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.

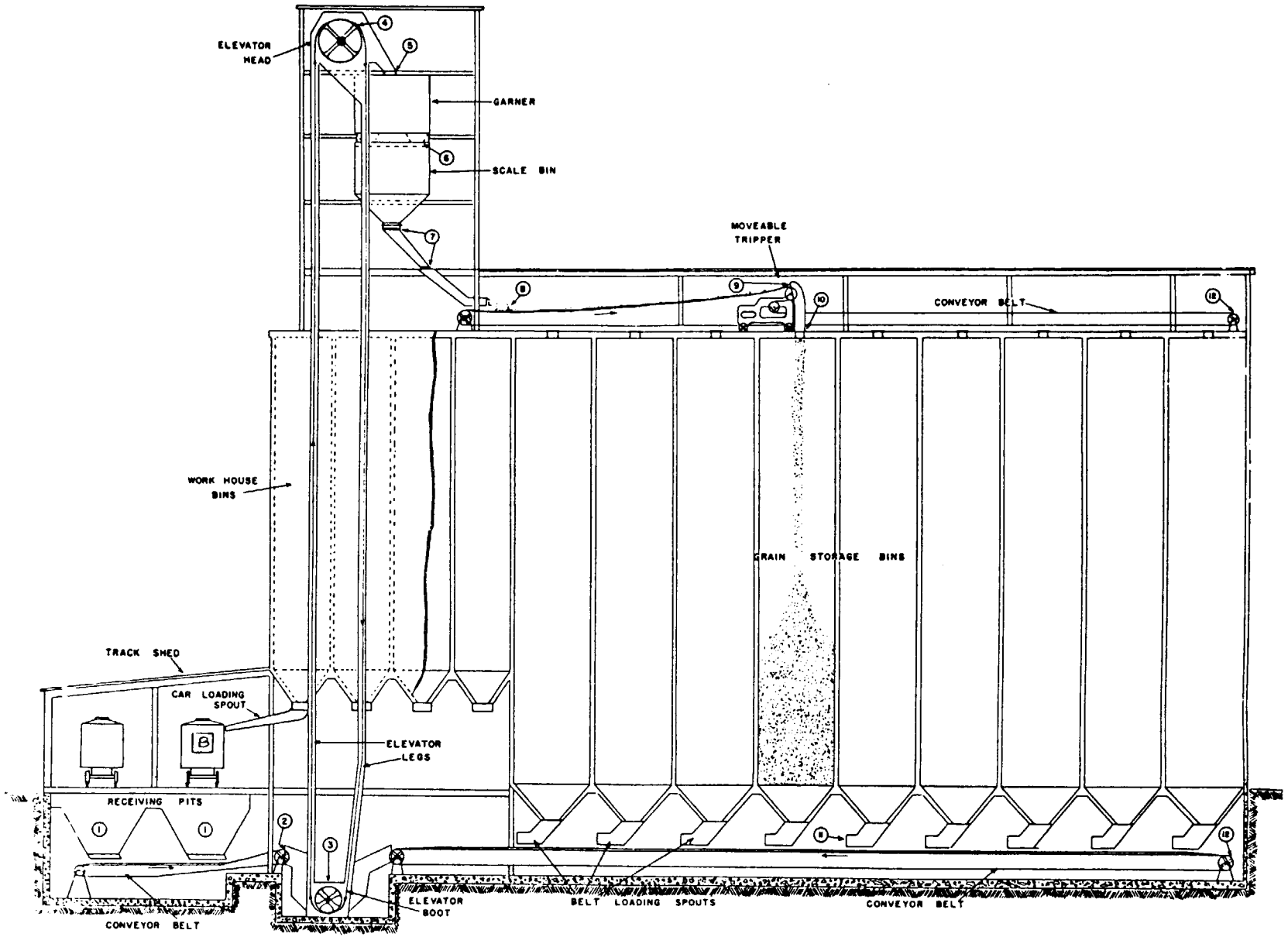

Figure 1. Diagrammatic section view of a terminal type grain elevator. Circled numbers indicate points at which dust clouds are likely to be emitted [6].

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
Grain Mill Products	204	
All Sizes		15.4
1 to 19		9.8
20 to 49		18.4
50 to 99		17.5
100 to 249		20.1
250 to 499		16.5
500 to 999		14.8
1,000 to 2,499		4.8
Farm Product Raw Materials	515	
All Sizes		9.7
1 to 19		7.7
20 to 49		9.4
50 to 99		15.2
100 to 249		13.9
250 to 499		9.7
500 to 999		7.7

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
Boxes, Barrels, Containers, Packages							
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				
Working Surfaces							
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
				Fracture	30	Head	10
		Caught in, under, or between in-running or meshing objects	21	Sprains, strains	22	Foot	10
		Struck against stationary object	15				
Conveyors	56	Struck against stationary object	12	Cut	19	Finger(s)	18
				Contusion	15		
		Caught in, under, or between, N	11				
Buildings and Structures							
Doors, gates	123	Caught in, under or between, N	23	Contusion	36	Finger(s)	35
				Cut	27	Back	14
		Struck by, N	20	Sprains, strains	26		
		Struck against stationary object	20				
Buildings and structures, N	57	Struck against stationary object	23	Contusion	16	Finger(s)	7
				Cut	12	Chest	6
		Fall onto or against objects	14			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
				Scratches	12	Back	17
		Contact by inhalation	8				
		Contact by adsorption	8				
Flame, Fire, Smoke	67	Contact with hot objects or substances	53	Burn (heat)	53	Multiple parts	26
						Respiratory system	8
		Contact by inhalation	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
		Struck by falling object	67	Fracture	59	Hand	43
				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
				Sprains, strains	10	Finger(s)	5
		Overexertion in lifting objects	4				
Vehicles							
Highway vehicles, powered	340	Struck against stationary object	33	Contusion	82	Multiple parts	72
				Fracture	79	Back	32
		Collision with oncoming vehicle	31			Chest	32
		Overturned	29				
Handtrucks	75	Struck by falling object	17	Sprains, strains	28	Back	12
				Contusion	21	Chest	8
		Overexertion in pulling	12			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
				Contusion	11	Leg	9
		Struck by, N	9				
		Overexertion in pulling	6				
Bodily Motion	460	Bodily reaction by involuntary motions	197	Sprains, strains	348	Back	170
						Knee	69
		Bodily reaction by voluntary motions	192			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
				Contusion	18	Toe(s)	13
		Caught in, under, or between in-running or meshing objects	12	Fracture	17		
		Struck by, N	12				
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
				Scratches	13	Finger(s)	11
		Rubbed by foreign matter in eyes	10				
Lumber	51	Struck by falling object	16	Sprains, strains	12	Finger(s)	8
				Cut	11	Back	7
		Overexertion in lifting objects	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
				Sprains, strains	11		
		Struck by	6				
		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
				Sprains, strains	19	Back	10
		Caught in, under, or	11				

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.