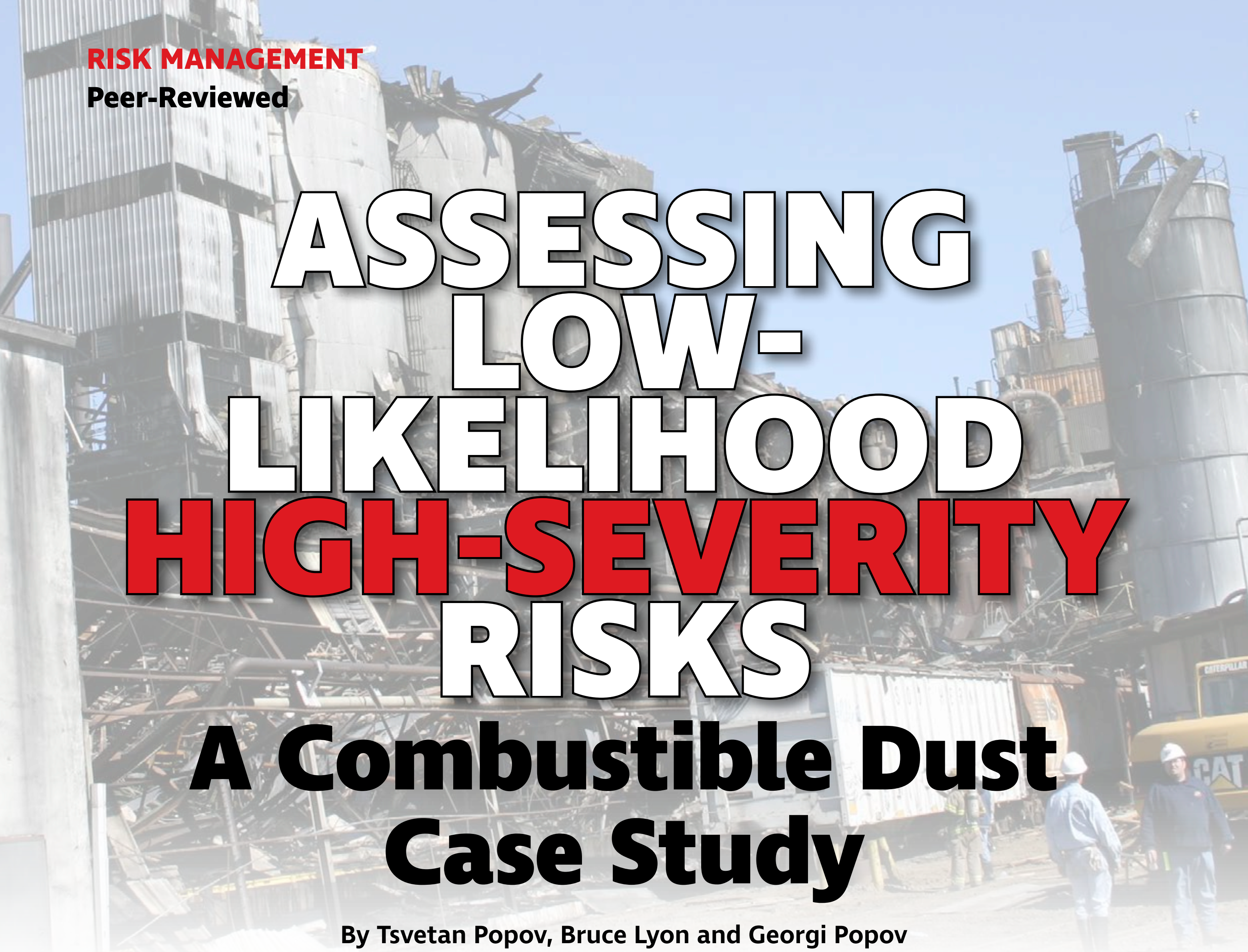


ASSESSING LOW-LIKELIHOOD HIGH-SEVERITY RISKS

A Combustible Dust Case Study

By Tsvetan Popov, Bruce Lyon and Georgi Popov

OFTEN, RISK ASSESSMENT EFFORTS within an organization are targeted based on the organization's past experiences, incident frequency trends and activities that present obvious dangers. These are all important sources of information that can help identify areas that need assessment and treatment. But what about serious or catastrophic risks that occur less frequently? Organizations have limited resources and can overlook such risks due to their infrequent nature. Unfortunately, low-likelihood, high-severity risks such as fires, environmental releases and natural disasters can result in serious injuries and fatalities (SIFs), and severely impact an organization.

To emphasize this point, one can look at recent incident trends. While incident rates have decreased over the past decade, SIFs have experienced a slight increase. According to the U.S. Bureau of Labor Statics (BLS, 2020), 5,333 fatal work injuries were recorded in the U.S. in 2019, a 2% increase from the 5,250 in 2018. This might suggest that risk-reduction efforts have been more concentrated or more effectively applied to higher frequency type risks than those that produce SIFs.

KEY TAKEAWAYS

- **Serious injuries and fatalities (SIFs) continue to occur despite efforts to reduce overall incident rates.**
- **SIFs such as combustible dust explosions are often caused by events that are considered to have a low likelihood of occurrence but result in high-severity consequences.**
- **Combustible dust explosion risks are often underestimated by organizations partly because the occurrence of such events is infrequent, giving a false sense of security.**
- **This article uses a combustible dust case study to demonstrate how such low-likelihood, high-severity risks can be assessed for their true risk potential.**

U.S. CSB/PUBLIC DOMAIN

Combustible Dust Risks

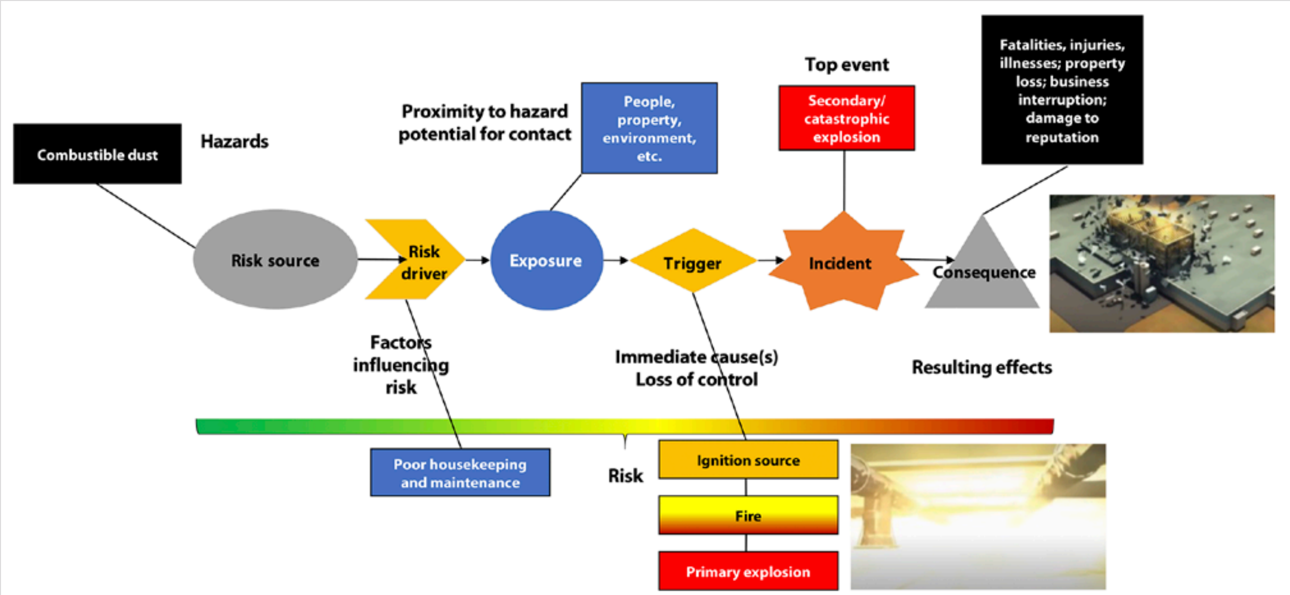
As described by OSHA (n.d.), any combustible material can burn rapidly when in a finely divided form. Dust from organic matter (e.g., grain, wood, plant fibers) as well as dust from inorganic materials (e.g., iron, glass, ceramic) will burn in the right conditions. If such a dust is suspended in air in the right concentration, it can become explosible under certain conditions. Even materials that do not burn in larger pieces (e.g., aluminum, iron) can be explosible in dust form given the proper conditions (OSHA, n.d.).

Unfortunately, combustible dust explosions caused and continue to cause numerous injuries, fatalities and substantial property losses. In 2003, CSB (2006) initiated a study of dust explosions in general industry and what can be done to reduce their risk. The final report was published in 2006.

In 2020, CSB published "Dust Hazard Learning Review," which emphasizes:

> Dust explosions are rare events that lull industrial organizations into a false sense of safety. While a

FIGURE 1
RISK PATHWAY OF A COMBUSTIBLE DUST EXPLOSION



Note. Explosion images captured from *Combustible Dust: An Insidious Hazard* [Video], by USCSB, 2009, YouTube.

> greater level of recognition of these risks is present in the industries than ever before, still far too many dust-related incidents occur as a result of ignorance or complacence. Because of the complex variables that must come together to enable a dust explosion, operations personnel are frequently unaware of the true likelihood of these events. (CSB, 2020)

While dust explosions are rare events, the consequences and their impacts are usually catastrophic. The main goal of OSH professionals is to protect people, property and the environment. Therefore, OSH professionals should not underestimate such low-probability, high-severity type risks. Combustible dust explosions can cause fatalities, multiple injuries, destruction of property, business interruption and environmental damage. For example, three workers were killed in a 2010 metal dust explosion in West Virginia (CSB, 2014; Lyon & Popov, 2020).

According to the Dust Safety Science's (2020) Combustible Dust Incident Report, since 2016, there have been 632 fires and 243 explosions recorded. Of these 875 incidents, 116 (13.2%) caused injury and 24 (2.7%) caused fatalities, resulting in 417 injuries and 45 deaths.

According to OSHA (n.d.):

> A wide variety of materials that can be explosible in dust form exist in many industries. Examples of these materials include food (e.g., candy, sugar, spice, starch, flour, feed), grain, tobacco, plastics, wood, paper, pulp, rubber, pesticides, pharmaceuticals, dyes, coal, metals (e.g., aluminum, chromium, iron, magnesium, and zinc). These materials are used in a wide range of industries and processes, such as agriculture, chemical manufacturing, pharmaceutical production, furniture, textiles, fossil fuel power generation, recycling operations, and metal working and processing which includes additive manufacturing and 3D printing.

To avoid or reduce the risk of such incidents, it is advisable to consider the risk pathway model for potential combustible dust explosion. The risk pathway model, shown in Figure 1 and described in the ASSP TR-31010-2020, Risk Management—Techniques for Safety Practitioners, is presented in linear form to demonstrate the interrelationships among the involved elements. However, risks are often multidimensional and should be assessed and treated as such. Combustible dust explosions in particular may be viewed as multidimensional, especially the triggering mechanisms. For instance, there is a possibility of stratified triggers or a combination of triggering components coming together to cause the incident.

According to CSB (2006), dust explosions can either be primary or secondary. A primary dust explosion occurs when a dust suspension within a container, room or piece of equipment is ignited and explodes. A primary explosion is not always catastrophic. A secondary explosion occurs when dust accumulated on floors or other surfaces is lofted and ignited by a primary explosion. The blast wave from the secondary explosion can cause accumulated dust in other areas to become suspended in air, which may generate additional dust explosions. Depending on the extent of the dust deposits, a weak primary explosion may cause extremely powerful secondary dust explosions (CSB, 2006).

An example of how a combustible dust explosion with stratified trigger events might occur is presented in Figure 1. In the figure, combustible dust is the risk source for the top event: a combustible dust explosion. Influencing factors or risk drivers such as poor housekeeping and lack of maintenance can increase the likelihood of the risk. The people, property and environment that would be impacted by the event are considered the exposure at risk and represent the severity of the risk. In this example, the trigger might be an ignition source that sets off a primary explosion that leads to a secondary explosion. Trigger mechanisms for combustible dust explosions may be viewed as multidimensional, as presented in Figure 1. Ignition source, fire and the primary explosion could be considered stratified triggering components coming together to cause the explosion. The catastrophic top event could be considered the secondary explosion. As noted, the consequences are usually high-severity outcomes, such as fatalities, injuries, property damage, business interruption and reputational damage.

CSB further states that the best way to prevent secondary dust explosions is to minimize dust accumulations. Ensuring good housekeeping, designing and maintaining equipment to prevent dust leaks, using dust collectors, eliminating flat surfaces and other areas where dust can accumulate, and sealing hard-to-clean areas (e.g., the area above a suspended ceiling) can effectively prevent secondary dust explosions (CSB, 2006; 2020).

Confusion still exists about the differences between prevention and mitigation risk treatment methods. Risk prevention is the act of keeping something from occurring that would otherwise cause risk or harm. The term “mitigation” is generally defined as the action of reducing the severity or seriousness of something, thus making a condition or consequence less severe (ASSP, 2020).

For example, consider Photo 1 from a facility. Portable fire extinguishers and buckets for dousing fires should not be considered preventive measures because they are used once a fire is detected. Fire extinguishing methods are designed to be used at the incipient stage of a fire to mitigate its spread and impact. As presented in this example, portable fire extinguishers were the only control measure for combustible dust fires observed. From a regulatory compliance standpoint, this may be acceptable; however, from a risk management perspective, relying upon a single mitigative layer of control for such risks is considered inadequate.

To examine how a combustible dust explosion risk can be assessed and treated with layers of preventive and mitigative control measures, the following case study is presented.

Combustible Dust Case Study

A midsize grain processing company wanted to improve the process and workplace conditions. Therefore, the organization needed to assess the risk of combustible dust explosion. Since the company did not have a full-time experienced safety professional on staff, it hired a consulting company. The consultants developed a scope of the project, which included an inspection, combustible dust analysis and likelihood estimates.

The purpose of the inspection was to determine the type of dust found on various surfaces throughout the property. Visible dust was readily observable on horizontal surfaces, ductwork, hoppers, augers and other equipment (Photos 2 and 3). As a next step, a basic air quality assessment was performed.

Air Quality Testing

The consultants began with particulate matter air quality testing, which included direct reading instruments (GrayWolf PC 3016A handheld optical particle counter) for air sampling, TSI DRX particulate measurement (PM) system and a visual inspection. For verification and further evaluation, the assessors collected samples (Zefon CSI) for particle identification and particle size measurements.

An optical particle counter capable of simultaneous measurement of six size fractions was used to determine whether there were a significant number of airborne particles. The instrument measures particle concentrations and was factory-calibrated at 0.3, 0.5, 1, 3, 5, and 10 µm size fractions. It is an effective instrument for tracking down particle contamination sources, classifying clean rooms and looking for filter leaks. The instrument is equipped with software for automated reporting of particle count and mass concentration data. The instrument was calibrated and HEPA filter field testing procedures performed. All six channels showed 0 particles per m^3 (Photo 4).

Different floors and areas of the facility were tested. The instrument detected an insignificant number of particles at 12 in. from the floor level. The report generator software was used to calculate the mass of the particles and different particle sizes. Several particle sizes were of particular interest: 2.5 µm; 5 µm; 10 µm and total particulate matter (TPM; Photo 5).

(Clockwise from top) Photo 1: Portable fire extinguishers and buckets for dousing fires should not be considered preventive measures because they are used once a fire is detected.

Photos 2 and 3: Visible dust on horizontal surfaces and floor.

Photo 4 (right): Optical particulate measurement system showing 0 particles per m³.

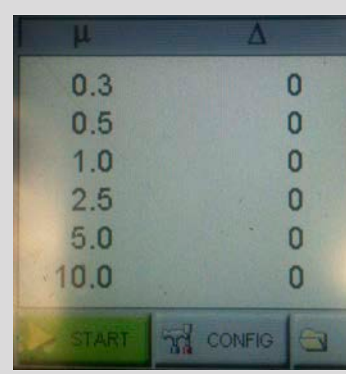


Photo 5 (below): Optical particulate measurement system results: 11.11 µg/m³ size 2.5 µm; 27.93 µg/m³ size 5 µm; 139.09 µg/m³ size 10 µm; and 388.71 particles per m³ (0.388 mg/m³) total particulate matter.

FIGURE 2
DUST CONCENTRATIONS, UNDISTURBED

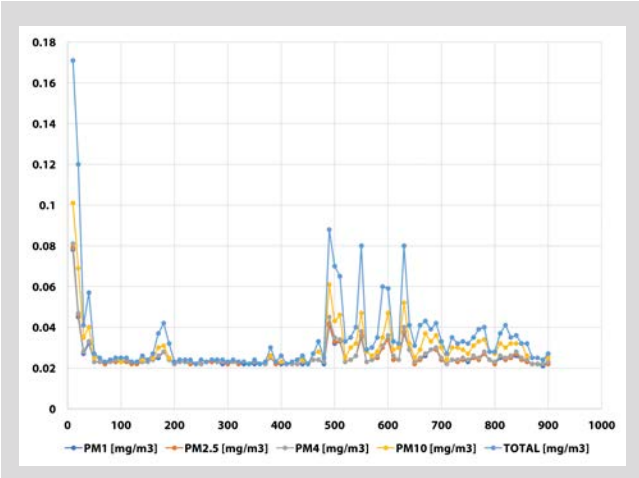
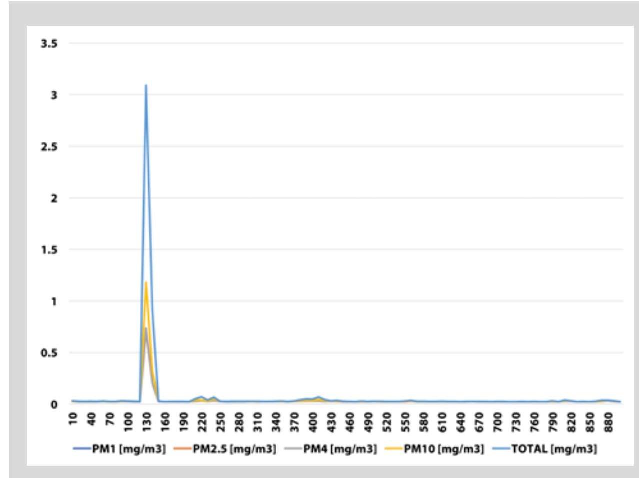


FIGURE 3
SIMULATED DUST DISTURBANCE



A second six-channel particle measurement system was used to supplement the optical PM system readings (results shown in Figure 2). The dust level readings at 15 minutes taken with the six-channel particle measurement system indicated that under normal conditions, dust levels were below EPA National Ambient Air Quality Standards levels. However, during simulated dust disturbance, the dust levels increased sharply as shown in the spike between 100 and 160 seconds, shown in Figure 3. Such readings should alert OSH professionals that under certain conditions sufficient quantities to form an explosible concentration of dust particles may become airborne.

Particles Testing & Characterization

OSHA (2013) defines combustible dust as:

> A solid combustible material, composed of distinct pieces or particles, that "presents a fire or deflagration hazard when suspended in air or some other oxidizing medium over a range of concentrations, regardless of particle size or shape." A number of voluntary standards prepared by the National Fire Protection Association (NFPA), FM Global and ASTM International suggest various tests, data and criteria that may be used to determine whether a material presents a combustible dust hazard.

OSH professionals must consider any hazards posed by a product in normal conditions of use and foreseeable emergencies or events that cause dust disturbance (OSHA, 2013). According to OSHA (2013):

> For combustible dusts, often the best information is actual experience with the product. . . . In the absence of information on a deflagration or dust explosion event, classifiers may use one or more of the following approaches in determining whether such hazards exist, depending on the information that is available.

OSH professionals can collect composite dust samples from various surfaces. Laboratory procedures should be followed to classify explosibility and combustibility parameters of the samples. In addition, a microscopy particles identification and sizing could be performed to determine the nature of the dust particles.

Dust Particle Size

As OSHA (2013) notes:

> For many years, NFPA 654 defined combustible dust as a "finely divided solid material 420 microns or smaller in diameter (material passing a U.S. No. 40 Standard Sieve) that presents a fire or explosion hazard when dispersed and ignited in air." OSHA used this definition in earlier combustible dust guidance, such as its 2005 safety and health information bulletin, and uses a similar criterion in defining "fugitive grain dust" in its Grain Handling Facilities Standard (see 29 CFR 1910.272(c)). Some NFPA standards still use a size criterion in defining combustible dust, such as NFPA 61 (2013) and NFPA 704 (2012).
>
> Other NFPA standards, however, have changed their combustible dust definition to remove the size criterion, but discuss size in their explanatory notes. In general, the notes concerning particle size state that dusts of combustible material with a particle size of less than 420 microns can be presumed to be combustible dusts. However, certain particles, such as fibers, flakes and agglomerations of smaller particles, may not pass a No. 40 sieve but still have a surface-area-to-volume ratio sufficient to pose a deflagration hazard. . . .
>
> If the material will burn and contains a sufficient concentration of particles 420 microns or smaller to create a fire or deflagration hazard, it should be classified as a combustible dust.

Examples of finely divided solid material 425 microns or smaller in diameter are presented in Photos 6 and 7. In this case example, microscopy particle sizing was performed. OSHA (2002) analytical method ID201SG for combustible material was used to evaluate explosibility and combustibility parameters of the samples. (The method can be accessed at **www.osha.gov/chemicaldata/sampling-analytical-methods**.) The results from the dust analysis are presented in Table 1. As the table indicates, 23.32% of the sample is considered combustible dust according to OSHA method ID201SG.

Precalibrated bio-pumps with a collector for scanning electron microscope identification (CSI) cassettes were used to collect air samples. The CSI is an air sampling cassette specifically designed for the rapid collection of a wide range of airborne aerosols including particles, mold spores, pollen, insect parts, skin cell fragments, fibers (e.g., asbestos, fiberglass, cellulose, clothing fibers) and inorganic particulate (e.g., ceramic, fly ash, copy toner).

In addition, tape-lift samples were collected from horizontal surfaces to identify and size the particles. In this case study, both air sample and surface sample confirmed that most of the dust particles were corn starch, quartz and plant fibers. The majority of the corn starch particles were between 10 and 20 μm in size, as shown in Photo 8.

Volatile Organic Compounds & Lower Explosive Limit Testing

For volatile organic compounds (VOCs) and lower explosive limit (LEL) air testing, a four-gas meter with photoionization detector (PID; RAE Systems) was used. In this case, both VOC and LEL readings showed 0 ppm and 0%, as shown in Photo 9.


Photos 6 and 7: Examples of finely divided solid material.

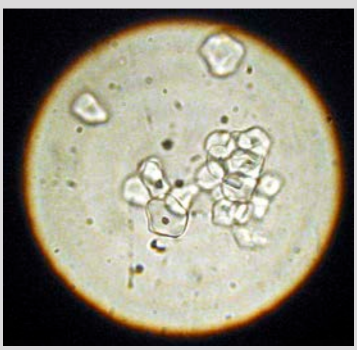



**Photo 8 (left): Microscopy image of separated cornstarch particles.
Photo 9: Readings from four-gas meter with PID.**

TABLE 1
DUST ANALYSIS RESULTS

Results of the dust analysis using OSHA method ID201SG to evaluate explosibility and combustibility parameters of the samples.

	1. Percent through 40 mesh	
	% through 40 mesh	39.3742
	2. Percent moisture content	
Sample 0101	Weight wet sample (net), g	6.4417
	Weight dry sample (net), g	5.9552
	% moisture content	7.5524
Sample 0102	Weight wet sample (net), g	7.4896
	Weight dry sample (net), g	6.9837
	% moisture content	6.7547
Sample 0103	Weight wet sample (net), g	7.4531
	% moisture content	6.9917
	% moisture content (average)	7.0996
	3. Percent combustible material	
Sample 0104	Weight wet sample (net), g	6.8933
	Weight ash sample (net), g	2.8144
	% combustible material	59.1719
Sample 0105	Weight wet sample (net), g	5.8380
	Weight ash sample (net), g	2.3943
	% combustible material	58.9877
Sample 0106	Weight wet sample (net), g	7.2006
	Weight ash sample (net), g	2.9175
	% combustible material	59.4825
	% combustible material (average)	59.2141
	4. Percent combustible dust	
	% Combustible dust	23.3151

The Fire Triangle & Combustible Dust Pentagon

As noted, according to the analysis method, 23.32% of the dust was considered combustible dust. However, there were very few places with sufficient dust accumulation to form a dust cloud.

Most solid organic materials (along with many metals and some nonmetallic inorganic materials) will burn or explode if finely divided and dispersed in sufficient concentrations (Eckhoff, 2003, as cited in CSB, 2006). Even seemingly small quantities of accumulated dust can cause catastrophic damage. Like all fires, a dust fire occurs when fuel (the combustible dust) is exposed to energy (an ignition source) in the presence of oxygen (typically from air). Removing any one of these elements of the classic fire triangle eliminates the possibility of a fire. A dust explosion requires the simultaneous presence of two additional elements: dust dispersion and confinement (Figure 4, p. 34).

Suspended dust burns rapidly, and confinement enables pressure buildup. Removal of either the suspension or the confinement element can prevent an explosion, although a dust fire can still occur. OSH professionals should be aware that dust can be a fire hazard if it collects near heaters, electronics or sockets. If sparks fly during welding operations, dust accumulations can ignite and cause a fire.

Based on the visual inspection, very few places at the surveyed location had sufficient dust accumulation. However, it was assumed that cornstarch dust accumulation existed in the ductwork, augers and hoppers. Since welding operations were planned, the project manager in coordination with the OSH professional wanted to determine the likelihood of a fire or primary explosion. An example of planned welding operation is presented in Figure 5 (p. 34).

Assessing the Risk

The terms "probability" and "likelihood" are often used interchangeably in assessing risk. However, "probability" is considered a mathematical term typically based on statistical data calculations, while "likelihood" is a broader, qualitative term described as "the chance that something will happen" (ANSI/ASSP/ISO, 2019; ASSP, 2020).

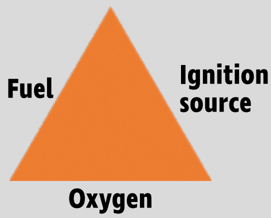
A risk assessment team was formed to estimate the risk of a dust explosion using a simple five-variable fault tree analysis (FTA) to calculate the probability and estimate the likelihood of dust fire or a primary explosion as shown in Figure 6 (p. 34).

The likelihood of combustible dust was assumed to be 23% based on Table 1 results. However, the likelihood of dispersion, ignition, sufficient oxygen and confinement was estimated based on professional judgment. The risk assessment team estimated combustible dust dispersion at 15% based on the air sampling results, which showed only moderate dispersion. The project manager estimated the likelihood of ignition source, due to hot work, reaching dust accumulation areas at 10%. The assumption was based on the fact that standard operating procedures (SOPs) for hot work were in place. Sufficient oxygen levels were estimated at 95% due to the possible displacement of 5% oxygen caused by other existing gases. Confinement likelihood was estimated in a similar way. Since all five variables must be present to cause a combustible dust fire, an FTA was used with an "AND" gate probability/likelihood scenario. As presented in Figure 6 (p. 34), the likelihood of a fire and a primary explosion was estimated to be very low (0.03278%), while the consequences were estimated to be potentially catastrophic.

With dust fire incidents, it is important to consider the potential of a secondary explosion with even greater catastrophic consequences. It is known that even a small amount of dust can fuel a secondary explosion, as the primary explosion causes more dust to be airborne, fueling a secondary explosion. To assess this secondary explosion risk, an event tree analysis (ETA) was used in combination with the FTA to produce a quantitative bow-tie analysis diagram, presented in Figure 7 (p. 35).

FIGURE 4
FIRE TRIANGLE VS. DUST EXPLOSION PENTAGON

A fire occurs when fuel is exposed to an ignition source in the presence of oxygen. Removing any one of these elements of the classic fire triangle eliminates the possibility of a fire.



A dust explosion requires the simultaneous presence of two additional elements: dust dispersion and confinement.

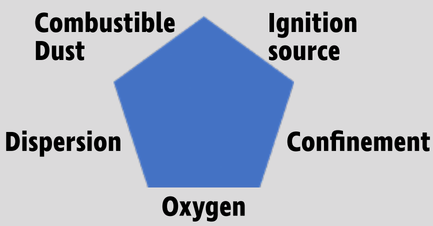


FIGURE 5
EXAMPLE OF PLANNED HOT WORK

FIGURE 6
EXAMPLE OF FTA WITH LIKELIHOOD ESTIMATION

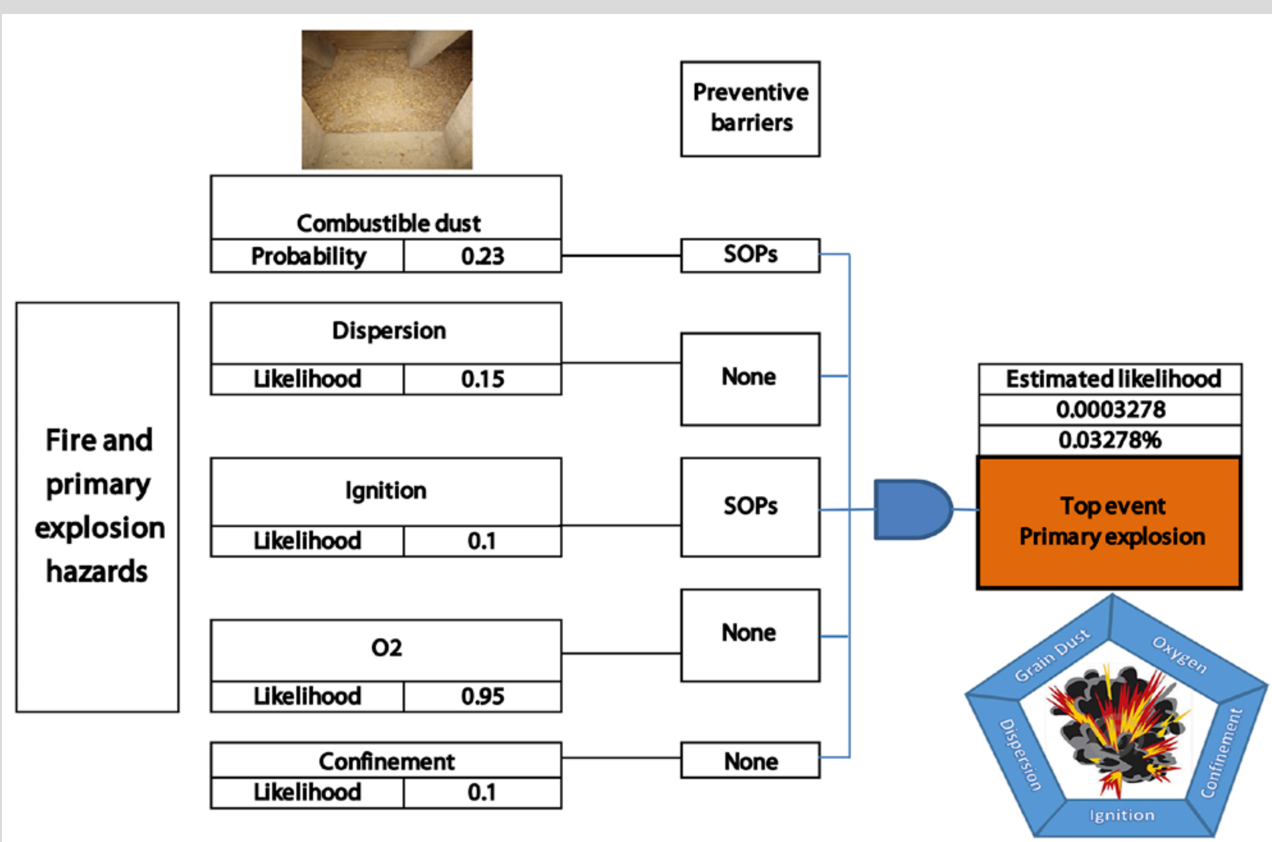
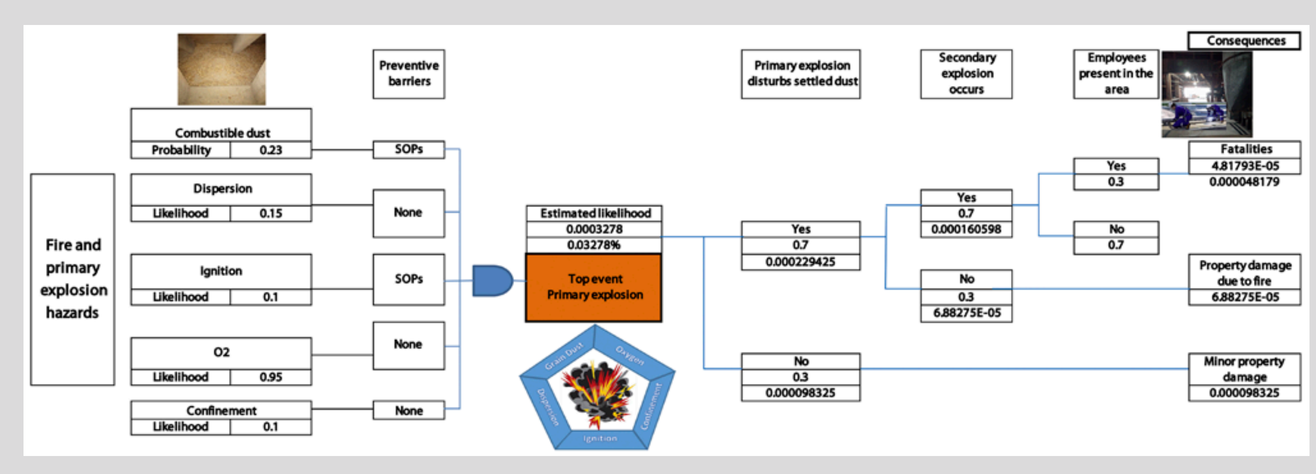


FIGURE 7

EXAMPLE OF QUANTITATIVE BOW-TIE DIAGRAM



Potential fatalities were estimated at 0.000048179 %, a very low likelihood. As one can imagine, the owner and the project management team looked at the likelihood analysis and said, "Looks like a big nothing"; "I can't even count the zeros"; "Dust is not a real risk; we have never had an explosion during the 20 years I've been here"; "Do we have to do this for compliance to avoid OSHA fines?" and "How much dust can we get away with?" The real questions management should ask are, "What are the risks and what are the potential consequences?" and "How many fatalities are we willing to tolerate?"

Might it have been better to first consider ways of eliminating and reducing dust generation and accumulation, rather than spending time and resources on quantifying dust levels? For example, efforts such as encapsulating ductwork, augers and hoppers; inspection and removal of fugitive dust sources; daily cleaning of horizontal surfaces; use of explosion-proof vacuum cleaners rather than push brooms; and wet method cleaning could be considered as preventive control measures.

OSHA (2008) also recommends several measures for controlling ignition sources:

- Use appropriate electrical equipment and wiring methods.
- Control static electricity, including bonding equipment to ground.
- Control smoking, open flames, sparks and friction.
- Use separator devices to remove foreign materials capable of igniting combustibles from process materials.
- Separate heated surfaces and heating systems from dusts.
- Ensure proper use of cartridge-activated tools.
- Implement an equipment preventive maintenance program.

Conclusion

Serious injury and fatality (SIF) risks such as dust explosions can be considered low-likelihood, high-severity events due to their low frequency of occurrence. However, such risks that can threaten an organization's people and operations should not be ignored. In addition to assessing common workplace risks, OSH professionals should be able to identify, assess and treat low-likelihood, high-severity risks that occur less frequently but have the potential to cause SIFs. Being able to assess and treat such risks, use appropriate risk assessment methods and apply layers of higher-level treatments will benefit OSH professionals and their organizations. Efforts to include higher-level treatments such as elimination, substitution, minimization and engineering controls are necessary to adequately prevent and mitigate such SIF risks. In some cases, OSH professionals may be required to calculate the likelihood of undesirable events. As evidenced in the case study, such estimates can be accomplished and communicated to decision-makers to help avoid catastrophic events such as combustible dust explosions and other low-likelihood, high-severity risks. **PSJ**

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