On July 29, 2008, John S. Bresland, CSB chair and CEO, testified before the U.S. Senate Committee on Health, Education, Labor and Pensions Subcommittee on Employment and Workplace Safety. He noted that since 1998, the year that CSB was established, three of the four deadliest accidents CSB had investigated were determined to be combustible dust explosions.

On Feb. 7, 2008, thirteen workers died and 39 were injured at the Imperial Sugar refinery in Port Wentworth, GA. Twenty-three people were burned from the fire and explosion, three of which were still hospitalized in a burn center after 5 months of treatment.

On Jan. 29, 2003, six workers were killed and 39 were injured in a polyethylene dust explosion at West Pharmaceutical Services in Kinston.

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NC. The fuel for the explosion was a fine plastic powder, which had accumulated above a suspended ceiling over a manufacturing area at the plant and had ignited.

And on Feb. 20, 2003, seven people were killed and 37 were injured in an explosion at CTA Acoustics, Inc. in Corbin, KY. This incident severely damaged a 302,000-sq.-ft. manufacturing plant and temporarily shut down four Ford Motor Co. vehicle manufacturing plants. Combustible phenolic resin dust had accumulated throughout the facility and was the fuel for the explosion.

In Nov. 2006, CSB completed a study on combustible dust. It found that combustible dust explosions have been a recurrent cause of disasters at U.S. industrial facilities. The study, which did not include primary grain handling or underground coal dust explosions, identified 281 dust fires and explosions that occurred at U.S. businesses between 1980 and 2005. These fires and explosions resulted in 119 deaths and 718 injuries. CSB called for a comprehensive OSHA regulatory standard to prevent dust explosions in general industry, improved training of OSHA inspectors to recognize dust hazards and improvements to MSDSs to better communicate dust hazards to workers.

**Combustible Dust Assessment**

Combustible dust assessments are performed to help management identify and define hazardous conditions and risks so they may be eliminated or controlled. The analysis should examine the process, systems, subsystems, components, actions (or lack of actions) and their interrelationships.

Assessment and review of what can go wrong may not be an easy task. Many dust losses are not the result of a single cause. Rather, they are the confluence of multiple events that occur simultaneously or in a chain of events. Systems should be designed using methods considered to create a “safe” situation.

Reliability of the components and assemblies must also be considered. When components or assemblies fail, the initial design parameters are compromised. The compromised system is outside of the normal scope of design, and a loss is much more likely to occur.

A dust hazard analysis may be used wherever a dust condition exists. It may be a process that involves drying a liquid sprayed into a drying chamber. It may involve grinding, sifting, screening or other manipulation of a product. The dust may be released from the process of pouring ingredients from a bag into a vessel. It may be dust within a conveying system. The dust may be tramp dust emissions or escape material from process leakage points in a manufacturing situation. Dust may also be present from inadequate housekeeping. Dust hazards may exist where large pieces of material are handled, but in the manufacturing process, dusts are created in small amounts and allowed to accumulate over time.

A well performed and documented dust hazard analysis will lessen the probability of a loss occurring. The analysis will help identify hazards and implement safeguards. Those hazards may be mitigated through design or procedures to prevent a loss from occurring.

A dust hazard analysis uses recognized standards and levels of conduct considered to be what a prudent person would normally do to prevent a loss. It shows that industry standards have been followed in design and operation. It is a documented methodology to defend one’s actions. After a loss, especially one that takes a person’s life, the documented dust hazard analysis will help determine the cause.

Compatibility is reviewed to ensure that compatible parts and methods are used and followed. It ensures that a level of specification is followed and that inferior components are removed from the process.

**What Is a Dust Explosion?**

Imagine trying to start a log on fire. By itself, it will be difficult to start and will require much energy to bring it to a sustainable burn. It will take hours to burn to ash. If the log is split into several smaller firewood pieces, it will be easier to ignite, will require much less energy to bring it to a sustainable burn, will burn with a higher rate of heat release and will burn to ash more quickly than the same amount of wood as a log. Taking those firewood-size pieces, further splitting them into small kindling wood and arranging them in a fashion that provides good air circulation will further change the ignition requirements. The energy required to ignite and bring a pile of kindling wood to a sustainable burn is even further reduced. The kindling will burn with a higher rate of heat release and will burn to ash very quickly. This is due to many factors but chiefly because the wood’s surface area has been greatly increased, the configuration of the wood in the pile is more conducive to ignition and the air around the wood supplies enough oxygen to readily support combustion.

Taking this analogy another step further, if the log is reduced to dust in fine particle size and suspended in a cloud with air around all of the many particles, the dust cloud will burn so violently, a flash fire will occur. The energy released within the few seconds that the cloud takes to burn depends on the particle size and the specific properties of the wood used. Think of the log taking hours to burn all of the wood to ash. That same wood and the energy needed to convert the log to ash are all released in a few seconds.

Imagine that dust in a cloud with perfect density in air and igniting in an open field with nothing around it. The sight of this burning is spectacular, and there is limited or no resultant damage other than the loss of the wood dust. This is often called a fireball or deflagration. Now, imagine that same energy release in a
confined space, such as a machine or a building, which acts like a vessel to contain the deflagration. The pressure wave from the rapid burning of the dust cloud tries to expand quickly. The vessel contains the pressure and allows it to build until it bursts out of its confinement in a rapid fashion. This is a dust explosion. In the wood dust cloud scenario, injury or death can occur to people nearby, and the machinery or building involved can suffer significant property loss.

**Explosible Range of Dust Clouds**

Not all dusts are considered combustible. Some, such as sand, cement and rock, are typically not combustible. Organic dusts, such as plant dusts, are combustible. These include a wide variety of materials, such as sugar, flour, grain, linens, etc. Many synthetic organic materials, such as plastics, organic pigments and pesticides, are combustible. Coal and peat is combustible, as are some metals, such as aluminum, magnesium, zinc and iron.

The mere presence of the dusts does not in and of itself make an explosive condition. Proper conditions must exist to realize a dust cloud deflagration or explosion. The dust must be of the proper size. A material needs to be of the correct particle size to enter into an explosive reaction. One difficulty of dust accumulations is that a pile of dust may have many varied sizes of particles. If even a small percentage of the particles are conducive to setting up an explosion condition, that small percentage of particles of the correct size and physical characteristics may ignite. Generally speaking, the smaller the dust particles, the more intense the rate of burning and the more devastating the explosion. A 40-mesh screen, or approximately a 420-micron particle, is a sufficient size for many dusts to be in the appropriate range. In the case of fibers, while they may not be able to easily pass through a screen, fine fibers are also candidates for rapid burning resulting in an explosion.

Dust cloud density must also be in the proper range for that particular material. This is usually measured in grams/cubic centimeter or grams/cubic meter. Explosible dust tables identify the density and particle size that will lend to an explosible condition.

The cloud must be in the proper dispersion proportions in an oxidizing medium, such as air, oxygen or other industrial gas mixture.

A cloud will not start to burn without an ignition source. Ignition sources may be from:
- smoldering or burning dusts;
- open flames from welding, cutting, matches or lighters;
...hot surfaces, such as heaters, ovens, furnaces or hot bearings;
• heat from mechanical impact;
• electrical discharges or arcs.

In addition to the ignition source, the material needs to be in the proper moisture content range. Typically, the drier the dust, the more susceptible it is to entering into the combustion process.

Many factors must come together at the same time for an explosion to occur. Some facilities may operate for many years without an explosion; then one day, all characteristics needed for a deflagration come together at the same time, and a violent dust explosion occurs.

**How Does One Know If a Dust Is Combustible?**

Many dusts are known to be combustible. Organic substances, such as sugar, wheat flour and corn starch, are known combustible materials. Reference the MSDS provided by the supplier or manufacturer. Reference books can identify if the material is combustible. Other materials may not be as readily identified as a combustible dust. In these cases, testing may be performed on the material. If the dust has not been tested and confirmed as noncombustible, it should be considered a combustible dust.

Considerations when determining whether a dust is combustible include the material, the size, the dispersion density, the oxidizing medium and the energy source. A laboratory may test the material. The laboratory may determine if the material is noncombustible, and that is many times the extent of the testing required. In the event the laboratory test identifies the material as combustible, it will determine the particle size, specific gravity, bulk density and moisture content. A report will identify the material properties.

Then, ignition testing may be performed. The laboratory will recommend the testing methods to employ and will work to fully identify the combustibility and energy production from the material.

**How Does a Dust Form a Cloud?**

Dusts may form clouds in many various ways. Grain discharging from a chute into the air when filling a silo can create a cloud. Emptying a silo through a valve at the base may also create a cloud. Pouring bags of dusts into a mixing chamber can create a dust cloud. Just about any bulk handling of dusts may lead to a potentially dangerous dust condition if the proper precautions are not followed.

Ducts in a plant may have a dust cloud condition inside the duct. The dust may be transported in a stream of air. Bag houses may also contain dust clouds. Ducting through plants is such a common fixture, many do not even think of a dust condition within the confines of the dust-collecting system. Motors, gears and bearings, which may be part of these systems, can lead to an ignition and resulting explosion if a malfunction occurs.

Dryers may contain a dust cloud. Some dryers have a particulate-laden liquid sprayed into a chamber under high pressure and temperature. As the material falls through the drying chamber, the moisture is removed, leaving a fine dry powder or dust in the base to be removed as a finished or intermediary product. At some point in the dryer between the top (100% moisture content) and the bottom (0% moisture content), an explosive condition is met in a portion of the vessel. No explosion occurs because the ignition source inside that portion of the chamber is insufficient. Some processes may use an inerting medium within the drying chamber to help prevent ignition.

Other processing equipment used in many various industries may also create dusts. Even if a primary process or product is not a dust-related product, dust hazards may still exist and should be safeguarded. Cutting equipment, such as saw blades, will create dust. Abrasion equipment used in sanding or polishing processes may create dust. Grinding, pulverizing, mixing and screening equipment produces dust in many various forms depending on the industrial process in use.

The operating area’s atmosphere may even create a potentially hazardous area. A coal mine by nature will have coal dust potential. The grinding, shoveling and conveying of coal lends itself to dust potential.

Dust in a manufacturing facility may accumulate on equipment and building surfaces. Any ledge in a building may be an accumulation point for dust. Roofing system members, such as bar joists, are also common accumulation points. A cloud may form when the dust falls from the equipment or building ledges. This may be during activities, such as cleaning. An equipment upset, earthquake or any other cause of building shaking may dislodge the dust from the members. As the dust falls, it disperses in the air. If the proper particle size, the density of dust in the volume of air and an ignition source come together, a dust cloud deflagration or explosion may result. The initial pressure wave may serve to loosen more dust from other building members creating a second, and potentially larger, cloud. This secondary resultant dust cloud may also ignite with a larger pressure wave. Additional and larger explosions may then occur, each larger than the last. Witnesses of dust cloud explosions have reported hearing one or two small bangs, followed by the lights going out, then a subsequent major explosion. This phenomenon may not be the lights going out, but rather a dust cloud...
forming in such proportion that it obscures the ceiling lights before exploding with major proportion.

**Codes & Standards**

Codes and standards are each written with an objective or purpose in mind, generally to help make a process or installation safer. The governing rules and regulations followed daily come from many sources. They may be acts of government, codes of conduct, codes of design, regulations, specifications and guidelines. An individual or entity may value the various governing rules with different levels of interest. Nonconformance to standards may not have a detrimental effect on most days and for long durations of time. However, one day when it is least expected, nonconformance to good practice may become evident. The evidence may be injury, loss of property, loss of business continuity, bad press or death of employees.

Standards are a basis for design, and most have been written as a direct result of a catastrophe, major loss or multiple deaths. There is usually a good reason behind every paragraph written into a standard. They are the minimum level of care and design required to make a process or task reasonably safe. Minimum standards are just that, minimum standards. If an installation, process or procedure fails to meet the minimum prescribed in a standard, it should be considered an unsafe situation.

**NFPA Standards & Dust Explosion**

The following NFPA standards pertain to dust explosion:

- NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids;
- NFPA 655, Standard for Prevention of Sulfur Fires and Explosions;
- NFPA 664, Standard for the Prevention of Fires and Explosions in Wood Processing and Woodworking Facilities;
- NFPA 61, Standard for the Prevention of Fires and Dust Explosions in Agricultural and Food Processing Facilities (2002 ed.);
- NFPA 68, Standard on Explosion Protection by Deflagration Venting;
- NFPA 69, Standard on Explosion Prevention Systems;
- NFPA 2113, Standard on Selection, Care, Use and Maintenance of Flame-Resistant Garments for Protection of Industrial Personnel Against Flash Fire.

One major code, NFPA 70, National Electrical Code (NEC), has many associated standards.

**Preventing Explosible Dust Clouds & Explosions Through Design**

There is no easy answer to preventing explosions. NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids, discusses many aspects of preventing dust explosions. One primary item is designing the processes and facilities that handle combustible particulate solids appropriately. The design must take into account the physical and chemical properties that establish the materials’ hazardous characteristics. The building and processes should undergo a thorough hazard analysis study. The study should look at equipment design, process procedures, worker training, inerting and other protection means.

The process system should be designed to limit fugitive dust emissions to a minimum. Any changes, additions or modifications to the system or process should be reviewed in a management of change (MOC) evaluation. Major objectives in the review should be life and property conservation. Structural integrity and damage-limiting construction are an important aspect. Mitigation for the spread of fire and explosion should be designed into the system. The design should adhere to existing codes and should be of sound, proven technology and technique. NFPA 654 provides many sound methods for the design of dust-related occupancies and references several other NFPA codes and standards for specific concerns.

Deflagration venting is a major factor in preventing an unvented dust deflagration. Buildings should be built of damage-limiting construction. This may include a blowout wall construction in which predesigned friction fit or frangible fastener panels are installed to relieve in the event of a dust ignition. Machines should be provided with venting. This may be performed in many ways, such as hinged, weighted doors, bursting disks and other acceptable features. Attention to such details can help decrease losses not only to buildings and equipment, but also to life.

**Automatic Suppression of Dust Explosions**

Fast-acting fire extinguishing systems may be installed in enclosures to help prevent an uncontrolled deflagration and pressurization. Pressure-sensitive, ultraviolet or infrared detectors are used to sense the dust cloud ignition early in its propagation and trigger the release of an extinguishing agent. In the past, halogenated agents were used in extinguishing systems. Today, due to environmental issues, powder extinguishing agents are typically in use.

**Management Programs, Training & Procedures**

Management is ultimately responsible to ensure that appropriate precautions are implemented and maintained. However, safety is not a top-down program. All employees should be a significant part of a proactive program.

Management should ensure that operating and maintenance procedures and emergency plans are developed. Regular and annual
reviews and updates should be provided. An initial training should be implemented, and regular refresher training should be provided for all employees involved in operating, maintaining and supervising facilities that handle combustible particulate solids. NFPA 654 also requires that the employer certify that the training and review for employees have been provided. In addition to employee training, it may be prudent to provide awareness and procedure training for contractors and visitors. In addition, self-inspection programs should be implemented. Ongoing maintenance to all equipment to ensure that it remains in proper working condition is also important.

**Self-Inspection Programs**

Self-inspection programs must be implemented to ensure safe conditions. The self-inspection program should be a frequent, written program, which is reviewed by management, and for which corrective actions are taken immediately when deficiencies are found. The self-inspection program should include housekeeping conditions and all of the systems in place to safeguard the operation from loss. Fire and explosion prevention and protection equipment should be inspected in accordance with applicable codes. Water-based systems should be inspected in accordance with NFPA 25, Standard for the Inspection, Testing and Maintenance of Water-Based Fire Protection Systems. Alarms should be inspected in accordance with NFPA 72, National Fire Alarm Code®.

Other systems should be inspected in accordance with their related codes and standards. Dust control equipment should be inspected. Potential ignition sources should be identified. Electrical systems and interlocks should be inspected. Identify process changes. The program should verify that maintenance, such as lubrication or bearings, is performed. Records of self-inspections and resultant maintenance and repairs performed should be well documented and maintained on file.

**Housekeeping**

Maintaining a facility in a state of good housekeeping is an important part of daily activities and is essential for processes that produce dusts. Good housekeeping will help keep dust accumulations outside of the explosible range. A tight process system operated with care should keep fugitive dust emissions to a minimum. However, it does not take the place of maintaining a regular cleaning schedule.

Dust accumulations should not exceed defined limits. NFPA 654, Paragraph 6.1.1.1., states, “Those portions of the process and facility interior where dust accumulations exist external to equipment in sufficient depth to prevent discerning the underlying surface color shall be evaluated to determine if a dust explosion hazard or flash fire hazard exists.”

Dust flash fire or dust explosion hazard areas should be evaluated by performing additional evaluations. The
four methods identified in NFPA 654 include layer depth criterion method, Mass Method A, Mass Method B or risk evaluation method. Each method is described in the standard.

NFPA 654 requires that regular cleaning frequencies be established for walls, floors and horizontal surfaces, such as equipment, ducts, pipes, hoods, ledges, beams and above suspended ceilings and other concealed surfaces, to minimize dust accumulations. The inspection program for housekeeping must be proactive and must actively seek areas known to accumulate dust. This includes roof members and hidden areas not readily visible from the floor level. Dust accumulations may be above the ceiling, as with the loss incident at West Pharmaceutical Services in Kinston, NC. Whenever fugitive dust emissions develop, an active repair program should be in place to make corrections to prevent future emissions. Vacuum systems should be used for cleaning dust emissions. Vigorous sweeping or blowing down with steam or compressed air produces dust clouds, and for that reason, is not generally recommended. However, if blowing down must be done, specific precautions in NFPA 654 must be met.

A LOOK BACK IN TIME

In the grand scheme of the Industrial Revolution, systemized educational curriculums for safety and hazard analysis are relatively recent. Only a few decades ago, finding a college curriculum majoring in safety, fire protection or process hazard safety was limited. However, today, such programs are more available and have sprung up at several colleges and universities around the country. Even in universities without dedicated safety programs, safety courses are offered, and even required, in many engineering curriculums. Safety is a topic of discussion in all aspects of engineering.

Early systematic processes were identified in aviation and military applications. Equipment or system failure at 20,000 ft. is not always a survivable event. Moving into the space age, National Aeronautics and Space Administration learned through failures that a systematic process must be followed to identify points of failure in each system installed and implemented into the space vehicles launched into outer space.

In the 1960s, the process and chemical industries embraced process hazard analysis. Hazard and operability method (HAZOP) became better identified and published in the 1970s. Its introduction into process safety regulations in the 1980s and 1990s caused a dramatic increase in the implementation of the process. Industries performing high-hazard operations have incorporated process hazard analysis into their design and analysis procedures.

Sometimes, product liability drives the need for safety analysis. Today, automakers perform hazard analysis for each vehicle they make, but this was not always so. Prior to the 1970s, safety hazard analysis studies were not routinely performed on new car
Dust assessment is not a cut-and-dry program or procedure. A dust assessment should be performance-based. A well-developed assessment depends on the discipline and ingenuity of those involved.

A dust assessment requires that the design of the fire and explosion safety provisions be based on a process hazard analysis. Performance-based. At this moment, a dust assessment needs to go a step further. Dust assessment should be performance-based. At this moment, there is no specific dust assessment analysis or procedure to follow. A well-developed assessment depends on the discipline and ingenuity of those involved.

Recognized and generally accepted good engineering practice (RAGAGEP) should be followed in the evaluation. A good basis for an analysis is to follow process safety management (PSM) procedures. Although PSM is designed for the chemical industry, the processes, procedures and documentation used in PSM will readily transfer to dust hazard analysis.

A good dust hazard assessment has many benefits, including:
- It reduces the probability and severity of a loss.
- It helps ensure compliance with regulatory standards.
- It helps bring management and employees together to solve a common problem.

A dust hazard assessment should be performed as a normal course of business. As the process changes, the hazard assessment should be updated through a MOC program. Senior management must drive the program and must initiate the program from top management down. Hazard assessment is not a delegated responsibility. Senior management should take an active part in the program and process and should incorporate hazard assessment into the corporate or plant safety culture.

**Methodology**

When a process is designed and installed, codes, regulations, standards and ordinances are followed in the construction process. The design is using these prescriptive methods to prevent a loss. A dust assessment needs to go a step further. Dust assessment should be performance-based. At this moment, there is no specific dust assessment analysis or procedure to follow. A well-developed assessment depends on the discipline and ingenuity of those involved.

**Hazard Analysis & Combustible Dust**

Regarding combustible dust, NFPA 654, Standard for the Prevention of Fire and Dust Explosions from the Manufacturing, Processing and Handling of Combustible Particulate Solids, requires that the design of the fire and explosion safety provisions be based on a process hazard analysis. NFPA 654, Section A.4.2.1 discusses that the requirement of a process hazard analysis may be satisfied when the analysis is conducted in accordance with the methods outlined by AIChE Center for Chemical Process Safety in Guidelines for Hazard Evaluation Procedures.

An important provision identified in the standard is that the process hazard analysis be reviewed and updated at least every 5 years. This is important to confirm the process integrity. It is an opportunity to review the process and procedures as they are currently implemented and to incorporate newly developed safety methodologies.

NFPA 654, A.4.2.1, identifies some key points to consider when determining if a dust deflagration hazard exists:
- Determine if the dust is explosive using laboratory testing.
- Determine where in the process a dust cloud may exist. Loss records and knowledge of process conditions should be used.
- Identify likely ignition sources. Recognize that ignition sources are complex and not always predictable. It is best to assume ignition is possible in all cases.
- Consider what the predictable consequences might be. Be conservative and assume a worst-case scenario. Both predictable primary events and less likely secondary events should be considered. Is the risk tolerable? How can the risk be reduced?
- Identify probabilities for an event to occur. Some materials will have a greater likelihood of an event than others.
- Assign accountability and responsibility for the program, including the implementation and follow-up of improvements.

**Should a Facility Have a Combustible Dust Assessment?**

Every facility that manufactures, processes, handles or otherwise has dust in its facilities should perform a dust hazard analysis. A multidisciplinary team of people should perform the analysis. This will allow for varied perspectives and backgrounds to provide input into the process.
WHO SHOULD BE INVOLVED IN THE HAZARD ASSESSMENT TEAM?

The assessment team’s makeup depends on the size or complexity of the process. The team may be as small as a few people or as many as eight to twelve. The team should be limited to the fewest number of people to provide an effective analysis. However, once the analysis is performed and documented, all levels of management, including the plant manager or CEO, should perform a review and upon acceptance, sign the document.

Most teams have three basic roles. A team leader should act as the facilitator. This person should be the main contact between the members, management and employees. A scribe should be designated to formally document the discussions and techniques used. It is important to document the team’s process and methodology. Remaining team members contribute to the study. Team members may be experts in the process, maintenance managers, safety managers, operators or department managers. Ultimately, top management is responsible for the assessment’s success.

HAZARD ASSESSMENT PREPARATION

Analysis and review should fit the process and should conform to RAGAGEP. The analysis includes three primary steps: preparing for the review, performing the review and documenting the results.

When preparing for the review, the team should gather and discuss possible sources of information to be used during the assessment. A conceptual plan should be outlined. The outline should identify the team’s scope and goals, team member responsibilities, schedules and deadlines, desired outcomes, communication procedures and other team requirements. Relevant information should be gathered and assessed.

The study’s scope should be clearly identified. Portions of the process to be evaluated should be clearly agreed to by the team before work begins. This may require breaking the process into separate hazard assessment parts to cover the entire process. The scope may also identify specific consequences to be addressed in the study. This study could be specific to PPE, property protection, exposure protection, business continuity or other significant consequence.

Team members should be selected based on the specific area of expertise they bring to the team. Each team member should be utilized to maximize his/her potential. Some team members may address multiple areas of expertise. It is important that team members work together to create a synergistic effect.

An outline of the objectives should be presented when the team is initially assembled. The process should be reviewed in detail so that all members have a common basis for the study. Flowcharts, flow diagrams and piping and instrument diagrams should be available for all members.

A total facility walk-down should be performed after the overview meeting. The walk-down should allow adequate time for questions and comments from team members. If the facility is not yet in operation, visiting another operating facility at another location may be helpful.

HAZARD IDENTIFICATION METHODS

Performing the review should identify hazards. These hazards should consider physical characteristics of the process and where breakdown in the process may occur. Causes of a dust explosion should be identified. Each cause should be quantified as to the severity and probability, how the cause is a hazard, location and ways to mitigate an explosion or undesired effect.

Selection of an appropriate hazard identification method should incorporate two separate and distinct steps. The first step is to identify the process hazards. The second step is to evaluate whether the existing or proposed safeguards are adequate to control those hazards.

A hazard is a physical, chemical, particle size or orientation characteristic that has the potential for causing harm to people, property, business continuity or the environment. Undesirable consequences should be identified. In the case of dust hazards, dust explosion and/or flash fire may be the primary consequence.

After the consequences are defined, the team can identify the systems, processes and plant characteristics that may be of interest in the hazard analysis. It is important that the hazard identification technique be thorough and that all important hazards are identified. The team should not discount hazards simply because the design or installation meets applicable codes or standards. Codes and standards are minimum requirements, and the team must understand that if the design does not extend beyond what is required in a code or standard, the process has been installed using a minimum permitted criteria. It is not an optimal installation with regard to protection safeguards. The team should not discount hazards based on an installation meeting minimum codes.

Past experiences of the process may provide important clues to hazards. Operators and maintenance employees should be interviewed for their thoughts and input. Even if they are not specifically on the team, the team can profit from their experiences.

Recommendations from outside consultants, insurance carriers, fire marshals, audit teams and others should be evaluated. These outside organizations have additional experiences beyond the facility and process. Capitalizing on their input may be advantageous.

Checklists are a good tool to use in identifying hazards and are available from many sources. Checklists from associated hazardous processes may help identify points also be found in the facility or process.

Physical characteristics of the materials handled should be fully and clearly identified. Physical characteristics of dust may vary.
even within the same process envelope. A grinder may produce a given particle size; however, there is a strong potential for smaller particle sizes to also be produced. Some of these small particles may become airborne and may land on building and equipment surfaces. Even off-specification materials should be evaluated as part of the hazard analysis.

After the hazards have been identified, they should be listed in assessment reports. A ranking system should be used to identify the severity and frequency of the consequences.

**Analysis Procedure**

The analysis procedure should cover all aspects of the hazard. The procedure should also identify undesired consequences and protection features installed. Alternatives that could reduce or eliminate the hazard should be identified. Some considerations to be incorporated into the review include:

**Site Selection**

Site identification is one important factor in mitigating major loss. Hazardous processes involving dust should be made based on separation from any other process or exposure. An upset and consequential dust explosion in a process may have major consequences. These consequences will be exponentially increased when other operations or areas of the plant facility become involved. This process site should be selected so that in the event of a catastrophic explosion, people, surrounding equipment, surrounding critical processes, areas significant to the business continuity of the operation and those surrounding the facility are not impacted.

**Equipment Hazards**

Equipment hazards should be identified. Some hazards may include mechanical sparking, introduction of foreign materials, frictional heat or bearings that may overheat. Some of the more difficult equipment hazards are those hazards not as readily observed, such as mechanical failure, breakdown or overheating.

**Electrical Sources**

Electrical sources are readily identifiable, such as electrical energy for motors, conveyors and material-moving equipment. One consideration is to identify the electrical classification of the area or room volume. NFPA 70, National Electrical Code, Chapter 5, Special Occupancies, addresses hazardous locations. It defines the classification of several special occupancies, such as flammable liquids, gases and vapors, combustible dusts and other materials. It is meant to integrate with other NFPA standards that more fully address the particular occupancy. For electrical issues, the NEC defines what electrical devices are permitted in a given area. The definitions located in Section 500.2 are important to know when addressing special occupancies. This section defines terms, such as dust ignition-proof, dust-tight and purged and pressurized.

Section 500.5 defines the classification of special occupancies. When discussing combustible dusts, most are classified as Class II locations. Class II locations are hazardous because of the presence of combustible dust.

**Safety-Related Equipment**

Many safety-related features are likely already built into a process. Some may be instrumentation interlocks to shut down the process upon upset or operations outside of given parameters. Fire protection systems may be installed to detect or discharge fire extinguishing agents. Fire sprinklers, deluge systems or vessel explosion suppression systems may be installed. Explosion venting may be installed to direct a blast to a safe location.

**Human Factors**

Human factors will vary as to the process and the amount of human intervention required. Modern systems depend on automation to perform many tasks. Process sensors send critical data to a control room operator and limit the amount of human intervention needed within the process enclosure. Despite the technological level involved in the process, an operator is ultimately responsible for the process. Operators and maintenance personnel may be required to enter the enclosure to inspect equipment, make adjustments, provide maintenance or make repairs. Operator intervention must be factored into the assessment. For almost every human activity, there is a positive and a negative factor.

**Housekeeping**

Good housekeeping cannot be stressed enough in any industry but even more so in occupancies where dust is present. Regular housekeeping should be provided in facilities that handle dust. Walls, floors, ledges and other surfaces should be vacuumed, broom-swept, water-washed or cleaned regularly so no dust accumulates. Keep elevated accumulations to a minimum. Avoid the practice of blowing down dust with compressed air. Housekeeping activities should be initiated whenever dust is spilled or released. In the event of a system upset or deflagration, dust located on elevated walls or ledges may be shaken loose and may form a cloud as it drops to the floor. Other areas of concern are where dusts are introduced into the production stream, such as where bags of material are poured into a reactor or vessel.

A documented, planned inspection process should be implemented to evaluate cleanliness, dust accumulation rates and housekeeping frequency required to maintain dust accumulations below threshold amounts. Areas and spaces that cannot be accessed should be sealed to prevent dust accumulations. One recent severe explosion involved dust that had accumulated above a drop ceiling. If no dust accumulations are present, the chance of a dust explosion or deflagration is significantly reduced.
External & Environmental Factors

External factors should be identified and evaluated. External factors that could impact a facility may be substantial. Natural hazards may play a significant role when dealing with dusts. Relative humidity at a given time may be a factor. Some studies suggest grain elevator explosions occur when the relative humidity is low. Lightning storms may be an external factor that could impact a process. A process may need to be shut down prior to the arrival of a lightning storm. Earthquakes may dislodge dust accumulations from high building members and can create a dust cloud.

Analysis Methods

Commonly used hazard evaluation procedures use various methods to evaluate hazards. Each method uses a thorough, orderly and systematic approach to determine what may go wrong in the process. OSHA identifies several methods in the PSM standard for chemical industries. Teams should identify and select the appropriate method best suited for the hazard and process complexity. Sometimes, more than one method may be used and multiple assessments may be performed.

The primary methods identified in PSM may also be used for combustible dust assessment. Primary methods used are well documented by OSHA as well as by Center for Chemical Process Safety.

What-if

The what-if analysis technique is a brainstorming approach. Experienced people familiar with the process ask questions based on an event and subsequent consequences. This method is particularly helpful if the team members are experienced. If not, the results may be incomplete or inaccurate.

What-if/Checklist Analysis

The what-if/checklist analysis is designed to identify hazards as they pertain to types of incidents that may occur in a process or activity. This experience-based technique requires well-versed and knowledgeable team members. The team uses established checklists and applies the what-if scenarios to the process. The checklist provides a systematic approach and may lead to additional discussion and identification of additional hazards. Conversely, if the checklist is not complete, significant hazards could be overlooked.

Hazard & Operability Study

The hazard and operability (HAZOP) study was developed to identify and evaluate safety hazards in a process plant and to identify operability problems. A HAZOP study’s purpose is to carefully review the process and operation in a systematic fashion to determine whether deviations from the design and operation may lead to undesirable consequences. Guide words are used to lead the team through process parameters. The team discusses deviations from normal operations, their possible causes and the consequences of the deviation. If the consequences are significant or the safeguards are inadequate, the team may recommend corrective action.

HAZOP’s primary advantage is the brainstorming that comes out of the meetings. The discussions should stimulate creativity and generate new ideas. The interaction between team members of diverse backgrounds and experiences build on one another.

Failure Mode & Effects Analysis

Failure mode and effects analysis (FMEA) identifies a single system or single piece of equipment and focuses on the hardware. FMEA is concerned with the process and the equipment and does not normally study human behavior or operations procedures. System failures are studied, and at each failure point, recommendations are generated to increase equipment reliability and to improve process safety.

Fault Tree Analysis

Fault tree analysis (FTA) focuses on a single event or main system failure. An FTA identifies combinations of equipment failures and human errors that may result in a failure event. This analysis method is primarily used for systems with high redundancy.

FTA uses a graphic model that displays various combinations of equipment failures and human errors. FTA relies heavily on Boolean logic gates to describe how equipment failures will impact the system train. Boolean logic is an algebra mathematical system that uses true or false statements. Based on the true or false condition, a path is selected in a flow chart of the system or process being evaluated. The analysis focuses on preventative measures for a single basic cause to reduce the likelihood of loss.

Assessment Documentation

Assessment documentation is an integral part of the process. It will identify all members involved in the process and their role. As the assessment progresses, the documentation should identify all steps taken, including methodologies that do not work for a variety of reasons. This will allow future assessment teams to review the work done and to understand why a particular assessment path was selected.

When a new process is being developed, good documentation will help justify the original system design. It can be a tool used in the MOC process.

The assessment should become a part of the information training for all operators. Operators may discover inherent hazards with the system, which could help them prevent a failure mode. Documentation made available to operators will aid in communicating essential information. Operators will be able to build on this information for future assessments.

A good hazard assessment may be used in the development of an effective emergency response program. The identified loss scenarios will enable emergency
responders to appreciate the process’s loss potential. It will assist their planning efforts to ensure that adequate manpower and equipment respond and that they are deployed to critical points around the facility. For large facilities with significant loss potential, staging areas may be set up away from the facility to reduce response time of relief crews or multiple alarm responders.

The analysis should identify response considerations, such as additional PPE and special extinguishing agents, in addition to identifying ineffective response protocols.

Assessment documentation should be maintained for the life of the process. When the assessment is updated, the previous assessment should be maintained in its entirety. This will provide historical information on the process and may be used in an incident investigation in the event of a catastrophic loss event.

The final documentation package should include a sheet listing all team members. Each team member should sign the document showing their agreement. In addition to the team members, all corporate managers should sign the document showing they have reviewed the procedures, the procedures are complete and they agree with the final results. Depending on the corporate structure and the magnitude of the process assessed, the plant manager and each department manager should review, agree to and sign the document. This accountability structure ensures that top management is aware of the relative hazards of their facility. In the event of a major catastrophic loss, they will be part of the accountability chain. By understanding the hazards and consequences, they will be better able to evaluate acceptable risk tolerances and they will be in a better position to allocate budgets for improvements when requested.

A complete documentation package for a process includes the design package, the construction documentation, calculations for various system components, sources of replacement equipment and process assessments. It is important to identify various portions of the documentation so that it may be easily retrieved in the future. Documentation should be stored electronically, and backup copies should be maintained offsite for redundancy.

**Implementing Assessment Recommendations**

A hazard assessment includes significant information about the process. It includes information regarding design criteria, construction details, process equipment, operating procedures, hazard identification, PPE, process safety considerations, fire protection systems and many more key concerns for the process’s safe operation. The properly documented assessment will be an encyclopedia of information.

Assessment documentation assists in developing meaningful recommendations to enhance the safe operation of the process. Based on consequence severity, key areas of deficiency may be identified for future improvement.

Top management should respond to the identified items in the hazard assessment. Resources may be allocated within the existing corporate structure, or additional resources may be obtained to address the key components identified as priority items in the hazard assessment.

Risk managers may use hazard assessment documentation to ensure that adequate insurance and risk mitigation techniques are in place. This is important when significant exposures are present. An explosion event in a combustible dust area may impact plant output in other departments and even in other interdependent plants within the organization.

Assessment documentation may also be used to incorporate items into business continuity procedures for the corporation. The business continuity plan for an organization identifies key considerations to maintain business operations in the event of major catastrophic loss.

Emergency plans should be updated to reflect the assessment’s findings. Additional manpower may be considered for the emergency response team. Additional job functions may be needed to address some of the considerations with the combustible dust process. Public-sector responders may be interested in the hazard assessment results. It will enable them to increase the number of fire engines, ladder trucks, rescue vehicles and ambulances needed for the initial dispatch. The local hospital may have additional supplies on
hand to respond to the challenges of critically burned patients.

The hazard assessment will be an invaluable tool in communicating hazards to operators and other employees who may be impacted by a system failure in the combustible dust handling process area. Maintenance operations may use some of the items identified in the dust hazard assessment to schedule maintenance frequencies. Departmental shutdown frequencies may be scheduled based on identified hazards. Spare parts may be maintained on-site or within a close geographical proximity for immediate delivery.

Management of Change

After the process is in operation, items may be identified, which require a change. For the most part, these items should be minor in nature. Any change initiated into the process, whether it be a physical change in equipment, a change in the process, a change in particle size or any other change, may constitute a significant system change. To control these changes, a documented MOC program should be implemented.

A change occurs whenever there is a replacement, which is not a “replacement in kind.” An example may be the replacement of a motor that is not of the same power rating. It could be changing a grinder with one of a larger or smaller size. Any physical replacement of equipment that is not identical should initiate an MOC.

Likewise, any process changes should initiate an MOC. If the process engineer changes the temperature in any part of the process, changes the amount of time the material is in any portion of the process, changes the pressure at which the process operates or introduces a new additive, an MOC should be initiated.

Prior to any change in the process taking place, a detailed analysis and evaluation of the proposed process change should be performed. When a problem with the system is identified and needs to be changed or corrected, a formal written request should be submitted to the assessment team. This initiation may be a suggestion for improvement, a requirement to replace a part that is obsolete or for any other reason. If the MOC process is not initiated, it is possible that changes will not be brought to the attention of management and the hazard assessment team.

The team is responsible for approving the change and should evaluate each suggestion as well as perform an initial review. This review will determine if the suggestion will be continued, or if it is not accepted, will indicate the imminent undesirable characteristic of the suggestion. Up to this point, there may be a limited number of individuals involved in the review. If accepted, the change request should be escalated to a more formal status, documented in more detail and submitted to the entire assessment team.

The assessment team should conduct a thorough desktop review to determine the feasibility of the change. The entire team should agree upon the effectiveness and safety of the change prior to its implementation. Each team member should sign the accepted sheet of the request and provide any positive or negative comments as they see fit.

Once accepted, the procedure manuals should be updated to reflect the changes. Any applicable limits in the operating procedures should be documented so operators do not exceed the new limits, procedures or methods. A notification and training procedure should be implemented so that all affected parties fully understand the change. Operators should be trained in any new procedures or methods in the process.

Once the review, notification and training are completed, the change may be implemented. The implementation process will depend on the degree of change that has been initiated. Some changes will require a slow ramp up to full capacity so the life changes may be studied during a gradual implementation. Once this step is completed, all documentation should be formally updated, and prior editions of the procedures should be retired. Retired procedures should be maintained so that future employees may track the process’s progression.

Benefits of a Good Combustible Dust Assessment

A dust hazard may exist wherever a combustible dust is handled. It may also exist as a result of handling and processing large pieces of
Management’s willingness to expend the resources to prevent losses, injury and death will stand as a testament to its dedication to safety.

material. Dust may be produced in small amounts as a byproduct of the process. Following good engineering practice will help identify dust accumulations before they become a hazard.

The combustible dust assessment is a complex process and is not a quick walkthrough of a facility. The team approach will help look for multiple weaknesses in the process that a single person may overlook.

Performing a thorough combustible dust assessment cannot guarantee that loss incidents will not occur. No assessment can identify every single hazard or possible loss occurrence. However, a well conducted and documented assessment will help reduce incidents over the life of the process. Incidents that occur may have reduced consequences, less property damage, less business interruption and fewer employee injuries.

Those involved in the assessment will have a deeper understanding of the process and the inherent hazards associated with it. Those reviewing the assessment for training and educational opportunity will learn from the assessment, have a better understanding of the process and may prevent loss incidents by using the gained knowledge to operate the process in a safer manner. It can be used to educate the plant emergency response team as well as public responders who will respond to the facility.

The cost to conduct, maintain and update an in-depth dust assessment may be considerable. Management may not be able to quantify the dollar value of the assessment based on incidents prevented. However, in hindsight after a loss event, they will be able to quantify the cost of not performing an adequate, in-depth assessment. Management’s willingness to expend the resources to prevent losses, injury and death will stand as a testament to its dedication to safety.

REFERENCES


Walter S. Beattie, CSP, CFPS, CSHM, served in the volunteer fire service for many years and continues to be involved in fire suppression, fire protection and risk consulting. He has worked in the highly protected risk (HPR) insurance field since 1979 in various capacities, including senior loss control specialist, HPR technical manager, underwriting special agent and account engineer. He is a past administrator of ASSE’s Fire Protection Practice Specialty and currently serves on ASSE’s Council on Professional Development.

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