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OCCUPATIONAL SAFETY IN GRAIN ELEVATORS AND FEED MILLS

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Worker safety in grain elevators and feed mills is described. The existing facilities are discussed and injury and hazard statistics are summarized. Sources of fire and explosion hazards as well as other hazards involving equipment are identified. Protective equipment, training, and work practices to improve safety are analyzed. Research directions on safety are recommended, and findings are compared to national and international safety standards. The authors conclude that the recommendations developed in this report should enable management and labor to develop better work practices resulting in safer work environments.

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The views expressed and conclusions in this document are the result of careful review of available evidence and consideration of comments from external reviews. These views and conclusions, however, are not necessarily those of the external reviewers or of the contractor.

ABSTRACT

This report presents the results of an investigation of worker safety in grain elevators and feed mills. The investigation was conducted in order to develop safe work practices and engineering controls which could be used to reduce the number of accidents and injuries in the workplace and to train workers in the identification and awareness of hazards and their controls.

A description of grain elevators and feed mills is included along with statistical data correlating accidents with the population at risk. Specific hazards associated with combustible dust are addressed, as well as other safety hazards which may be encountered in the industry.

Guidelines are included for training, use of personal protective equipment, control of combustible dust, control of ignition sources, emergency planning, bin entry, isolation and lockouts, machine guarding, safe use of equipment and tools, and other work practices which could reduce worker exposure to occupational safety hazards.

Existing national and international standards are reviewed and compared with the developed guidelines. Recommendations for research are provided and ongoing research projects are identified.

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INTRODUCTION AND SCOPE

This report contains safe work practices and engineering controls which were developed to reduce worker exposure to safety hazards in grain elevators and feed mills. Workers may be exposed to hazards as the result of lack of knowledge of the potential problems, inadequate training or lack of implementation of hazard controls. Workers are exposed to safety hazards associated with fires and dust explosions, as well as other general safety hazards associated with the daily handling, storage, and processing of grain. Workers may also be subjected to health hazards as the result of exposures to grain dust and pesticides. Primarily, this report covers safety hazards. Health hazards are addressed only to acknowledge their existence and the need for their control. Safety precautions related to the use of fumigants in grain-handling facilities are included in National Fire Protection Association 61B-1980, "Standard for the Prevention of Fire and Explosions in Grain Elevators and Facilities Handling Bulk Raw Agricultural Commodities."

After evaluation of available data and consultation with others, guidelines were developed to provide for the safety of workers. The data base consisted of information obtained from literature searches, facility visits, and consultation with knowledgeable individuals from industry, labor, Government, and the academic community.

The guidelines are intended to cover all facilities classified as grain elevators or feed mills. Although it is recognized that some grains such as rice are less susceptible to dust explosions, no attempt was made to correlate the recommended guidelines with the relative hazard of the commodity being handled. In general, all commodities should be considered hazardous unless it can be demonstrated otherwise through scientific means or statistically. The majority of grain elevators and feed mills are included in Standard Industrial Classification (SIC) Codes 5153 and 2048; however, they may be coded otherwise in multibased establishments. The guidelines are intended primarily to reduce the number of accidents and injuries in existing facilities. Additional construction and design techniques that should be considered when building new facilities or renovating existing facilities are contained in National Fire Protection Association Standards 61B-1980, "Standard for the Prevention of Fire and Explosions in Grain Elevators and Facilities Handling Bulk Raw Agricultural Commodities," and 61C-1973, "Standard for the Prevention of Fire and Dust Explosions in Feed Mills."

The recommendations are broadbased, to accommodate variations between facilities and the wide range of operations and processes encountered, and are performance oriented wherever possible. Many of the recommendations, such as those addressing the use of protective equipment and ladders, are consistent with the OSHA General Industry Standards contained in 29 CFR 1910. Other recommendations, such as those addressing dust control and confined space entry, are addressed only generally in OSHA standards or not at all.

The recommendations are not intended to inhibit flexibility or to restrict development of safer procedures or techniques. Instead, they should enable management and labor to develop better work practices and more appropriate training programs that will result in safer work environments. Simply complying with the recommended guidelines should not be the final goal.

The original objective of this research project was to develop a vertical standard for occupational safety in grain elevators and feed mills. This objective was subsequently changed for several reasons. First, development of a vertical standard for a specific industrial classification is not fully compatible with existing regulations. Current occupational safety and health standards contained in 29 CFR 1910 are primarily horizontal standards which apply to all industries. Second, the scope of the study was limited to grain elevators and feed mills, although similar operation and processes are encountered in flour mills and other grain-processing facilities. Likewise, many of the hazards encountered in these facilities also exist outside of the grain-handling and -processing industries. There is a need to look at these related industries prior to developing standards for grain elevators and feed mills alone. In addition, health hazards, which were not addressed in the scope of this study, should be considered as part of a comprehensive standard. Third, the need for additional research in the area of grain dust explosions is apparent. Although hazard controls can be postulated, there is often a lack of scientific or statistical data to fully substantiate the recommendations. There is some danger in postponing implementation of recommended hazard controls while awaiting additional data from projected research projects. However, several ongoing projects, such as the grain dust explosion study being conducted by the National Academy of Sciences, are expected to add significantly to current knowledge.

Although the initial objective of this study has changed, the basic intent to develop and recommend safe work practices and engineering controls has not been altered. In spite of current efforts by Government, industry, and labor, awareness of hazardous conditions in grain-handling and -processing facilities is far from universal. This report should be of value to both management and workers as an aid in identifying hazardous conditions, implementing hazard controls, and developing effective training programs.

DEFINITION OF THE PROBLEM

INTRODUCTION

There are approximately 15,000 grain storage and handling facilities in the United States [1]. These facilities include grain elevators, feed mills, and other grain-processing plants. Many are multiuse facilities and may be included in more than one classification.

Fires and explosions in these facilities have been reported in this country and abroad for almost 200 years. This danger is inherent in the industry because of the physical characteristics of organic dust generated while handling and processing grains. Workers are also exposed daily to a wide variety of other work-related hazards capable of causing bodily injury, illness, and death.

This section describes grain elevators and feed mills and provides data correlating accidents with the population at risk. Overall injury statistics are presented along with data defining the number, causes, and locations of fire and explosion incidents.

INDUSTRY DESCRIPTION

Grain elevators are establishments which provide storage space and serve as collection and transfer points for grain and beans. Auxiliary operations such as sampling, weighing, blending, drying, cleaning, and fumigating may be performed. Feed mills are establishments engaged in the manufacture of feeds for animals. A description of these establishments and associated operations is included below.

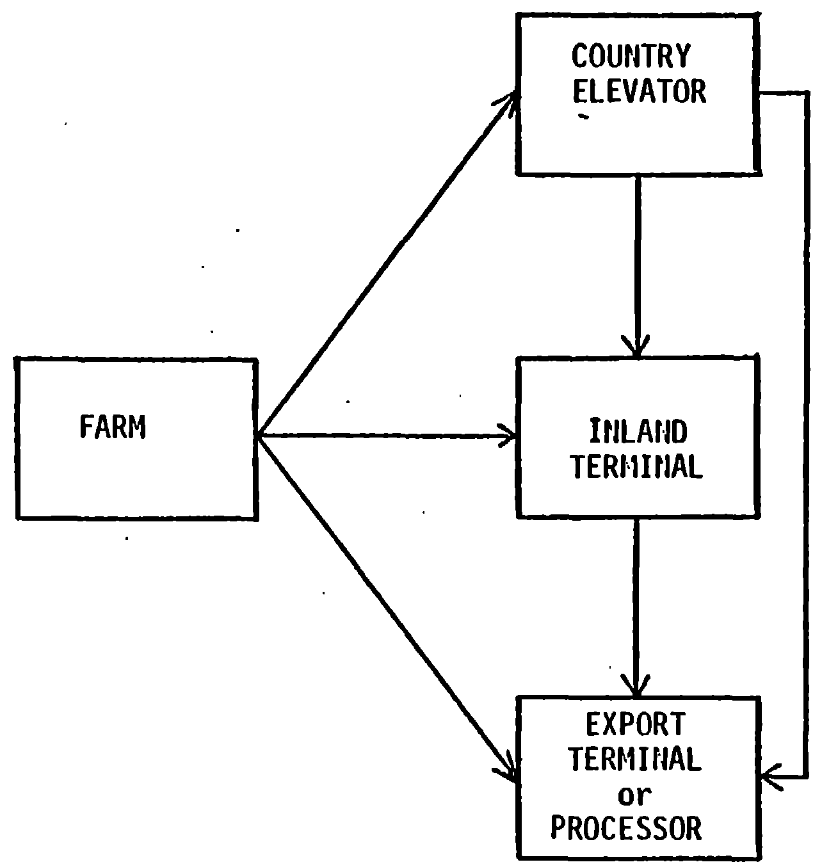
Grain Elevators

Grain elevators may be classified as country elevators, inland terminals, or export terminals [1]. Country elevators receive grain from farms for future delivery to a terminal grain elevator or grain processor. Storage capacities vary widely; however, country elevators typically have capacities of 100,000 to 1,000,000 bushels. Inland terminals receive grain from farms and country elevators for direct export or delivery to grain processors or export terminals. Inland terminals and export terminals are normally the largest facilities, reaching capacities of over 10,000,000 bushels. Export terminals have the highest grain-handling rates and are generally located at major trade or export centers. Typical flow of grain from farm to market is shown in Figure 1.

According to the National Grain and Feed Association, there are approximately 9,472 country elevators, 413 inland terminals, and 82 export terminals in operation in the United States at this time [2]. Grain elevators employ from 2 to 3 people in small country elevators to 150 or more in the large export terminals. Grain elevators may operate year-round or seasonally, with great fluctuations in

Figure 1

Grain Flow From Farm to Market



the work force. Multishift operation is common during peak periods. In addition to personnel employed by the grain elevator, workers may include grain inspectors, maintenance and construction crews, truck drivers, and longshoremen.

There are three general types of grain elevator construction: Concrete, steel frame, and wood frame. The newer establishments are usually constructed of reinforced concrete or steel frames sheathed with steel. Older establishments may be wood frame structures, sometimes sheathed with steel [3].

Typically, there are two sections of a grain elevator: The storage bins and the workhouse. Storage bins are usually built in the form of hollow cylindrical towers called silos. The workhouse contains several levels where equipment for receiving, elevating, weighing, cleaning, and distributing grain is located. It also contains bins for holding, shipping, and mixing purposes. The height of the workhouse can reach 250 feet and is generally 40 to 60 feet higher than the storage bins. The height is used to minimize the amount of mechanical transfer when moving grain, and it provides the space needed for the handling equipment. The terms workhouse and headhouse are usually used interchangeably, although sometimes that portion of the workhouse that extends above the bins is called the headhouse because the head pulleys of the bucket elevators are located there. In some facilities, elevating and distributing equipment may be freestanding and the need for a workhouse is eliminated. A gallery, or Texas longhouse, usually covers the bin floor area and extends the length of the bins. Enclosed conveyors or gravity spouts from the workhouse to the bins may eliminate the need for this structure. A typical grain elevator is shown schematically in Figure 2.

Grain-handling operations are similar at all grain elevators; however, storage capacities, handling speeds, equipment types, and specific operations may differ extensively. Incoming grain may be received by truck, rail, or barge. Most large facilities have hydraulic truck lift platforms. Hopper-bottom and self-dumping trucks are also common. Rail receiving may be by hopper or box cars. Box cars may be processed by hydraulic unloaders, which lift and tilt the cars, or by front-end loaders or power shovels. Rail cars may be moved by rail engines, other powered vehicles, or winches. Barges are usually unloaded with movable marine bucket elevators. Final barge cleanout may be by front-end loaders, power shovels, or vacuum systems.

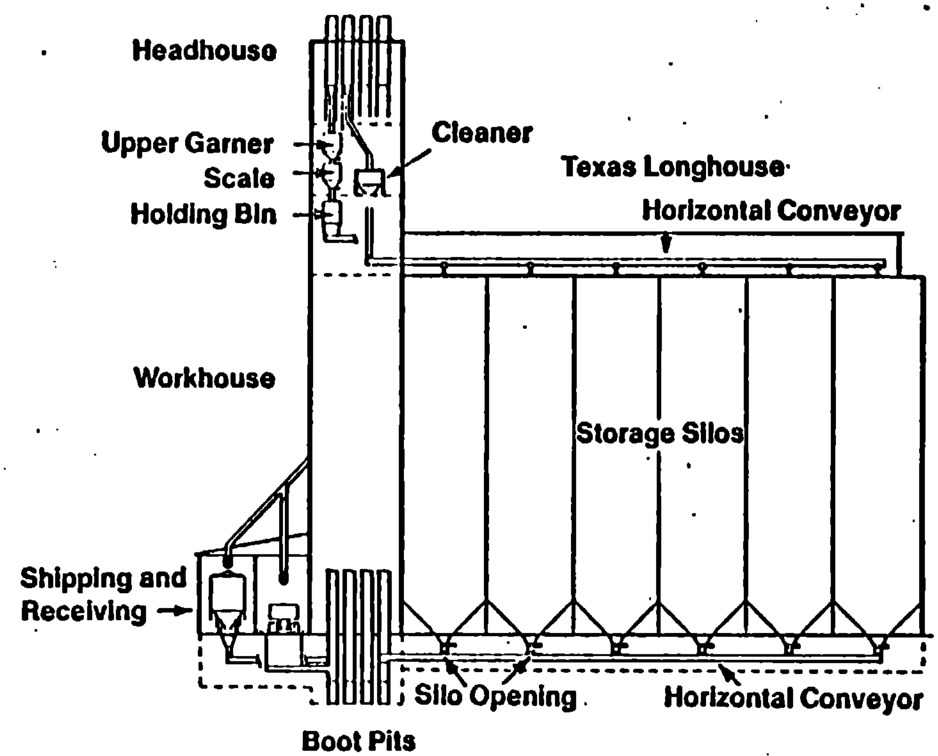
Incoming grain inspection is usually accomplished by manually driving long probes into the grain before the grain is unloaded. Unless a platform is provided, personnel must climb onto or into the vehicle to obtain samples. Sampling is accomplished mechanically in some facilities. Internal hopper scales are used for weighing grain although platform scales are frequently located in the truck receiving areas.

Grain movement throughout the grain elevator is accomplished primarily by bulk conveyors, bucket elevators, and the associated gravity spouts and distributors. Conveyor types, in order of use, include continuous belts and drag and screw conveyors. Drag and screw conveyors are normally enclosed.

Drying may be required if the grain has a high moisture content. Continuous flow column dryers usually are used, but batch dryers are also common. Cleaning may be required to achieve desired grade levels. Cleaning normally is accomplished with simple screening machinery that may be shaken, rotated, or slanted such that grain will flow across the surface.

Figure 2

Grain Elevator Schematic



Dust-collection systems are provided in many grain elevators. Dust pickup is provided at selected locations of high grain turbulence and dust dispersal such as receiving dumps and grain transfer points. Dust is pneumatically conveyed to collection devices, usually bag filters. Cyclone collectors have been used extensively in the past but currently are used much less because of clean air laws which limit discharge of dust into the outside air. Dust may be returned to the grain stream or stored for subsequent shipment from the facility. Anderson and Foley [4] reported that of the dust separated from the grain stream in elevators, 41.0% was added back to the grain stream, 33.9% was sold or given to users, 17.6% was sent to landfills, 3.7% was exhausted to the air, 3.1% was added to screenings, 0.3% was mixed with reground oat hulls, 0.3% was mixed with corncobs, and 0.1% was collected by a mist of water and discharged into a ditch. In 56.6% of the elevators the dust was returned to the grain stream at the elevator leg. Frequent housekeeping is usually required to prevent excessive accumulation of dust even when a dust-collection system is used. Housekeeping is usually accomplished with brooms, although use of vacuum systems and blowing down with compressed air are also common.

Feed Mills

Feed milling is primarily a grinding and mixing process in which a variety of grain and grain byproducts is blended with protein concentrates, food industry byproducts, vitamins, drugs, and minerals. Estimates vary as to the number of feed mills in operation in the United States. However, in a 1975 study, the Department of Agriculture cited 6,340 feed-manufacturing facilities producing over 100,000,000 tons of feed per year. This figure includes 4,454 facilities with outputs of up to 9,999 tons per year; 1,329 facilities with outputs of 10,000 to 49,999 tons per year; and 556 facilities with outputs of over 50,000 tons per year [5].

Incoming grain is generally received by truck or rail, or in some cases, from an adjacent grain elevator. Receiving operations are very similar to those in grain elevators. However, receiving areas tend to be smaller, are less likely to have facilities such as truck dump platforms, and generally have much lower handling rate capacities.

Grain and feed handling is accomplished by bulk conveyors and bucket elevators. Systems are generally much smaller and slower than those in grain elevators. Drag and screw conveyors are used more extensively, and some ingredients may be transferred pneumatically. Grain and major feed ingredients are stored in bins, generally concrete silos, or steel tanks. Other ingredients such as vitamins, minerals, and drugs may be stored in bags or barrels. Liquids such as fats and molasses are stored in tanks, frequently below the floor away from the main processing area.

Whole grain is ground prior to mixing. Hammermills, roller mills, or other types of grinders may be used to reduce the grain to the desired size. Grain, liquids, and other ingredients are measured or weighed and blended in mixers. Mixers generally contain helical ribbons or paddles attached to a horizontal or a vertical shaft.

Some feed ingredients, especially grains, are routed through cleaning equipment prior to grinding or mixing. Scalpers, which are cleaning machines with various size screens, are frequently used to remove large oversize trash. Scalpers also may be used to separate feed into uniform sizes.

Feed may be pelletized by extruding steamed feed through dies of the desired size. Pellets are usually air cooled after extrusion. A crumbler, or roller mill, may also be used to obtain the desired consistency. Pellets are passed between rollers which are adjustable to obtain the proper spacing.

Dust-control equipment may be provided in areas of high dust generation such as the receiving areas. Dust generation tends to be much less in feed mills than in grain elevators because of slower grain transfer speeds, less grain handled, and the tendency to use enclosed conveyors. Dust-control equipment may also be provided in locations such as the bagging, grinding, and mixing areas.

Feed may be shipped in bulk or bags. Bagging is frequently a semiautomatic process where a set amount of feed is released from a holding bin into a bag which is positioned by an operator. The bag is then sewn shut and routed to the warehouse area. Storage and shipping of bagged grain usually takes place in a warehouse adjacent to the feed-processing area. Bags may be handled manually and/or stored on pallets. Pallets may be transported by lift trucks or hand trucks.

INJURY STATISTICS

The number and severity of injuries in grain elevators and feed mills may be estimated from information contained in Bureau of Labor Statistics (BLS) Bulletin 2019, Occupational Injuries and Illnesses in the United States by Industry, 1976 [6]. Table 1 shows average annual employment, total injury cases per 100 full-time workers, lost workday cases, and lost workdays for SIC Codes 204, Grain Mill Products; 2048, Prepared Feeds; and 515, Farm Product Raw Materials for 1975 and 1976. Information for all industries (private sector) and manufacturing industries is shown for comparison. These data show a total of about 8,000 annual injuries in feed mill establishments, with an injury incidence rate approximately 1.7 times that of total industry and 1.2 times higher than all manufacturing industries.

Bulletin 2019 does not provide data for the four-digit SIC code 5153. The three-digit SIC code 515, Farm Product Raw Materials, includes other industries in addition to those engaged in buying and marketing grain.

Additional information on grain elevators and grain mills is included in the 1977 edition of Accident Facts prepared by the National Safety Council (NSC) [7]. This edition records the results of a 3-year study performed on the basis of reports to the NSC. Table 2 includes injury frequency rates and severity rates per 1,000,000 hours for grain mills and grain elevators for the 3-year period from 1974 through 1976. The rates are not directly comparable to the BLS data since: (1) The NSC base of 1,000,000 hours corresponds to 500 full-time workers rather than 100 full-time workers, and (2) the NSC data include only disabling work injuries while the BLS data include total injuries. The data presented by the NSC over the 3-year period are most significant when compared with the overall industry rates. For grain mills (corresponding to the three-digit SIC code 204), the frequency rate of disabling injuries is about 1.7 times higher than the industry average, with the severity rate about twice as high as the industry average. For grain elevators, the frequency rate is only about 1.5 times higher than the industry average; however, the severity rate is nearly 6 times as high. Comparable records for recent years are not available.

Table 1

INDUSTRY EMPLOYMENT/OCCUPATIONAL INJURY INCIDENT RATES

SIC CODE	1976 EMPLOYMENT (THOUSANDS)	TOTAL CASES PER 100 WORKERS 1975	TOTAL CASES PER 100 WORKERS 1976	LOST WORKDAY CASES 1975	LOST WORKDAY CASES 1976	LOST WORKDAYS 1975	LOST WORKDAYS 1976
All Industries		8.8	8.9	3.2	3.4	54.6	57.8
Manufacturing		12.5	12.6	4.3	4.6	72.9	76.7
204	135.1	15.3	15.0	5.9	6.5	106.1	110.8
2048	53.4	15.2	14.9	6.0	6.8	89.8	94.6
515	138.8	8.7	9.3	3.3	4.5	61.3	79.3

Source: Bureau of Labor Statistics Bulletin 2019 (1979)
SIC 204 - Grain Mill Products
SIC 2048 - Prepared Feeds
SIC 515 - Farm Product Raw Materials

Table 2

INDUSTRY INJURY RATES

INDUSTRY	FREQUENCY RATE DISABLING WORK INJURIES PER 1,000,000 HOURS 1974 TO 1976	SEVERITY RATE WORKDAYS LOST PER 1,000,000 HOURS 1974 TO 1976
All	10.87	668
Grain Mills	18.70	1,389
Grain Elevators	16.64	3,902

Source: National Safety Council Accident Facts, 1977 Edition

Also of interest are data included in BLS Bulletin 2019, covering occupational injury and illness rates by employment size (Table 3). For grain mill products, the lowest incident rates are achieved by employers with over 1,000 and less than 20 personnel. For farm products, a similar trend exists, with the lowest rates achieved by the largest and smallest employers.

FIRE AND EXPLOSION STATISTICS

The single largest safety concern in grain-handling and -processing facilities is that of dust fires and explosions. Of all the industrial dust explosions in the United States, those in grain elevators are most frequent and cause the most injuries and property damage [3]. According to the National Fire Protection Association, about 48 percent of the total number of dust explosions in the United States during the period from 1900 to 1956 have occurred in industries handling grain, feed and flour [8]. Information presented by Verkade and Chiotti [3] for the 17-year period from 1958 through 1975 includes records of dust explosions in 137 grain elevators and 50 feed and cereal mills in the United States, resulting in 336 injuries and 51 deaths.

A later listing of explosions was compiled and individually verified by the United States Department of Agriculture (USDA) [1] from several sources, including Verkade and Chiotti. This compilation included 250 explosions in U.S. grain elevators and feed mills in the 21-year period from 1958 through 1978 which resulted in 605 injuries and 164 deaths. A recently updated USDA compilation includes 399 explosions in U.S. grain-handling facilities in the 23-year period from 1958 through 1980 which resulted in 679 injuries and 185 deaths. The number of deaths per year ranged from 0 to 8 with the exception of 1968 (13 deaths), 1974 (13 deaths), 1976 (22 deaths), 1977 (65 deaths) and 1980 (10 deaths). In 1979, 29 incidents resulting in 18 injuries and 2 deaths were reported. In 1980, there were 45 reported incidents resulting in 10 deaths and 50 injuries. Yearly explosions ranged from a high of 45 incidents during 1980 to a low of 8 incidents during 1961 and 1965. Verkade and Chiotti and the USDA both reported the lack of an accurate, comprehensive, and uniform reporting system, indicating that many additional incidents may not be recorded.

The USDA report [1] also estimated fire experience for the period from 1958 through 1975 on the basis of data provided by the National Fire Protection Association. The number of fires in the grain-handling industry during this 18-year period averaged about 2,700 incidents per year. On the basis of limited data, the USDA indicated that these numbers may have been understated by at least a factor of 2. Fires in grain elevators and feed mills result in the loss of millions of dollars in both direct expenses and lost time. Injuries can occur as a direct result of the firefighting activities or as a result of explosions which may be triggered by the fire.

The probable ignition sources in the 250 explosion incidents compiled by the USDA [1] are shown in Table 4. It is significant to note that in 103 of the 250 incidents, the probable ignition source is unknown, largely because of the lack of formal accident investigations. In other cases the probable cause was reported on the basis of speculation by inexperienced investigators. Where the probable cause was reported, 43 of the 250 incidents were attributed to welding or cutting. The next four most probable causes are electrical failure, tramp metal, fire other than welding or cutting, and unidentified foreign objects. One contributor to the large number of incidents attributed to cutting and welding

Table 3

OCCUPATIONAL INJURY AND ILLNESS INCIDENT RATES, PRIVATE SECTOR, BY INDUSTRY AND EMPLOYMENT SIZE, UNITED STATES, 1976

INDUSTRY AND EMPLOYMENT SIZE	SIC CODE	MEAN INCIDENT RATE PER 100 FULL-TIME WORKERS
Grain Mill Products:	204	
All Sizes		15.4
1 to 19		9.8
20 to 49		18.4
50 to 99		17.5
100 to 249		20.1
250 to 499		16.5
500 to 999		14.8
1,000 to 2,499		4.8
Farm-Product Raw Materials	515	
All Sizes		9.7
1 to 19		7.7
20 to 49		9.4
50 to 99		15.2
100 to 249		13.9
250 to 499		9.7
500 to 999		7.7

Source: BLS Bulletin 2019 (1979)

Table 4

PROBABLE IGNITION SOURCES

	Number of Facilities	Percent of Facilities
Unknown	103	41.2
Welding or cutting	43	17.2
Electrical failure	10	4.0
Tramp metal	10	4.0
Fire other than welding or cutting	10	4.0
Unidentified foreign objects	9	3.6
Friction from choked leg	8	3.2
Overheated bearings	7	2.8
Unidentified spark	7	2.8
Friction sparks	7	2.8
Lightning	6	2.4
Extension cords caught in legs	4	1.6
Faulty motors	4	1.6
Static electricity	3	1.2
Fire from friction of slipping belt in leg	3	1.2
Leaking flammable vapor	3	1.2
Smoldering grain or meal handled	2	0.8
Smoking material	2	0.8
Lighted firecracker	1	0.4
Volatile chemical escaped from soybean processing	1	0.4
Fire from cob pile outside facility	1	0.4
Heating system	1	0.4
Pocket of gas in bin ignited	1	0.4
Extinguishing fire	1	0.4
Leak in gas pipe ignited	1	0.4
Electric control panel exploded	1	0.4
Slipping conveyor belt	1	0.4
Sample size	250	100.0

may be that evidence of hot work is easily traced. The hazards associated with cutting and welding should not be minimized; however, it is likely that for most of the incidents where the cause was unknown, the ignition source was a condition other than hot work. The probable locations of the primary explosion in the cases compiled by the USDA are shown in Table 5. The probable location is reported in 143 of the 250 incidents. Bucket elevators account for 58 of the 143 reported incidents, followed by grinding equipment and storage bins in 17 and 13 incidents, respectively.

SUMMARY AND CONCLUSIONS

The grain dust explosion hazard has been known for many years. The United States Department of Agriculture has compiled a listing of 399 explosion incidents in grain elevators and feed mills in the United States over the 23-year period from 1958 through 1980. These incidents resulted in 679 injuries and 185 deaths. Explosions in recent years, with the attendant loss of life and injuries to personnel, have focused attention on these spectacular disasters. However, available statistics indicate that the injuries resulting from explosions are only a small percentage of overall injuries. For example, in 1976, 23 injuries were reported as the result of explosions in feed mills [1]. In the same year, according to the Bureau of Labor Statistics, approximately 8,000 injury cases were reported in feed mills, of which approximately 3,600 injuries resulted in loss of work attendance of 1 day or more [6]. The lost workday injuries alone are more than two orders of magnitude greater than injuries caused by explosions. From the above, it appears that:

1. Solutions for prevention of fire and explosion are required.

2. Reduction in work-related injuries is required.

Although solutions to the fire and explosion problem must be derived and implemented, overall safety cannot be achieved unless additional effort is made to reduce the number of other work-related injuries.

Table 5

PROBABLE LOCATION OF PRIMARY EXPLOSION

	Number of Facilities	Percent of Facilities
Unknown	107	42.8
Bucket elevator	58	23.2
Hammermills, roller mills, or other grinding equipment	17	6.8
Storage bins or tanks	13	5.2
Headhouse	9	3.6
Adjacent or attached feed mill	8	3.2
Basement	4	1.6
Processing equipment	3	1.2
Dust collector	3	1.2
Tunnel	2	0.8
Distributor heads	2	0.8
Passenger elevator or manlift shaft	2	0.8
Grain drier	2	0.8
Outside and adjacent to facility	2	0.8
Pellet collector	2	0.8
Conveyor system	2	0.8
Receiving pit	2	0.8
Other handling equipment	2	0.8
Processing plant	1	0.4
Down spout	1	0.4
Corn tester	1	0.4
Feed room	1	0.4
Sampler	1	0.4
Storage room	1	0.4
Boiler or feed mill	1	0.4
Electrical switch	1	0.4
Auger conveyor	1	0.4
Electrical panel	1	0.4
Sample size	250	100.0

IDENTIFICATION OF THE HAZARD

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, and 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 may have been prevented if safe work practices had been observed or if engineering or management controls had been instituted.

FIRES AND EXPLOSIONS

A dust explosion hazard exists whenever combustible dusts accumulate or are generated as a result of grain handling or processing. For a grain dust explosion to occur, four conditions must be met:

1. Airborne dust must be present in a concentration within the explosive limits.

2. Oxygen must be present in a concentration sufficient to sustain rapid combustion.

3. An ignition source of sufficient energy and duration must be present.

4. Ignition must occur in an enclosed space.

Airborne Dust Concentration

The generation of grain dust is inherent in grain-handling operations. Grain breakage occurs initially at harvest and continues through each subsequent handling. Particles range in size from respirable particles of 10 microns or less to particles of 100 microns or more.

In contrast to gaseous mixtures, the lower explosive limit for grain dust is not well defined, and different results can be found for the same kind of dust [9]. Differences can be attributed in part to test variables such as turbulence, uniformity of the dispersion, and duration of the ignition source. Most sources report a lower explosive limit of 20 to 70 grams per cubic meter which has been likened to a dense fog. Although it is improbable that this concentration would exist in the work areas, it is likely that it does exist within enclosures such as bucket elevators, conveyor housings, bins, and connecting spouts [10]. The upper explosive limit also varies, ranging from 2,000 to 3,000 grams per cubic meter. Peak explosive pressures generally occur near concentrations of 1,000 grams per cubic meter [11].

The explosiveness 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 explosiveness. Increases in particle size also decrease explosiveness [12]. To facilitate evaluation of the explosiveness of dusts and to give a numerical rating for the relative hazard, an empirical index of explosiveness was developed by the U.S. Bureau of Mines [13]. The index provides a relative rating of explosiveness as a function of ignition temperature, ignition energy, explosive concentration, explosion pressure, and rate of pressure rise. The indices of explosiveness of corn and wheat dusts within this system are 8.4 and 2.5, respectively, when compared with Pittsburgh coal which has an index of 1.0.

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 [14] [15]. Laboratory testing, however, has indicated that the minimum amount of energy required to ignite fumigated grain dust may be reduced [16].

Although grain dust must be airborne for an explosion to occur, the presence of layered dust is also a significant problem. Dust settles not only on floors, ledges, and other horizontal surfaces, but also, to some extent, on vertical surfaces and ceilings. Layered dust may lead to explosive airborne concentrations if agitated. Burning or smoldering dust may also ignite airborne dust concentrations. Dust on warm surfaces on machinery, motors, bearings or lighting fixtures tends to dry out and becomes susceptible to ignition at temperatures as low as 200°C (392°F) [8]. In addition, layered dust is generally acknowledged to be the source of immensely damaging secondary explosions [12]. 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.

Oxygen Concentration

The amount of oxygen in air is more than adequate to support grain dust explosions. Oxygen concentrations above approximately 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 [17]. The use of inert gases such as nitrogen or carbon dioxide to replace air may be advantageous in some cases; however, inert gas atmospheres are not considered practical on a large scale basis.

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 [13]. Ignition may occur as the result of thermal, mechanical, or electrical energy release. 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 cause. Fires and explosions caused by hot work generally occur because inadequate precautions have been taken to remove or protect combustibles, or because other dust-producing operations are performed concurrently with or immediately after the hot work is performed.

A grain elevator explosion in January 1976, in which 5 workers were killed and 11 injured, was attributed to welding/cutting operations [18]. Investigators concluded that cutting and welding equipment being used to install a new spouting system ignited dust in the 12-story elevator. The initial blast which occurred on the scale floor, was followed by at least two others. The company was charged with failing to properly clean and isolate the area and failing to shut down dust-producing machinery in nearby areas.

In another case, explosions in a pet food mill in December 1977 resulted in 4 people killed and 15 injured [19]. Two explosions, which occurred almost simultaneously, blew out the walls of the mill building and did extensive damage to equipment. The cause of the explosion has not been 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. This blew wheat grain dust into the bin and the dust exploded.

Other thermally related ignition sources include open flames such as matches, lighters, cigarettes, and space heaters. Most personnel in grain-handling facilities are aware of the hazards associated with open flames; however, incidents still occur. In one case reported by Verkade and Chiotti [3], an explosion occurred in a grain elevator when the manager lit a cigarette while walking between the facility and a box car. No other personnel were injured and damage was moderate.

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. Following bucket elevators, explosions are most likely to initiate in hammermills, 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 January 1980, resulting in one injury and extensive damage to the facility [20]. Evidence suggests that a particle of stone or metal passed through a hammermill 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 whether the sparks generated when the foreign materials strike metal casings or moving parts contain sufficient energy to ignite a dust cloud [10]. Mechanical sparks or heating can also occur as the result of equipment malfunction or during use of equipment such as power tools and shovels.

Bucket elevators are the most frequent location of primary explosions. 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 [21]. There were 2 people killed and 39 injured, and the explosion destroyed 2 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 [22] reported an explosion in a medium-sized elevator in 1979 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. This allowed burning belt to fall into the dust cloud, which caused the explosion.

Electrical ignition sources may be associated with the use of electrical power or 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. Verkade and Chiotti [3] list several cases in which electrical equipment is 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 and motors can exceed the ignition temperature of layered dust, although hot surfaces on exposed light bulbs probably account for more fires. Kauffman [22] reported an explosion in a small country elevator in 1979 which resulted in one injury. On the day of the explosion, milo had been ground and loaded. Dust had accumulated on the headhouse floor as well as on the top of a light fixture. The dust on the fixture apparently ignited and fell to the headhouse floor, igniting the dust there. The fire surrounded a metal-cased bucket elevator leg and subsequently ignited the belt, which then burned through and dropped, leading to the explosion.

Kauffman [22] also reported an explosion at a medium-sized grain elevator resulting in two injuries and substantial facility damage. 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, and the dust was ignited by the existing fire. A series of explosions propagated throughout the facility; however, bin damage was minimized by effective venting.

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. Static electricity buildup on belt conveyors is common, and discharges have been observed; however, no instances of fires or explosions from static discharges on belt conveyors have been reported. In one report [21], static electricity discharges were observed from a plastic pipe prior to an explosion in a small feed mill in January 1978 in which three people died and six others were injured. At the time, contractor personnel were salvaging a powdered feed ingredient which had been spilled into the basement of the mill building. The salvaged ingredient was being pneumatically pumped through the pipe to the top of a silo and into a bin. "Popping" sounds had been heard. Personnel were in the process of shutting down, because of observation of static sparks, when the explosion occurred. Based on eyewitness accounts and an inspection of the damaged facility, OSHA investigators concluded that the dust cloud, generated by the feed ingredient or grain dust in the area, was probably ignited by a static electric discharge from the plastic pipe.

Lightning strikes are also reported to have caused dust explosions in grain elevators and feed mills. A company spokesman and OSHA investigators indicated that lightning was the apparent cause of an explosion in a processing mill which injured six persons [23]. The explosion, which destroyed the facility, occurred during a thunderstorm. Following the initial explosion, a fireball went throughout the facility causing extensive damage.

The potential ignition sources for grain dust have been known for many years, and solutions to the problem can be readily identified. However, lack of data on the specific circumstances of most explosions makes it difficult to know which actions would be most effective. It is generally agreed that hot work, open flames, and smoking should be precluded 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 degree of hazard [10].

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 an adequate pressure relief vent area exists. For most grain elevators and feed mills, vent areas do not provide sufficient pressure relief to prevent destructive pressure levels [11].

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.

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 particularly difficult to walk on round commodities such as soybeans. Inadequate storage and poor work practices may result in various materials 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 grating. Bin and floor openings can account for serious injuries as the result of trips or falls [24]. 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 off a stalled manlift or personnel elevator. Most ladders are kept in good condition because they are used frequently, and defects are likely to be found. However, deterioration of ladders that are infrequently used, such as emergency ladders, may take place without being noticed. Slippery rungs and the improper use of the ladders are causes of accidents that also need to be addressed [25]. 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 [26]. Falls may also occur as a result of lack of attention, carelessness or fatigue. 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 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 results in a requirement to work 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 the employees to the chance of a serious injury. Additionally, there is a possibility that workers could drop equipment or tools, causing an injury to someone below. Access to areas below workers should be restricted where the possibility of falling items exists.

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 particularly dangerous. Although guards are required by OSHA regulations, adequate devices are not always provided [26]. 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 into which the worker was pulled and trapped [27].

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 could 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 [28].

Maintenance and repair are ongoing processes in any industry. Operations may be performed by employees or outside contractors. Many serious accidents occur when someone activates equipment on which work is being done 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 [29] [30]. Present industry practices vary from nonorganized 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 procedure was not followed [31].

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 of the men 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 [27].

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.

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. 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. Personnel may also 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. These hazards are common to all industries; however, their frequent occurrence when unloading barges, boxcars, and steel bins, and during general material and equipment handling, merits extra consideration.

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.

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 [32].

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. Suspended dust may limit visibility and necessitate the use of dust masks or respirators. These conditions tend to magnify an occurrence which normally would be a minor incident [33].

Lack of suitable atmosphere as the result of poor ventilation or 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 formation of rust or because of fermentation of grain. In a case reported by the National Safety Council [34], 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. 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 [26] [35]. 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 [34].

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 [34].

Some grains act like quicksand, and the hazard is intensified if material is being drawn from 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 [36].

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 dust levels below accepted TLV nuisance dust (15 milligrams per cubic meter) appeared to affect workers' performance and sense of well being [37]. 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 safety problems. Other health problems in grain-handling and -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.

SAFE WORK PRACTICES, ENGINEERING CONTROLS AND TRAINING NEEDS

INTRODUCTION

This section contains the practices recommended as a means of reducing accidents and injuries in grain elevators and feed mills. The recommendations are designed to make the workplace safer, and to make workers and management aware of the hazards normally associated with these facilities. The recommendations are performance oriented where possible, stating the goal to be achieved. Successful and unsuccessful methods of achieving the goal, and the criteria upon which the recommendations are based, are addressed where applicable.

DEFINITION OF TERMS

The following definitions are used for purposes of this document:

Bucket Elevator. A continuous conveyor belt with equally spaced buckets attached, which elevates and discharges material into a spout or other receiver. Elevation is usually vertical although some bucket elevators are sloping. The main sections of a bucket elevator are usually referred to as the head, boot and leg. The head is the top section of a bucket elevator where the drive is located and the material is discharged. The boot is the bottom section where material enters the bucket elevator and is picked up by the buckets. The leg is the section between the head and boot.

Choke Feeding. A condition of material buildup in a spout or hopper without stoppage of discharge flow. Choke feeding may be used to provide an even feeding rate or reduce grain breakage and dust generation.

Choked Condition. A condition of material buildup in spouts, hoppers, or equipment that results in stoppage of material flow in a conveying system.

Class II Locations. Locations that are hazardous because of the presence of combustible dust. Class II locations include the following:

1. Class II, Division 1. A Class II, Division 1 location is a location: (1) In which combustible dust is or may be in suspension in the air under normal operating conditions, in quantities sufficient to produce explosive or ignitable mixtures; or (2) where mechanical failure or abnormal operation of machinery or equipment might cause such explosive or ignitable mixtures to be produced, and might also provide a source of ignition through simultaneous failure of electrical equipment, operation of protection devices, or from other causes; or (3) in which combustible dusts of an electrically conductive nature may be present.

2. Class II, Division 2. A Class II, Division 2 location is a location in which (1) combustible dust will not normally be in suspension in the air in quantities sufficient to produce explosive or ignitable mixtures; and dust accumulations are normally insufficient to interfere with the normal operation of electrical equipment or other apparatus; or (2) dust may be in suspension in the air as a result of infrequent malfunctioning of handling or processing equipment, and dust accumulations resulting therefrom may be ignitable by abnormal operation or failure of electrical equipment or other apparatus.

Combustible Dust. A dust capable of undergoing combustion or of burning when subjected to a source of ignition in the presence of atmospheric oxygen.

Confined Space. An enclosed or partially enclosed space which: (1) Has limited openings for entry and exit, (2) is not intended for continuous employee occupancy, and (3) because of its design, atmosphere, contents or other condition, may be hazardous to a worker required to enter it.

Dust. Any finely divided solid material formed by disintegration processes whether product or waste.

Explosion. Combustion of a dust, vapor, or gas which results in the rapid development of heat and pressure within an enclosed space.

Feed Mill. An establishment primarily engaged in manufacturing feed for animals.

Foreign Material. Any unwanted objects or materials inadvertently mixed with the grain or feed. Foreign materials may include nails, bolts, sticks, stones, dirt, and other similar items.

Grain Elevator. An establishment primarily engaged in the receipt, handling, storage, and shipment of grain (such as corn, wheat, oats, barley, and unpolished rice) and beans. Facilities may be classified as country elevators, inland terminals, or port terminals, or may be operated in support of grain-processing facilities.

Group G Atmospheres. Atmospheres containing flour, starch, or grain dust.

Headhouse. A portion of a grain elevator used to house grain-handling equipment. The headhouse may include equipment to elevate grain, weigh grain, clean grain, direct grain flow to bins or conveyors, sample grain, or perform other operations. The terms headhouse and workhouse are usually used interchangeably, although sometimes the section of the workhouse that extends above the bins is referred to as the headhouse because the head pulleys of the bucket elevators are located there.

Hot Work. Work involving electric or gas welding, cutting, brazing, or similar heat-producing operations, as well as work such as grinding which produces a potential source of ignition.

Jogging. Repeated starting of drive motors in an attempt to clear choked equipment.

Lagging. A covering on drive pulleys used to increase the coefficient of friction between the pulley and the belt. Lagging may have a smooth or grooved surface and is usually installed on belt conveyor and bucket elevator head pulleys as well as flat belt power transmission pulleys.

Lower Explosive Limit (LEL). The minimum concentration of a flammable or combustible gas, vapor, or dust in air which will allow flame propagation.

Permissible Exposure Limit (PEL). The maximum amount of any airborne contaminant to which an employee may be exposed as listed in 29 CFR 1910 Subpart Z.

Permit. An authorization and approval in writing that specifies the location and the work to be performed, and certifies that all hazards have been evaluated by a qualified person and necessary protective measures have been taken to ensure the safety of each worker.

Qualified Person. A person, designated by the employer, capable (by reason of training and/or experience) of recognizing and evaluating exposure to unsafe conditions and specifying necessary controls and/or actions to ensure worker safety.

Scalper. Screening machinery used to remove foreign material larger than the grain or feed itself.

Tramp Metal. Any metallic objects or materials that are inadvertently mixed with the grain or feed. Tramp metal may include nails, bolts, wires, tools, or any other metallic items.

Tripper. A device used to divert grain or material from a conveyor belt into a bin opening, hopper spout, or machine.

Turnhead. A device that distributes or routes grain or material from one spout, bin hopper or machine to two or more bins, spouts, or machines.

TRAINING

Occupational hazards are caused by the interaction between workplace, machine, and humans. Studies have shown that 85% or more of all industrial injuries and illness are caused by unsafe acts. Without emphasis on the human element, a safe workplace cannot be achieved.

The value of employee training is recognized throughout industry. A safe operation largely depends upon employees who are properly informed and aware of the potential hazards. To be effective, training must be done by a knowledgeable person and must address safe performance of the assigned tasks as well as other relevant aspects of hazard recognition and control within the workplace [38] [39] [40] [41] [42] [43]. The employer is responsible for establishing a training program commensurate with the tasks to be performed and safe work practices to be followed.

Personnel need to be made aware of the general hazards which may be encountered in grain elevators and feed mills, the specific hazards which may be encountered in the performance of their assigned tasks, and the necessary actions or precautions to be taken to prevent accidents. In addition to training for the equipment, machinery, and vehicles which the employee will operate or use to accomplish the assigned tasks, training should cover the use of personal protective equipment, emergency procedures, and other applicable work practices recommended in this report.

Training programs should include both general orientation sessions and on-the-job training. Safety orientation should include classroom sessions addressing safety rules and policies and a walk-through of the facility. After the employee has received a basic understanding of the operation and the hazards involved, on-the-job instruction including demonstrations and supervised participation in actual work practices should be provided. Training should not be considered complete until it has been demonstrated to the satisfaction of the employer, or the person designated by the employer to conduct the training, that the employee is able to perform the assigned tasks safely and is familiar with the precautions that must be taken in the workplace to prevent injuries. Retraining should be conducted as needed to assure that workers are able to perform their duties in a safe manner.

Safety orientation programs should also be developed for contractor personnel. The program should address safety rules and policies, hazards associated with combustible dust, and other specific hazards that may be encountered in grain elevators and feed mills with which the contractor personnel may not be familiar.

ADMINISTRATIVE CONTROLS

The first step in an effective safety program is management commitment. To reduce accidents, it is essential that management be fully committed to work safety and insist that all employees be involved. Employers are required by law to provide a place of employment free from recognized hazards. To achieve this end, management must ensure that hazards are identified and effective hazard controls are developed, implemented, and remain in continuous use [44] [45]. Persons responsible for safety in the facility should be clearly identified.

Identification of hazards and associated safe work practices can best be accomplished by conducting a system safety analysis of the facility and operations. Various techniques such as a "job safety analysis," which breaks jobs into a sequence of steps that can be more easily addressed, can be applied. Safety analyses can be done informally; however, a formal approach which results in detailed operational procedures is usually most effective. Analysis should initially be accomplished on operations where experience indicates accidents and injuries are most likely to occur.

The following administrative controls should be implemented as a part of an effective safety program.

1. Establish an effective training program.

2. Ensure that a comprehensive dust control program is developed and implemented.

3. Ensure that all equipment and machinery are in a safe operating condition, are capable of safely performing the job for which they are used, and are regularly maintained and inspected.

4. Ensure that adequate procedural controls are developed and implemented for hot work, confined space entry and other potentially hazardous operations.

5. Establish and enforce general safety rules. Rules should address use of smoking material, alcohol, drugs, and weapons as well as policies covering use of protective equipment and accident reporting systems. Compliance with safety policies should be stipulated as a condition of employment.

6. Establish necessary controls for visitors and outside contractors.

7. Ensure compliance with safety and health regulations.

8. Ensure that the safe work practices contained in the report are evaluated and applied where applicable.

Employee safety committees can be key elements of industrial safety programs. Committees typically meet periodically with management representatives to examine potential safety issues and recommend abatement procedures. Committee members may also perform safety inspections and review accident reports and perform other safety-related functions.

PERSONAL PROTECTIVE EQUIPMENT

Many cases have been recorded of traumatic injury, respiratory distress, and dermal exposure to toxic and corrosive substances in grain elevators and feed mills. A review of the literature indicates a significant number of injuries could have been prevented by the use of protective equipment. Engineering and administrative controls should be used where possible as the primary means of protection from workplace hazards. Use of personal protective equipment is necessary, however, where known controls are not fully effective or while controls are being implemented [46] [47] [44] [38] [48].

Although some types of personal protective equipment are needed in most facilities, specific requirements vary and should be determined by a qualified person on the basis of the facility, operations, location and other considerations of the work environment. Major concerns which may necessitate the use of protective equipment in grain elevators and feed mills include the chance of falling objects, the presence of atmospheric dust, use of fumigants, and the need to enter confined spaces. Other potential hazards which should be evaluated include exposure to high noise levels, overhead obstructions, temperature extremes, electrical equipment, sparks and flying objects, and irritating, corrosive and toxic substances [46] [47] [44].

Protective equipment must be properly maintained and inspected on a regular basis. Visual inspections should normally be conducted before each use, and more thorough scheduled inspections accomplished depending on the equipment. The type and frequency of required maintenance and inspection are usually available from the supplier or manufacturer or included in applicable OSHA standards. Written records should be kept that reflect scheduled inspection dates, inspection results, and maintenance performed. Logs should also be kept on limited life items.

The employer is responsible for the provision of adequate protective equipment and its proper use by employees. This can more easily be accomplished if the workers understand the necessity of the equipment and the equipment is not overly uncomfortable or cumbersome. Instruction and training are necessary to ensure that workers understand the limitations of the equipment and are able to use it properly.

Items normally needed to protect personnel from injury or illness include: Hard hats, safety glasses or goggles, respirators, safety belts, harnesses, and lifelines. Other protective equipment such as ear plugs, protective footwear, gloves and flotation devices may be required in some applications.

Head Protection

Protective headgear is needed where there is a possibility of impact from falling or flying objects or overhead obstructions. Specialized headgear may be required to protect against specific hazards such as electrical shock, burns, and exposure to cold weather. Headgear provided for protection from falling or flying objects must meet the requirements specified in 29 CFR 1910.135. Protective headgear should be visually inspected before each use and repaired or replaced when cracked, chipped, or otherwise damaged.

Eye and Face Protection

Suitable protection is needed where there is a chance of injury from flying objects or exposure to irritating substances. Impact-resistant safety glasses or safety goggles are required where there is a chance of injury from flying particles, sparks, or other small objects. Optically corrected safety glasses or safety goggles that can be worn over optically corrected glasses may be needed for persons using corrective lenses. Safety goggles may be required where eye-irritating chemicals, vapors, or dusts are present. A full coverage face shield is needed if both the eyes and face are exposed to a hazard. Protective eye and face equipment must meet the requirements in 29 CFR 1910.133. Persons engaged in welding and cutting operations must use goggles and shields in accordance with 29 CFR 1910.252. Contact lenses should not be worn in grain-handling or milling areas where airborne dust is present. Equipment should be visually inspected before each use for loose, scratched, pitted, or otherwise damaged components that may reduce protection or obscure vision.

Respiratory Protection

Appropriate respiratory protective equipment is needed whenever personnel are exposed to particulate, gas, or vapor contaminants exceeding the permissible exposure limit (PEL), or an oxygen deficiency. The type of respiratory equipment used should be determined by a qualified person on the basis of the specific conditions and atmospheric test results. Respirators must be NIOSH and OSHA approved devices and be fitted, used, and maintained in accordance with 29 CFR 1910.134.

Dust masks for protection from particulate contaminants are the most frequently used respiratory devices in grain-handling and -processing facilities. Dust masks may be disposable or have a reusable frame with a disposable filter element. Some facilities provide enclosed, forced air respiratory devices for excessively dusty operations such as bin cleaning. Chemical cartridge respirators are used to provide protection from low concentrations of known gases and vapors in areas where there is no oxygen deficiency. Supplied air respirators or self-contained breathing apparatus are needed in oxygen deficient atmospheres.

Safety Belts, Harnesses, and Lifelines

Safety belts or harnesses are needed whenever employees are required to work at elevated stations 10 feet or more above grade level and are not otherwise protected from falls. The belts or harnesses must be attached to a secure point or other device designed to prevent uncontrolled movement. Lanyards and lifelines should be sized or adjusted to minimize free-fall distance consistent with freedom of movement. In no case should free-fall distance exceed 6 feet (1.8 m). On vehicles such as rail cars, where no reasonably effective secure point exists, other means of protecting workers, such as providing access platforms, should be considered. Belts or harnesses with lifelines are also needed when entering bins from above and in other applications where their use could prevent serious injury or enhance rescue.

Equipment should comply with the requirements contained in American National Standard A10.14, "Construction and Use of Individual Safety Belts, Harnesses, Lanyards, and Droplines." Prior to each use, equipment should be inspected for dry rot, chemical, mechanical, or other damage that may affect its strength. Defective lifelines should not be used. Care should be taken to ensure that the line is not placed over a sharp edge, or cut or pinched.

Hearing Protection

Ear plugs, ear muffs, or other suitable devices are needed when workers are exposed to ambient sound levels exceeding the permissible exposure levels specified in table G-16 of 29 CFR 1910.95. Sound level meters used to measure noise levels must be compatible with the environment in which they are used. Rotation of personnel, restricting personnel access to noisy areas, use of barriers and other administrative and engineering controls should be used where possible as the primary means of limiting exposure.

Foot Protection

Personnel exposed to foot injuries as the result of impact from falling or rolling objects should be provided with protective footwear. The footwear should be slip resistant on dusty or wet surfaces and provide protection against penetration by sharp objects. Specialized footwear may be needed to protect against specific hazards such as electrical shock. Protective footwear must meet the specifications set forth in 29 CFR 1910.136.

Hand Protection

Protective gloves may be required to protect workers exposed to sharp or abrasive surfaces or irritating chemicals. The type of glove needed is dependent upon the specific hazard. Impervious gloves should be worn when handling irritating chemicals. Other specialized gloves may be required when hands are exposed to hazards such as electrical shock or thermal extremes.

Flotation Devices

U.S. Coast Guard approved personal flotation devices are needed whenever an employee is exposed to danger of falls into water, such as when working on barges and unprotected docks. At least one 30-inch U.S. Coast Guard approved life ring with not less than 90 feet of line attached is required on docks, in the vicinity of barges or vessels, and in other locations where employees work near water.

SAFE WORK PRACTICES

Dust Control

A comprehensive dust-control program is central to the control of fires and explosions in grain-handling and -processing facilities. Grain dust explosions can occur in enclosed areas whenever airborne dust concentrations are within certain limits and an ignition source is present. Good design and management can reduce the chance of a source of ignition being present. In practice, however, all potential sources of ignition cannot be completely eliminated. The exclusion of sources of ignition cannot be relied upon as the sole method of protection against explosion [8] [12] [49].

Dust control can be achieved by various methods. For this reason, a requirement to use a specific method of dust control is not appropriate. Rather, a comprehensive dust-control program should be developed by a qualified person on the basis of the specific conditions at the facility. An effective dust-control program must address both airborne and layered dust. Although they may be considered separately, they are complementary. Layered dust cannot be adequately controlled if airborne dust levels are excessive. Application of dust-control techniques may also be necessary for environmental or health purposes in open areas such as those used for barge or ship loading or unloading. However, the recommendations contained in this section do not specifically address these areas.

Good housekeeping is probably the single most important factor in reducing the risks associated with grain dust explosions. Even with effective airborne dust controls, some dust will escape and settle on floors, equipment, ledges, and other surfaces. Burning dust can cause a serious fire, or if disturbed or transported to a turbulent area, could initiate an explosion. In addition, dust accumulations can provide the fuel for extremely destructive secondary explosions. In many cases, a relatively minor primary explosion has been followed by a series of devastating secondary explosions, fueled by layered dust thrown into suspension by the shock of previous explosions [8] [12] [40] [50] [51]. Although the value of good housekeeping is recognized throughout the industry, there is no consensus of what constitutes a clean plant. The Canadian Grain Handling Association [50] and several other sources [40] [51] recommend that layered dust levels should not exceed 1/8 inch, with the provision that every effort be made to do better. Although the 1/8-inch limit, if maintained, would improve cleanliness levels in many facilities, it is considered excessive. Dust accumulations as little as 1/64 inch could support secondary explosions if dispersed into the air [12] [52]. Because of the importance attributed to cleanup is recommended that thorough cleanup of floors, stairs, ledges, girders, machinery, spouting, and other surfaces within grain-handling and -processing areas where dust may accumulate be accomplished at least daily. Emphasis should be placed on cleanup of layered dust on motors, generators, bearings, and other heat-generating equipment and warm surfaces. In facilities where significant amounts of dust accumulate during a workday, daily cleanup may not be adequate, and additional dust cleanup should be provided, concurrent with operations [40]. When possible, dust should be cleaned up whenever it leaves visible tracks. The housekeeping program must address hidden, as well as visible dust. Layered dust within enclosures, and in other areas which are not easily accessible should be cleaned at regular intervals determined by a qualified person. Daily housekeeping should be supplemented by periodic facility shutdown and thorough cleanup, including washing down where possible. These thorough cleanups should be accomplished at least yearly.

The method of dust cleanup should minimize generation of airborne dust. The most effective way to accomplish this is to use a control vaccum system. Portable vacuum systems can be used, but they are usually less efficient and can be difficult to maneuver around equipment. Vacuums must be approved for use in Class II, Group G, locations. Brooms are frequently used for cleaning layered dust. Brooms should be soft, and generation of excessive airborne dust should be avoided. Compressed air is used in some facilities for "blowing down" surfaces and equipment which are not otherwise easily accessible. Since blowing down generates airborne dust, this must be done only after shutting down and locking out equipment in the area and eliminating other possible ignition sources. Sweeping dust from tops of equipment or ledges requires similar precautions if resulting airborne dust levels are within or near explosive limits.

Housekeeping considerations, such as minimizing horizontal ledges and blind or inaccessible areas, should be included in the facility design. Techniques such as the addition of sloped flashings to ledges can be used in existing facilities.

Airborne dust levels can be controlled by various techniques. Pneumatic dust-collection systems, when properly designed and operated, effectively control dust levels at conveyor transfer points, distributors, cleaners, and other areas of turbulence. Pneumatic systems use bag filters and cyclone separators, although cyclones are not being used in most new applications because they discharge some of the finer dust into the atmosphere. Cyclones are sometimes used in conjunction with bag filters to reduce the amount of dust collected in the filters. Although this can be effective, the setup is more complicated and less energy efficient. Removal of the larger particles in the cyclone may also contribute to clogging of the bag filters. Bag collectors and dust storage units should be vented or located outside the facility to reduce the explosion hazard.

Guidelines for the safe design and operation of dust-collection systems are contained in Section 8.3 of NFPA 61B-1980 for grain elevators and Section 603 of NFPA 61C-1973 for feed mills. Inspection, servicing, and maintenance of dust-control equipment should be accomplished on a regular basis. Handling and processing equipment should not be operated unless the associated dust-collection systems are also operating properly. Provisions for monitoring pressure in dust collectors are recommended to aid in verification of proper system operation. Pressure taps on branch dusts can be used to verify proper air velocity within the ducts.

Use of enclosed equipment, such as auger and drag conveyors, is effective in reducing airborne dust levels. Enclosed belt conveyors are also used in some facilities. However, enclosed equipment can pose a substantial explosion hazard if internal suspended dust levels exceed the lower explosive limit or if excessive dust deposits accumulate within the enclosure.

Ducts, spouts, and equipment casings should be dust tight. Access and inspection doors on bins, conveyors, bucket elevators, mixers, and other dust-producing equipment should be designed to be dust tight and should be kept closed when not in use. Other means of reducing airborne dust levels include speed reduction and deeper troughs on belt conveyors, speed reduction and larger capacity buckets on bucket elevators, use of choke feeding at discharge points, pressurization systems, and venting systems on scales, garners, and bins.

The effectiveness of the method used for airborne dust control can be measured in two ways. First, dust levels at grain transfer points and within handling and processing equipment should be maintained below the lower explosive limit. Although this level will not always be attainable, it should be the goal. Second, airborne dust control must be such that, in conjunction with housekeeping activities, layered dust levels do not become excessive. (In addition, when workers are present, exposure to airborne dust levels must be limited in accordance with the requirements contained in 29 CFR 1910.1000.)

The hazards associated with returning collected dust to the grain are widely debated. Some individuals and organizations argue that limiting reintroduction of dust will not eliminate the problem since not all of the dust is removed from the grain, and repeated handling generates additional dust [53] [54]. Other organizations recommend complete removal of all collected dust from the facility, a practice followed in grain elevators in Canada and Australia. The U.S. Department of Agriculture believes that this single practice could significantly reduce the magnitude of the current explosion problem. Dust collected in bag type filters usually contains a high percentage of very fine particles at reduced moisture content, which are easier to ignite and potentially more destructive. Since removal of this fine, artificially dried dust should alleviate the problems [1] [53] [41], reintroduction of dust in grain elevators where it may be rehandled in the facility is not recommended. Dust should never be reintroduced in areas of high turbulence, such as the boot pits of bucket elevators, where dust may be thrown into suspension. In feed mills where amounts of collected dust are usually much smaller and the dust is subsequently processed along with the grain, reintroduction of dust is considered acceptable.

Hot Work

Facility modifications and equipment repair frequently require welding and cutting in grain elevators and feed mills. These operations are potentially the most hazardous performed. Hot work has accounted for more fires and explosions in grain-handling facilities than any other known cause [1]. The extremely high temperatures and sparks generated during welding and cutting operations dictate the need for strict control. Use of a permit system is an effective means of providing control [39] [53] [55] [56] [57] [58]. Permits are needed for all hot work performed outside of designated maintenance areas to ensure necessary precautions have been taken. Hot work permits should be used for welding, cutting, brazing, soldering, grinding, using explosive actuated tools, and any other operations which could produce high amounts of heat or energy.

The permit provides written authorization of a supervisor or other qualified person for performing the work. It is signed only after the work site has been inspected and it has been verified that the necessary precautions have been taken. The permit is also signed by the persons performing the work and support personnel to indicate that they are aware of the potential hazards and safe work practices that must be followed. It is particularly important that contractors follow the permit requirements since they may not be familiar with the fire and explosion hazard in grain-handling and -processing facilities [8] [40] [53]. Prior to issuing a permit it should be determined by the supervisor or qualified person that the work cannot reasonably be moved to a designated maintenance area or a nonhazardous area outside the facility. Alternate methods such as the use of hand saws or bolt fasteners may also eliminate the need for hot work. Although these alternate techniques are not always practical, they should be evaluated prior to issuing the permit because of the potential safety benefits [40] [53] [55].

The expiration time for permits is not normally addressed in the literature. Some sources imply that a permit should be issued for each specific job. Others indicate that the permit should be renewed daily or at the beginning of each shift. Since a major intent of the permit is to verify that the operator is familiar with the hazards and the safety precautions, it is recommended that the permit be renewed at the beginning of each shift.

Personnel performing welding, cutting, or other hot work must be properly instructed and qualified to operate the equipment and be made aware of the hazards and associated safe work practices. Carelessness or lack of knowledge of the danger of dust explosions by the person performing the work has resulted in many explosions [59] [58]. Workers should receive training in proper use, maintenance, and inspection of equipment, ventilation requirements, and requirements for protective equipment. Where work is accomplished in hazardous areas such as in confined spaces, in areas containing combustible materials, or on elevated work platforms, additional training is needed to cover the specific safe work practices. Outside contractors must be instructed on the specific fire and explosion hazards that they may encounter in grain-handling facilities.

Special precautions are necessary when there is an exposure to Class II, Group G areas [2] [40] [53] [55] [57]. Complete shutdown of the facility prior to conducting any hot work in these areas is recommended. Where the entire facility cannot reasonably be shut down, dust-producing operations must be terminated within the work area and in adjacent areas where airborne dust could reach the work area. Necessary precautions, such as lockout techniques, should be taken to prevent inadvertent startup of equipment while it is being worked on or where airborne dust could be produced. Equipment should remain off until the hot work has been completed and cooled, and the area has been inspected for residual heat and smoldering fires.

Combustible materials within 35 feet of the work area should be removed. When materials cannot reasonably be removed, they must be protected by fire-resistant shields or covers. Wetting of combustible materials in the area is recommended as an additional precaution. Care must be taken to protect combustibles such as plastic spout liners and leg belts which pose special problems since they may be concealed from view.

Floors, ledges, and other surfaces within 35 feet of the hot work area must be thoroughly cleaned of dust and debris. Cleanup must include removal of dust in overhead areas that could be disturbed during the hot work operation. Where hot work is performed on or near equipment or ducts, the interiors must be thoroughly cleaned or protected from high temperatures. Where hot work is performed near walls or floors, adjacent areas must also be inspected and cleaned. Wall, floor and other openings where sparks or slag may reach must be sealed.

A standby person with fire-extinguishing equipment is needed to monitor the area while the hot work is being performed and for at least 1/2 hour after cessation of the hot work. Additional checks up to 2 hours or more are recommended. A thorough inspection of the work area and adjacent areas should be made for residual heat and smoldering fires before the standby person leaves. If a security guard is employed during nonoperating hours, he should be advised that hot work has taken place.

Welding, cutting and brazing equipment should be used in accordance with manufacturer's instructions. Personnel must be provided with proper eye protection and other necessary protective equipment. Mechanical ventilation should be provided as necessary. Operations and equipment must comply with the requirements contained in 29 CFR 1910.252.

Smoking, Open Flames and Hot Surfaces

Flames are potent sources of ignition for dust suspensions [60]. Because of the effectiveness of flames for igniting dust suspensions and the ease with which smoldering materials may be converted into flames, it is universally agreed that smoking and open flames must not be allowed in grain-handling, -storage and -processing areas [10] [24] [61] [53] [62] [63]. To minimize the chance of matches, cigarettes or other smoking materials being thrown into those areas, smoking and open flames must also be precluded in immediately adjacent areas.

Smoking may be permitted in areas specifically designated by management, such as pressurized control rooms, which are free of dust and other flammables and combustibles. Although some sources recommend that smoking be completely banned within facilities, there is no evidence to indicate that smoking within dust-free areas designated by management presents a significant hazard. Smoking and nonsmoking areas must be clearly marked and smoking rules must be strictly enforced.

Heating equipment must be suitable for the location in which it is used. Other exposed surface temperatures of heated devices, including steam pipes, hot water pipes, and hot air ducts, should be kept below 71°C (160°F) [64].

Inspection and Maintenance

Workers in grain elevators and feed mills can receive injuries as a direct result of equipment failures. In addition, a significant number of dust fires and explosions in these facilities have been attributed to machinery malfunctions. A program of periodic surveillance and preventive maintenance is a necessary and effective means of keeping equipment and machinery functioning properly and reducing the number of unplanned failures [10, 61, 53, 65, 66, 52, 67].

A program of regular surveillance and preventive maintenance should be implemented at all plants to facilitate operations. As a minimum, a program is needed for safety equipment, emergency equipment and operational equipment where a malfunction could result in a direct injury or cause a fire, explosion or other hazardous condition.

Inspection and maintenance requirements vary widely between facilities. Specific requirements should be established by a qualified person who is familiar with the facility and the equipment and its use. Requirements should follow manufacturer's recommendations, although some modifications may be required depending upon the specific use environment of the equipment. All safety and emergency equipment such as fire extinguishers, hoses, standpipes, lifelines, and emergency ladders should be inspected periodically. Other equipment and components requiring periodic inspection and maintenance in grain elevators and feed mills include bucket elevators, grain dryers, grinders, dust-collection systems, conveyors, cleaners and scalpers, bearings, drive belts, manlifts and passenger elevators, powered vehicles, and electrical equipment. Inspection and maintenance should be performed at regularly scheduled intervals. Where normal nonoperating periods do not accommodate maintenance planning, scheduled periods of downtime should be allocated [39, 41, 66, 67, 42].

Recordkeeping requirements also vary between facilities. Written records, however, are normally needed to ensure that necessary inspection and maintenance have been planned and are accomplished as scheduled. A list of equipment, including inspection and maintenance requirements, is needed to properly plan and implement a preventive maintenance program. Records maintained on the equipment should include the date, maintenance performed and/or the results of the inspection. Records of equipment failures should also be maintained in order to identify possible deficiencies in inspection and maintenance planning. Many programs include work order systems to provide a record of maintenance performed. Personnel should be instructed to report any abnormal equipment operations whenever detected; however, this technique should be used to supplement a maintenance program, not replace it [38, 61, 53, 65, 66, 67, 42]. Inspection and maintenance shall be performed only by trained and authorized personnel.

Emergency Planning

The value of emergency planning as a means of conserving life and property is generally recognized throughout industry [24] [68] [53] [69]. Timely and efficient action can mean the difference between a minor incident and a major catastrophe. Coordination with local emergency organizations is strongly recommended. Fire departments and rescue organizations in particular should be requested to tour facilities to become familiar with the particular problems that may be encountered.

Preplanning is needed to determine specific duties, responsibilities and actions that should be taken to enhance worker safety during emergencies. Written procedures should be developed in accordance with 29 CFR 1910.38 for fires, explosions, medical emergencies and other emergencies or natural disasters that could reasonably occur. Other areas to be addressed and the specific content of the procedures should be determined by a qualified person on the basis of the facility size, conditions at the facility, and geographical location. Procedures may include provisions for limiting facility damage if this can be accomplished without additional risk; however, safety of personnel must take precedence. The procedures should include but not be limited to definition of the following:

1. Methods and responsibilities for reporting emergency conditions. Provisions for prompt reporting of emergencies should always be a primary consideration. Manual pull box devices can be provided or emergencies can be reported over intercoms or public address systems. Telephones or radios may also be used to report emergencies to a central, continously manned location.

2. Evacuation procedures and location of evacuation routes. Routes should be posted in conspicuous and convenient locations.

3. Methods and responsibilities for contacting emergency agencies. Emergency phone numbers should be posted in suitable locations.

4. Methods and responsibilities for firefighting, rescue, providing medical aid and other special assignments. Fire brigades, when established by an employer, must comply with the requirements contained in 29 CFR 1910.156. Specific training in fighting grain fires should be included.

5. Location of firefighting, medical, and other emergency equipment.

6. Methods and responsibilities for accounting for workers, visitors, or contractor personnel who may be in the facility.

A means of informing workers of an emergency should be an integral part of the emergency plan [24] [68] [61]. An alarm system must be provided that is (1) capable of being activated in a timely manner, (2) detectable in all areas where personnel are located, and (3) distinct from other signals and alarms. Requirements for alarm systems vary widely. In small facilities, voice communications are acceptable if they can be heard by all employees. In medium-size facilities, a single bell or siren is usually adequate. In larger facilities, several devices may be needed. Special codes to designate the type and location of the emergency are successfully used in some facilities, although simple systems are preferred to avoid confusion. Alarm systems must be maintained and tested in accordance with 29 CFR 1910.165.

For the emergency plan to be effective it must be thoroughly understood by all affected personnel [24] [68] [61]. Training and instruction should be accomplished when a worker is initially hired and subsequently whenever the worker's actions or responsibilities change or procedures are modified. Retraining and/or drills should be conducted periodically to ensure that workers remain familiar with the procedures. Additional training is needed at least annually where personnel are assigned special duties such as firefighting and rescue or may be required to use emergency equipment. Training should be commensurate with the functions to be performed. Fire drills are recommended several times a year, depending on the size of the facility and employee turnover.

Confined Spaces

Entry into confined spaces such as grain bins, hoppers, and other storage tanks is frequently required for cleaning, inspection or maintenance. The inherent dangers associated with a confined space clearly indicate the need for strict control measures. The literature [31, 34, 70, 71, 68, 72, 73] has shown that the development of sound procedures, including the use of a permit system, is a very effective method of attaining control.

Procedures should be developed and implemented whenever workers are required to enter bins or other confined spaces. The procedures should include preentry preparation, entry, exit, work performed in the confined space, and emergency operations. Procedures for confined space entry may vary widely depending on the type and location of the confined space and the work to be performed. Procedures should be specifically designed for each type of entry.

The permit provides written authorization for entering and working in confined spaces, and clearly indicates the precautions which must be taken to ensure the safety of the worker. The permit should include the location and description of the work to be performed, hazards that may be encountered, results of atmospheric testing, precautionary measures, and safety and protective equipment required. The permit should be signed by a supervisor or other qualified person, the persons performing the work and support personnel. Prior to signing the permit, it must be determined that the entry requirements have been met and necessary actions have been accomplished. Although permits may vary throughout the industry, they serve the same purpose; i.e., to ensure the safety of the worker.

One primary hazard associated with confined space entry is the possibility of atmospheric contaminants. Toxic contaminants may exist where pesticides or fumigants have been used. Composition changes in stored products or rusting of metal walls of the container may, over a period of time, reduce the oxygen content below safe levels. The need for atmospheric evaluation prior to confined space entry is reflected throughout the literature [31, 34, 70, 71, 68, 72, 73].

Confined spaces should be thoroughly ventilated, where possible, prior to entry. Openings should remain open while the confined space is occupied to provide continuous ventilation. Forced air ventilation, where available, should continue when workers are in confined spaces, unless prevented by conditions such as excessive dust levels. Atmospheric testing is needed whenever natural or forced ventilation is not sufficient to ensure oxygen levels are above 19.5%. Testing is also needed whenever the confined space may contain fumigant vapors or deteriorated products. If reduced oxygen levels or other harmful substances exist, additional ventilation may be provided to obtain acceptable levels. If safe levels cannot be obtained, entry must not be made unless appropriate respiratory protection equipment is worn.

Another major hazard associated with storage vessels is entrapment and suffocation in flowing grain. Release of bridged materials or materials adhering to sides of containers has resulted in many fatalities. Some grains act like quicksand and a person can sink into them. The danger is much greater if the material is being drawn from the bottom of the bin. Confined spaces should be inspected for suspended materials prior to entry. Personnel should never work at levels below suspended material or while standing on materials which could break loose and bury them. Materials must not be fed into or drawn from bins which are occupied. Fill and discharge equipment, as well as equipment inside the confined space, must be isolated or locked out whenever inadvertent operation could create a hazard. Notification of personnel in control rooms and on all work levels that interface with the confined space should be included in the procedures [34, 70, 68, 74, 75].

Many fatalities in confined spaces can be directly attributed to a lack of communications with outside workers. Provisions for a standby person continuously monitoring workers in the confined space, and the use of proper protective equipment, including lifelines, provide further protection for the worker [33, 34, 70, 71, 68, 72, 73, 74]. The standby person and necessary rescue equipment should always be stationed outside the confined space when it is occupied. The standby person should have continuous communication capability with the workers in the confined space and be able to summon additional assistance if necessary. The standby person should not enter the confined space until adequate assistance is present and appropriate precautions are taken to prevent the rescuers from becoming disabled.

Necessary protective equipment, as determined by the qualified person, should be provided for workers in the confined space. Safety belts or harnesses with lanyards are needed in all applications where confined spaces are entered from above or where harmful atmospheres may exist. Safety harnesses are preferred. In many cases a safety belt would not properly support an individual in an upright position to permit removal of the individual from a typical silo or bin opening or other narrow opening. Respiratory equipment is needed where harmful atmospheres may exist. Air-supplied respiratory equipment is required if the oxygen level is below 19.5%. Other protective equipment and clothing may also be needed. Hard hats are required whenever there is a possibility of items falling into an occupied confined space.

Personnel who are required to work in a confined space or in support of those working in a confined space should be trained to recognize the hazards and know the safe work practices associated with entering, working in, and exiting that area. Personnel should receive training in normal and emergency entry and exit procedures; proper use of respirators, lifelines and harnesses, and other required protective equipment; isolation and lockout procedures; atmospheric testing requirements and procedures; purging and ventilating procedures; communications and emergency signals; and other safe work practices associated with the specific location, type and function of the confined space and the operation to be performed. Personnel who work in the vicinity of confined spaces should be aware of the associated hazards. Equipment required to support operations in confined spaces, including boatswain's chairs, winches, protective equipment, and rescue equipment should be inspected prior to use to ensure the equipment is in good condition. All equipment must be approved for the atmosphere in which it is to be used.

Isolation and Lockouts

Many needless accidents occur when energy is inadvertently applied to equipment that is being worked on. Energy isolation is needed during maintenance and repair activities to prevent worker injuries from unwanted startup of machinery, application of electrical energy to electrical lines or components, or other inadvertent application or release of energy. Accidents occurring under these circumstances frequently result in serious injury or death. Use of isolation and lockout procedures is a proven safety technique which should be used in all facilities to prevent injuries during maintenance, repair, servicing, inspection, cleaning, troubleshooting and other similar activities [30, 47, 44, 38, 68, 76, 77]. Documented procedures provide assurance that the isolation technique is clearly defined and uniformly applied. Verification by a supervisor or other qualified person provides additional assurance that the procedures are correctly applied and the isolation technique has been effective in isolating and/or dissipating hazardous energy.

For the isolation procedures to be effective, energy must be isolated or blocked at a point or points of control that cannot be bypassed. The point of control must be secured by a device or technique which prevents unauthorized persons from reenergizing the equipment or machinery. Stored energy that constitutes a personnel hazard must be dissipated or blocked. Key-type padlocks are normally used in grain elevators and feed mills and are recommended for securing energy control points. Other techniques such as use of tags alone are successfully used in some industries; however, these techniques rely heavily on highly trained and experienced personnel, controlled access, and other procedural techniques not easily achievable in grain-handling and -processing facilities.

Key-type padlocks, when properly used, provide positive protection and can be applied in most cases where isolation is required. Padlocks should be fastened and removed only by the person performing the maintenance task. Keys should be issued only to the employee performing the task, and they should be kept on his person at all times. When two or more employees are engaged in an operation that requires a lockout, each individual should have his own lock which has been installed in such a manner that the isolation device cannot be removed until each employee has removed his own lock.

Electrical isolation can be achieved by locking circuit breakers and/or main disconnects in the "OFF" position. Where more than one switch or disconnect supplies power to equipment, multiple padlocks are required. Mechanical isolation of moving parts can be achieved by disconnecting linkages, removing drive belts, or using chains. It may be necessary to block or chain moving mechanical parts to prevent rotation, in addition to electrically isolating the equipment. Potential energy sources such as compressed springs and pneumatic and hydraulic pressure must be recognized and controlled by isolating, blocking, or otherwise neutralizing the energy. After the isolation procedure has been completed, an attempt must be made to operate the machinery or otherwise verify that the lockout device has been effectively applied. Any controls or switches operated during this verification should be returned to the "OFF" position.

Inspection, servicing, or troubleshooting should not be performed on operating equipment or machinery unless it can be determined that hazards are controlled with the energy present. Hazards must be evaluated by a qualified person and procedures must be developed which adequately control those hazards. Protective equipment and other special equipment needed should be included as part of this procedure.

All workers should receive general instruction on the equipment, operations, and types of energy isolation required at the facility. Specific lockout procedures, devices and techniques should be addressed as applicable. Training should be sufficient to enable an employee to recognize the sources of energy which must be isolated, apply the isolation techniques properly, and recognize responsibilities with respect to equipment which has been isolated by other employees. Retraining should be accomplished as necessary to maintain proficiency and whenever procedures are modified.

Machine Guards

Machinery with rapidly moving external components is used in most grain elevators and feed mills. Unguarded nip points, shafts, sprockets, wheel drive mechanisms and other moving parts are common hazards which have been responsible for many serious injuries. Many of the injuries would not have occurred if adequate guards had been provided. Requirements for guards vary widely and must be established by a qualified person on the basis of the specific configuration and location of the equipment in the facility. The exact configuration of the guard or barrier is not critical, as long as it covers or restricts access to moving parts in such a manner that they cannot be contacted [26, 47, 38, 39, 68, 76, 41].

Safeguards must be provided wherever there is a chance of personnel injury from contact with power transmission drives such as chain, belt, and rope drives; rotating shafts and sprockets such as those on bucket elevators, grinders, mixers, and trippers; nip points such as those occurring at the main pulleys on belt conveyors; and other rotating or translating machinery parts. Fixed or portable auger conveyors must never be operated without guards. Point of operation guarding must be provided for equipment such as sewing machines. Consideration should also be given to guarding heavily loaded lines and ropes such as those used in rail car pullers, where breakage could result in serious injury.

Complete enclosure of moving components is the preferred method of guarding although guarding may be accomplished by the use of fences or barricades or by location of equipment in areas inaccessible to employees. When guarding by barricades or location is used, necessary precautions should be taken to prevent employees from entering areas where equipment is located. Guards designed and installed by equipment manufacturers are usually the most effective and should be specified where possible. When guards are built in-house, a major consideration should be ease of installation and removal. Guards should be removed only by trained and authorized personnel, after necessary precautions such as equipment shutdown and lockout have been taken to minimize the chance of injury. Guards must comply with the requirements contained in 29 CFR 1910 Subpart O.

Labeling and Posting

Signs and labels are necessary to inform both workers and visitors of hazardous conditions in the workplace and precautions to be taken to prevent accidents. Although the use of accident prevention signs is infrequently mentioned in the literature, it is among the most widely used safety measures throughout industry [38]. Signs or labels should be provided whenever failure to recognize the condition could result in an unsafe action.

To be effective, signs must be concise, yet easily understood, and readily visible to persons entering or working in the area where the hazard exists. Persons unable to read or understand signs or labels should be informed of the hazardous condition reflected and associated instructions. When a significant number of workers read languages other than English, consideration should be given to printing signs both in English and the predominant language of the non-English-reading workers. Established symbols should be used whenever possible.

Signs needed in grain elevators and feed mills are varied, and requirements must be established by a qualified person. Signs are normally used to designate: (1) Areas where specific practices such as smoking and hot work are prohibited; (2) areas where protective equipment is needed; (3) areas where combustible, flammable, and toxic materials are used or stored; (4) areas to which access is restricted; (5) special precautions or instructions needed for safe operation of vehicles, machinery, or equipment such as manlifts; (6) emergency evacuation routes and location of building exits (exits used only for emergencies should be designated); and (7) location of safety-related items such as first aid and fire-fighting equipment.

Facilities should be inspected periodically to determine if signs or labels have been removed or become illegible, or additional signs are necessary because of facility, equipment, or operational changes. Specifications for accident prevention signs and tags are contained in 29 CFR 1910.145.

Other Safe Work Practices

Lightning Protection - -

Lightning has been reported as the probable cause for a significant number of dust explosions in grain-handling and -processing facilities [1]. Facilities in areas where lightning may occur should be provided with a lightning protection system. Guidelines for the installation of lightning protection systems are contained in NFPA 78, "Lightning Protection Code."

Foreign Material - -

Foreign objects such as tramp metal, stones and wood are frequently found in grain and feed stock. Introduction of these materials into the facility can produce sparks within the equipment. In addition, larger materials may jam between buckets and the casing in bucket elevators, causing sparks, frictional heating, or equipment damage that could contribute to an explosion. Allen and Calcote [78] found that a shower of metal sparks of sufficient energy, such as might occur in continuous, high speed grinding operations, could ignite an explosive dust cloud. It was not determined, however, whether sporadic or occasional sparking incidents would cause ignition. Although the degree of risk associated with sparks arising from impact is not fully defined, most sources recommend that precautionary measures be taken to remove foreign materials [10, 61, 60, 53, 79, 51, 69].

Several methods are commonly used to minimize the entry of foreign material into handling and processing equipment. In grain elevators, the main consideration is minimizing the amount of foreign material entering the grain-handling equipment, primarily bucket elevators, where most primary explosions in these facilities occur. Grates or screens are frequently used in receiving areas to remove materials that may be contained in the grain or feed. Although grating does not remove all foreign material, it is effective in removing larger materials regardless of composition. The spacing of the grating should be as small as possible, consistent with the commodity handled. Spacing of 1 1/2 inches is often recommended and should be used where possible [79, 80]. Some facilities, however, require a spacing of 2 1/2 inches or more to accommodate handling rate and some variation may be required [81].

Magnets are used in many receiving areas to remove ferrous materials that may pass through the screens or grates. Although magnets do not always extract all ferrous materials entrained in the grain stream, medium- and large-sized materials can be removed with high efficiency when magnets are properly selected and installed. Although the best protection is achieved by the use of both gratings and magnets, magnets cannot be easily accommodated in many existing facilities and are not considered essential if other effective means of protecting against the entry of foreign material are used.

In feed mills or grain elevators where equipment for grinding, pulverizing, and similar operations is used, additional precautions are needed [10, 61, 60, 81, 62]. Statistics indicate that hammer mills, roller mills and other equipment where impact is part of the operation are second only to bucket elevators as the location of primary explosions [1]. Multiple magnets are used in some applications to remove ferrous materials, with feeding spouts arranged so that the materials pass over the magnets at low speeds. Pneumatic separators, gravity separators and scalpers are also used upstream of grinders to effectively remove foreign materials. When screening type devices are used, they should be designed to exclude from the processing machinery all foreign material larger than the grain being processed. Equipment used to collect or separate foreign materials shall be kept in good repair and cleaned regularly.

Walking/Working Areas - -

Slips and falls traditionally have accounted for a high percentage of injuries in grain elevators and feed mills. A significant number of the work injuries can be attributed to slippery or uneven footing. Good housekeeping and care of walking and working surfaces are necessary to reduce the number of injuries [26, 32, 82, 83]. Work areas should be kept free of debris which could cause slips, trips, falls, fires or other hazards. Debris such as lumber with protruding nails should not be allowed to accumulate in receiving areas. Grain, grain dust, moisture, and ice can also cause serious accidents unless cleaned up or cleared as soon as possible.

Falls from heights usually result in more serious injuries than those that occur on the same level. These can normally be prevented by covering or guarding openings in floors, walls, and work platforms which are accessible to workers [47, 68]. Bins and other containers with floor openings should be kept covered when not being used. Where operational considerations such as the use of automated trippers dictate that bins be open continuously, other forms of protection and/or special procedures should be established for use by maintenance or housekeeping personnel required to work in those areas. Grating inserts are successfully used in many facilities to prevent falls into bins and distributor floor openings.

Floors, stairs, doors, ramps, and walkways should be kept in good repair and kept clear to provide unimpeded egress. At least two means of emergency escape should be provided from all general work areas normally occupied by personnel. Escape routes should be separated to the extent that a single event will not reasonably prevent access to all means of escape. Exits should be clearly marked. Specific recommendations for egress in grain elevators are contained in NFPA 101, "Code for Safety to Life from Fire in Buildings and Structures."

Static Electricity - -

The magnitude of the hazard associated with static electricity in grain elevators and feed mills is not clearly defined. Although it is known that electrostatic charges are generated in the processing, transportation and general handling of dusts, static electricity has never been proven to have caused a grain elevator explosion. One suspected case in a grain mill involved static discharges in a pneumatic conveying system. The statistical data are inconclusive, however, since the cause in over 40 percent of the reported explosions is unknown [1], and the presence of static electricity would not be traceable following an explosion.

The extent of problems associated with electrostatic charging has been the subject of numerous investigations; however, valid predictions for practical applications have not been made. Dahn [64] found that although grain can accumulate moderate amounts of electrostatic charges when moving across spouts and chutes, such charges dissipate quickly when grain comes into contact with a device or structure that is well grounded. He also notes that if equipment is poorly grounded or isolated from ground, a potentially hazardous situation might quickly develop. The approach suggested by most sources is to assume that static charges will be generated and take precautions to minimize the hazard [10, 68, 61, 60, 53, 51, 62]. Palmer [60] indicates that dusts with a minimum ignition energy of less than 25 millijoules should be regarded as prone to ignition by static electricity. This energy is near the lower end of the ignition energy range usually attributed to grain dusts, suggesting that static electricity is a possible, but not a major source of ignition.

The primary areas of concern in grain-handling and -processing facilities are pneumatic conveyors and bucket elevators. Necessary precautions for these conveying systems include electrical bonding and grounding of frames and casings [10, 68, 61, 53, 51, 62]. Similar precautions are recommended on high speed continuous belt conveyors, although the problem is less significant if airborne dust levels are maintained below the lower explosive limit. Slow moving continuous belt systems such as those used for personnel transport (manlifts) or transport of bagged materials are not normally considered a problem. Use of electrically conductive belting is recommended by many sources; however, there is no agreement on the level of conductivity. Studies have indicated that use of a conductive belt, in conjunction with a well grounded frame, safely dissipates static charges. Belts with the highest conductivity, however, can produce the highest spark discharge energy level in an ungrounded system [84]. For this reason, no specific recommendations are made relative to the use of electrically conductive conveyor belt material. When conductive belts are used, it is essential that a conductive path be provided from the belt to a well grounded frame. Usually, metal pulleys will pick up a charge from the belt and communicate that charge to the supporting shaft and through bearings to the equipment frame without special provisions. However, conditions such as the use of nonconductive lagging or bearing lubricants, or isolated frame sections may prevent components from being electrically common. Static collectors are also used in some facilities to remove electrostatic charges from conveyor systems. Guidelines for electrically bonding, grounding and using static collectors are contained in NFPA 77, "Static Electricity."

Hazardous Material Storage - -

Toxic materials, explosives, flammable and combustible fluids and gases and other hazardous materials must be stored in suitable containers and contents clearly identified. Where possible, hazardous materials should be stored outside the facility in detached buildings or approved tanks. Supplies of materials needed for daily operations or other hazardous materials stored within the facility must be located in controlled rooms or areas consistent with the hazards associated with the specific material.

EQUIPMENT AND TOOLS

Bucket Elevators

Statistics indicate that the bucket elevators are by far the most hazardous equipment in grain-handling and -processing facilities [1]. More primary explosions have occurred in bucket elevators than any other known location. Investigations have indicated that elevator legs routinely contain amounts of dust exceeding the lower explosive limit [85]. Intense heat can be generated on the drive pulley in the event of belt stalling. Belts may burn through and drop into the leg, resulting in ignition of dust from burning fragments or sparks generated by metal components striking the casing [10, 53, 85, 86].

Bucket elevators should be located outside the facility where possible. When bucket elevators are located inside buildings, belt speed monitoring devices are needed to detect belt slowdown and allow corrective action to be taken before frictional heating ignites the belt or grain [68, 53, 81, 85, 86, 87]. When the bucket elevator speed drops below a predetermined value, the slowdown detection device should activate an alarm, initiate stoppage of the supply of material to the bucket elevator, and cut off power to the elevator drive motor. The best method of detecting slippage is to monitor the drive and tail pulleys for variations in the speed ratio. Since operating speed is nearly constant in most cases, simpler devices which monitor belt or tail pulley speed are usually adequate. Shutdown can be accomplished automatically, by sending a signal to a device which turns off power to the drive motors, or manually. To prevent unnecessary shutdowns, a short time delay may be incorporated into the system to allow the bucket elevator to attempt to clear after the supply of material to the elevator has been stopped. If shutdown is to be accomplished manually, procedural controls must be established to assure that corrective action is taken in a timely manner. Necessary procedural controls include having a worker continuously stationed in the vicinity of the elevator controls and in a location where the alarm can be detected at all times. The worker must be instructed to shut down the bucket elevator immediately or after a short time delay to give the equipment a chance to clear.

The exact setting of the slowdown detection device is dependent on the specific application. Typically, speed reductions from 5% to 20% of normal operating speed indicate a significant problem [85, 88, 50]. For most applications, a setting of 5% to 10% of normal operating speed is adequate to detect malfunctions without causing accidental tripping during normal operations. The slowdown detection device should be fail-safe (i.e., sound an alarm or initiate equipment shutdown if the device malfunctions) or be checked regularly to verify proper operation.

Ammeters and dual level monitoring devices may also be used to give an indication of slowdown before the cutoff speed is reached. Use of ammeters alone, however, does not provide a positive method of detecting belt slippage because the meters are not always monitored and slippage is not always a direct function of motor current. Reliance upon thermal cutoffs on drive motors to shut down elevators in the event of belt slowdown is not considered acceptable because of possible long delay times before thermal limits are exceeded or motors that may continue to drive the head pulley without overheating [85].

If a choked leg does occur, the problem must be identified and corrected prior to restarting the motor. Written procedures should be developed by a qualified person and implemented for safe shutdown, clearing, and startup. Jogging drive motors may result in belt slippage and should never be attempted [68, 86]. Thermal protection on drive motors should not be bypassed. In addition to checking and clearing the boot pit, the belt, buckets, and head need to be inspected to see if they are clear. Equipment must be checked for damage after it is cleared and repaired if necessary. Belt movement should be monitored during startup. Power to the drive motor must be cut off if the belt does not move or if slippage occurs. After restarting, equipment should be monitored for unusual noises, excessive motor loading, or other abnormal operating conditions.

Other potential ignition sources associated with bucket elevators, including overheated bearings, pulleys or belts rubbing on frame or casing, and metallic buckets striking the frame or casing, dictate the need for regular inspection and maintenance [53, 81, 85, 86]. Bearings should be located on the outside of the casing whenever possible. Periodic inspection is needed for proper alignment, tension, and tracking of belts; loose or damaged buckets; adequate clearances between belts/buckets and casings; excessive wear on belt or lagging, defective belt splices, worn or defective bearings; and loose or slipping drive mechanisms. Inspections should be conducted at least once during each shift in which the equipment is operated. Adequate inspection and cleanout doors are needed to support this operation. Only trained and authorized personnel should service or operate equipment. In addition to scheduled inspection, workers should be instructed to report any unusual equipment noise or defective equipment whenever it is observed. Instrumentation such as plug or level sensors, bearing temperature sensors, belt alignment sensors and vibration sensors are also used in many applications to assist in early detection of equipment malfunctions.

Bucket elevators located inside facilities should be provided with explosion venting to the outside atmosphere. Although venting does not prevent explosions, it does reduce the pressure buildup and helps to limit the amount of destruction [10]. Research conducted by Gillis [89] indicates that explosion venting can be used effectively to protect bucket elevators from explosions. Explosion venting on new bucket elevators should be accommodated in the initial design. Venting of existing bucket elevators is not always feasible; however, it can be provided in many applications. In the case of interior bucket elevators that extend through the headhouse roof, venting may be provided at the head of the elevator. Although not fully effective, this particular vent would provide relief for explosions occurring in the proximity of the elevator head. Guidelines for explosion venting techniques are included in NFPA 68, "Explosion Venting."

Grain Dryers

Dryers are used in many grain elevators to reduce moisture to levels low enough to preserve quality. A relatively small number of explosions have occurred in dryers; however, they are one of the most frequent causes of fires [1] [10]. Because of the heat generated by dryers and the high chance of fires, location of dryers is of primary importance. Dryers should be located or isolated to minimize ignition potential to handling and storage areas and adjacent structures. Locating dryers away from the storage unit is one method of minimizing the risk of serious fires and explosions in the storage areas [10].

Necessary precautions must be taken to minimize the chance of ignition of grain within the dryer and, if a fire occurs, to prevent burning materials from entering storage or processing areas. Instrumentation is needed to detect excessive air stream temperatures at the inlet and outlet of the drying chamber and excessive product temperatures at the product discharge. Detection of excessive temperatures should result in automatic shutdown of the dryer, stoppage of the product flow and activation of an alarm at a constantly attended location. Even when equipment is working normally, operation should be continuously monitored by personnel.

Grain dryers are normally provided with adequate safety devices by the manufacturer; however, exposure to weather, moist grain, and temperature extremes eventually causes malfunctions. Thorough cleaning, inspection, and testing on a regular basis are necessary to maintain proper operation.

Operation and maintenance should be conducted only by trained and authorized personnel. Personnel operating dryers must be thoroughly familiar with equipment controls, gauges and safety devices. Training should include detection of abnormal operating conditions, and safety and contingency procedures. Maintenance personnel should be instructed in inspection, cleaning, maintenance and repair procedures. Proper operating and maintenance techniques should be obtained from the equipment manufacturer or supplier.

Additional guidelines for the design and safe operation of grain dryers, including provisions for rapidly unloading the dryer contents, use of temperature limit controls and alarms, monitoring operation, instructing operators on safe operation of the dryer, and periodic inspection and maintenance are included in NFPA 61B, "Standard for the Prevention of Fires and Explosions in Grain Elevators and Facilities Handling Bulk Raw Agricultural Commodities."

Electrical Equipment

The need for controls on the use of electrical equipment in grain elevators and feed mills is reflected throughout the literature [10, 40, 61, 60, 53, 65, 79, 81]. In addition to the electrical shock hazard, sparks or heat produced during the normal working of switches, contact breakers, commutator motors and other electrical equipment can ignite dusts. Energy available in electrical equipment is usually greatly in excess of the amount of energy required to ignite common grain dusts [10, 40 60].

Safeguards from hazards associated with the use of electricity are included in 29 CFR 1910 Subpart S. Maintenance of equipment should be in accordance with manufacturers' recommendations. In areas designated as Class II, Divisions 1 and 2, which are hazardous because of the presence of combustible dust, special precautions are required. Additional requirements for hazardous locations are contained in 29 CFR 1910.307. In general, equipment, wiring methods, and installations of equipment in Class II, Divisions 1 and 2 locations in grain elevators and feed mills must be (1) approved as intrinsically safe for that area; (2) approved for that location and atmospheric Group G, or (3) of a type and design which the employer demonstrates will provide protection from the hazards arising from the presence of combustible grain dust. The National Electrical Code, NFPA No. 70, Articles 500 and 502, contain design, installation and maintenance guidelines for "dust-ignition-proof" equipment which is safe for use in Class II, Divisions 1 and 2 locations. Equipment must be enclosed to prevent entry of dust which could ignite or affect performance. In addition, sparks or heat generated inside the equipment cannot cause ignition of external layered or atmospheric dust. For equipment that is not subject to overloading, maximum surface temperature in this class is 165°C (329°F). For equipment such as motors or power transformers that may be overloaded, maximum surface temperature during normal operation is 120°C (248°F); maximum surface temperature during abnormal operation is 165°C. "Explosion-proof" equipment may not be acceptable for use in grain-handling and -processing areas and should not be used unless specifically approved for Class II locations. Equipment approved for Class II, Division 1 locations can be safely used in Class II, Division 2 locations.

When possible, electrical equipment should be placed in non-Class II locations such as building areas other than those used for grain storage and processing, separate buildings adjacent to the storage and processing areas or in enclosures supplied with positive pressure ventilation from a source of clean air. When pressurized enclosures are used to obtain classification as a nonhazardous location, positive means must be provided to detect malfunctions of the pressurization equipment. Guidelines for the design of pressurized enclosures are contained in NFPA 496, "Purged and Pressurized Enclosures for Electrical Equipment."

In addition to compliance with 29 CFR 1910 Subpart S, special precautions must be taken when using portable lighting inside equipment. When portable lighting must be lowered into bins, pits, bucket elevators or other equipment or enclosures containing dust, care must be taken to prevent damage to the light or cord. Lighting shall not be supported by the electrical cord unless designed for that purpose. The light must not be dropped or struck on walls or casings. Several explosions have occurred because of damage to portable lights lowered into equipment while it was operating [1, 59]. Equipment such as bucket elevators must not be operated while lights are inside to prevent entanglement and shorting of the light or cord. Lights should not be lowered into bins when materials are being withdrawn to prevent the light from being drawn into the material and damaged. If portable lights do become entangled or caught, they should be disconnected from the power source before any force is applied which could damage the light or cord.

Manlifts

Manlifts are used in many facilities to provide access to the various work levels. Faulty equipment, lack of safety devices, and improper use of manlifts can cause serious injury. Workers must be instructed in the proper use of manlifts to ensure that they are familiar with the precautions that must be taken for safe operation [26, 44,90, 68].

Manlifts must be used for conveyance of personnel only. Transportation of freight, packaged goods, sacks and other materials on manlifts must be avoided since it may prevent the operator from using the manlift safely or materials being transported may fall and injure personnel on lower levels. Employers are responsible for ensuring that manlifts are not used for freight; however, enforcement can be difficult unless other convenient means are provided to transfer materials between levels. Caution signs informing employees of restrictions on conveyance of materials may be effective. Carrying of hand tools should also be avoided on manlifts unless the tools can be adequately secured in pockets or tool belts. Bulky tool belts, which significantly reduce clearances, must be avoided.

Guards must be provided to prevent inadvertent contact with moving parts and access to floor openings by personnel other than those using the manlift. Other specific requirements for the construction, maintenance, inspection, and operation of manlifts are contained in 29 CFR 1910.68. Manlifts should be used only by persons authorized by the employer and trained in their use. Instruction should include proper techniques for entering, riding, exiting, starting and stopping manlifts. Employees must be cautioned against transporting equipment and unsecured or protruding tools. A demonstration of proper operating techniques should be given at the manlift site and, following instruction, employees should use the manlift while being monitored by the instructor.

Firefighting Equipment

Portable fire extinguishers in a fully charged and operable condition should be provided throughout all buildings, unless employees are specifically instructed not to fight fires and to evacuate the facility if a fire occurs. Portable fire extinguishers provided for employee use must meet the requirements defined in 29 CFR 1910.157 to ensure that the extinguishers are readily available and in good operating condition. Training is essential for employees required to use extinguishers and other firefighting equipment since improper use can create additional hazards. Instruction should include the proper type of extinguishers to use on the different classes of fire and the proper technique to extinguish fires without disturbing layered dust. Foam extinguishers are sometimes recommended to minimize dispersal of dust when fighting fires.

Standpipes and hoses are frequently recommended in grain-handling and -processing facilities to aid firefighting operations [51]. Specific needs should be determined on the basis of the facility and consideration of local fire department and insurance company recommendations. Dry standpipes are usually recommended to prevent freezing in cold weather and loss of facility water supplies if pipes rupture in an explosion. Automatic sprinkler systems are also recommended by most insurance companies to limit facility damage where construction or equipment is combustible, or where combustible materials other than grain are stored [40, 51]. Sprinkler systems may also eliminate the need for manual firefighting. Where standpipes and sprinklers are provided, they must meet the requirements in 29 CFR 1910.158 and 29 CFR 1910.159, respectively. Fog nozzles are sometimes recommended on hoses used for fighting dust fires. Use of fog nozzles, however, does not guarantee that dust will not be dispersed and caution must still be exercised.

Hand and Portable Power Tools

Proper selection and use of hand and portable power tools are necessary in any industry to prevent worker injuries. Literature reviewed reflects the need for using tools properly, keeping them in good repair and performing periodic inspection and maintenance [44, 38, 91, 39].

Tools must be kept in good condition and repaired or discarded when defective. Most defects can be detected visually by the user. Impact tools with mushroomed heads, hammers with faulty handles or loose heads, and wrenches with sprung jaws must be repaired or discarded. Periodic verification of the grounding system is needed on electrical equipment, as well as inspection of cords and plugs for defective insulation or other damage. Employers are responsible for the safe condition of tools. Regular inspection and maintenance should be performed to ensure tools are kept in good repair. Workers should be instructed in the proper selection and operation of tools they will be using, including protective equipment that is required.

Portable power tools, when used, must comply with the requirements contained in 29 CFR 1910.243. Portable electrical tools must be in accordance with 29 CFR 1910 Subpart S; i.e., be equipped with a grounding conductor terminating in ground fault circuit interrupters or a grounding type attachment plug; be protected by an approved double-insulation system; or be used in circuits provided with ground fault circuit interrupters. Tool grounding system continuity should be verified at least quarterly. Checks should be made more often if equipment is subjected to heavy usage. Electrical tools with defective grounding systems, insulation, or plugs must not be used. Electrical tools should not be used in Class II locations unless layered dust in the work area has been cleaned up thoroughly, dust-producing equipment in the vicinity has been shut down, and airborne dust has settled.

Pneumatically powered equipment is frequently used in Class II locations to reduce the risks associated with the use of ordinary electrical tools. Pneumatic equipment can be used safely; however, precautions must still be taken to minimize airborne and layered dust in the work area since local heating or sparks may be generated by drill bits, grinding wheels or other attachments [33]. When pneumatic power is used, care must be taken to ensure that the tools and associated hoses and fittings are compatible with the pressure at which they are used.

Nonsparking shovels and other hand tools are used in some grain-handling and -processing facilities, although statistics indicate the degree of risk associated with ordinary tools is low. Cross [92] reported that available accident data are not statistically significant for completely addressing metal sparks as an ignition source. He found that high friction and continuous sparking incidents could be an ignition source in some cases, but that additional research is needed before a determination is made of whether sporadic or occasional sparking incidents are a hazard. The use of nonsparking tools is recommended by some sources [34, 70, 71] in confined, dusty locations as a precautionary measure. A data sheet prepared by the American Petroleum Institute [71A], however, indicates that the use of special tools is not warranted. A blanket recommendation for nonsparking tools cannot be justified.

Industrial Trucks

Powered industrial trucks are frequently used in and around grain elevators and feed mills for unloading bulk materials from flat storage bins, rail cars and barges, and for other material-handling and utility purposes. Regardless of application, powered industrial trucks must contain appropriate safeguards for both the operator and the other personnel. Procedures for safe operation, inspection, and maintenance should be established. Trucks should always be operated within their design capacities and perform only operations for which they are intended. Overloading and operating at excessive speeds should be avoided. Special care is needed when operating on slippery, uneven, or sloped surfaces. Fueling should be accomplished only in designated areas. Adequate ventilation must be provided whenever powered industrial trucks are used within building and other enclosures. A truck which is operated improperly may also cause serious injury. Only properly trained and authorized personnel should operate or service industrial trucks [38, 93, 94, 95].

Training for operators of industrial trucks should include classroom instruction, demonstrations and practice sessions. Instruction should include identification and operation of controls and gauges, loaded and unloaded maneuvering techniques, material-handling techniques, and other safe operating practices. Operating manuals and other training guidelines should be obtained from manufacturers or suppliers and used to develop training programs. Following training, personnel should demonstrate the ability to operate vehicles to the satisfaction of the instructor.

Design, maintenance and use of fork trucks, tractors, lift trucks, motorized hand trucks, and other powered industrial trucks must comply with the requirements of 29 CFR 1910.178. Powered trucks used in Class II, Group G locations must be designated for use in that location and be labeled or marked to indicate the approval of a recognized testing laboratory.

Ladders and Scaffolds

Ladders and scaffolds are frequently used in grain-handling and -processing facilities for maintenance and repair operations. Ladders are also commonly used for normal access between work levels and emergency escape routes. Accidents may be caused by climbing or descending improperly, overreaching, and failing to secure movable equipment. Falls from ladders and scaffolds frequently result in serious injuries. Instruction in the proper use of ladders and scaffolds is necessary to ensure that workers are familiar with the precautions which must be taken to prevent accidents [44, 38, 96].

Portable ladders must be structurally sound, adequately secured and properly sized for the specific task. Both tops and bottoms must be positioned against solid objects and, where necessary, held, tied, or otherwise securely anchored to prevent slipping. Additional precautions are needed if the ladder is positioned where it could be struck by vehicles, doors, or other moving objects. Metal ladders must not be used where there is a possibility of contacting live electrical parts. Ladders should be inspected for loose, cracked, or otherwise defective parts prior to use. Defective ladders should be conspicuously marked or removed to prevent inadvertent use. Portable ladders must meet the care and use requirements contained in 29 CFR 1910.25 and 1910.26.

Devices to prevent uncontrolled falls are needed for fixed ladders over 20 feet (6 m) in unbroken length. Cage guards are most commonly used, although safety devices which incorporate safety belts and friction brakes or sliding attachments are also used. Friction brakes and sliding attachments can provide more positive protection than cage guards; however, specialized training is needed for their use. Safety devices should not restrict use of ladders by persons with rescue or other emergency equipment. Fall protection devices are not considered mandatory by OSHA on ladders used exclusively as a means of egress from fires and like emergencies. Fixed ladders must be inspected regularly for loose, worn, or damaged parts and comply with the requirements in 29 CFR 1910.27. Inspection is especially important for emergency ladders where defects may not be noticed during normal operations.

Scaffolds must be designed to support at least four times the maximum load and be adequately secured when in use. Guardrails or other safety devices are required where workers are exposed to falls of 10 feet (3 m) or more. Safety belts or harnesses in conjunction with lifelines are needed for workers on suspended scaffolds or platforms. Lifelines must be attached to a secure point other than the scaffold. Movable scaffolds should not be relocated while workers are on them. Scaffold decking must be secure and provide adequate traction. Scaffolds should be inspected for defects by a competent person at least daily when in use and must meet the requirements contained in 29 CFR 1910.28.

Compressed Gas Equipment

Compressed gas is frequently used for cleaning, pneumatic tools and other applications in grain-handling and -processing facilities. Improper use of compressed air can be highly dangerous. Compressed air jets directed toward a worker's body or clothing can drive particles into the skin, break eardrums and cause other serious injuries [28, 44, 38]. Nozzle pressure of compressed air equipment used for cleaning purposes must not exceed a static pressure of 30 psi. Respiratory and eye protective equipment should always be provided to prevent particles from entering the workers' eyes or mouth when using compressed air for cleanup. Equipment in the area must be shut down and other potential ignition sources eliminated before dislodging dust.

Caution must also be exercised when using compressed gas cylinders. Cylinders must be clearly marked or color coded to identify the contents. Cylinders should be protected from damage during storage and handling. Special storage and handling racks or holders are recommended. Cylinders must be stored where they are not exposed to excessive heat or moisture and flammable gases must be stored away from the main buildings. Cylinder valves should be turned off when not in use and valve protection caps must be in place. Cylinders and compressed air receivers must have relief devices installed and meet the requirements contained in 29 CFR 1910 Subpart M. Cylinders used in welding, cutting, or brazing must meet the additional requirements contained in 29 CFR 1910.252. Only trained and authorized persons should interface with compressed gas equipment.

Hoisting Equipment

Hoists and other lifting devices are frequently used for transporting heavy equipment and machinery. Hoists are also used for lowering personnel into bins for cleaning and inspection. To prevent accidents, loads must be secure and stable and equipment inspected and maintained in accordance with manufacturers' recommendations. Equipment should only be used by personnel thoroughly instructed and trained in their use [44, 38].

Equipment must be used within its rated capacity. All equipment, including slings, cables, ropes, hooks and other attachments, should be visually inspected for defects prior to use. Brakes must also be tested before lifting. Loads must be adequately secured and balanced to prevent materials from becoming disengaged. Operators must verify that all personnel are clear of the lifting area prior to raising the load. Design and use of hoists, cranes, derricks, and slings used to elevate equipment must comply with the requirements of 29 CFR 1910.179, .181, and .184. Hoists must not be used to transport personnel unless a working platform designed for that purpose is provided.

Additional precautions are needed when using boatswain's chairs suspended from hoists. When portable equipment is used, the footing must be secure. The boatswain's chair should be attached by four legs to assure stability, in a manner which assures positive engagement. Safety belts or harnesses with lifelines should always be provided for personnel using boatswain's chairs. All hoisting operations must be conducted by trained personnel. Experienced persons should be designated to supervise the operation.

Operator training should include instruction in proper use of the equipment, including use of brakes and other safety features. Operators should also be trained to recognize defective or excessively worn parts. Additional training should be provided when personnel operate hoisting equipment used to lower workers into bins. Methods of properly securing and balancing loads should be emphasized. Following instruction and training, operators should demonstrate their ability to use the equipment to the satisfaction of the instructor. Periodic retraining should be accomplished.

FIRST AID

Prompt first aid treatment following an injury may prevent the condition from becoming more severe. Medical personnel or someone currently trained in basic first aid procedures and an adequate supply of first aid equipment should be readily available to all workers. Workers should be made aware of how to obtain emergency medical attention.

Facilities for drenching or flushing the eyes are needed in the immediate area wherever there is a chance of corrosive or otherwise harmful chemicals being splashed into the eyes. A shower should be provided whenever there is a chance of corrosive or otherwise harmful chemicals contacting a large portion of the body. Stretchers for transporting injured workers should also be available in the facility or through nearby fire departments or other emergency organizations. Basket stretchers should be available where injured workers may have to be lifted or lowered from areas which are not easily accessible.

COMPARISON WITH NATIONAL AND INTERNATIONAL STANDARDS AND CORRELATION WITH OSHA STANDARD

INTRODUCTION

This section addresses national, international, and consensus standards applicable to grain elevators and feed mills. A cross-reference of the recommendations contained in this report to the OSHA standard is included.

OSHA GENERAL INDUSTRY STANDARDS

The General Industry Safety and Health Standards (29 CFR 1910) of the Occupational Safety and Health Administration are broadbased standards. As such, they address many areas of general safety which grain-handling and -processing facilities share with all industry. Although the general industry standards specifically do not address grain elevators and feed mills, many of the regulated areas parallel conditions in these facilities and should provide adequate worker protection if directly applied. These areas include hand and portable power tools, ladders and scaffolds, compressed gas equipment, manlifts, hoisting equipment, firefighting equipment, walking and working areas, machine guards, and emergency planning, as well as electrical equipment and industrial trucks.

Other general industry standards would be considered adequate for grain elevators and feed mills with some modification. For example, regulations in 29 CFR 1910.252 are comprehensive and address most precautions necessary for welding in hazardous areas. However, this section does not require use of a written permit, which is recommended for grain elevators and feed mills.

Areas in the general industry standards considered deficient with respect to providing a comprehensive standard for grain elevators and feed mills include the following:

1. Protective and safety equipment. General requirements for the use of lifelines, stretchers and personal flotation devices should be addressed.

2. Equipment and machinery. Specific recommendations relative to the safe operation and use of bucket elevators, grain dryers, grinders and other potentially hazardous equipment and machinery should be addressed.

3. Isolation and lockouts. Requirements for the use of lockouts and isolation techniques for specific applications in grain elevators and feed mills should be addressed.

4. Confined space entry. Comprehensive regulations addressing entry into bins and other confined spaces are needed.

5. Inspection and maintenance. An overall inspection and maintenance program should be addressed, in addition to the inspection and maintenance requirements currently included in the individual subsections.

6. Dust control. Comprehensive requirements for dust control should be addressed. Housekeeping requirements in the general industry standards are inadequate for control of dust in grain elevators and feed mills.

7. Training. An overall training program should be addressed, in addition to the specific training requirements included in the individual subsection.

NATIONAL CONSENSUS STANDARDS

National Fire Protection Association Standards 61B and 61C address design practices, operating practices, and protective features for preventing fires and explosions in grain elevators and feed mills. These standards were developed primarily as guidelines for designers and operators building new facilities or making major modifications.

An extensive revision of NFPA 61B has recently been completed, providing more comprehensive and up-to-date guidelines for grain elevators. Although some operational considerations are included, the majority of the guidelines are design considerations for equipment. Many of these guidelines are consistent with the recommendations contained in this report. Adoption of the sections of NFPA 61B which could be applied to existing facilities, such as those addressing bucket elevators, grain dryers, and dust-control systems, in addition to the operational guidelines and other recommendations contained in this report, would provide a firm base for development of reasonable and effective regulations.

INTERNATIONAL STANDARDS

Several Canadian regulations and standards on grain-handling and -processing facilities were reviewed. Alberta Province Occupational Health and Safety Regulations contain an addendum covering grain elevators and feed mills. The regulations are brief and principally address personal protective equipment, scaffolding, machine guarding and manlifts. They do not adequately address dust control, specific hazardous equipment used in grain elevators, or entry into confined spaces.

Ontario, Canada, industrial safety regulations also address grain elevators. These regulations are equipment oriented and are very similar to NFPA 61B in areas of facility construction, bucket elevators, grain dryers, and dust-control systems.

TABLE 6

CROSS-REFERENCE OF RECOMMENDED SAFE WORK PRACTICES FOR GRAIN ELEVATORS AND FEED MILLS TO THE OSHA STANDARD

RECOMMENDED SAFE WORK PRACTICE	OSHA STANDARD
Personal Protective Equipment	1910.28(j)(4) 1910.95 1910.132 1910.133 1910.134 1910.135 1910.136 1910.137 1910.156(e) 1910.252(e)(1) 1910.252(e)(2) 1910.252(e)(3) 1910.252(e)(4)(iv)
Dust Control	1910.22(a) 1910.176(c)
Hot Work	1910.252(c)(4)(ii) 1910.252(d)(1) 1910.252(d)(2) 1910.252(e)
Smoking, Open Flames and Hot Surfaces	- - - - - -
Inspection and Maintenance	- - - - - -
Emergency Planning	1910.36(b)(5) 1910.36(b)(7) 1910.37(n) 1910.38 1910.156 1910.165

RECOMMENDED SAFE WORK PRACTICE	OSHA STANDARD
Confined Spaces	1910.28(j)(4) 1910.134(e)(3)(i) 1910.134(e)(3)(ii) 1910.134(e)(3)(iii) 1910.252(e)(4)(iv) 1910.252(f)(4)(iv)
Isolation and Lockouts	- - - - - -
Machine Guards	1910.212(a)(1) 1910.212(a)(2) 1920.212(a)(3) 1910.219
Labeling and Posting	1910.36(b)(5) 1910.37(q) 1910.145 1910.176(e) 1910.252(a)(2)(iii)(a) 1910.252(e)(4)(vii)
Lightning Protection	- - - - - -
Foreign Material	- - - - - -
Walking/Working Areas	1910.22(a) 1910.22(b)(1) 1910.22(c) 1910.23(a) 1910.23(b) 1910.23(c) 1910.36(b)(1) 1910.36(b)(4) 1910.36(b)(5) 1910.36(b)(8) 1910.37(e) 1910.176(c)
Static Electricity	1910.219(p)(2)(iii) 1910.309
Hazardous Material Storage	1910.106 1910.176(c)
Bucket Elevators	- - - - - -
Dryers	- - - - - -
Electrical Equipment	1910.308 1910.309
Manlifts	1910.68

RECOMMENDED SAFE WORK PRACTICE	OSHA STANDARD
Firefighting Equipment	1910.37(m) 1910.157 1910.158 1910.159 1910.181(j)(3) 1910.252(d)
Hand and Portable Power Tools	1910.242(a) 1910.243(a)(5) 1910.243(b)(2)
Powered Industrial Trucks	1910.178(a)(3) 1910.178(c)(2)(vi) 1910.178(c)(2)(vii) 1910.178(1) 1910.178(q)
Ladders and Scaffolds	1910.25(b)(1)(i) 1910.25(d) 1910.26(a)(1) 1910.26(c)(1) 1910.26(c)(2) 1910.26(c)(3) 1910.27 1910.28(a)(3) 1910.28(a)(4) 1910.28(a)(5) 1910.28(a)(6) 1910.28(a)(7) 1910.28(a)(11) 1910.28(a)(14) 1910.28(a)(19) 1910.28(a)(26) 1910.28(j)
Compressed Gas Equipment	1910.166 1910.167 1910.168 1910.169 1910.242(b) 1910.252(a)(2)(i)(a) 1910.252(a)(2)(i)(b) 1910.252(a)(2)(iii)(a) 1910.252(a)(2)(v)(b)(2) 1910.252(a)(2)(v)(b)(6) 1910.252(a)(2)(v)(b)(7) 1910.252(a)(2)(v)(b)(15) 1910.252(a)(2)(v)(b)(18)(ii)(c)(2) 1910.2 52(b)

RECOMMENDED SAFE WORK PRACTICE	OSHA STANDARD
Hoisting Equipment	1910.179(b)(8) 1910.181(b)(3) 1910.181(f) 1910.181(d) 1910.184(e)(5) 1910.184(f)(1)
First Aid Equipment	1910.151

SAFETY RESEARCH

INTRODUCTION

In developing the guidelines for reducing accidents and injuries in grain elevators and feed mills, the need for research to supplement limited or questionable data was apparent. Recommendations for research in several areas where additional study should prove beneficial are contained in this section. Extensive research in many needed areas is currently being conducted or sponsored by industry, the Government and the academic community. A summary of these ongoing research projects is also included.

RESEARCH RECOMMENDATIONS

Dust Control

The value of dust control in grain elevators and feed mills is recognized throughout the industry. Housekeeping is thought by many to be the most important factor in reducing the risks associated with grain dust explosions. Although the value of a clean facility is recognized, there is no clear definition of what is meant by "clean." Some literature implies that anything more than a trace of dust must be cleaned up. Other literature indicates that accumulations should not exceed 1/64, 1/16 or 1/8 inch. One source indicates that some facilities are so dirty that, in comparison, even dust levels up to the tops of shoes could be considered clean. Research to determine definitive guidelines for the degree of cleanliness that is considered safe would be of value throughout the industry. The guidelines should address all surfaces where dust may accumulate, both inside and outside of enclosures, as well as techniques which can be used to measure the level of cleanliness.

Of equal importance is the need to investigate airborne dust levels within enclosed handling and processing equipment. In many cases airborne dust levels exceed the lower explosive limit, even with air aspiration systems operating. Explosive dust concentrations, combined with rapidly moving components within the equipment which may provide the ignition source, result in a continuously hazardous operation. This condition must be corrected before the problem of grain dust explosions can be resolved. Development of practical techniques for measuring airborne dust levels should be included as part of this effort.

A third area requiring resolution is the practice of returning dust from pneumatic collection systems to the grain. Many experts indicate that limiting reintroduction of dust improves safety. However, other experts question whether the safety benefits justify the economic cost and the potential problems associated with handling the dust separately. Research should be conducted to determine the relative safety benefits of total restriction of returning dust to the grain, partial restriction, and no restriction, for the various sizes and types of grain-handling and -processing facilities. Research should include an investigation of the techniques that may be used to return dust without subsequently throwing the dust into suspension.

A fourth area needing additional study is the practice of using additives to reduce emissions of dust from grain during handling and processing operations. This approach shows promise; however, there appears to be very little positive response from within or outside the industry. The most obvious question to be resolved is the possibility of additives altering the taste or quality of the product. Additional investigation is needed to answer this question and other relevant aspects associated with the use of additives.

Bucket Elevators

Bucket elevators are by far the most hazardous equipment used in grain elevators and feed mills. Tests have shown that elevator legs routinely produce airborne dust levels exceeding the minimum explosive concentration. Although all locations where dust is present can be hazardous under the proper conditions, bucket elevators appear to be exceptionally so. Development of specific preventive and protective measures for bucket elevators should be given high priority. Certain techniques, such as the use of slow speed legs, appear advantageous and should be further developed. The advantages of using plastic buckets to reduce the chance of sparks should be evaluated, along with the possible disadvantages associated with the addition of flammable materials, the possibility of static charge buildup on plastic buckets, and the possibility of health hazards from the burning of plastic materials. The advantages and disadvantages of PVC versus rubber belt material should be evaluated. Investigation of internal dust levels with respect to the location, configuration, and capacity of the dust-collection system would also be valuable. Other aspects of bucket elevators including basic design, reliability and maintainability should be investigated from a system safety standpoint.

Explosion Venting

Explosion venting is frequently recommended in the literature as a method of limiting the destructive effects of an explosion. Venting is usually recommended for bins, bucket elevators, dust collectors, pneumatic conveyors and other equipment and building enclosures. However, specific recommendations for the configuration and type of venting best suited for the various applications and the needed relief area are often poorly defined or conflicting.

The practice of extending bucket elevator casings above the roof is common; however, most sources concede that this practice is not fully effective because of the rapid pressure rise rate associated with most explosions. Recommendations for venting of storage bins also vary widely. Effective venting of concrete bins is usually not practical because of the large height-to-diameter ratio and lack of venting considerations in the initial design.

Research to determine the optimum venting configuration for each application would be valuable. Research should be conducted separately for new construction applications and for existing facilities. Research for new construction should consider basic design changes in the equipment to accommodate or lessen the need for venting, as well as recommendations for the best location of the equipment. Research for existing facilities should consider the most efficient and cost-effective means of adding relief vents.

Confined Space Entry

Literature associated with confined space entry reflects the potential hazard of worker exposure to oxygen deficient atmospheres. It is generally noted that oxygen deficiencies in grain storage vessels may occur as the result of composition changes in stored materials or rusting of metal containers.

To prevent worker exposure to oxygen deficiencies, conditions in the confined space must be evaluated prior to entry. Many sources recommend atmospheric testing to accomplish this evaluation; however, this is probably because the specific criteria needed to make a subjective evaluation of the atmospheric conditions and ventilation adequacy are not apparent. If these criteria could be identified, it is likely that in many cases atmospheric testing would not be necessary to ensure worker safety. Specific data on the likelihood and characteristics of oxygen deficiencies in confined spaces in grain-handling and -processing facilities would be a valuable aid in fully understanding the degree of hazard and the necessary hazard controls.

General Safety Studies

The need for additional research into the various causes and controls of fires and explosions in grain elevators and feed mills and investigation of actual incidents is obvious. Not so apparent, however, is the need for investigation of the many accidents and injuries suffered daily by workers in the performance of their assigned tasks. It is known that back injuries, cuts, bruises and sprains are among the most frequently occurring injuries. Information indicating the type of equipment most often involved in accidents can also be obtained to some extent. However, data of sufficient detail to enable the accurate identification of the contributing factors and the actual causes of accidents are not readily available. A system to provide these causative data would be a valuable aid in establishing specific safety guidelines and effective training programs for the entire industry.

ONGOING RESEARCH

Government-Sponsored Research

In addition to this study sponsored by NIOSH, several ongoing projects are currently being funded by NIOSH and OSHA grants. Those include:

1. Prevention of Grain Elevator and Mill Explosions. The purpose of this project is to develop comprehensive recommendations for the prevention and control of dust explosions in grain elevators and mills. The study is being conducted by National Academy of Sciences Panel on Causes and Prevention of Grain Elevator Explosions. A handbook on dust-collection systems is also being developed as a result of the study.

2. Explosion Hazards Related to Grain and Feed Dusts. The intent of this project is to gain a better understanding of the phenomenon involved in vegetable dust explosions, to provide a model for dust flame propagation

in confined spaces, and to furnish data for dust collection, venting, and flame quenching for design engineers. The study is being conducted at the University of Michigan.

3. Safety in Grain Bins. The purpose of this project is to determine the magnitude and characteristics of forces acting on a person trapped in a mass of grain flowing to an outlet from a bulk storage bin under normal and faulty (abnormal) grain conditions. The study is being conducted at the University of Kentucky.

Industry-Sponsored Research Completed

Industry has also chosen to pursue practical research to resolve unanswered questions surrounding explosion incidents and to find workable methods for reducing these hazards [97]. Research projects are being coordinated by the Fire and Explosion Research Council of the National Grain and Feed Association. Completed projects include the following:

1. Elevator Design Conference. Conducted in September 1979 in Kansas City, Missouri, the conference examined elevator design and its impact upon safety. It focused upon current state-of-the-art design concepts for grain-handling facilities. The conference resulted in the publication of a 518-page reference book, entitled "A Practical Guide to Elevator Design."

2. Combustible Gases in Grain Elevators. Research indicated that combustible gases and vapors do not emanate from decomposing or fumigated grain in amounts sufficient to contribute to the explosiveness of grain dust. Research also indicated that no detectable levels of gases were absorbed by the grain dust.

3. Literature Survey of Alternative Dust Uses. In a literature study conducted by Kansas State University, Manhattan, Kansas, it was determined that only 23 research articles have been written on this subject. The report indicates that grain dust, when separated from grain and collected, is used primarily as a feed ingredient.

4. Electrostatic Characteristics of Grain and Grain Dust. This research indicated that although grain can accumulate moderate amounts of electrostatic charges when moving across spouts and chutes, such charges dissipate quickly when grain comes into contact with a device or structure that is well grounded. The project also found that moisture content of the grain has a significant effect upon its resistance to electrical charges.

5. Electrostatic Charge Levels on Belt Conveyors. In a study of the electrostatic charges on conducting and nonconducting conveyor belting, it was found that the potential charge levels accumulating on conductive belting were higher in winter than in summer. But at no time did such charge levels reach a hazardous level. Further, there was no relationship between the charge level on the belts, and the ambient temperatures or relative humidity existing within the facility. The research also showed that static eliminators have limited usefulness.

6. Concentrations of Gases Following Fumigation. Results of this project show that concentrations of phosphine and carbon disulfide used during the fumigation process do not accumulate to flammable levels. This research indicates that flammable fumigant levels are unlikely to occur in grain-handling facilities, particularly if a minimal amount of air is circulated in confined portions of the facility, such as the tunnel.

7. Grain Dust Ignition by Frictional Sparks. This project found that a shower of metal sparks of sufficient energy could ignite an explosive dust cloud, such as might occur in continuous, high speed grinding operations. However, the study did not determine if sporadic or occasional sparking incidents would ignite an explosion.

8. Current Utilization of Grain Dust. This project was to learn more about how the industry currently collects, handles, and utilizes grain dust. A survey indicated that grain dust that is separated and handled apart from grain is used most frequently as livestock feed. The average percentage of grain dust collected by dust-collection systems was 0.18% of the unit weight of grain handled. The survey indicated that much of the grain dust was retained in the grain or grain products.

9. Explosion Venting and Suppression of Bucket Elevators. This research showed that explosion venting can be used effectively to protect bucket elevators from explosions. The research also showed that suppression systems can be successful in halting explosion propagations at their earliest stage. In a second phase of the project, it was found that a grain distributor having a single-spout opening was effective in limiting flame propagation.

10. Survey of Literature on Ignition of Dusts by Friction and Impact Sparks. This project provided additional information on the role of metal sparks as an explosion ignition source. The report concludes that available accident data are not statistically significant for fully addressing metal sparks as a dust ignition source. The survey found that high friction and continuous sparking incidents could be an ignition source in some cases, but additional research and data are needed before a complete evaluation can be made of whether sporadic or occasional sparking incidents are a hazard.

Industry Sponsored Research in Progress

Research projects sponsored by the National Grain and Feed Association that are now underway include:

1. Effectiveness of Additives in Reducing Grain Dust. This project is examining the potential use of water and oil additives to reduce dust emissions during handling operations. The project consists of adding various percentages of soybean oil, mineral oil and water to corn, wheat and soybeans at an elevator facility in Ohio. Long term effects of the oils on the condition of grains are being analyzed, as is the long term effectiveness of the oils in reducing dust concentrations. The project is measuring the reduction of airborne dust in several locations throughout the elevator.

2. Ignition Due to Electrostatics in Powder Systems. This study examines electrostatic hazards that may occur in a full-scale bulk handling system. The research consists of the measurement of electrostatic charges that occur during handling of various bulk powders.

3. Dust Hazard Index and Minimum Fuel. This project examines in a laboratory apparatus the amount of dust necessary for a secondary explosion to occur. A second goal is to determine the minimum explosible concentrations and minimum ignition energies of various dusts to provide operators with information eoncerning hazardous airborne concentrations and accumulations of grain dust.

4. Explosive Power of Grain Dust in a 20-Liter Chamber. This research project is to study the explosive characteristics of grain dust. Data for various grain dusts and their lower explosive concentrations are being developed.

5. Examination of Dust Layers as a Fuel Source. Research of the role that smoldering combustion may play in the ignition of elevator explosions is being conducted. The project is investigating the effect that varying thicknesses of dust layers has on the dust's heat content and the probability of its breaking into flames.

6. Venting of Galleries. This is examining dust explosion propagation in simulated galleries. The project is studying the venting of duct-like structures (structures with a high ratio of length-to-cross-sectional area) such as galleries, bridge structures, and tunnels common in grain facilities.

7. Electrical Grounding Characteristics of Grain Elevators. This study examines the grounding characteristics utilized in grain-handling facilities. The project will measure the resistances to earth and the total capacitances of equipment to determine where electrostatics need to be examined.

8. Reducing Dust Concentrations in Bucket Elevators. This research is examining the effectiveness of several methods of reducing grain dust concentrations in bucket elevators. The project is aimed at finding methods of limiting or preventing the occurrence of explosive concentrations in bucket elevators.

9. Static Electricity Field Strengths in Grain Bins. This study is to determine whether electrostatic charges accumulate in grain bins during filling, and whether such charges are hazardous. The project is investigating the electrostatic field strengths within the bins of a grain terminal in Tilbury, England. The research also is investigating the charge levels on grain as it is transported on a conveyor belt and as it falls into the bin.

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