III. IDENTIFICATION OF THE HAZARDS

A. INTRODUCTION

Workers in grain elevators and feed mills are exposed to a wide variety of conditions in the performance of their everyday tasks which could lead to accidents and injuries. This section addresses in detail hazards associated with fires and explosions as well as other applicable industrial hazards. Health hazards are included primarily to acknowledge their existence and the need for their control. Also included are case histories of accidents/incidents that might have been prevented if safe work practices had been observed or if engineering or management controls had been instituted.

B. FIRES AND EXPLOSIONS

1. Components of a Grain Dust Explosion

For a grain dust explosion to occur, the following conditions must be met:

- o Grain dust must be present.
- o An ignition source must be present.
- o Oxygen must be present in a concentration to sustain rapid combustion.
- o The grain dust must be well mixed with the oxygen at a concentration above the lower explosive limit.
- o Ignition must occur in an enclosed space.

The above five conditions are also referred to as the "explosion pentagon" [2, 21].

Kauffman [21] states that for an explosion to occur, dust must be well mixed with air from both the chemical and physical points of view. For heterogeneous combustion, the rate of reaction is dependent upon the surface area of the dust particles. Small particles may be easily dispersed ensuring that the maximum available surface area is in contact with the surrounding air. If combustion initiates in this mixture, confinement causes an increase in pressure. The high pressure gases resulting from the combustion process will try to flow toward a low pressure area, thereby creating a flow velocity which ensures the mixing of more dust with the air. The rate of combustion increases with increasing pressure, thereby creating even more high pressure gases, thus resulting in an explosion. If the requirements for mixing or confinement are not met, a fire rather than an explosion may result.

It is possible to prevent an explosion by deleting any one of the five conditions. In any fire and explosion protection program, these conditions must be eliminated or controlled so that a fire and/or explosion will not occur [21].

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2. Dust Concentration

Grain breakage occurs initially at harvest and continues through each subsequent handling. Particles range in size from respirable particles of about 17 microns or less to particles of 120 microns or more [2]. The dust may be suspended in the air, settled out onto horizontal surfaces, or adhered to vertical surfaces.

In contrast to gaseous mixtures, the lower explosive limit for grain dust is not well defined, and different values can be found for the same kind of dust [22, 23]. Differences can be attributed mainly to test variables such as turbulence, uniformity of the dispersion, and duration of the ignition source. A number of sources [1, 2, 19, 23] report lower explosive limits ranging from 20 to 55 grams per cubic meter(g/m^3) for grain dust clouds. Even for a lower explosive limit as low as $20g/m^3$ (the lowest required for an explosion), a grain dust cloud with this concentration resembles a very dense fog [19, 23]. Although it is improbable that this concentration would exist in the work areas, it is very likely that it does exist within enclosures such as bucket elevators, conveyor housings, bins, and connecting spouts [2, 23]. For the upper explosive limit, also not well defined, estimates vary from 2,000 to $3,000g/m^3$. Peak explosive pressures generally occur near concentrations of 1,000 g/m^3 [24]. The explosive properties of some common grain dusts are given in Table 11.

The explosibility of a particular dust is determined by its concentration in air and influenced by factors such as chemical composition and particle size. The presence of noncombustibles, such as mineral matter or moisture, decreases the explosibility. Increases in particle size also decrease explosibility [25]. To facilitate evaluation of the explosibility of dusts and to give a numerical rating for the relative hazard, an empirical index of explosibility was developed by the U.S. Bureau of Mines [26]. The index provides a relative rating of explosibility as a function of ignition temperature, ignition energy, explosion concentration, explosion pressure, and rate of pressure rise as compared to a standard Pittsburgh coal dust (index equal to 1.0). For a weak explosion the index of explosibility would be less than 0.1; moderate, 0.1 to 1.0; strong, 1.0 to 10; and severe, greater than 10.. The indices of explosibility of corn and wheat dusts within this system are 8.4 and 2.5, respectively.

The synergistic effect between grain dust and fumigants has also been suggested as a factor contributing to explosions in grain elevators and feed mills. Surveys sponsored by the National Grain and Feed Association indicate that gases and vapors emanating from decomposing or fumigated grain do not present an explosion hazard in grain elevators [27, 28]. Laboratory testing, however, has indicated that the presence of the fumigants did lower the minimum ignition energy from 0.180 joules to 0.125 joules [29].

The presence of layered dust is a significant problem. Dust settles not only on floors, ledges, and other horizontal surfaces, but also to some extent on vertical surfaces and ceilings. If agitated, layered dust may lead to explosive airborne concentrations. Burning or smoldering dust which is settled may also ignite airborne dust concentrations or become airborne itself. Dust on warm surfaces such as machinery, motors, bearings, or lighting fixtures tends

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Table 11

Explosive Properties of Common Grain Dusts [26]

Type of Dust	Maximum Pressure (kPa)	Maximum Rate of Pressure Rise (MPa/s)	Ignition Temperature Cloud (°C)	Ignition Temperature Layer (°C)	Minimum Ignition Energy (J)	Lower Explosive Limit (g/m^3)
Alfalfa meal	455	7.6	460	200	0.32	100
Cereal grass	360	3.5	550	220	0.80	200
Corn	655	41	400	250	0.04	55
Corncob grit	760	21	450	240	0.045	45
Corn dextrin pure	725	48	400	370	0.04	40
Cornstarch commercial product	745	48	380	330	0.04	45
Cornstarch through 325 mesh	790	62	390	350	0.03	40
Flax shive	560	5.5	430	230	0.08	80
Grain dust, winter wheat, corn, oats	790	38	430	230	0.03	55
Grass seed, blue	165	1.4	490	180	0.26	290
Rice	640	18	440	220	0.05	50
Rice bran	420	9	490	---	0.08	45
Safflower meal	580	20	460	210	0.025	55
Soy flour	540	5.5	540	190	0.10	60
Soy protein	660	65	520	260	0.05	35
Wheat, untreated	710	25	500	220	0.06	65
Wheat flour	655	26	380	360	0.05	50
Wheat starch, edible	690	45	420	---	0.025	45
Wheat straw	680	41	470	220	0.050	55

to dry out and becomes susceptible to ignition at temperatures as low as 200°C (392°F) [19]. The layered dust is acknowledged to be the source of immensely damaging secondary explosions [25]. The primary explosion resulting from ignition of airborne dust may be relatively small; however, pressure waves and structural vibrations dislodge layered dust which, in turn, explodes and dislodges more dust, propagating the explosion through the entire facility.

3. Ignition Source

The minimum amount of energy required to ignite common grain dusts, such as corn and wheat, is in the range of 30 to 60 millijoules [26]. Ignition may occur as the result of releasing thermal, mechanical, or electrical energy. The primary cause of ignition in the thermal category is hot work. Extremely high temperatures and sparks generated during welding and cutting operations have resulted in more fires and explosions than any other identified source. Fires and explosions caused by hot work generally occur because inadequate precautions have been taken to remove or protect combustibles, or because dust-producing operations are performed concurrently with, or immediately after, the hot work is performed.

Explosions in a pet food mill in December 1977, resulted in 4 people killed and 15 injured [30]. Two explosions, which occurred almost simultaneously, blew out the walls of the mill building and resulted in extensive damage to equipment. The cause of the explosion has not been conclusively determined; however, OSHA investigators believe that a hot weld was the most likely source of ignition. Based on eyewitness accounts and an examination of the damages, OSHA investigators concluded that immediately after a weld was completed on a wheat bin, the grinder feeding the bin was started. The wheat grain dust blown into the bin exploded.

Other thermally-related ignition sources include open flames such as matches, lighters, cigarettes, and space heaters.

Internal combustion engines used in front-end loaders and other industrial trucks may also generate sufficient surface temperatures to cause ignition of grain dust; however, no instances of explosions being caused by these vehicles have been reported.

Mechanical ignition sources generate sparks or heat as the result of friction or impact. Sparks can occur from the introduction of foreign materials such as metal or stones into fast-moving handling and processing equipment. Entry of foreign material into high speed grinding equipment is the acknowledged cause of several explosions [6, 31]. Following bucket elevators, explosions are most likely to initiate in hammer mills, roller mills, and other grinding equipment [1]. An explosion may occur in the grinder, or burning materials may initiate an explosion in downstream storage areas or conveying equipment such as bucket elevators.

Foreign materials in a grinder are thought to have caused a series of explosions in a feed mill in Victoria, Australia in January 1980, which resulted in one injury and extensive damage to the facility [31]. Evidence suggests that a particle of stone or metal passed through a hammer mill into a nearly empty bin where the air/dust ratio was conducive to ignition. Following the initial explosion, a continuous series of explosions propagated through interconnecting spouts, turnheads, and internal portholes.

Entry of foreign material into other handling equipment, such as bucket elevators, is also a potential problem, although there is some question as to whether sparks which are generated when foreign materials strike metal casings or moving parts contain sufficient energy to ignite a dust cloud [23]. Mechanical sparks or heating can also occur as the result of equipment malfunction or during routine use of equipment such as power tools and shovels. In addition, foreign materials can jam operating equipment leading to friction fires.

Bucket elevators are the most frequent location of primary explosions [2]. Potential ignition sources in bucket elevators include sparks or friction from tramp metal, misaligned belts or pulleys, and metallic buckets striking the leg casings. However, friction resulting from belt slippage under choked conditions is more likely to generate the amount of energy required for ignition. If slippage continues, dust deposits may ignite or belt burn-through may occur, resulting in the belt dropping down the elevator leg.

A jammed elevator leg was reported to be the probable cause of an explosion in a feed mill in April 1978 [32], where two people were killed and 39 were injured. The explosion destroyed two headhouses and damaged several silos. The facility was supposed to have been turned off at the end of a shift; however, officials believed that at least one elevator leg was still operating and had jammed. The problem was not detected and, as the drive motor continued to operate, the belt burned through allowing the buckets to fall into the leg. Kauffman [33] reported an explosion in a medium-sized elevator in 1979 that was caused by a choked bucket elevator. One fatality and three injuries occurred along with severe damage to the facility. The shipping elevator leg had choked and had been jogged, resulting in a fire at the head pulley. The access panel to the boot was removed in an attempt to clear the choke by hand. The belt subsequently burned through and dropped creating a dust cloud in the boot area and splitting the metal leg casing. The burning belt ignited the dust cloud and the explosion resulted.

Electrical ignition sources may be associated with the use of electrical power or the buildup of electrostatic charges. Sparks generated by normal operation of electrical components such as switches, contacts, motors, and fuses can generate sufficient energy to ignite dust clouds. Arcing from equipment malfunctions, damaged wiring, or broken light bulbs may also ignite dust. Chiotti and Verkade [6] list several cases in which electrical equipment was reported as the cause. In one incident, a light bulb with a faulty extension cord was being used to illuminate a bucket elevator boot pit. Although the head guard and grip of the light were approved as being dust-tight, the extension cord shorted, causing a dust explosion which resulted in one injury and moderate damage to the facility.

Surface temperatures of electrical equipment such as heaters, motors, and exposed light bulbs can exceed the ignition temperature of layered dust. Kauffman [33] reported an explosion at a medium-sized grain elevator which resulted in two injuries and substantial damage to the facility. A fire resulted from a permanent light fixture being buried in accumulated dust in the boot well of a bucket elevator. The water stream applied to the fire by the fire department dispersed grain dust into the air which was then ignited by the existing fire. A series of explosions propagated throughout the facility; however, bin damage was minimized by effective venting.

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Electrostatic charges are generated in the normal handling of grain on equipment such as conveyors and spouts. Electrostatic discharge is generally considered a potential ignition source; however, the degree of risk is not well understood. Buildup of static electricity on belt conveyors is common and discharges have been observed; however, no instances of fires or explosions directly attributable to static discharges on belt conveyors have been conclusively reported.

Lightning strikes are also reported to have been probable ignition sources for dust explosions in grain elevators and feed mills [1, 34].

A number of potential ignition sources for grain dust have been known for many years. However, lack of data on the specific circumstances of most explosions makes it difficult to judge what actions would be most effective for the control of ignition sources. It is generally agreed that hot work, open flames, and smoking should be prohibited or conducted under tightly controlled conditions. Other ignition sources, such as static electricity and sparks from foreign material striking metal bucket elevator cups, are widely debated. There are various opinions on the extent and degree of the hazard [23].

4. Oxygen Concentration

The amount of oxygen in ambient air is more than adequate to support grain dust explosions. Oxygen concentrations above 12% are sufficient to sustain combustion. The lower explosive limit in the presence of 13% oxygen is approximately 40 times greater than that in 20% oxygen. The minimum ignition energy is increased by a similar amount [35]. The use of inert gases such as nitrogen or carbon dioxide to replace oxygen may be advantageous in some cases; however, inert gas atmospheres are not considered to be practical for use on a large scale.

5. Mixing of Dust

The mixing of dust with oxygen occurs mainly at transfer points, where grain is falling, and within enclosures. It is desirable to keep the grain stream from entraining large quantities of air. If this is not possible, the dust mixture should be collected through the use of a dust collection system [21].

6. Confinement

Dust explosions occur only in relatively enclosed spaces. Confinement may occur in elevator legs, bins, grinders, dust-collection equipment, and in many cases, the basic facility structure. Pressure buildup resulting from explosions may be well above the rupture strength of common construction materials, and extensive damage can occur unless adequate pressure relief vent areas exist. In addition, this pressure buildup creates the air flow velocity necessary to suspend layered dust, which provides fuel for devastating secondary explosions. For most grain elevators and feed mills, vent areas do not provide sufficient pressure relief to prevent destructive pressure levels [24].

C. GENERAL INDUSTRIAL HAZARDS

Employees in grain elevators and feed mills may be exposed to a wide variety of hazardous conditions during the performance of their jobs. The majority of these hazards exist, to some extent, throughout industry, although certain characteristics of grain elevators and feed mills may magnify the degree of risk. Specific hazardous conditions which could result in accidents are discussed below.

1. Facility Interfaces

Accidents may occur as a direct result of the interface with facility walking surfaces, stairs, ladders, and manlifts. Overhead obstructions, narrow aisleways, or elevated work stations may also contribute to accidents.

Hazards associated with walking surfaces vary considerably. Floors may be slippery because of loose grain, grain dust, dampness, oil, or grease. Loose dust gives little traction, causing many slips and falls. It is especially difficult to walk on round commodities such as soybeans. Inadequate storage and poor work practices may result in various materials being placed in walkways. Trash and debris may block escape routes or contain exposed nails or other sharp objects. Accidents may also be caused by uneven walking surfaces or loose or defective gratings. Bin and floor openings can account for serious injuries as the result of trips or falls [36]. Bin openings usually have covers, but they are not always replaced after use.

Fixed and portable ladders are frequently used in the grain industry for access to different work levels and equipment, emergency egress, or as means of escape from a stalled manlift or personnel elevator. Slippery rungs and the improper use of the ladders are causes of accidents that need to be addressed [37]. Various types of safety devices are available to minimize the chance of falls from ladders, but these are not always provided or used.

Belt manlifts are commonly used to transport employees from one work level to another. A belt manlift consists of a vertical, continuous belt with platforms and handles attached. The frame and drive system of a manlift are similar to those used on a bucket elevator, although the manlift is operated at a slower speed. The manlift connects the various work levels through openings in the floors. The belt may run the entire height of the facility. Accidents may result from loose or broken platforms and handholds; or, employees may be injured by contacting the structure when moving through the floor openings [4]. Falls may also occur as a result of lack of attention or carelessness. Another danger is the lack of a guard rail to prevent employees from falling into the floor openings. Although intended for personnel only, manlifts are sometimes used to transport equipment between floors, increasing the chance of a fall or of material being dropped on someone below. Employees may also use manlifts without being properly instructed in safe operating procedures.

Overhead obstructions and narrow aisleways are common in many grain elevators and feed mills. Obstructions include ducts, pipes, spouts, machinery, catwalks, conveyors, and physical parts of the facility. Injuries can occur if proper head protection is not worn. Narrow aisleways may result in personnel injury from contact with moving equipment or machinery.

The multilevel construction of many facilities frequently requires that work be performed at elevated levels. Maintenance and repair on freestanding equipment or equipment on platforms, such as marine towers, are common. Working at heights or at any work station with one or more sides open exposes workers to the chance of a serious injury. Additionally, workers at elevated levels could possibly drop equipment or tools, causing injury to someone below. Access to areas below workers should be restricted where the possibility of falling items exists.

2. Equipment Interfaces

Employees of grain elevators and feed mills frequently interface with moving machinery such as conveyors, drive motors, drive belts, gears, and pulleys.

Hazards associated with moving machinery include pinch points and nip points where two moving pieces of machinery come together or where a moving piece of machinery travels close to a stationary object. These points can catch a person's clothing, hair, or other parts of the body and draw them into the dangerous area, causing a crushing type of injury. Injury may also occur as the result of contact with unguarded rotating or translating equipment. Unguarded augers can be especially dangerous. Although guards are required by OSHA regulations, adequate devices are not always provided [4]. In one reported incident, a man was crushed and killed when trapped between a conveyor and a tension roller. Fencing was provided by the manufacturer on the basic installation; however, the tension roller had been added later. The fixed fencing provided for the other rollers was not extended to cover the nip point of the tension roller into which the worker was pulled and trapped [38].

Belt conveyors frequently run for long distances. Unless adequate crossovers are provided, employees may attempt to step on or over the belt. Conveyors could be started remotely, or the employee could lose his balance over a running conveyor. Either case could result in a serious injury.

Compressed air equipment is a common source of injury. Improper use may result in direct eye injury, or dislodged materials may enter the eye or be ingested. Direction of the air stream toward the body can also drive foreign materials under the skin. Pressure regulation devices are often unused or bypassed and protective equipment may not be used [39].

Maintenance and repair are ongoing processes in any industry. Operations may be performed by employees or outside contractors. Many serious accidents occur when employees activate equipment unaware that work is being done on the equipment by other employees. The chance of equipment being inadvertently started during maintenance is a problem that usually can be attributed to the lack of a lockout or tagout system, or failure to implement the system [40, 41]. Present industry practices vary from non-organized systems to fully documented techniques rigidly enforced by management. One worker was killed as he leaned into the machine to clean the ribbon blades while performing a routine cleanup of a batch mixer. The main switch for the mixer was on a separate floor and was located adjacent to another switch box. Another employee operated the switch and inadvertently turned on the machine. He knew the mixer was being cleaned, although he thought the job had been completed earlier. Company policy dictated the use of lockout procedures for all maintenance and cleaning operations; however, the procedures were not followed [42]. In another case, two workmen were standing on a stationary belt conveyor preparing to remove a chute above it. As they were standing there, the conveyor started. One man was thrown against the side of the chute and was killed. It was later determined that the conveyor had not been isolated, although there was an established procedure to do so [38].

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Other general maintenance problems may occur from improper use of hand or power tools or while using grinding, cutting, or welding equipment. Except for those flammability considerations addressed previously, the associated hazards are not unique to grain elevators and feed mills.

3. Vehicles and Lifting Equipment

Various types of vehicles and lifting equipment are used for material and equipment handling in and around grain elevators and feed mills. In addition to the vehicles used for shipping and receiving, small industrial trucks are common. Lifting devices, such as hoists, are also used in most facilities.

The receiving and shipping areas of grain elevators are generally the areas of highest activity. Rail receiving areas are probably the most dangerous as the result of moving rail cars and engines. Injuries may also occur from use of heavy equipment, car pullers, or the use of large pry bars for opening boxcar doors or hopper car dump valves. Employees may be required to climb rail cars for sampling or other activities, and falls may occur. In addition, contact with overhead electric wires can cause electrocution. Use of restraints when working on rail cars is not always feasible. Barge receiving and shipping areas introduce hazards associated with water and with movement of the barges during loading and unloading. Footing is frequently poor in dock areas. Truck receiving hazards include the possibility of being struck by a moving vehicle or falling into an open dump platform pit. In some cases, trucks can fall from an elevated platform if not properly secured or if the load shifts rapidly due to the collapse of a trailer which is in poor mechanical condition. Also, personnel may be required to crawl under hopper-type trucks to open and close dump valves.

Industrial trucks include forklifts and front-end loaders. Associated hazards are usually related to lack of adequate training, operating outside of design limits, or lack of employee attention.

Hoists are also used extensively for lifting large components and equipment. Smaller units are used for lowering personnel into bins. Accidents may result from defective or inadequately secured equipment or from working on unprotected, elevated platforms. Ropes, cables, boatswain's chairs, slings, hooks, winches, braces, and their interconnections should be properly maintained and inspected periodically.

4. Manual Handling

Many handling operations are performed manually. These operations result in numerous back injuries and sprains from improper handling techniques or handling oversize or overweight material. Employees should be instructed in proper handling techniques [43].

5. Confined Spaces

Entering and working in confined spaces such as bins, tunnels, tanks, and pits are common. Accessibility and maneuverability are frequently difficult, and there may be a lack of direct communication to standby personnel. Dust in

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suspension may limit visibility and necessitate the use of dust masks or respirators. These conditions tend to magnify an occurrence which normally might be a minor incident [44].

Lack of a suitable atmosphere as the result of poor ventilation or possibly the use of fumigants can be a problem when entering confined spaces. Oxygen may be consumed as the result of chemical reactions such as the fermentation of grain. In a case reported by the National Safety Council [45], a man evidently was overcome by a lack of oxygen at the bottom of a flat-bottomed bin. Since he was out of his boatswain's chair, fellow workers were not able to rescue him. In another case, a worker suffocated when lowered by hoist into a grain storage bin to clear a blockage of grain. The worker was employed by an outside firm, hired by the grain company. Tests by safety inspectors later showed that the oxygen level in the bin was as low as 3 percent. Officials said the grain blocking the bottom of the bin had fermented, using up most of the oxygen. The atmosphere in the bin was not tested for oxygen deficiency before sending the worker inside.

Entrapment and suffocation are special hazards in grain bins. Suspended grain or crusted surfaces may suddenly break loose and bury workers. Entrapment and burial can occur within a matter of seconds [4, 46]. In one incident, a man was swinging in a boatswain's chair suspended on a 3/8-inch steel rope in a bin containing soybean meal. While poking down some of the meal, he allowed the chair to swing below the level of the material. The meal released suddenly and fell on him, breaking the steel rope and carrying him to the bottom [45].

In another case, two men were working outside a bin which was being emptied of grain. They thought the bin was clear enough to be entered through the bottom access door. One of the men entered and was buried by material which was adhering to the sides of the bin. He was unable to find the access door, and the other man failed to locate him in time to save him [45].

Some grains act like quicksand, and the hazard is intensified if material is being drawn from the bottom of the bin. A fatality occurred as the direct result of running an auger to remove grain while workers were cleaning a bin. One worker was trapped by the suction created by the auger and was not able to free himself, even with the assistance of another employee in the bin. The other employee was not able to communicate with other employees or egress the bin in time to save the worker [47].

6. Health Hazards

The primary health hazards in grain elevators and feed mills are: (1) Exposure to toxic fumigants and pesticides and (2) exposure to grain dust. In addition to being a "nuisance dust," grain dust can contain insects, fungi, and molds. It was concluded in a recent study that grain handlers had a higher prevalence of respiratory symptoms than comparable nongrain-handling workers. On certain occasions, the symptoms of exposure to time-weighted average (TWA) total dust levels below accepted TWA nuisance dust recommendations ($15 mg/m^3$) (29 CFR 1910.1000(c)) appeared to affect workers' performance and sense of well being [48, 49]. All workers are exposed to dust to some degree; however, dust levels vary widely between facilities and specific locations within facilities. Various tasks, such as cleaning and sweeping, usually result in high airborne dust levels. Dust masks are used in nearly all facilities; however, types of masks and degree of their usage are inconsistent.

Applying fumigants and pesticides, without taking proper precautions or using adequate protective equipment, can be harmful. Hazards are usually correlated with the individuals applying the chemicals; however, other personnel may be exposed. Fumigants applied at the bin top may leak into basements where personnel are working, or employees may enter a tank which still contains vapors. Grain may also be fumigated in one facility and shipped without the receiving facility being informed. Although not specifically addressed in this document, exposure to dust, fumigants, and pesticides needs to be considered as one of the overall health problems.

Other health problems in grain-handling and grain-processing facilities may include exposure to noise and vibration. High noise levels can occur as a result of machinery operation as well as grain being thrown against casings or spouts. Vibration results from the operation of various machinery and associated drive motors and gears.