Session No. 522

Combustible Dust Hazard: Protecting Workers from Combustible Dust with FR Clothing

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Introduction

Nearly 300 combustible dust explosions have injured or killed over 800 workers since 1980.[1] As yet, there is no official standard regulating combustible dust for all affected industries, though such a standard has been discussed by policy makers for several years. A recent explosion in 2008 at the Imperial Sugar Company spurred widespread media attention and prompted OSHA to re-intensify its Combustible Dust National Emphasis Program from 2007 targeting a range of industries. Currently, policy makers are working to create an effective, enforceable, all-encompassing standard, yet regulating the dangers posed by combustible dust presents many challenges.

An insidious and often undetected hazard, combustible dust poses an immense threat for dozens of industries from chemical manufacturing to food processing. Over 1,000 firms in a number of different industries have been investigated for potential combustible dust hazards, and over 87% of these firms have received multiple citations.[2] Multi-step, industry-specific combustible dust mitigation processes are required to prove effective, and the difficulty of hazard assessment and standard development cannot be underestimated. Adequate cleaning, worker awareness, safety equipment, effective hazard analysis, and ventilation will help to minimize the possibility of combustible dust explosions; however, the use of flame resistant clothing as a secondary mitigation strategy for at-risk groups of employees will provide a last vestige of protection that may result in the difference between minor injury and death in the event that such an explosion does occur. Flame resistant clothing has been proven to reduce significantly worker injury and employer costs in similar industries with similar hazards. Because primary mitigation strategies may potentially be impractical, impracticable, or inadequate, flame resistant clothing is a safe, cost-effective secondary mitigation strategy to protect an employer’s most valuable asset: his workers.

Combustible Dust: An Insidious Hazard

In busy manufacturing environments fraught with hazards, the slow, steady accumulation of fine “dust” particles in often unseen areas such as ductwork, ceilings, and machinery can seem innocuous compared with more immediately obvious dangers of bodily injury posed to workers. Since the 1920s, a general understanding of the dangers posed by combustible dust has been widely shared in the manufacturing sector.[3] As yet, no enforceable combustible dust regulation currently exists, although many voluntary consensus standards have provided helpful information about hazard mitigation. Because a combustible dust explosion involves a complex chain of events contingent upon many variables, the challenges of policy making have deterred rule-makers at OSHA from constructing an official standard. In the meantime, several explosions over the past few years have cost companies millions of dollars and have taken many worker lives. Safety professionals desiring maximum explosion mitigation should take the time to become educated in the complexities of the hazard as well as in recognized mitigation strategies, regardless of the existence of an enforceable standard. Common-sense, practical, and cost-effective mitigation strategies can significantly diminish the possibility of an explosion at your firm if vigorously executed.

What is combustible dust? As yet, no official definition of combustible dust has gained widespread acceptance because of the many variables involved in an explosion. OSHA's definition provides an accurate generalization of the elements needed as follows: "organic or inorganic dust particles that are finely ground and pose a deflagration or other fire hazard when suspended in air or another oxidizing medium over a range of concentrations." [4] Prior to an explosion, finely divided dust is disturbed from its resting position and suspended in the air or introduced to another oxidant. An ignition source such as static, a spark, an ember, a hot surface, friction heat or flame comes in contact with dispersed dust, causing an explosion. OSHA has defined a dangerous accumulation of dust to be 1/32 of an inch or thicker, about the thickness of a US dime.[5] Dust particle size and density affect combustibility; the more finely divided dust is, the more likely it is to combust. Moreover, confined, poorly ventilated areas are more likely targets for combustible dust explosions than well-ventilated workplaces. Ignition source heat and moisture play an essential role in the severity of a dust explosion. All of these factors contribute to the interplay of an explosion. As a rule, these five elements interact in order for an explosion to occur (see Figure 1):

1. Combustible dust (fuel)
2. Ignition source (heat)
3. Oxygen (oxidizer)
4. Dispersion of dust particles in sufficient quantity and concentration
5. Confinement of the dust cloud

Figure 1. Dust Fire and Explosion Pentagon illustrates variable interaction.

In many cases, an initial explosion such as the one above propagates secondary explosions, which are often far more powerful and deadly than primary explosions.[6] The interplay of the five above variables can result in powerful, unpredictable, and often fatal dust explosions.

As part of its National Emphasis Program, OSHA first identified 48 industries potentially affected by combustible dust to target, and later revised the number to 64.[7] Many industries not listed by OSHA's National Emphasis Program may also be at risk for explosions. Industries including, but not limited to: agriculture, food products, chemicals, textiles, forest and furniture products, metal processing, tire and rubber manufacturing, paper products, pharmaceuticals, wastewater treatment, recycling operations, coal/dust handling are particularly at risk for a combustible dust explosion. In Figure 2 below, the Chemical Safety Board breaks down targeted industries by percentage in its Combustible Dust Investigation Report:[8]

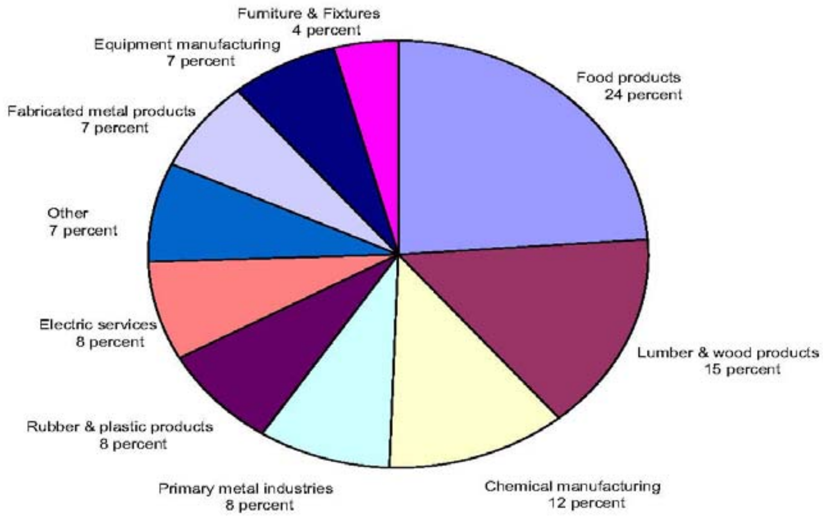

Figure 2. Combustible dust affects many industries.

The types of combustible dust are as numerous as the industries affected by them and include such materials as: metal dust, wood dust, coal or carbon dust, plastic dust, organic dusts such as sugar, flour, paper, soap, or dried blood, and certain textile materials. In Figure 3, the CSB's Combustible Dust Investigation Report addresses some of the many types of dust:[9]

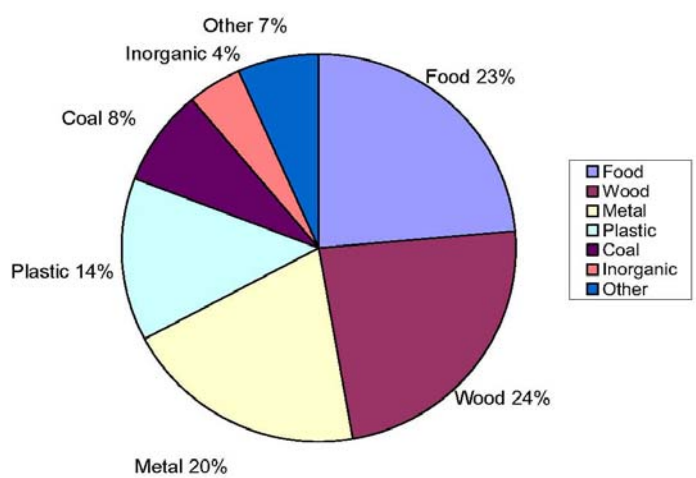

Figure 3. Dust accidents encompass a variety of dust materials.

The data above indicates the complexity and extensive scale of the combustible dust explosion hazard. In 71% of the explosions investigated by the CSB, fatalities occurred.[10] Due to the extensive nature of the hazard, OSHA's list of firms is a list of target industries and may exclude many industries with a known combustible dust hazard.

Hazard Assessment

Since combustible dust is a flash fire hazard, the challenges of accurate hazard assessment cannot be understated. Flash fire hazards, because of their unpredictable nature and the variability of their origin, leave an element of guesswork even in the best hazard assessment. The first step to mitigate any hazard in the workplace is to conduct a hazard assessment. Variables such as climate, temperature, dust density, and ventilation all play a part in the combustibility of dust. Even two scenarios with the exact same type, volume and density of dust, ventilation source, and ignition source may produce entirely different explosions at different times. Though hazard assessment under these circumstances is difficult at best, testing for dust explosiveness is both possible and practical.

Thus far, scientists have identified a way to assess the combustibility of dust deposits as well as the likelihood of an explosion, although these testing methods may provide an incomplete hazard assessment. The Environmental Molecular Sciences Laboratory, Materials Science Division divides testing into two categories: (1) *Explosive probability*, which measures how likely it is for an explosion to occur and (2) *Explosive power*, which measures the potential destructive power of any probable explosion.[11] Bulk samples of dust material in plastic bottles between 2-2.5 lbs are taken from several facility locations and tested for a general NFPA-classified "Kst" number as noted in the chart below.[12] (Kst is a generalized number used to estimate the anticipated behavior of dust deflagration, or explosion.) Class 1 dusts are rated below 200 Kst, Class 2 dusts range from 200 to 300 Kst, and Class 3 dusts are rated above 300 Kst (see Table 1).

Dust Explosion Class	Kst (bar.m/s)	Characteristic
St 0	0	No explosion
St 1	>0 and ≤ 200	Weak Explosion
St 2	>200 and ≤ 300	Strong Explosion
St 3	>300	Very Strong Explosion

Table 1. Combustible dust is rated by its explosiveness (Kst).

Even Class 1 dusts with relatively low Kst values (such as 50) are considered explosive. Dusts such as limestone, fume silica, and rock dust are examples of dusts with a 0 Kst rating. Dusts with high explosiveness (class 3) include magnesium and aluminum powder. Some dusts, such as salt, will never burn no matter what the intensity of the ignition source. Table 2 below contains common dusts and their Kst values:

Common Dusts	Kst Value
Aluminum Powder	400
Barley Grain Dust	240
Charcoal	117
Cotton	24
Magnesium	508
Soap	111
Sulphur	151
Tobacco	12
Wood Dust	102

Table 2. Common dusts have varying Kst levels.

When a facility opts to have testing performed, minimum dust concentration, minimum ignition temperature, and minimum ignition energy are evaluated by analyzing samples of dust from several locations, such as ceilings, ductwork, and corners. Once these elements are evaluated, the dust's Kst number can be placed into one of four categories ranging in severity from "no explosion" probability to "very strong explosion" probability. Though the testing data provided to firms who undergo testing cannot take into account all combustible dust variables such as moisture, climate, and ventilation, the numbers resulting from these tests may be the best way for firms to assess necessary safety precautions. Any firm with even a low risk of an explosion and any known dust accumulation above 1/32 of an inch should take safety precautions.

Case Studies

The mounting death toll resulting from combustible dust explosions demonstrates both the complexity and the variability of the hazard. The inconsistency of the combustible dust hazard poses a challenge to standard-makers. A few case studies instigated by OSHA and the Chemical Safety Board, differing in complexity and causation, illustrate the difficulty of policy making. Common explosion causes are shared by many investigations, however.

Georgia Sugar Company Explosion (14 killed, 36 injured). An initial dust explosion occurred in the enclosed steel belt conveyer located below the sugar silos. The recently installed steel cover panels on the belt conveyer allowed for sugar dust accumulation. An unknown source ignited the sugar dust, causing a violent explosion that resulted in multiple secondary explosions. The US Chemical Safety and Hazard Investigation Board determined that multiple dust explosions were caused by the following:

1. Sugar and cornstarch conveying equipment was not designed or maintained to minimize the release of sugar and sugar dust into the work area.
2. Inadequate housekeeping
3. Airborne combustible sugar dust accumulated above the minimum explosive concentration inside the newly enclosed steel belt assembly.
4. An overheated bearing in the steel belt conveyer most likely ignited an explosion.
5. The primary explosion triggered massive secondary explosions.

6. The 14 fatalities resulted from the secondary explosions.
7. Imperial Sugar emergency evacuation plans were inadequate.

Michigan Electrical Power Generation Facilities (6 killed, 14 injured). An initial explosion of natural gas in a power boiler was followed by second explosion of coal dust. Investigators determined that the cause of the explosion was a natural gas buildup in a boiler that was being isolated for maintenance. 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/m2 on floors and overhead beams. The following, as cited by the CSB, most likely caused the accident:

1. Lack of worker awareness
2. Inadequate housekeeping

Mississippi Rubber Manufacturing (5 killed, 6 injured). Accumulation of rubber dust ignited and exploded in the ceiling, causing numerous secondary explosions. In this scenario, the CSB cited the following as causing the explosion:

1. Lack of worker awareness
2. Improper building construction

Massachusetts Foundry Explosion (3 killed, 9 injured). A fire initiated in the shell molding machine from an unknown source extended into the ventilation ducts by burning heavy deposits of phenol formaldehyde resin dust. A small explosion occurred within the ductwork, followed by a secondary explosion that lifted the roof and caused wall failures. The investigation report of this explosion by OSHA revealed the following:

1. Inadequate housekeeping to control dust accumulations
2. Poor ventilation system design
3. Poor maintenance of ovens
4. Inadequate equipment safety devices

North Carolina Pharmaceutical Plant Explosion (6 killed, 38 injured). An accumulation of polyethylene dust above the suspended ceilings fueled an explosion, although the Chemical Safety Board was unable to determine what ignited the initial fire or how the dust was dispersed to create the explosion in the hidden ceiling space. The following were cited by the CSB:

1. No hazard assessment
2. No hazard communication
3. Poor engineering management

Kentucky Insulation Manufacturing Plant Explosion (7 killed, 37 injured). In February 2003, a Kentucky acoustics insulation manufacturing plant had an explosion caused by a dust cloud beside a small oven. A deadly succession of secondary explosions then occurred throughout the plant. The CSB revealed that the following were causes:

1. No hazard assessment
2. No hazard communication
3. No maintenance procedures
4. Poor building design
5. Inadequacy of investigation of previous fires

These case studies, conducted by the Chemical Safety Board as well as OSHA, illustrate the severity of the combustible dust hazard among many industries.[13] The causes of these explosions have extensive overlap. Common citations include: no hazard assessment, no hazard communication, and inadequate ventilation. In recent years, the hazard has been on the increase. Figure 4 below from the Chemical Safety Board Investigation Report reveals the increasing trend of dust explosions.[14]

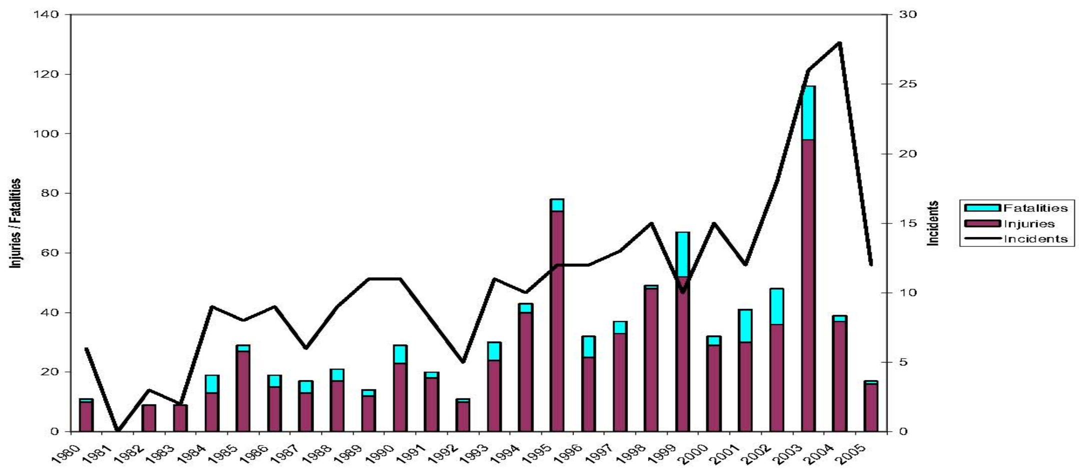

Figure 4. Dust explosions have been on the increase in recent years.

In almost all cases, the elements causing explosions were entirely preventable. In almost all cases, fatalities occurred. Though the sudden increase of explosions may be entirely coincidental, combustible dust explosions have caused extraordinary damage. Each facility was unaware of hazard violations or improperly educated regarding the dangers posed by the accumulation of dust in often unseen places. The penalty for this lack of awareness, in addition to millions of dollars in fines, was the irreparable loss of worker life accompanied by each explosion.

Mitigation Strategies

Combustible dust, though unpredictable and contingent on many factors, can be mitigated to reduce the hazard to workers. Companies should perform all practicable known dust containment strategies to mitigate explosions and minimize damage should an explosion occur; it is also practical for a facility to have dust testing conducted. Flame resistant clothing can function as a secondary protective strategy. Oil refineries and other industries subject to flash fire hazards often use flame resistant clothing as a best practice model even though flame resistant clothing is not yet part of an enforceable OSHA regulation. The National Fire Protection Association has identified numerous additional strategies in addition to the use of Personal Protective Equipment to prevent and mitigate explosions. NFPA 654 makes the following recommendations to control dust:

- Minimize escape of dust from process equipment or ventilation systems
- Use dust collection systems and filters
- Utilize surfaces that minimize dust accumulation and facilitate cleaning
- Provide access to all hidden areas to permit inspection
- Inspect for dust residues in open and hidden areas, at regular intervals,

- Clean dust residues at regular intervals
- Use cleaning methods that do not generate dust clouds, if ignition sources are present.[15]

According to OSHA, the following elements should be carefully watched and guarded against:

- Materials that can be combustible when finely divided
- Processes which use, consume, or produce combustible dusts
- Open areas where combustible dusts may build up
- Hidden areas where combustible dusts may accumulate
- Means by which dust may be dispersed in the air
- Potential ignition sources[16]

Combustible dust vacuums, ventilation systems, housekeeping, safety training, and safety equipment are all useful in preventing the collection and accumulation of combustible dust. Workers are always the first line of defense in preventing and mitigating fires and explosions. "If the people closest to the source of the hazard are trained to recognize and prevent hazards associated with combustible dust in the plant, they can be instrumental in recognizing unsafe conditions, taking preventative action, and/or alerting management."[17] Perhaps the most important component of hazard mitigation is raising employee awareness.

Hazard assessment, safety training, and communication are the first line of defense against a combustible dust explosion; flame resistant clothing is the last line of defense. Mitigation strategies used to reduce the likelihood of combustible dust explosions may do much to prevent explosions, but additional precautions should be taken to ensure that in the event that an explosion does occur, workers are protected. Flame resistant clothing is a secondary protective strategy providing protection from momentary burns and flames. It has been proven a cost-effective and successful measure for employers to take in protecting their employees from flash fire hazards such as combustible dust.

What is Flame Resistant Clothing?

All flame resistant clothing must be tested for safety and durability. NFPA 2112 says that flame resistant clothing must protect the wearer by, "not contributing to the burn injury of the wearer, providing a degree of protection to the wearer, and reducing the severity of burn injuries resulting from accidental exposure to hydrocarbon flash fires."[18] The following tests are used to establish the flame resistance of garments in a flash fire scenario:

- **The Vertical Flame Test**, as specified by ASTM D6413, determines whether a fabric will continue to burn after the source of ignition is removed. Using a 12 second methane flame and a special testing apparatus, afterflame, afterglow, and char length are measured. Flame resistant fabric must exhibit less than a two-second afterflame and less than 6" char length.[19]
- The **Three-Second Manikin Test**, ASTM 1930, is the test method for evaluating a garment's flame resistance using an instrumented manikin. A garment is exposed to a heat flux of 2.0cal/cm2.sec for three seconds. If the garment displays less than 50% total body burn, the fabric achieves a passing performance. This test method is commonly cited in NFPA 2112.[20]
- Another commonly cited test method in NFPA 2112 is the **Thermal Protective Performance** test (TPP). The 2007 edition of NFPA 2112 requires the Thermal Protective Performance test to be performed both with the fabric against the sensor and with a ¼" spacer. A minimum TPP rating of 6.0" for "spaced" and 3.0" for "contact" is required to meet the standard.[21]

To protect against flash fire, FR clothing must pass the above tests. Clothing that meets these performance thresholds has been shown to reduce significantly the cost and injury in industries associated with flash fire hazards.

FR Clothing: Proven Protection

Mitigation strategies, however helpful, can be impractical logistically or economically to a firm. Though every firm should use available resources to prevent combustible dust explosions, flame resistant clothing can provide the secondary protection needed should a firm be unable to implement every known mitigation strategy. The effectiveness of flame resistant clothing in preventing and mitigating worker injuries in flash fire scenarios has been proven. Additionally, the cost-effectiveness and durability of flame resistant clothing provide additional incentives. Although precise flash fire analysis is difficult at best, the effectiveness of flame resistant clothing in minimizing and preventing worker injury cannot be underestimated. Where any flash fire hazard exists, using flame resistant clothing is a common-sense method to significantly reduce the chance of worker injury in the event of an explosion.

On top of preventing the added burn injury inherent in the melting and dripping of non-flame resistant fabrics, the cost of flame resistant clothing is minimal compared to the devastation of a burn injury on a worker personally and economically. In the 1970s, before OSHA required utility workers to wear flame resistant clothing, an average of 9.5 burn accidents and 14.7 burn injures per 100 workers resulted in devastating personal and economic costs to utilities.[22] After OSHA implemented 1910.269, the Standard for electric generation, transmission, and distribution in the 1990s, worker burn injury rates in the 2000s decreased to 4 accidents and 6.2 injures per 100 workers.[23]

Although few statistics exist on the specific number of burn injuries *prevented* by FR, the American Burn Association (2006) provides data on burn injuries aggravated by factors such as not wearing flame resistant clothing. The American Burn Association conducted a 10-year study (1995-2005) of acute burn admissions and reported the following:

- Ignition of flammable material caused the second-highest number of incidents (of the top ten causes of burn injury). Of the 60,480 victims injured by the top ten leading causes of burns, 10,753 (or 17%) of the victims experienced burn injuries aggravated by the ignition of non-flame resistant clothing.[24]

One firm identified the following costs associated with a single burn injury:

- $650,000 for initial medical treatment, including five surgeries
- $250,000 for five additional reconstructive surgeries
- $250,000 for five years of rehabilitation
- Indirect costs plus direct costs total between $5M and $23M[25]

Clearly, the psychological, economic, and moral cost of worker burns to firms is staggering.

Innovative technology has ensured that FR fabrics can be comfortable, durable, and attractive. Flame resistant clothing may pay for itself even if a single burn injury never occurs. Flame resistant garments come in a wide variety of styles and colors to suit employee and employer taste. There is no reason why the provision of flame resistant clothing to employees should not be a priority for firms subject to the combustible dust hazard in addition to preventative hazard mitigation strategies. Though the primary strategy should always be to remove the hazard, flame resistant clothing is indeed a last line of defense for workers in the event that these strategies fail.

Summary: Preventing and Protecting Against Combustible Dust

Combustible dust does not have to claim another life. A complex hazard demanding multi-step analyses, combustible dust is nonetheless, for the most part, preventable. Safety professionals and workers alike can take many steps to ensure that combustible dust will not do any physical or structural damage to a firm and its employees. Reviewing current standards, remaining current on the development of OSHA's standard, assessing whether your company may be at risk, and choosing mitigation strategies are all instrumental to keeping combustible dust at bay. No mitigation strategy will provide 100% protection against a combustible dust explosion for an at-risk firm. Choosing flame resistant clothing is an effective method to protect at-risk employees if, for any reason, primary mitigation strategies are economically or practically ineffective—and even if primary mitigation strategies *are* effective and employers want to prevent or minimize worker injury.

The following standards will prove helpful for safety professionals in researching combustible dust preventative measures:

OSHA
1910.22(a)(1)—Housekeeping, allowable dust accumulations
1910.22(a)(2)—Housekeeping, allowable dust accumulation on floors
1910.178(c)—Classification in hazardous environments
1910.307—Hazardous Locations
5(a)(1)—General Duty
1910.272—Grain Handling Standard

NFPA
NFPA 68—Guide for Venting of Deflagrations
NFPA 85—Boiler and Combustion Systems Hazards Code
NFPA 69—Standard on Explosion Prevention Systems
NFPA 499—Classification of Combustible Dusts
NFPA 654—Prevention of Dust Explosions from Manufacturing Processing, and Handling of Dust
NFPA 61—Prevention of explosions in agricultural and food processing facilities
NFPA 484—Metal Dust Standard
NFPA 664—Wood Dust Standard

At present, OSHA has issued an Advance Notice of Proposed Rulemaking, and a standards committee has been established and OSHA has conducted stakeholder meetings to solicit input on the language and approach of such a standard. With recent and repeated occurrences of explosions and fires related to combustible dust, there is general emphasis on developing a standard specific to this hazard as quickly as is feasible. It is important for Safety Managers and Administrators in relevant industries to understand the development of standard making, particularly with regards to the National Emphasis Program, to ensure that they are in compliance.

After becoming educated in the current and developing standards, the next step to preventing an explosion is to assess whether your company is at risk. Assessing your dust accumulation of any material, ventilation, ignition sources, and testing dust samples for explosive probability and explosive power are all important initial steps. The standard that OSHA develops in the future will most likely contain more specific instructions for conducting a hazard assessment, but until this occurs, sending dust samples to a testing facility is a good strategy. Any dust at your facility that is tested at a Kst of 1 or greater should be considered combustible, and your facility should be considered at risk for a combustible dust explosion.

Once the likelihood of an explosion of any severity has been determined, safety professionals should educate workers on effective methods for hazard removal. This might include housekeeping instructions, ensuring proper ventilation, removing or monitoring ignition sources, and providing safety equipment. The extent of hazard removal will depend on the company, the breadth of the hazard, and the feasibility of prevention methods. Until OSHA develops an official regulation, reliance on the above NFPA Standards will provide an excellent measure of protection.

Though flame resistant clothing is not yet required for workers exposed to flash fire hazards, its procurement may be the last and most important step a company can take to insure the lives of workers. Many companies have already taken this preventative measure to avert worker injury. Mitigation strategies, though effective, are often not practical for a small or mid-size company. Even companies that implement all known mitigation strategies will find that cost-effective flame resistant clothing will offer peace of mind in the event that an explosion ever does occur. Until there is a unified, enforced standard regarding this hazard, voluntary compliance with the current recommendations is necessary to ensure worker safety. Preventing the thousands of worker burn injuries that occur every year should be on the forefront of each employer's priority list.

Endnotes

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