark)

Background. The control of combustible dust fire and explosion hazards in tissue manufacturing operations requires housekeeping procedures even when effective dust collection systems are used to capture and control fugitive dust emissions from the process. The tissue converting process described in this paper did have both a dust collection and a room HVAC system. Together, these systems captured 99% of the dust released from the process. The remaining 1% accumulated in the tissue machines and on building overhead structures, requiring cleaning to prevent dust accumulations from exceeding levels that could create a fire or explosion hazard. Development of an effective and safe housekeeping program required determination of the dust threshold accumulation which could result in a potential fire or explosion hazard, measurement of the dust accumulation rate, calculation of cleaning frequency, and development of cleaning procedures that minimized fire and safety risks associated with manual overhead cleaning activities. The following narrative details how a housekeeping program was developed for the tissue converting production area.

Determination of the Dust Accumulation Threshold. Tissue dust created by tissue converting operations has a bulk density much lower than typical combustible dusts, does not accumulate uniformly making it difficult to estimate depth accurately over a large overhead area, and is difficult to accurately measure bulk density because it agglomerates readily when disturbed. Figure 2 shows the clumping that occurs during collection.

Figure 2 – Paper Dust Clumping

These unique properties make it difficult to determine hazardous dust levels using methods described in NFPA 654 (2006 edition) and FM 7-76,[10] which are based on depth and dust density measurements. An alternative method was developed for determining the dust threshold for triggering overhead surface cleaning using equation 1.

Kimberly-Clark is not proposing this equation for general use, but only as an example of how an alternative dust threshold determination may be made.

Equation 1:
$$M_{d\max} = \left(\frac{0.031 \times \mathrm{C_{opt}} \times \mathrm{V_{room}}}{\mathrm{A_{dust}}} \right)$$

Where:

M_{dmax} = Mass of dust (dust accumulation threshold) that could create a room explosion hazard, g/m^2
C_{opt} = Optimum dust concentration which creates maximum pressure rise, g/m^3
V_{room} = Volume of the room, m^3
A_{dust} = Overhead area where dust collects, m^2

The equation calculates the total mass of dust estimated to create an explosion hazard in a room of volume V_{room}. A safety factor of 2 was applied by establishing a target maximum dust accumulation threshold in the overheads equal to ½ of M_{dmax}.

Measurement of Dust Accumulation Rates. The total dust loading and dust accumulation rate in the overheads was estimated so that an overhead cleaning frequency could be established to ensure the accumulated dust mass was maintained below the target dust accumulation threshold. Dust accumulations were not uniform in the overheads and dust depth or bulk density could not be accurately measured. Therefore, a dust accumulation measurement method that did not rely on dust depth or bulk density was devised. The method required measuring the accumulated dust mass from six representative locations in the overhead building structures on a monthly basis for 6 months. Surfaces selected included round and rectangular duct work and roof trusses, with areas ranging from 4 to 10 ft^2 (0.38 to 0.93 m^2). Samples were collected in pre-weighted 1-gallon paint cans. The dust from flat surfaces was moved into the paint cans with a paint brush (Figure 3). A battery operated vacuum cleaner with a cyclonic dust collection bin (Dyson model DC 16) was used to vacuum dust from round duct work and other surfaces where the dust could not be easily collected with a 2 inch paint brush or 6 inch drafting brush (Figure 4). The sample masses were determined on a dry basis by placing the opened paint cans containing samples in a 100 deg C oven for 12 hours.

Figure 3 – Sample Collection by Bush

Figure 4 – Using portable vacuum to collect dust from round duct work

Calculation of Cleaning Frequency. From this data, the cleaning frequency was calculated based on the worst case dust accumulation rate, according to equation 2.

Equation 2: $$CF\,(days) = (0.5 \times M_{dmax})\ x\ \frac{ET}{AVE\ MR_d}$$

Where:

CF = Required Cleaning Frequency, days.
ET = Elapsed Time between cleaning or sampling, days
AVE MR_d = Average measured dust mass accumulation, based on the six samples collected over six one month cleaning cycles, g/m^2.

Housekeeping (Cleaning) Procedure. Figure 5 shows a typical cross-section of the overhead area that required cleaning. The structure is congested which made access difficult and increased safety risks associated with working at heights when cleaning.

Figure 5 – Overhead Structure

To address these issues**,** a written housekeeping procedure was developed that provided detail instructions of the order, method, and personal safety requirements for conducting overhead cleaning. The procedure required all accessible areas to be vacuum cleaned followed by compressed air blowdown for removing dust from surfaces inaccessible to vacuum cleaning. A color-coded diagram showing the cleaning sequence and areas to be cleaned by vacuum cleaning was developed and attached to the scissor lifts used by the cleaning crews. The vacuum cleaning was performed by a contracted service and was completed with the process operating. It was agreed that portable vacuums meeting NEC class II, division 2 electrical requirements would be used. Pneumatically-driven vacuums from a recognized manufacture of such equipment were selected. Only attachments provided by the manufacturer and meeting dust ignition proof criteria were used.

The manufacturing process was shut down and all electrical systems (except for the lighting and motor control systems, which were NEMA 12 compliant) was de-energized during compressed air cleaning. The vacuuming and compressed air cleaning were conducted from scissor lift platforms. Scissor lift operators were trained and licensed. PPE requirements included safety glasses, safety shoes, bump hat, and a fall arrest harness.

Ignition sources were controlled when compressed air cleaning was being conducted. No hot work was permitted in the area during compressed air cleaning and all other ignition sources capable of igniting a dust cloud were removed or shut down. Fork-lift truck traffic was prevented from entering the area during compressed air cleaning. It was discovered that scissor lifts meeting hazardous area classification requirements are not commercially available. To address the potential ignition risk, the lifts used during compressed air cleaning were inspected and kept free of dust and were not moved (horizontally or vertically) until any visible dust cloud in the immediate area had dissipated. To minimize fire risks when the lifts were moved, any dust accumulations on the floor in the path of movement were required to be swept prior to moving the lifts.

Overhead Oscillating Fans – Easing the Housekeeping Burden

Overhead oscillating fans were first used by the textile industry 40 years ago to minimize the risk of structural fires by preventing combustible lint from accumulating on overhead structures. With the recent heightened emphasis on combustible dust fire and risk mitigation, other industries are currently evaluating these fans as a relatively inexpensive tool to ease the housekeeping burden.

The function of the overhead oscillating fans is to prevent accumulation of dust in the overhead structure of manufacturing and processing facilities where combustible dust is handled or produced. The fans are intended to maintain dust in suspension until it can settle in locations more easily reached by traditional housekeeping measures. It should be noted that the fans are not intended to take the place of an effective dust collection system. Instead, the fans are intended to prevent dust that is not captured by collection systems from depositing in locations where housekeeping may be difficult to safely achieve; e.g., in overhead areas on horizontal structures, ductwork, ledges, light fixtures, cable trays, etc.

Typically, the fans rotate through 360º over a 15 minute period, oscillating from 70 degrees above horizontal to 50 degrees below horizontal, while discharging a constant air flow rate. Oscillation radius can be adjusted based on ceiling and equipment configurations. The effective "reach" of air movement from each fan is from 35 to 40 feet. The fans are typically spaced 25 feet from the nearest wall in a dusty area, and 50 feet between fans in a matrix to fully cover the area. It should be noted that some dead spots may occur where overhead obstructions prevent adequate airflow, requiring periodic cleaning of such areas. Overall, however, the net housekeeping burden should be reduced by the fans.

Figure 6 – Oscillating Fan Installation

Each fan comes with a bracket that mounts to overhead trusses or purloins. Two support arms mount the fan to the bracket and secondary structural members (Figure 6).

After fan installation and prior to fan operation, all overhead areas should be cleaned by vacuuming using safety controls previously outlined in this paper. Once activated, the fans should operate continuously when the dust generating equipment is running. This will prevent the dust accumulation and subsequent dispersal that would occur if the fans were to stop and start on a periodic basis. Controls should be considered to shut down the fans when fire alarms are activated.

In summary, overhead oscillating fans may help reduce the cost, risks, and potential liability associated with manual overhead cleaning. Some industries have found them to be very effective in overhead dust elimination and control, resulting in significant reduction of overhead combustible dust load and fire risk.

Pros and Cons of the Two Approaches:

The overhead fan approach has several advantages. Most importantly, it reduces the risk of creating a hazardous dust cloud during cleaning. Although it requires a capital expenditure and ongoing operating costs, these costs are offset by ongoing labor and equipment costs associated with manual cleaning. The fan system also reduces the need for working at heights and the associated personnel safety risks. Use of the fans may be limited in some situations. For example, the building configuration must have sufficient roof clearance for fan installation and operation. The placement locations must be carefully selected to ensure they do not interfere with the manufacturing process, cranes, hoists and other overhead equipment, and sprinkler systems used for fire protection. Use of the overhead fans may be less effective with higher density dusts that require higher air velocities to prevent settling. Periodic inspections may also be required to ensure that dead zones are identified in the overhead structures where the fans are not effective in preventing dust accumulations from occurring.

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1 The first six incidents are described in further detail by Frank in "Dust – The Other Explosion Hazard," *Process Safety Progress,* September 2004

2 http://www.csb.gov/completed_investigations/docs/CSB_WestReport.pdf

3 http://www.csb.gov/completed_investigations/docs/CSBFinalReportCTA.pdf

4 "Joint Foundry Explosion Investigation Report," OSHA, Massachusetts Office of the State Fire Marshall, Springfield (Massachusetts) Arson and Bomb Squad.

5 OSHA press release on Rouse Polymerics investigation, November 18, 2002: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=NEWS_RELEASES&p_id=9830.

6 Howell, S. M., and Routley, J. G., "Manufacturing Mill Fire, Metheun, Massachusetts," United States Fire Administration.

7 Zalosh, R., "A Tale of Two Explosions," 34th Annual Loss Prevention Symposium, American Institute of Chemical Engineers, March 2000

8 http://multimedia.savannahnow.com/media/pdfs/OSHAPP.pdf

9 http://www.csb.gov/news_releases/docs/BreslandSenateDustTestimony7.29.08.pdf

10 Property Loss Prevention Data Sheet 7-76, "Prevention and Mitigation of Combustible Dust Explosions and Fire," FM Global, March 2009.

11 Zeeuwen, P., "Dust Explosions: What Is the Risk? What Are the Statistics?," Euroforum Conference, Paris, France, March 1997.

12 Standard on Explosion Protection by Deflagration Venting

13 Standard on Explosion Prevention Systems