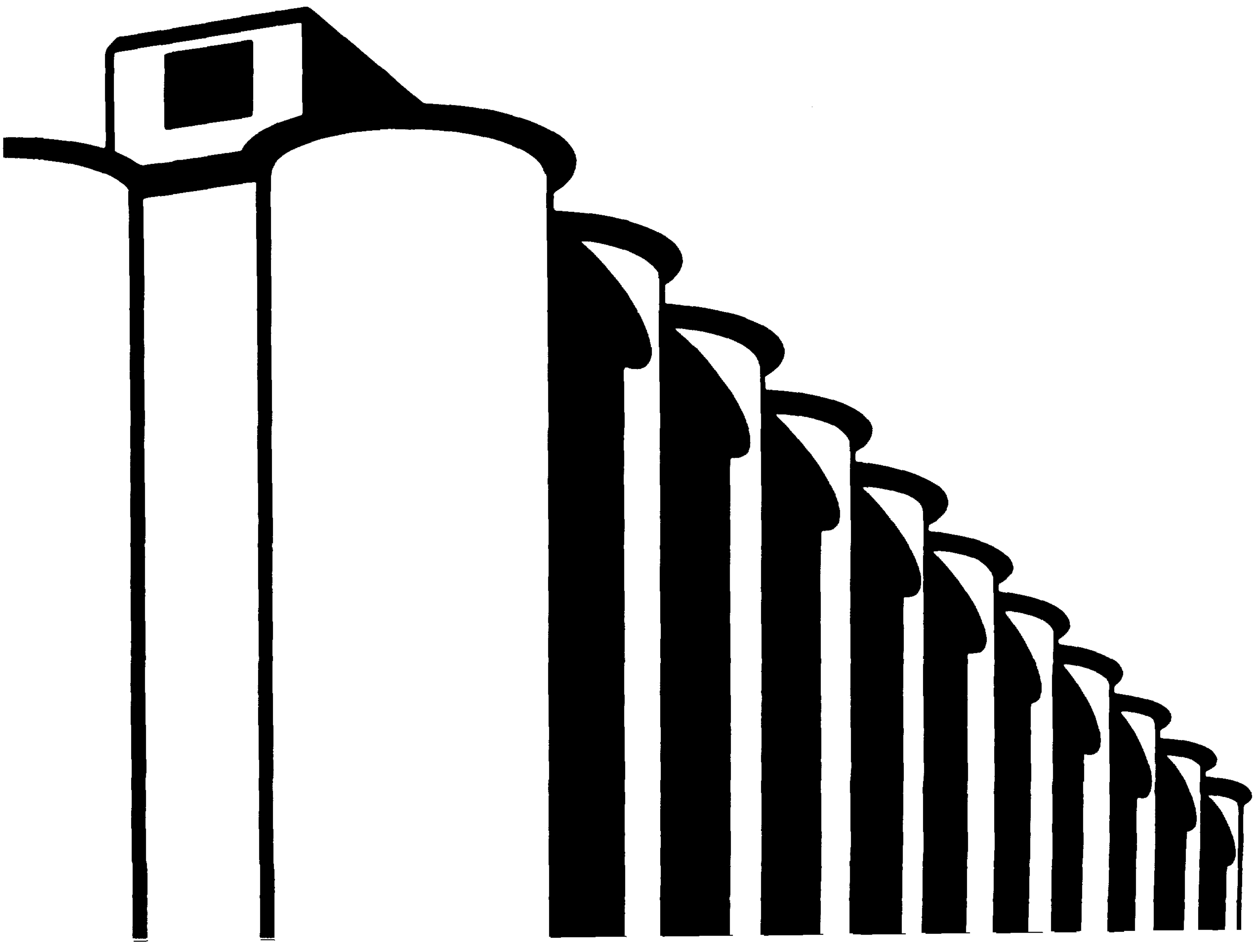
U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health

Occupational Safety in Grain Elevators and Feed Mills



OCCUPATIONAL SAFETY IN

GRAIN ELEVATORS AND FEED MILLS

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control
National Institute for Occupational Safety and Health
Division of Safety Research
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PREFACE

The Occupational Safety and Health Act of 1970 (Public Law 91-596), states that the purpose of Congress expressed in the Act is "to assure so far as possible every working man and woman in the Nation safe and healthful working conditions and to preserve our human resources...by," among other things, "providing for research in the field of occupational safety and health...and by developing innovative methods, techniques, and approaches for dealing with occupational safety and health problems." Later in the Act the National Institute for Occupational Safety and Health (Centers for Disease Control, Atlanta, Georgia) is charged with carrying out this policy. A principle means by which this information is communicated, is through the publication by NIOSH of Technical Guidelines.

Technical Guidelines are published for the purpose of disseminating comprehensive information about occupational hazards so that these hazards may be reduced in order to prevent injury and disease among workers. Technical Guidelines focus attention on occupational exposures which, though previously recognized, have never before been subjected to systematic and comprehensive analysis. Technical Guidelines present recommendations for reducing the hazards by a variety of means including compliance with any existing pertinent regulations. The Guidelines may also be used to support development of Federal safety and health standards.

Technical Guidelines are distributed to representatives of organized labor, industry, public health agencies, academic institutions, and public interest groups, as well as to those Federal agencies, such as the Department of Labor, which have responsibilities for protecting the safety and health of workers. It is our intention that anyone with the need to know should have ready access to the information contained in these documents; we welcome suggestions concerning the content, style, and distribution of them.

This document provides guidance for protecting workers in grain elevators and feed mills. It was prepared by the staff of the Division of Safety Research, NIOSH, (944 Chestnut Ridge Road, Morgantown, WV, 26505), in conjunction with the Division of Standards Development and Technology Transfer, NIOSH (Robert A. Taft Laboratories, 4676 Columbia Parkway, Cincinnati, OH, 45226). I am pleased to acknowledge the many contributions to this document made by consultants; reviewers selected by the National Grain and Feed Association (NFGA), the American Feed Manufacturers Association (AFMA), the Grain Elevator and Processing Society (GEAPS), the Rice Millers' Association (RMA), the American Federation of Grain Millers (AFGM); and the Allied Industrial Workers of America (AIWA); other reviewers; representatives of other Federal agencies; and, of course, the staff of the Institute (a list of consultants reviewing the document appears on v). However, responsibility for the conclusions reached and recommendations made belongs solely to the Institute. All comments by reviewers, whether or not incorporated into the final version, are being sent with this document to the Occupational Safety and Health Administration (OSHA) for consideration in standard setting.

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The views expressed, conclusions reached and recommendations presented in this report are those of the National Institute for Occupational Safety and Health. They are the result of careful review of available literature, site visits, review of existing industry guidelines and Federal safety standards, and consideration of comments from external reviews.

This report was developed by the Division of Safety Research (DSR), National Institute for Occupational Safety and Health. Mr. Ted A. Pettit and Mr. Peter M. Bochnak, Standards and Consultation Branch, DSR, served as Project Officer and Criteria Manager, respectively. Technical editing of this report was provided by Herbert Linn, DSR. Support was provided under Contract No. 210-79-0024 by Boeing Aerospace Company, Houston, Texas.

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.

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I. 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 addresses safety hazards. Health hazards are discussed only to acknowledge their existence and the need for their control.

After evaluation of available data, guidelines have been developed to provide for the safety of workers. The data base consists 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 grain facilities, such as rice mills, are less susceptible to dust explosions, no attempt has been 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. The recommendations are broad-based, 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 concerning 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.

In spite of current efforts by government, industry, and labor, awareness of hazardous conditions in grain-handling and grain-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.

Supporting information on the prevention of grain elevator and feed mill explosions can be obtained from the National Academy of Sciences (NAS) report, "Prevention of Grain Elevator and Mill Explosions," NMAB 367-2, which was jointly funded by the National Institute for Occupational Safety and Health (NIOSH), the Occupational Safety and Health Administration (OSHA), and the U.S. Department of Agriculture (USDA). The systems approach was used in the

NAS report to identify grain elevator explosion hazards and develop recommendations for preventive actions. Additional construction and design techniques that should be considered when building new facilities or renovating existing facilities are contained in National Fire Protection Association (NFPA) Standards 61B-1980, "Standard for the Prevention of Fires 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."

Safety precautions related to the use of fumigants in grain-handling facilities are included in NFPA 61B-1980, "Standard for the Prevention of Fires and Explosions in Grain Elevators and Facilities Handling Bulk Raw Agricultural Commodities."

This report also identifies areas, such as dust control, bucket elevators, explosion venting, and fire extinguishing methods, where additional research is necessary and provides recommendations for this research.

II. DEFINITION OF THE PROBLEM

A. INTRODUCTION

There are approximately 15,000 grain-handling and grain-processing facilities in the United States [1, 2]. 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 ever-present in the industry because of the physical characteristics of organic dust that is generated while handling and processing grains. Also, workers are exposed daily to a wide variety of other work-related hazards that are 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.

B. 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 grain elevators and feed mills along with associated operations is presented below.

1. 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.

There were 9,472 country elevators, 413 inland terminals, and 82 export terminals in operation in the United States during 1977-78 [3]. On the average, from 2 to 4 people are employed in small country elevators and 40 to 50 in the terminals [4]. Grain elevators may operate year-round or seasonally, with great fluctuations in 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. An estimate of approximately 63,000 total workers for grain elevators can be arrived at by using an average of 4 workers for country elevators and 50 workers for terminals.

This estimate compares well with the Bureau of Census's "1977 Census of Wholesale Trade" which reports 70,059 workers (production and support staff) for the grain elevator industry [5]. 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, although in some parts of the Northwest, wood is still used for small elevator construction. Older establishments may be wood frame structures, sometimes sheathed with steel [6].

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 also 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 additional height minimizes the amount of mechanical transfer when moving grain, and provides the space needed for the handling equipment. The terms "workhouse" and "headhouse" are usually interchangeable, 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, eliminating the need for a workhouse . A gallery 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 tunnel, which contains grain-conveying equipment, is usually located at the bottom of the bins and extends the length of the bin area. A typical terminal type grain elevator is shown schematically in Figure 1.

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 belt and drag and screw conveyors. Drag and screw conveyors are normally enclosed.

Drying may be required if the grain has a high moisture content. Usually, continuous-flow column dryers are used, but batch dryers are also used.

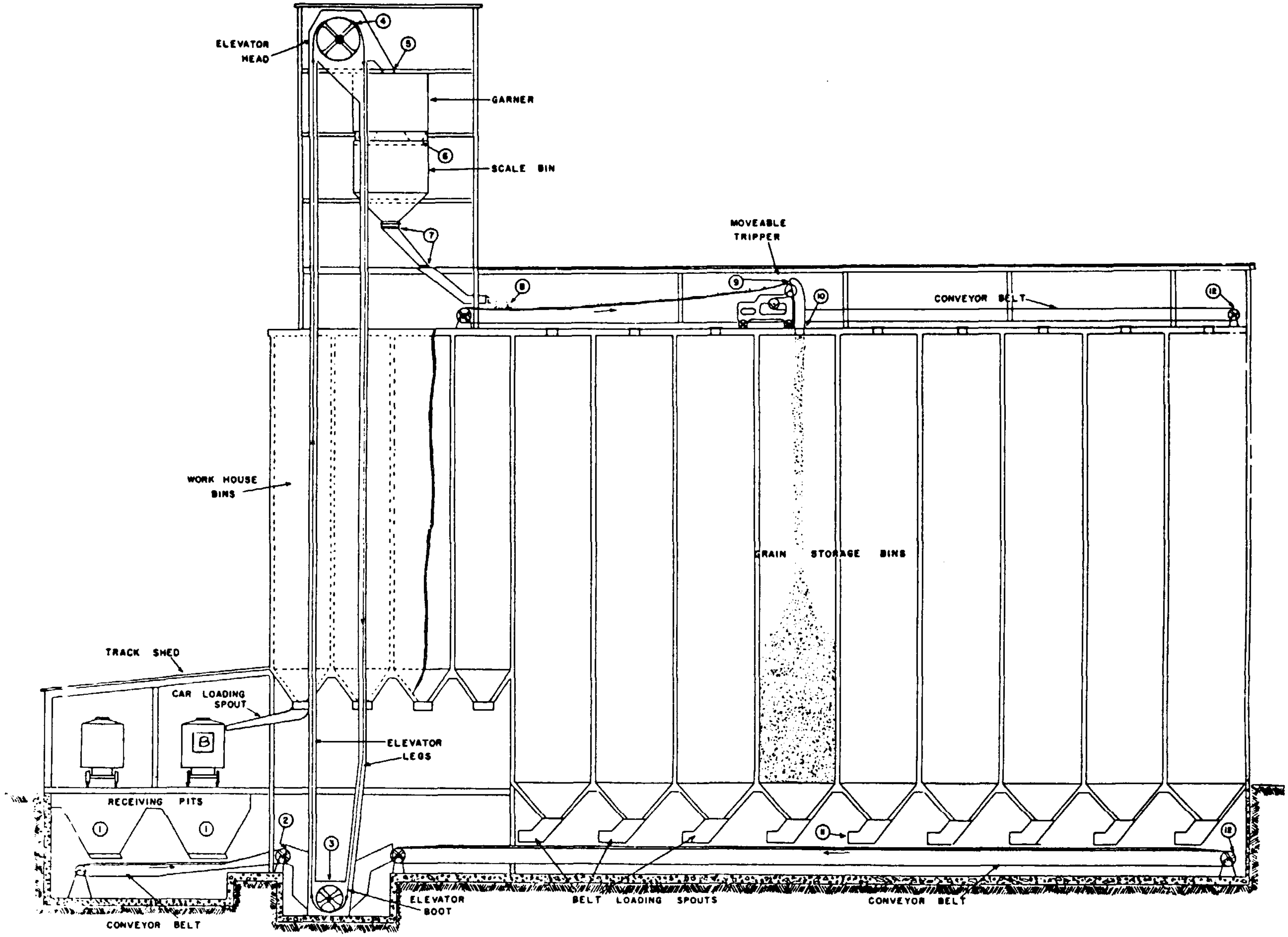

Figure 1. Diagrammatic section view of a terminal type grain elevator. Circled numbers indicate points at which dust clouds are likely to be emitted [6].

Cleaning may be required to achieve desired grade levels. Cleaning is normally accomplished with simple screening machinery that may be shaken, rotated, or slanted such that grain will flow across the surface.

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 [7] 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 55.8% of the elevators where dust was added back to the grain stream, 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 vacuum systems are also used.

2. Feed Mills

Feed milling is primarily a grinding and mixing process in which various grains and grain byproducts are blended with protein concentrates, food industry byproducts, vitamins, drugs, and minerals. In a study conducted in 1975 and reported in 1978, the U.S. Department of Agriculture cited 6,340 feed-manufacturing facilities producing over 100,000,000 tons of feed per year. This figure included 4,454 facilities with outputs less than 10,000 tons per year, 1,329 facilities with outputs between 10,000 and 50,000 tons per year, and 556 facilities with outputs of over 50,000 tons per year [8]. There was an estimated average of 57,500 workers in the feed mill industry (1975-1980) (Table 1).

Incoming grain is generally received by truck or rail, or in some cases, from an adjacent grain elevator. Receiving operations in mills 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 which are 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 that are frequently below the floor away from the main processing area.

Whole grain is ground prior to mixing. Hammer mills, 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. Also, scalpers 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 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 sewed 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.

C. INJURY STATISTICS

1. Injury Incidence Rates

The number and severity of injuries in grain elevators and feed mills may be estimated from information reported by the Bureau of Labor Statistics (BLS), U.S. Department of Labor [9-14]. Table 1 shows average annual employment and incidence rates (per 100 full-time workers) from 1975 through 1980 for total injury cases, lost workday cases, nonfatal cases without lost workdays, and lost workdays. For comparison, average incidence and lost workday rates are shown for specific industries (SIC Codes 204, Grain Mill Products; 2048, Prepared Feeds; and 515, Farm Product Raw Materials) as well as for all private sector industries combined. These data show a total of approximately 8,500 annual injuries (employment times total case incidence rate divided by 100) in feed mill establishments. Feed mills had an average injury incidence rate of 14.8 and an average lost workday incidence rate (severity rate) of 112.3, which are respectively 1.7 and 1.9 times the average rates exhibited by total industry.

The Bureau of Labor Statistics does not report data for the four-digit SIC code 5153 which includes grain elevators. The three-digit SIC code 515, Farm Product Raw Materials, includes other industries in addition to grain elevators.

Currently, occupational accident and injury information from participating states, derived from employers' first report of injury forms, is compiled and reported by the BLS Supplementary Data System (SDS) [15]. Of the states which

Table 1

Average Occupational Injury Incidence Rates for

Selected Industries, 1975 - 1980

Industry	Employment (Thousands Per Year)	Incidence Rates per 100 Full-Time Workers: Total Cases	Lost Workday	Nonfatal Cases w/o Lost Workdays	Lost Workdays
All	69,513.7	8.9	3.7	5.2	60.7
Grain Mill Products (SIC 204)	141.3	14.9	6.7	8.2	118.3
Prepared Feeds (SIC 2048)	57.5	14.8	6.7	8.1	112.3
Farm Product Raw Materials (SIC 515)	138.8	8.9	4.3	4.6	67.1

Reported by the Bureau of Labor Statistics, U.S. Department of Labor [9-14].
Note: Data for 1977 - 1979 were not reported for SIC 515, and employment for SIC 515 was reported for 1976 only.

report SIC 5153 and 2048 injury data to SDS, a total of 18 states also reported average grain-handling activity for the years 1977-1980 (Table 2). The proportion of total grain-handling activity based on average off-farm storage facilities, off-farm storage capacities, and total crop production (1977-1980) for these states, as a percentage of national figures, was 45.7%, 43.0%, and 52.2% respectively. Table 2 contains the SDS injury data, reported between 1977 and 1980, for the states that reported both injury statistics for Grain Elevators (SIC 5153) and Feed Mills (SIC 2048) and data on off-farm storage facilities, off-farm storage capacities, and total crop production [1,16,17].

Additional information on grain elevators and grain mills is included in the 1977 edition of "Accident Facts" prepared by the National Safety Council (NSC) [18]. This edition records the results of a 3-year study performed on the basis of reports to the NSC. Table 3 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, (2) the NSC data include only disabling work injuries while the BLS data include total injuries, and (3) NSC and BLS accident reporting requirements differed during the 3-year period. The data presented by the NSC over the 3-year period are most important when compared with the overall industry rates. For grain mills

Table 2

Grain Elevators (SIC 5153) and Feed Mills (SIC 2048) Injury Distribution and Grain-Handling Activity in SDS Reporting States for 1977-1980[1]

State[2]	Injuries per year			Off-Farm Storage Facilities/Year	Off-Farm Storage Capacity/Year (X 1,000 bu.)	Total Grain Production[3] (X 1,000 bu.)
	SIC 2048	SIC 5153	SIC 2048 & 5153			
Arkansas (3)	83.0	3.7	86.7	271.0	203,157	255,720
Colorado (4)	46.0	67.0	113.0	202.3	93,040	162,993
Delaware (4)	4.8	1.3	6.0	27.8	17,573	25,824
Idaho (4)	140.3	189.5	329.8	235.0	68,405	137,059
Iowa (4)	126.5	137.8	266.8	1,136.0	651,388	1,819,755
Kentucky (4)	67.5	39.0	106.0	204.3	49,228	171,792
Michigan (4)	23.3	43.8	67.0	366.8	92,008	241,463
Minnesota (4)	108.0	236.3	319.3	892.5	377,425	1,034,433
Missouri (4)	459.8	206.5	666.3	613.3	210,908	447,327
Montana (4)	111.3	136.3	247.5	291.5	52,743	213,393
Nebraska (4)	503.5	531.5	1,030.5	733.3	498,440	1,024,759
New York (3)	69.3	9.3	80.3	239.3	66,437	68,930
Oregon (4)	50.8	39.5	90.3	237.0	65,075	66,785
South Dakota (3)	59.0	247.7	306.7	387.0	84,270	400,505
Tennessee (4)	64.8	8.9	73.5	138.8	49,148	110,959
Utah (4)	39.5	16.5	56.0	58.3	17,288	14,951
Washington (3)	71.0	237.0	308.0	323.3	189,170	168,468
Wisconsin (4)	128.8	23.0	151.8	579.0	125,023	342,340
Total	2,157.2	2,174.6	4,035.5	6,936.5	2,910,726	6,707,456
National Total				15,171	6,762,807	12,856,760
% of National				45.7	43.0	52.2

[1] Compiled from BLS, Supplementary Data System [17] and data from U.S. Department of Agriculture [16].

[2] Number of years reporting (3 or 4).

[3] Reported for 1978 only.

(corresponding to the three-digit SIC code 204), the frequency rate of disabling injuries is approximately 1.7 times higher than the industry average, with the severity rate approximately 2.1 times higher than the industry average. For grain elevators (corresponding to the four-digit SIC code 5153), the frequency rate is approximately 1.5 times higher than the industry average; however, the severity rate is approximately 5.8 times as high. Comparable records more recent than 1976 are not available.

Also of interest are data included in Table 4, which address occupational injury and illness rates by employment size. For Grain Mill Products, the lowest incidence rates are achieved by employers with over 1,000 or less than 20 personnel. For Farm Products Raw Materials, a similar trend exists, with the lowest rates achieved by those companies employing the most and least number of workers.

2. General Accident Statistics

The purpose of the SDS system is to report occupational accident/injury information in sufficient detail to alert users to patterns and relationships of injury causal factors. Information from the workers' compensation first report of injury forms is entered into each of four major groupings [15]:

- o Source of injury
- o Type of accident
- o Nature of injury
- o Part of body affected.

Tables 5 and 6 summarize the SDS accident/injury data for feed mills and grain elevators.

The information presented in Tables 5 and 6 is sufficient to detail the most prevalent natures of injuries incurred in feed mills (sprains and strains, 32.8%; cuts, 16.1%; and contusions, 14.5%) and the most common parts of the body injured (back 20.1%; fingers, 12.8%; and eyes, 7.4%). This information also details the most prevalent natures of injuries incurred in grain elevators (sprains and strains, 27.5%; cuts, 16.2%; and contusions, 13.7%) and the most common parts of the body injured (back, 17.8%; fingers, 11.1%; and eyes, 7.4%). However, the depth of analysis offered is insufficient for the purposes of defining actual accident causal factors beyond the quantification of incidents associated within the broad injury source categories (working surfaces, metal items, boxes, etc.).

3. Supplementary Data System - Accident/Injury Analysis

The SDS differentiates the major "source of injury" categories into nearly 300 subcategories [15]. These categories are representative of tools and/or equipment used in all varieties of manufacturing processes in all types of industries. In many instances, the "source of injury" categories are still not useful for the purposes of quantifying accidents specific to grain elevator and feed mill industries. An additional constraint in the applicability of the data base is that some of the tools and equipment used in grain elevators and feed mills are fairly unique to the industries (e.g.,

Table 3

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

Reported by the National Safety Council [18].

Table 4

Occupational Injury and Illness Incidence Rates,
Private Sector, By Industry and Employment Size,
United States, 1976

INDUSTRY AND EMPLOYMENT SIZE	SIC CODE	MEAN INCIDENCE RATE PER 100 FULL-TIME WORKERS
<u>Grain Mill Products</u>	<u>204</u>	
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
<u>Farm Product Raw Materials</u>	<u>515</u>	
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

Reported by the Bureau of Labor Statistics, U.S. Department of Labor [10].

Table 5

Summary of SDS Accident/Injury Profile, 1976-1979, for the Feed Mill Industry (SIC 2048)

	No. of Accidents	%		No. of Accidents	%
Source of Injury			Type of Accident		
Boxes, barrels, containers	1580	15.4	Overexertion	2162	21.2
Working surfaces	1433	14.0	Struck by	2063	20.2
Metal items	1114	10.9	Struck against	1064	10.4
Vehicles	1060	10.4	Fall from elevation	903	8.8
Bodily motion	600	5.9	Caught in, under, or between	874	8.6
Machines	582	5.7	Fall on same level	852	8.3
Handtools, not powered	511	5.0	Bodily reaction	646	6.3
Buildings and structures	241	2.3	Rubbed or abraded	492	4.8
Wood items	234	2.3	Contact with caustics	379	3.7
Particles	211	2.1	Motor vehicle accidents	239	2.3
All other classifiable	2299	22.5	All other classifiable	333	3.3
Nonclassifiable	361	3.5	Nonclassifiable	219	2.1
Nature of Injury			Part of Body Injured		
Sprains, strains	3351	32.8	Back	2051	20.1
Cut	1647	16.1	Finger(s)	1313	12.8
Contusion	1487	14.5	Eye(s)	755	7.4
Fracture	869	8.5	Hand	529	5.2
Scratches	464	4.5	Multiple parts	529	5.2
Burn (heat)	217	2.1	Foot (not ankle or toes)	482	4.7
Dislocation	191	1.9	Ankle	421	4.1
Hernia	152	1.5	Knee	418	4.1
Multiple injuries	137	1.3	Wrist	318	3.1
Amputation	119	1.2	Chest	317	3.1
All other classifiable	977	9.6	All other classifiable	2993	29.2
Nonclassifiable	615	6.0	Nonclassifiable	100	1.0

Compiled from Bureau of Labor Statistics' Supplementary Data System [17].

Table 6

Summary of SDS Accident/Injury Profile, 1976-1979, for the Grain Elevator Industry (SIC 5153)

	No. of Accidents	%		No. of Accidents	%
Source of Injury			Type of Accident		
Working surfaces	1237	16.6	Struck by	1528	20.5
Metal items	994	13.3	Overexertion	1209	16.2
Boxes, barrels, containers	720	9.7	Fall from elevation	831	11.1
Vehicles	712	9.6	Struck against	796	10.7
Bodily motion	460	6.2	Caught in, under, or between	671	9.0
Handtools, not powered	403	5.4	Fall on same level	656	8.8
Machines	360	4.8	Bodily reaction	496	6.6
Wood items	235	3.2	Contact with caustics	335	4.5
Chemicals and chemical compounds	197	2.6	Rubbed or abraded	326	4.4
Buildings and structures	187	2.5	Motor vehicle accidents	166	2.2
All other classifiable	1709	22.9	All other classifiable	273	3.7
Nonclassifiable	241	3.2	Nonclassifiable	168	2.3
Nature of Injury			Part of Body Injured		
Sprains, strains	2047	27.5	Back	1329	17.8
Cut	1210	16.2	Finger(s)	826	11.1
Contusion	1021	13.7	Eye(s)	550	7.4
Fracture	857	11.5	Multiple Parts	448	6.0
Scratches	374	5.0	Foot (not ankle or toes)	397	5.3
Dislocation	189	2.5	Hand	375	5.0
Multiple injuries	155	2.1	Ankle	343	4.6
Hernia	150	2.0	Knee	314	4.2
Burn (chemical)	120	1.6	Chest	265	3.6
Burn (heat)	97	1.3	Shoulder	196	2.6
All other classifiable	739	9.9	All other classifiable	2324	31.2
Nonclassifiable	496	6.7	Nonclassifiable	88	1.2

Compiled from Bureau of Labor Statistics' Supplementary Data System [17].

hammer mills, grain dryers, bucket elevators, and scalpers) and are not individually categorized. Accident and injury data from these specific sources are frequently grouped by the SDS into categories such as "Not Elsewhere Classified."

A further difficulty encountered in the data base, when using it for analysis of accident causal factors, is that, by definition, the "source of injury" is the object identified as most responsible for causing the injury. This may, in fact, not be directly associated with the actual cause of the accident. For example, if a worker cuts his finger while using a saw, the "source of injury" is the saw, which also is the tool most clearly associated with the accident causal factor. However, if a worker falls from a ladder and fractures his leg on the floor of the facility, the "source of injury" is the floor, which probably contributed very little to the actual cause of the accident.

However, once the data constraints of the SDS reporting system are recognized, the information included can be applied to further identify some of the hazards associated with tasks, tools, and equipment used in grain elevators and feed mills. A computer analysis was performed on the four classifications of information reported to the SDS in 1976 - 1979. In the cross analysis, the "source of injury" was cross-tabulated with the "type of accident", "nature of injury", and "body part."

The analysis of the SDS accident/injury data was performed for 39 "source of injury" categories that identified tools/tasks/equipment used in feed mill operations and for 38 "source of injury" categories in grain elevator operations. A total of 10,226 injuries were reported to the SDS data base from the feed mill industry in 1976 - 1979; 7,370 were included in the cross analysis. A total of 7,455 injuries were reported to the SDS data base from the grain elevator industry in 1976 - 1979; 5,266 were included in the cross analysis. The remaining cases fell into categories that were not related to the industry, categories too general to be beneficial to the accident analysis, or "source" categories that were numerically/statistically insignificant. The results of the cross analysis of the SDS data are summarized in Tables 7 and 8. The total number of accidents/injuries appears in the "Source of Injuries" column. The numbers that define the "Type of Accident", "Nature of Injury", and "Body Part Injured" are the most frequent subcategories in each major heading and are not expected to total with the "Source of Injury" number. This information does not define actual accident causal factors; rather, it demonstrates relationships between tools and equipment used in grain elevator and feed mill operations and general accident and injury classifications.

D. FIRE AND EXPLOSION STATISTICS

The threat of dust fires and explosions and the corresponding severity of injuries and damage prompts the greatest safety concern in grain-handling and grain-processing facilities. Of all the industrial dust explosions in the United States, those in grain elevators are the most frequent and cause the most injuries and property damage [6]. According to Theimer [19], the National Fire Protection Association stated about 48 percent of the total number of dust explosions in the United States during the period from 1900 to

Table 7

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Feed Mill Industry (SIC 2048)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
<u>Boxes, Barrels, Containers, Packages</u>							
Containers, N	1010	Overexertion in lifting objects	624	Sprains, strains	780	Back	600
		Overexertion, N	128				
		Overexertion in holding	78				
Boxes, crates, Cartons	147	Overexertion in lifting objects	85	Sprains, strains	90	Back	68
				Contusion	20		
		Struck by falling object	19				
Barrels, keys, drums	118	Overexertion in lifting objects	31	Sprains, strains	35	Finger(s)	34
				Contusion	23	Back	24
		Struck by falling object	21	Cut	18		
				Fracture	17		
Boxes, barrels, containers, packages	99	Overexertion in lifting objects	65	Sprains, strains	77	Back	53
						Shoulder(s)	11
Bundles, bales	97	Overexertion in lifting objects	49	Sprains, strains	63	Back	38
						Abdomen	11
		Struck by falling object	19			Shoulder(s)	10
Tanks, bins	87	Struck against stationary object	14	Sprains, strains	28	Back	20
				Cut	20	Finger(s)	18
		Struck by, N	10	Contusion	12		
		Overexertion in lifting objects	10				
<u>Working Surfaces</u>							
Floor	478	Fall to the walkway	210	Sprains, strains	179	Back	87
		Fall from ladders	69	Contusion	110	Knee	53
		Fall to lower level, N	60	Fracture	93	Ankle	49
		Fall on same level	29			Multiple parts	49
		Fall on stairs	23				
Ground	445	Fall from vehicles	132	Sprains, strains	184	Back	81
		Fall to the walkway	95	Fracture	80	Ankle	67
		Fall to lower level, N	58	Contusion	76	Multiple parts	40
						Wrist	35
Working surfaces	170	Fall to the walkway	73	Sprains, strains	73	Knee	26
				Contusion	32	Back	25
						Ankle	22
Working surfaces, N	157	Fall to the walkway	46	Sprains, strains	62	Back	29
		Fall from vehicles	29	Contusion	35	Ankle	26
Stairs, steps	89	Fall on stairs	78	Sprains, strains	29	Back	16
				Contusion	28	Multiple parts	14

Table 7

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Feed Mill Industry (SIC 2048) (Continued)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
Metal Items							
Metal items, N	543	Struck by, N	95	Cut	187	Eye	117
		Struck by falling object	89	Scratches	96	Finger(s)	112
		Struck against stationary object	85	Contusion	87		
		Rubbed by foreign matter in eyes	75				
Metal items	259	Struck against stationary object	48	Cut	105	Eye	57
		Rubbed by foreign matter in eyes	33			Finger(s)	47
		Struck by, N	29				
Pipe	92	Struck by falling object	17	Contusion	25	Finger(s)	11
		Struck against stationary object	15	Cut	24	Foot	10
		Struck by, N	15	Sprains, strains	22		
Beams, bars	78	Struck by falling object	18	Contusion	30	Back	14
		Struck by, N	18			Finger(s)	10
Nails, spikes	61	Struck against stationary object	43	Cut	58	Foot	42
Vehicles							
Highway vehicles, powered	432	Overturned	76	Contusion	118	Multiple parts	78
		Struck against stationary object	60	Sprains, strains	93	Back	54
Handtrucks	259	Struck by, N	65	Contusion	91	Back	49
		Struck by falling object	53	Sprains, strains	88	Foot	38
		Overexertion in pulling objects	40				
Forklift	144	Struck by, N	36	Contusion	65	Foot	30
		Caught in, under, or between a moving and a stationary object	26	Fracture	20	Finger(s)	19
Vehicles	137	Struck against stationary object	30	Sprains, strains	39	Multiple parts	23
		Struck by, N	18	Contusion	26	Finger(s)	17
Rail vehicles	60	Struck against stationary object	16	Sprains, strains	23	Back	10
		Overexertion in pulling objects	13	Contusion	14	Finger(s)	10

Table 7

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Feed Mill Industry (SIC 2048) (Continued)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
Bodily Motion	600	Bodily reaction by involuntary motions	298	Sprains, strains	505	Back	226
						Ankle	109
		Bodily reaction by voluntary motions	217				
Handtools, Not Powered							
Knives	200	Struck by, N	165	Cut	190	Finger(s)	82
						Hand	35
Handtools, not powered, N	69	Struck by, N	27	Cut	32	Finger(s)	19
Hammers, sledges, mallets	67	Struck by, N	36	Contusion	22	Finger(s)	19
				Cut	16	Hand	11
Shovels, spades	61	Overexertion in holding	20	Sprains, strains	49	Back	42
Wrenches	57	Struck by, N	28	Sprains, strains	14	Back	13
Machines							
Machines, N	219	Caught in, under, or between	50	Cut	62	Finger(s)	87
				Contusion	45	Hand	29
		Struck against stationary object	41	Sprains, strains	39	Back	25
		Caught in, under, or between in-running or meshing objects	25				
Agricultural machines, N	77	Struck against stationary object	18	Cut	31	Finger(s)	16
				Sprains, strains	15	Hand	13
		Struck by, N	8			Back	10
		Caught in, under, or between, N	7				
Particles	211	Rubbed by foreign matter in eyes	157	Scratches	131	Eye	200
Wood Items							
Wood items	104	Struck by, N	16	Cut	27	Finger(s)	21
		Overexertion in lifting objects	11	Sprains, strains	19	Eye(s)	15
				Contusion	19	Back	12
Skids, pallets	91	Struck by falling object	30	Sprains, strains	30	Back	25
				Fracture	12	Foot	14
		Overexertion in lifting objects	13				

Table 7

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Feed Mill Industry (SIC 2048) (Continued)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
Conveyors							
Powered conveyors	137	Caught in, under or between, N	22	Cut	42	Finger(s)	49
		Caught in, under, or between in-running or meshing objects	21	Fracture	30	Head	10
		Struck against stationary object	15	Sprains, strains	22	Foot	10
Conveyors	56	Struck against stationary object	12	Cut	19	Finger(s)	18
		Caught in, under, or between, N	11	Contusion	15		
Buildings and Structures							
Doors, gates	123	Caught in, under or between, N	23	Contusion	36	Finger(s)	35
		Struck by, N	20	Cut	27	Back	14
		Struck against stationary object	20	Sprains, strains	26		
Buildings and structures, N	57	Struck against stationary object	23	Contusion	16	Finger(s)	7
		Fall onto or against objects	14	Cut	12	Chest	6
						Knee	6
Chemicals and Chemical Compounds, N	143	Contact by absorption	65	Burn (chemical)	48	Eye(s)	59
		Contact by inhalation	25	Scratches	22	Multiple parts	16
		Rubbed by foreign matter in eyes	23			Respiratory system	15
Grains and Grain Products	69	Overexertion in lifting objects	22	Sprains, strains	24	Eye(s)	17
		Contact by inhalation	8	Scratches	12	Back	17
		Contact by adsorption	8				
Flame, Fire, Smoke	67	Contact with hot objects or substances	53	Burn (heat)	53	Multiple parts	26
		Contact by inhalation	8			Respiratory system	8

Compiled from Bureau of Labor Statistics' Supplementary Data System [17].

Note: N = Not Elsewhere Classified

Table 8

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Grain Elevator Industry (SIC 5153)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
Working Surfaces							
Ground	485	Fall from vehicles	155	Sprains, strains	184	Back	116
		Fall to the walkway	85	Fracture	104	Ankle	76
		Fall on same level, N	54			Knee	40
Floor	279	Fall to the walkway	76	Sprains, strains	99	Back	60
		Fall from ladders	47	Fracture	59	Ankle	26
		Fall to lower level, N	33	Contusion	55	Multiple parts	22
Working surfaces, N	224	Fall to the walkway	54	Sprains, strains	66	Back	39
		Fall to lower level, N	39	Contusion	51	Ankle	38
				Fracture	48	Foot	21
Working surfaces	129	Fall to the walkway	52	Sprains, strains	55	Multiple parts	22
				Contusion	28	Back	19
				Fracture	27		
Stairs, steps	52	Fall on stairs	33	Sprains, strains	15	Mouth	9
				Contusion	14	Back	7
						Ankle	5
Metal Items							
Metal items, N	494	Struck by, N	116	Cut	224	Finger(s)	109
		Struck against stationary object	72	Scratches	72	Eye(s)	87
				Fracture	59	Hand	43
		Struck by falling object	67	Contusion	54		
Metal items	173	Struck against stationary object	28	Cut	71	Finger(s)	28
				Fracture	24	Eye(s)	26
		Struck by falling object	25	Contusion	21	Hand	17
				Sprains, strains	20		
		Struck by	25	Scratches	9		
Nails, spikes	117	Struck against stationary object	76	Cut	110	Foot	76
Beams, bars	67	Struck by, N	26	Contusion	21	Head	13
		Struck by falling object	16				
Pipe	43	Struck by falling object	10	Cut	19	Hand	9
				Sprains, strains	8	Back	8
		Struck by, N	10				
		Overexertion in lifting objects	8				

Table 8

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Grain Elevator Industry (SIC 5153) (Continued)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
Boxes, Barrels, Containers, Packages							
Containers, N	527	Overexertion in lifting objects	307	Sprains, strains	346	Back	269
		Overexertion	62				
Boxes, crates, cartons	66	Overexertion in lifting objects	32	Sprains, strains	22	Back	34
				Contusion	19	Chest	8
Barrels, kegs, drums	47	Overexertion in lifting objects	19	Sprains, strains	29	Back	24
Bundles, bales	47	Overexertion in lifting objects	27	Sprains, strains	27	Back	19
				Hernia	11	Abdomen	13
Tanks, bins	33	Struck against stationary object	5	Contusion	10	Back	9
		Overexertion in lifting objects	4	Sprains, strains	10	Finger(s)	5
Vehicles							
Highway vehicles, powered	340	Struck against stationary object	33	Contusion	82	Multiple parts	72
		Collision with oncoming vehicle	31	Fracture	79	Back	32
		Overturned	29			Chest	32
Handtrucks	75	Struck by falling object	17	Sprains, strains	28	Back	12
		Overexertion in pulling	12	Contusion	21	Chest	8
						Foot	7
Forklift	72	Struck by, N	13	Contusion	20	Foot	15
		Caught in, under, or between a moving and stationary object	12	Fracture	18	Toe(s)	8
Rail vehicles	59	Struck against stationary object	18	Sprains, strains	16	Back	11
		Struck by, N	9	Contusion	11	Leg	9
		Overexertion in pulling	6				
Bodily Motion	460	Bodily reaction by involuntary motions	197	Sprains, strains	348	Back	170
		Bodily reaction by voluntary motions	192			Knee	69
						Ankle	69
Machines							
Machines, N	148	Caught in, under, or between, N	45	Cut	37	Finger(s)	38
				Fracture	30	Hand	23

Table 8

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Grain Elevator Industry (SIC 5153) (Continued)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
Agricultural machines, N	89	Overexertion in lifting	16	Cut	20	Abdomen	14
		Caught in, under, or between in-running or meshing objects	12	Contusion	18	Toe(s)	13
		Struck by, N	12	Fracture	17		
Wood Items							
Wood items	96	Struck by, N	21	Cut	25	Finger(s)	16
		Overexertion in lifting objects	17	Contusion	22	Eye(s)	12
				Sprains, strains	20	Back	11
Wood items, N	58	Struck against stationary object	12	Cut	21	Eye(s)	14
		Rubbed by foreign matter in eyes	10	Scratches	13	Finger(s)	11
Lumber	51	Struck by falling object	16	Sprains, strains	12	Finger(s)	8
		Overexertion in lifting objects	7	Cut	11	Back	7
				Contusion	11		
Skids, pallets	30	Struck by falling object	17	Contusion	16	Foot	10
Handtools, Not Powered							
Handtools, not powered, N	57	Struck by, N	27	Cut	18	Finger(s)	11
						Lower leg	10
Hammers	43	Struck by, N	24	Cut	16	Finger(s)	15
				Fracture	10		
Shovels	43	Overexertion in holding	20	Sprains, strains	26	Back	22
Wrenches	42	Struck by falling object	13	Fracture	16	Chest	11
		Struck by	6	Sprains, strains	11		
		Overexertion in pulling	5				
Particles	169	Rubbed by foreign matter in eyes	123	Scratches	140	Eye(s)	155
Chemicals and Chemical Compounds, N	167	Contact by absorption	104	Burn (chemical)	90	Eye(s)	48
		Contact by inhalation	35	Poisoning effects due to toxic materials	10	Multiple parts	38
						Respiratory system	27
Conveyors							
Powered conveyors	88	Caught in, under, or between, N	16	Cut	26	Finger(s)	21
		Caught in, under, or	11	Sprains, strains	19	Back	10

Table 8

Summary of Cross-Analysis Tabulation of SDS Accident/Injury Profile, 1976-1979, for the Grain Elevator Industry (SIC 5153) (Continued)

Source of Injury	Number	Type of Accident	Number	Nature of Injury	Number	Body Part Injured	Number
Conveyors	58	Caught in, under, or between, N	12	Contusion	18	Finger(s)	14
				Cut	15	Back	8
		Overexertion in lifting objects	10	Sprains, strains	9		
Flame, Fire, Smoke	105	Contact with hot objects or substances	79	Burn (heat)	54	Multiple parts	64
				Multiple injuries	27		
Buildings and Structures (doors, gates)	99	Struck by, N	19	Contusion	29	Finger(s)	25
		Caught in, under, or between, N	12				
Grains and Grain Products	89	Contact by inhalation	31	Scratches	18	Respiratory system	32
		Rubbed by foreign matter in eyes	14	Sprains, strains	16	Eye(s)	21
		Overexertion in lifting objects	10				
Mechanical Power Transmission (chains, ropes, cables)	45	Caught in, under, or between, N	6	Fracture	8	Finger(s)	14
				Sprains, strains	8	Back	4
		Overexertion in pulling	4				

Compiled from Bureau of Labor Statistics' Supplementary Data System [17].

Note: N = Not Elsewhere Classified

1956 have occurred in industries handling grain, feed, and flour. Information presented by Chiotti and Verkade [6] for the 18-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 Chiotti and Verkade [6]. This USDA compilation includes 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 434 explosions in U.S. grain-handling facilities in the 25-year period from 1958 through 1982 which resulted in 776 injuries and 209 deaths [20]. Yearly explosions ranged from a high of 45 incidents during 1980 to a low of 8 incidents during 1961 and 1965. The number of deaths per year ranged from 0 to 65, but normally was 8 or less. Chiotti and Verkade and the USDA both reported the lack of an accurate, comprehensive, and uniform reporting system, indicating that many additional incidents may not have been recorded.

The probable ignition sources in the 250 explosion incidents (1958 through 1978) compiled by the USDA [1] are listed in Table 9. It is important 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 ignition source was reported on the basis of speculation by inexperienced investigators. Where the probable ignition source was reported, 43 incidents were attributed to welding or cutting. The next three most probable ignition sources are electrical failure, tramp metal, and fire other than welding or cutting. The probable locations of the primary explosions in the cases compiled by the USDA are presented in Table 10. The probable location is unknown in 107 of the 250 incidents. Where the probable location was reported, bucket elevators accounted for 58 of the 143 reported incidents (41%), followed by grinding equipment and storage bins in 17 (12%) and 13 (9%) incidents, respectively.

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.

E. SUMMARY AND CONCLUSIONS

The explosion hazard of grain dust has been known for many years. The U.S. Department of Agriculture has compiled a listing of 434 explosion incidents in grain elevators and feed mills in the United States over the 25-year period from 1958 through 1982. These incidents resulted in 776 injuries and 209 deaths. Explosions in recent years, with the attendant loss of life and injuries to personnel, have focused attention on these spectacular disasters. In addition, available BLS statistics indicate that feed mills (2048) had an average injury incidence rate of 14.8 and an average severity rate of 112.3.

Table 9

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

Reported by U.S. Department of Agriculture [1].

Table 10

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

Reported by U.S. Department of Agriculture [1].

From the statistics reported in this chapter, it appears that solutions for prevention of fire and explosion and reduction in work-related injuries are necessary.

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.

III. IDENTIFICATION OF THE HAZARDS

A. INTRODUCTION

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

B. FIRES AND EXPLOSIONS

1. Components of a Grain Dust Explosion

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

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

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

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

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

2. Dust Concentration

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

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

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

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

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

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Table 11

Explosive Properties of Common Grain Dusts [26]

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

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

3. Ignition Source

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

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

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

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

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

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

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

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

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

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

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

by the existing fire. A series of explosions propagated throughout the

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

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

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

4. Oxygen Concentration

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

5. Mixing of Dust

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

6. Confinement

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

C. GENERAL INDUSTRIAL HAZARDS

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

1. Facility Interfaces

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

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

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

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

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

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

2. Equipment Interfaces

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

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

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

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

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

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

3. Vehicles and Lifting Equipment

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

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

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

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

4. Manual Handling

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

5. Confined Spaces

Entering and working in confined spaces such as bins, tunnels, tanks, and pits are common. Accessibility and maneuverability are frequently difficult, and there may be a lack of direct communication to standby personnel. Dust in suspension may limit visibility and necessitate the use of dust masks or respirators. These conditions tend to magnify an occurrence which normally might be a minor incident [44].

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

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

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

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

6. Health Hazards

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

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

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

IV. SAFE WORK PRACTICES, ENGINEERING CONTROLS, AND TRAINING NEEDS

A. 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 methods of achieving the goal, and the criteria upon which the recommendations are based, are addressed where applicable.

B. 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 [49, 50]:

- 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 protective devices, or from other causes; or (3) in which combustible dusts of an electrically conductive nature may be present.

- Class II, Division 2--A Class II, Division 2 location is a location: (1) in which 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 apparatuses; or (2) in which 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 apparatuses.

Combustible Dust. A dust which may explode or burn when subjected to a source of ignition in the presence of atmospheric oxygen.

Confined Space. A space which by design has limited openings for entry and exit, unfavorable natural ventilation which could contain or produce dangerous air contaminants, and which is not intended for continuous employee occupancy. Confined spaces include but are not limited to storage tanks, compartments of ships, process vessels, pits, silos, vats, degreasers, reaction vessels, boilers, ventilation and exhaust ducts, sewers, tunnels, underground utility vaults, and pipelines.

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 beyond the confinement capability of 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, weigh, sample, and clean grain; to direct grain to bins or conveyors, or to perform other operations. The terms "headhouse" and "workhouse" are usually interchangeable, 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 [49].

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.

C. TRAINING

Occupational hazards are caused by the interaction between workplace, machines, and humans.

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 [51-57]. 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 hazards of dust explosions, 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 ensure 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.

D. SAFETY PROGRAM AND ENGINEERING 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 [58, 59]. 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 performed 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.

As a part of an effective safety program, management should:

- Ensure compliance with safety and health regulations
- Establish an effective training program
- Establish emergency preparedness plans
- Establish necessary controls for visitors and outside contractors
- Ensure that a comprehensive dust control program is developed and implemented
- Ensure that the safe work practices contained in the report are evaluated and applied where applicable

- 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

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

- Establish and enforce general safety rules. Rules should address use of smoking materials, 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.

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, review accident reports, and perform other safety-related functions.

E. EMERGENCY PLANNING

The value of emergency planning as a means of conserving life and property is generally recognized throughout industry [36, 60-62]. 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 and should also have an awareness of how to deal with a fire in a grain-handling facility.

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 [49] 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 geographic 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, the following:

- Methods and responsibilities for reporting emergency conditions. Provisions for prompt reporting of emergencies should always be a primary consideration. Protective signaling systems 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, continuously manned location.

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

- Location of firefighting, medical, and other emergency equipment

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

- 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 [49]. Specific training in fighting grain fires should be included.

- Methods and responsibilities for accounting for workers, visitors, or contractor personnel who may be in or immediately around the facility

A means of informing workers of an emergency should be an integral part of the emergency plan [36, 61, 63]. An employee alarm system must be provided, maintained, and tested in accordance with 29 CFR 1910.165 [49].

For the emergency plan to be effective it must be thoroughly understood by all affected personnel [36, 61, 63]. 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 the rate of employee turnover.

F. 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 personal 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 [51, 58, 64-66].

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, the 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 [58, 64, 65].

Protective equipment should 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 upon 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 should be 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 for the equipment and if 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 the equipment 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.

1. 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 [49]. Protective headgear should be visually inspected before each use and repaired or replaced when cracked, chipped, or otherwise damaged.

2. 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 [49]. Persons engaged in welding and cutting operations must use goggles and shields in accordance with 29 CFR 1910.252 [49]. Contact lenses should not be worn in grain-handling or milling areas where airborne dust is present. Protective equipment should be visually inspected before each use for loose, scratched, pitted, or otherwise damaged components that may reduce protection or obscure vision.

3. Respiratory Protection

Appropriate respiratory protective equipment is needed whenever personnel are exposed to particulate, gas, or vapor contaminants exceeding the permissible exposure limits (PEL's), 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/MSHA approved devices and be fitted, used, and maintained in accordance with 29 CFR 1910.134 [49].

Dust masks for protection from particulate contaminants are the most frequently used respiratory devices in grain-handling and grain-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 apparatuses are needed in oxygen-deficient atmospheres.

4. Fall Protection

Safety belts or harnesses are needed whenever employees are required to work at elevated stations 6 feet or more above grade level and are not otherwise protected from falls [67]. The belts or harnesses should 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. 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, "Requirements for Safety Belts, Harnesses, Lanyards, Lifelines, and Drop Lines for Construction and Industrial Use" [68]. 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.

5. 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 [49]. 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 to limit exposure.

6. Foot Protection

Personnel exposed to potential foot injuries as the result of impact from falling or rolling objects should be provided with protective footwear. 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 [49].

7. 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

Protective gloves may be required to protect workers exposed to sharp or abra-

irritating chemicals. Other specialized gloves should be worn when hands are exposed to hazards such as electrical shock or thermal extremes.

8. 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 (29 CFR 1926.106) [69].

G. SAFE WORK PRACTICES

1. Dust Control

A comprehensive dust-control program is central to the control of fires and explosions in grain-handling and grain-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 [2, 19, 25, 70].

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, airborne and layered dust are complementary. Layered dust cannot be adequately controlled if airborne dust levels are excessive. Dust concentrations at grain transfer points and within handling and processing equipment should be maintained below the lower explosive limit. Airborne dust control should be such that, in conjunction with housekeeping activities, layered dust levels do not become excessive such that if made airborne the concentration would not exceed the lower explosive limit. 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 [49].

Good housekeeping is probably the single most important factor in reducing the risks associated with secondary 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, can 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 [19, 25, 53, 71, 72]. This layered dust need not be in open areas but may be hidden within bins and equipment. Although the value of good housekeeping should be recognized throughout the industry, there is no consensus of what constitutes a clean plant. Several sources, including the Canadian Grain Handling Association and Factory Mutual Research Corporation, recommend that layered dust levels should not exceed 1/8 inch, with the provision that every effort be made to do better [53, 71, 72].

Although the 1/8-inch limit, if maintained, would improve cleanliness levels in many facilities, it is considered excessive since dust accumulations as little as 1/64 inch could support secondary explosions if uniformly dispersed into the air [2, 21, 25, 73]. Because of the importance attributed to cleanup, it is recommended that thorough cleanup of floors, stairs, ledges, girders, machinery, spouting, and other surfaces within grain-handling and grain-processing areas where dust may accumulate be accomplished at least daily. The National Academy of Sciences [2] recommends, as a guideline, that layered dust in each gallery, tunnel, and workhouse not exceed 1/64 inch and if made airborne the concentration would not exceed 40 g/m^3 (0.04 oz/ft^3) for the total volume of the area. Grain spills would not be considered when using this guideline, only material that will pass through a 200-mesh screen (74 microns or smaller in diameter). 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 [53]. When possible, dust should be cleaned up whenever visible tracks are recognized. The housekeeping program should 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 as 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 central vacuum system. Portable vacuum systems can be used, but they are usually less efficient and can be difficult to maneuver around equipment. Vacuums should be acceptable for use in Class II, Group G, locations [74]. Vacuum cleaning systems are preferred for removal of static dust on surfaces in order to prevent resuspension of the dust in the air as is caused by brushing down with brooms or using compressed air ("blowing down") [2, 74]. If brooms are used for cleaning layered dust, they should be soft, and generation of excessive airborne dust should be avoided. If compressed air is used in facilities for "blowing down" surfaces and equipment which are not otherwise easily accessible, this must be done only after shutting down and isolating or locking out energy to equipment in the area and eliminating other possible ignition sources. Cleaning with compressed air should only be used to remove light films of dust where other means are not possible [75]. 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, maintained, and operated, effectively control dust levels at conveyor transfer points, distributors, cleaners, and other areas of turbulence [76]. Pneumatic systems use bag

cleaners, and other areas of turbulence [76]. 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 away from personnel to reduce their exposure to the explosion hazard.

Guidelines for the safe design, operation, and maintenance of pneumatic dust-collection systems are contained in the NAS report, "Pneumatic Dust Control in Grain Elevators: Guidelines for Design Operation and Maintenance, NMAB 367-3" [76]. 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 at accessible locations in dust collectors are recommended to aid in verification of proper system operation. Pressure taps on branch ducts 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. In addition, enclosed belt conveyors are 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 effective means of reducing airborne dust levels include speed reduction and the use of deeper troughs on belt conveyors, speed reduction and the use of larger capacity buckets on bucket elevators, the use of choke feeding at discharge points, the use of pressurization systems, the use of air aspiration systems, and the use of venting systems on scales, garners, and bins.

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 explosion problem, since not all of the dust is removed from the grain and repeated handling generates additional dust [60, 77]. Other organizations recommend complete removal of all collected dust from the facility, a practice followed in grain elevators in Australia [75]. A strict dust control program, including the practice of not returning dust to the grain stream at any stage, and efforts in removing the possibility of ignition sources are thought to be the major reasons that Western Australia has not had a grain dust explosion over the past 50 years [78]. Their relative success compared to the United States may partly depend on the smaller number of facilities, the smaller volumes of grain handled, and the types of grain handled [1].

The U.S. Department of Agriculture believes that this single practice of not returning dust to the grain stream could significantly reduce the magnitude of the current explosion problem. Dust collected in bag filters usually contains a high percentage of very fine particles at reduced moisture content, which is easier to ignite and potentially more destructive. Since removal of this fine, artificially dried dust should alleviate the problems [1, 54, 60, 74], dust should not be reintroduced to the grain stream in grain elevators where it may be rehandled in the facility. 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.

2. 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. 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 controls. Use of a permit system is one effective control measure [52, 60, 79-82]. 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 by support personnel to indicate that they are aware of the potential hazards and safe work practices that should 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 grain-processing facilities [19, 53, 60]. Prior to issuing a permit, the supervisor or qualified person should determine whether the work can 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 minimize or eliminate the need for hot work. Although these alternate techniques are not always practical, they should be considered and evaluated prior to issuing the permit [53, 60, 79].

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 should 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 [82, 83]. Workers should receive training in proper use, maintenance and inspection of welding 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 should 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 an area that has a hazard classification of Class II, Group G [3, 53, 60, 79, 81]. 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, must 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, the area has been inspected for residual heat and smoldering fires, and the equipment has been approved for restart.

Combustible materials within 35 feet of the work area must be removed (29 CFR 1910.252) [49]. 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 should be taken to protect combustibles such as plastic spout liners, leg belts, and cups 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 (29 CFR 1910.252) [49]. When hot work is elevated, the area under this, accounting for the wind draft of the slag and sparks, should be similarly cleaned. Cleanup should 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 should be thoroughly cleaned or protected from high temperatures. Where hot work is performed near walls or floors, adjacent areas should also be inspected and cleaned. Wall, floor and other openings must be sealed where sparks or slag may reach.

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 or she should be advised that hot work has taken place.

Welding, cutting, and brazing equipment should be used in accordance with the manufacturers' 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 [49].

3. Smoking, Open Flames, and Hot Surfaces

Flames are potent sources of ignition for dust suspensions [84]. Since flames can ignite dust suspensions and smoldering materials are easily converted into flames, it is universally agreed that smoking, smoking materials, or open flames should not be allowed in grain-handling, grain-storage, and grain-processing areas, or in immediately adjacent areas [23, 36, 60, 63, 85, 86].

Smoking may be permitted in areas specifically designated by management and isolated from ignition-susceptible areas, 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 should be clearly marked and smoking rules must be strictly enforced.

Heating equipment should 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) [74].

4. 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 [23, 55, 60, 63, 87-89].

A program of regular surveillance and preventive maintenance should be implemented at all plants to facilitate uninterrupted and safe 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, the equipment, and its use. Requirements should follow manufacturers' 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 [52, 54, 55, 88, 89].

Recordkeeping requirements also vary between facilities. Written records 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 when detected; however, this practice should be used to supplement a maintenance program, not replace it [51, 55, 60, 63, 87-89]. Inspection and maintenance should be performed only by trained and authorized personnel.

5. 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 confined spaces clearly indicate the need for strict control measures. According to the literature [42, 44, 45, 61, 90-93], 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 pre-entry 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 should 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 should 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 may, over a period of time, reduce the oxygen content below safe levels or generate toxic materials. The need for atmospheric evaluation prior to confined space entry is reflected throughout the literature [42, 44, 45, 61, 90-93].

Confined spaces should be thoroughly ventilated 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 to ensure that the atmosphere is safe. Testing is needed to determine oxygen content, flammability, and presence of toxic materials [44]. 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 should not be made unless appropriate respiratory protective equipment is worn.

Another major hazard associated with storage vessels is entrapment in flowing grain, which can lead to suffocation of personnel. 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 rapidly. 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 should not be fed into or drawn from bins which are occupied. Fill and discharge equipment, as well as equipment inside the confined space, should 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 [45, 61, 90, 94, 95]. Many fatalities in confined spaces can be directly attributed to a lack of communication 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 [44, 45, 61, 90-94]. 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 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% [44]. Other protective equipment and clothing may also be needed. Hard hats are needed 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 should be approved for the atmosphere in which it is to be used.

6. Isolation and Lockouts

Many 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 [41, 51, 58, 61, 65, 96, 97]. Documented procedures ensure that the isolation technique is clearly defined and uniformly applied. Verification by a supervisor or other qualified person further ensures that the procedures are correctly applied and the isolation technique has been effective in isolating and/or dissipating hazardous energy.

For isolation procedures to be effective, energy should be isolated or blocked at a point or points of control that cannot be bypassed. The point of control should be secured by a device or technique which prevents unauthorized persons from reenergizing the equipment or machinery. Stored energy that constitutes a personnel hazard should 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 grain-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 should be kept on his or her person at all times. When two or more employees are engaged in an operation that requires a lockout, each individual should have his or her own lock which has been installed in such a manner that the isolation device cannot be removed until each employee has removed his or her 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 needed. 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 should be recognized and controlled by isolating, blocking, or otherwise neutralizing the energy. After the isolation procedure has been completed, an attempt should 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 should be evaluated by a qualified person and procedures should 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 should 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.

7. Machine Guards

Machinery with rapidly moving external components are 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 should 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 [4, 51, 52, 54, 61, 65, 96].

Safeguards should 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 should never be operated without guards. Point of operation guarding should 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 that are 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 should comply with the requirements contained in 29 CFR 1910 Subpart O [49].

8. 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 [51]. Signs and/or labels should be provided whenever failure to recognize the condition could result in an unsafe action.

To be effective, signs should 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 vary depending on the application. Recommendations should 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 have 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 [49].

9. Other Safe Work Practices

a. Lightning Protection

Lightning has been reported as the probable cause for some dust explosions in grain-handling and grain-processing facilities [1]. Facilities in areas exposed to a substantial risk from lightning should have a lightning protection system. Guidelines for risk assessment and installation of lightning protection systems are contained in NFPA 78, "Lightning Protection Code" [98].

b. 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 [99] reported 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 that may result in generation of sparks [23, 60, 62, 63, 72, 84, 100].

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 gratings do not remove all foreign materials, they are effective in removing larger materials regardless of composition. The spacing of a grating should be as small as possible consistent with the commodity being handled. Spacing of 1 1/2 inches is often recommended [100, 101]. Some facilities, however, require a spacing of 2 1/2 inches or more to accommodate special handling rates [102]. It is recommended that the receiving leg feeds be protected by a grate where the greater dimension is less than the cup projection and the lesser dimension is 1/2 the cup projection [2].

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, installed, and maintained. 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 materials are used.

In feed mills or grain elevators where equipment for grinding, pulverizing, and similar operations is used, additional precautions are needed [23, 63, 84, 85, 102]. 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 (that may result in generation of sparks) larger than the grain being processed. Equipment used to collect or separate foreign materials should be kept in good repair and cleaned regularly.

c. Walking/Working Areas

Slips and falls traditionally have accounted for a high percentage of injuries in grain elevators and feed mills [17]. 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 [4, 43, 103, 104]. Work areas should be kept free of debris which could cause slips, trips, falls, fires, or other accidents. 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 [61, 65]. 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 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. Other general requirements for means of egress are contained in 29 CFR 1910 Subpart E [49]. Specific recommendations for egress in grain elevators are contained in NFPA 101, "Code for Safety to Life from Fire in Buildings and Structures" [105].

d. 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 ignition source in over 40 percent of the reported explosions is unknown [1], and the presence of static electricity is difficult to trace following an explosion.

The extent of problems associated with electrostatic charges has been the subject of numerous investigations; however, valid predictions for practical applications have not been made. Dahn [106] found that although grain can accumulate moderate amounts of electrostatic charges when moving across spouts and chutes, such charges dissipate quickly when the grain comes into contact with a device or structure that is well grounded. It was also noted that if equipment is poorly grounded or isolated from ground, a potentially hazardous situation might quickly develop. The approach suggested by most professional sources is to assume that static charges will be generated; therefore, precautions should be taken to minimize the hazard [23, 60, 61, 63, 72, 84, 85]. Palmer [84] indicates that dusts with a minimum ignition energy of less than 25 millijoules should be regarded as prone to ignition by static electricity. This value 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 grain-processing facilities are pneumatic conveyors and bucket elevators. Necessary precautions for these conveying systems include electrical bonding and grounding of frames and casings [23, 60, 61, 63, 72, 85]. 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 degree 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 [107]. 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, "Recommended Practice on Static Electricity" [108].

e. Hazardous Materials Storage

Toxic materials, explosives, flammable and combustible fluids, and gases and other hazardous materials should be stored in suitable containers with their contents clearly identified. Hazardous materials should be stored outside the facility in detached buildings or approved tanks.

H. EQUIPMENT AND TOOLS

1. Bucket Elevators

Statistics indicate that bucket elevators are by far the most hazardous equipment, with respect to dust explosions, found in grain-handling and grain-processing facilities [1, 2].

More primary explosions have occurred in bucket elevators than in any other known location. Investigations have indicated that elevator legs routinely contain amounts of dust which exceed the lower explosive limit [2, 109]. 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 from sparks generated by metal components striking the casing [23, 60, 109, 110].

Bucket elevators should be located outside the facility where possible. In bucket elevators, belt speed monitoring devices are needed to detect belt and pulley slowdown and to allow corrective action to be taken before frictional heating ignites the belt or grain [60, 61, 102, 109-111]. 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, simple devices which monitor belt and pulley speed are usually adequate. Manual shutdown can be accomplished or it can be done automatically by sending a signal to a device which turns off power to the drive motors. To prevent unnecessary shutdowns, a 30-second 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 should be established to ensure 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 should 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 [71, 109, 112]. 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 [109].

If a choked leg does occur, the problem should 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 [61, 110]. 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 should be checked for damage after it is cleared and repaired if necessary. Belt movement should be monitored during startup. Power to the drive motor should 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 [60, 102, 109, 110]. Bearings should be located on the outside of the leg casing. 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 clean-out 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 should be used to assist in early detection of equipment malfunctions [2].

Exterior bucket elevators 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 [23]. Research conducted by Gillis [113] 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, "Guide for Explosion Venting" [114].

2. 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, 23]. 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 [23].

Necessary precautions should 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 cause 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 should 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, using temperature limit controls and alarms, monitoring operation, instructing operators on safe operation of the dryer, and periodically inspecting and performing maintenance are included in NFPA 61B, "Standard for the Prevention of Fires and Explosions in Grain Elevators and Facilities Handling Bulk Raw Agricultural Commodities" [74].

3. Electrical Equipment

The need for controls on the use of electrical equipment in grain elevators and feed mills is reflected throughout the literature [23, 53, 60, 63, 84, 87, 100, 102]. 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 [23, 53, 84].

Safeguards from hazards associated with the use of electricity are included in 29 CFR 1910 Subpart S [49]. 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. In general, equipment, and methods of wiring and installing equipment in Class II, Divisions 1 and 2 locations in grain elevators and feed mills should 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 NFPA 70, "National Electrical Code" (Articles 500 and 502) contains design, installation, and maintenance guidelines for "dust-ignition-proof" equipment which is safe for use in Class II, Divisions 1 and 2 locations [50]. Equipment should 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 (329°). "Explosion-proof" equipment may not be acceptable for use in grain-handling and grain-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 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 should be provided to detect malfunctions of the pressurization equipment. Guidelines for the design of pressurized enclosures are contained in NFPA 496, "Standard for Purged and Pressurized Enclosures for Electrical Equipment in Hazardous (Classified) Locations" [115].

In addition to compliance with 29 CFR 1910 Subpart S [49], special precautions should be taken when using portable lighting inside of equipment. When portable lighting must be lowered into bins, pits, bucket elevators, or other equipment or enclosures containing dust, care should be taken to prevent damage to the light or cord. Lighting should not be supported by the electrical cord unless so designed for that purpose. The light should 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, 83]. Equipment such as bucket elevators should not be operated while lights are inside so as to prevent entanglement and shorting of the light or cord. Lights should not be lowered into bins when materials are being withdrawn in order to prevent the light from being drawn into the material and becoming 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.

4. 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 should be instructed in the proper use of manlifts to ensure that they are familiar with the precautions that should be taken for safe operation [4, 58, 61, 116].

Manlifts should be used for conveyance of personnel only. Transportation of freight, packaged goods, sacks, and other materials on manlifts should be avoided since it may prevent the operator from using the manlift safely. In addition, 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. 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 should be avoided.

Guards should 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 [49]. 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. Emphasis should be made to employees against transporting equipment and unsecured or protruding tools on manlifts. 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.

5. Hand and Portable Power Tools

Proper selection and use of hand and portable power tools are necessary in any industry to minimize worker injuries. It is important to use tools properly, keep them in good repair, and perform periodic inspection and maintenance [51, 52, 58, 117].

Tools should 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 should be repaired or discarded. Periodic verification of the grounding system is necessary on electrical equipment, as well as inspection of cords and plugs for defective insulation or other damage. Employers and employees share the responsibility 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 any protective equipment that is required.

Portable power tools, when used, must comply with the requirements contained in 29 CFR 1910.243 [49]. Portable electrical tools must be in accordance with 29 CFR 1910 Subpart S [49]: 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 should not be used. Electrical tools should not be used in Class II locations unless dust in the work area has been cleaned up thoroughly and dust-producing equipment in the vicinity has been shut down.

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 should 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 [45]. When pneumatic power is used, care should be taken to ensure that the tools and associated hoses and fittings are compatible with the pressure at which they are being used.

Nonsparking shovels and other hand tools are used in some grain-handling and grain-processing facilities, although statistics indicate the degree of risk associated with ordinary tools is low. Cross [118] reported that available accident data are not statistically significant for completely addressing metal sparks as an ignition source. She 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 involving malfunctioning equipment and foreign material are a hazard. The use of nonsparking tools in confined, dusty locations is recommended by some sources [45, 90, 91] as a precautionary measure. A blanket recommendation for nonsparking tools cannot be justified.

6. Industrial Trucks

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 [49]. Powered trucks used in Class II, Group G locations must be designated for use in these locations and be labeled or marked to indicate the approval of a recognized testing laboratory.

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 should contain appropriate safeguards for both the operator and other personnel. Procedures for safe operation, inspection, and maintenance should be established. Trucks should always be operated within their design capacities and perform only those 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 buildings and other enclosures. Only properly trained and authorized personnel should operate or service industrial trucks [51, 119-121].

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.

7. Ladders and Scaffolds

Ladders and scaffolds are frequently used for maintenance and repair operations in grain-handling and grain-processing facilities. Ladders are also commonly used for normal access between work levels and emergency escape routes. Accidents may be caused by climbing or descending improperly, over-reaching, 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 should be taken to prevent accidents [37, 51, 58, 122].

Portable ladders should be structurally sound, adequately secured, and properly sized for a specific task. Both tops and bottoms should 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 should 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, repaired expeditiously, or removed to prevent inadvertent use. Portable ladders must meet the care and use requirements contained in 29 CFR 1910.25 and .26 [49].

Devices designed to prevent uncontrolled falls are needed for fixed ladders over 20 feet (6 m) in unbroken length (29 CFR 1910.27) [49]. 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 should be inspected regularly for loose, worn, or damaged parts and comply with the requirements in 29 CFR 1910.27 [49]. 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 (29 CFR 1910.28) [49]. Guardrails or other safety devices are required where workers are exposed to falls of 10 feet (3 m) or more (29 CFR 1910.28) [49]. Safety belts or harnesses in conjunction with lifelines are needed for workers on suspended scaffolds or platforms. Lifelines should be attached to a secure point other than the scaffold. Scaffold decking should be secure and provide adequate traction. Scaffolds must 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 [49].

8. Compressed Gas Equipment

Compressed gas is frequently used for cleaning, powering pneumatic tools, and for other applications in grain-handling and grain-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, or cause other serious injuries [39, 51, 58]. Respiratory and eye protective equipment should always be provided to prevent particles from entering the worker's eyes or mouth when using compressed air for cleanup.

Equipment in the area should be shut down and other potential ignition sources eliminated before dislodging dust.

Caution should also be exercised when using compressed gas cylinders. Cylinders should be clearly marked or color coded to identify the contents. Cylinders should be protected from damage during storage and handling. Cylinders should be stored where they are not exposed to excessive heat or moisture, and flammable gases should be stored away from main buildings. Cylinder valves should be turned off when not in use and valve protection caps should be in place. Cylinders and compressed air receivers must have relief devices installed and meet the requirements contained in 29 CFR 1910 Subpart M [49]. Cylinders used in welding, cutting, or brazing must meet the additional requirements contained in 29 CFR 1910.252 [49]. Only trained and authorized persons should interface with compressed gas equipment.

9. 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 should be secure and stable and equipment should be inspected and maintained in accordance with manufacturers' recommendations. Equipment should only be used by personnel thoroughly instructed and trained in its use [51, 58].

Equipment must be used within its rated capacity [49]. All equipment, including slings, cables, ropes, hooks, and other attachments should be visually inspected for defects prior to use. Also, brakes should be tested before lifting. Loads should be adequately secured and balanced to prevent materials from becoming disengaged. Operators should verify that all personnel are clear of the lifting area prior to raising a 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 [49]. Hoists should 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 should be secure. The boatswain's chair should be attached by four legs to obtain stability in a manner which ensures positive engagement. Safety belts or harnesses with lifelines should be provided for personnel using boatswain's chairs.

All hoisting operations should be conducted by trained personnel. Experienced persons should be designated to supervise the operations. 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 may operate hoisting equipment for the purpose of lowering 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.

demonstrate their ability to use the equipment to the satisfaction of the

I. FIRE PROTECTION

1. Portable Fire Extinguishers

Portable fire extinguishers in a fully charged and operable condition must be provided throughout all buildings, unless employees are specifically instructed not to fight fires and to evacuate the facility if a fire occurs (29 CFR 1910.157(b)) [49]. Portable fire extinguishers provided for employee use must meet the requirements defined in 29 CFR 1910.157 [49] to ensure that the extinguishers are readily available and in good operating condition. Training is essential for employees required to use extinguishers and other fire fighting 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. Foam extinguishers are sometimes recommended to minimize dispersal of dust when fighting fires.

2. Standpipes and Hoses

Wet or dry standpipes and hoses should be installed in all areas located more than 75 feet above ground level in which combustible materials other than grain are stored [72, 74]. Dry standpipes are usually recommended to prevent freezing in cold weather and loss of facility water supplies if pipes rupture in an explosion. Standpipes should be provide with 1 1/2-inch hose lines and combination fog/straight stream nozzles. Where standpipes are provided, they must meet the requirements in 29 CFR 1910.158. [49]

3. Automatic Sprinklers

Automatic sprinkler systems are recommended in areas containing combustible construction or equipment [53, 72]. Where sprinkler systems are provided, they must meet the requirements in 29 CFR 1910.159 [49].

4. Hydrants

Either public or private hydrants should be provided for fire fighting use. Hydrants should be supplied by an adequate water supply [74].

5. Explosion Suppression

Explosion suppression systems are available for use in areas such as bins, distributors, tanks, dust collectors, etc. The use of these systems should be considered in unusually hazardous areas (e.g. elevator legs), in dust collection systems, and in locations where other means of control are not necessarily suitable [74]. Where explosion suppression systems are provided, they must meet the requirements in 29 CFR 1910.160 and .162 [49].

6. Fire Fighting Operations

Initially, the contents and the extent of the fire should be determined. If the fire involves equipment, the general procedure should be to shut down the equipment, isolate the fire if possible, extinguish and remove any burning material, and inspect for damage before restarting the equipment.

With dust fires, it is of critical importance to avoid extinguishing methods which spread or disperse the dusts into suspension. The use of water from a hose under high pressure may throw large quantities of dust into suspension and raise an extreme risk of explosion. Fire fighters should exercise caution in fighting grain dust fires. Some sources recommend the use of water applied as low pressure fog or fine mist although one case is known where this resulted in the dispersal of burning dust and a subsequent explosion. Until better extinguishing methods are developed, and where it can be done safely, it may be better to carefully remove burning grain and dust from the grain facility by using buckets and shovels and then complete the extinguishment of the burning grain outside the facility [2, 74, 123-126].

J. 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 (29 CFR 1910.151) [49]. 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.

V. NATIONAL AND INTERNATIONAL STANDARDS APPLICABLE TO GRAIN ELEVATORS AND FEED MILLS

A. 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 (Table 12).

B. OSHA GENERAL INDUSTRY STANDARDS

The General Industry Safety and Health Standards (29 CFR 1910) of the Occupational Safety and Health Administration are broad-based standards [49]. As such, they address many areas of general safety which grain-handling and grain-processing facilities share with all industry. Although the general industry standards do not address grain elevators and feed mills specifically, 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, man-lifts, 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 [49] 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 either not addressed or lacking in sufficient coverage with respect to requirements for grain elevators and feed mills, where applicable, include the following:

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

- 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.

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

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

- 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.

- Dust control. Comprehensive requirements for dust control should be addressed.

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

C. 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 [74, 127]. These standards were developed primarily as guidelines for designers and operators building new facilities or making major modifications. Although some operational considerations are included, the majority of the guidelines are design considerations for facilities and equipment. Many of these guidelines are consistent with the recommendations contained in this report.

D. INTERNATIONAL STANDARDS

Alberta Province Occupational Health and Safety Regulations (Alberta, Canada) contain an addendum covering grain elevators and feed mills [128]. 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 [129]. 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 12

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
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

TABLE 12

Cross-Reference of Recommended Safe Work Practices for Grain Elevators and Feed Mills to the OSHA Standard (Continued)

RECOMMENDED SAFE WORK PRACTICE	OSHA STANDARD
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
Fire Protection	1910.37(m) 1910.157 1910.158 1910.159 1910.160 1910.162 1910.181(j)(3) 1910.252(d)
Hand and Portable Power Tools	1910.242(a) 1910.243(a)(5) 1910.243(b)(2)

TABLE 12

Cross-Reference of Recommended Safe Work Practices for Grain Elevators and Feed Mills to the OSHA Standard (Continued)

RECOMMENDED SAFE WORK PRACTICE	OSHA STANDARD
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)
	1910.252(b)
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

VI. SAFETY RESEARCH NEEDS

A. INTRODUCTION

Recommendations for research in several areas where additional study should prove beneficial are contained in this chapter.

B. RESEARCH RECOMMENDATIONS

1. Dust Control

The value of dust control in grain elevators and feed mills should be recognized throughout the industry. Housekeeping is thought by many to be the most important factor in reducing the risks associated with secondary 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 should be cleaned up. Other literature indicates that accumulations should not exceed 1/64, 1/16 or 1/8 inch. 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 measure airborne dust levels at grain transfer points and 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. Although monitoring devices for dust concentrations [25] have been developed, additional testing of the device on a large scale basis with numerous types of grain would be desirable. This testing and the development of additional 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 grain-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

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.

The synergistic effect between grain dust and fumigants has also been suggested as a factor contributing to explosions in grain elevators and feed mills. There is an indication from some of the research conducted that the minimum amount of energy required to ignite fumigated grain dust may be reduced due to the presence of fumigants. One of the problems with grain dust is there are many marginal but possible ignition sources. Additional investigation is needed to determine the difference in ignition energies between various grain dusts and dusts with fumigants added.

A detailed comparison of the grain-handling operations of the United States and Australia should be conducted with respect to volumes and types of grain handled, dust control, and equipment safety devices. This information could then be used to determine the feasibility of applying the operational and safety techniques which have proved successful in Australia to United States grain-handling facilities.

2. 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 any location where dust is present can be hazardous under certain conditions, bucket elevators are exceptionally hazardous. 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. The possibility of removing the suspended dust should be considered. Various safety features such as interlocks, alignment devices, speed monitors, and choke detectors should be examined.

3. 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 (with the exception of recently completed research concerning venting of bucket elevators) [113] and the needed relief area are often poorly defined or conflicting, especially for large height-to-diameter configurations.

The practice of extending bucket elevator casings above the roof is common; however, most experts concede that this practice is not fully effective because of the rapid pressure rise rate associated with most explosions [2]. Recommendations for venting of storage bins also vary widely. Effective venting of existing 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. Venting should be considered on a large scale in new construction; i.e., the entire side of a headhouse or gallery. Little information is readily available on such a large vent configuration. 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.

4. Fire Extinguishing Methods

Extreme caution must be exercised in fighting grain dust fires. It is important to avoid extinguishing methods which might spread or disperse the dust into suspension, thereby raising the risk of explosion. Effective methods need to be developed for extinguishing grain and grain dust fires in order to eliminate this risk. In addition, deep-seated fires in grain bins pose special problems that need to be adequately addressed by developing effective extinguishing methods.

5. General Safety Studies

The need for additional investigation 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.

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