Prevention of Grain Elevator and Mill Explosions (1982)

Pages
147

Size
8.5 x 10

ISBN
NI000544

Panel on Causes and Prevention of Grain Elevator Explosions, Committee on Evaluation of Industrial Hazards, Commission on Engineering and Technical Systems, National Research Council

PREVENTION OF GRAIN ELEVATOR AND MILL EXPLOSIONS

Report of the Panel on Causes and Prevention
of Grain Elevator Explosions
of the
Committee on Evaluation of Industrial Hazards

NATIONAL MATERIALS ADVISORY BOARD
Commission on Engineering and Technical Systems
National Research Council
National Academy of Sciences

Publication NMAB 367-2
National Academy Press
Washington, D.C.
1982

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The report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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This study by the National Materials Advisory Board was conducted under Contract No. J-9-F-8-0137 with the Occupational Safety and Health Administration (OSHA). Funding was provided by OSHA, National Institute for Occupational Safety and Health, and the Department of Agriculture.

This report is for sale by the National Technical Information Service, Springfield, Virginia 22151.

Printed in the United States of America.

ABSTRACT

The panel, in this second report of the causes and prevention of grain elevator explosions, presents an overview of the dust explosion problem in grain-handling facilities. Recommendations are made that could reduce the present danger of explosions.

A systems approach to risk management was employed that permits all aspects of a situation to be considered simultaneously rather than separately or sequentially. An attempt was made to identify every possible hazard that contributes to grain dust explosions in elevators and mills. Each identified hazard was evaluated in terms of its significance to explosion potential--the most consequential having the highest ranking and the least consequential the lowest. Based on these rankings, the panel formulated its recommendations, balancing those actions that address the most significant hazards with those that cost the least to implement.

Discussed in some detail are preventive measures to forestall a dust explosion, constraints imposed by the cost of dust control measures, insurance against loss and injury, cooperation between government regulatory agencies and industry, the legal environment, elevator operator housekeeping practices, and the psychological factors involved.

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, by focusing attention on the materials aspects of problems and opportunities, and by making appropriate recommendations for the solution of such problems and the exploitation of the opportunities.

The panel members toured a number of elevators and mills ranging in size from small country elevators to large export elevators, investigated a number of explosions that occurred during the panel's tenure, and visited the research facilities of Cargill, Inc., in Minneapolis, Minnesota and the Department of Agriculture in Manhattan, Kansas. A number of tutorial sessions were held during which members of industry, labor, and government presented technical information and expressed their views on managerial and administrative matters affecting safety in the industry. The chairman, on behalf of the panel, gratefully acknowledges the contributions of these individuals: Ludwig Benner, Jr., Ernest Davis, and Brad Grose of the National Transportation Safety Board; Robert E. Frey and Sidney Orem of the Industrial Gas Cleaning Association; James Maness and Mark Goedde of the National Grain and Feed Association; John Healy of the Grain Elevator and Processing Society; Joseph Gillis of Fenwal, Inc.; Larry Barber of the American Federation of Grain Millers; Thomas Gillum of the Allied Industrial Workers; Max Spencer of the Continental Grain Corporation and the NFPA; Walter Kellog of the Kellog Grain Company; Gary McDaniel of MAC Pneumatic Systems, Inc.; Charles Rockwell of CEA Carter-Day Company; Philip Sheeler of the Food and Drug Administration; James Nutter of Scandura, Inc.; G. D. Grant of Uniroyal, Inc.; Roger Myhre of Koppel, Inc.; William Fox of Lakeland Engineering Equipment Company; Bruce Beelman of the U.S. Department of Labor; and Robert Schoeff of the University of Kansas. Appreciation also is extended to the liaison representatives of the panel and to the NMAB support staff.

This report of the panel presents an overview of the dust explosion problem in grain-handling facilities and includes recommendations for reducing the present danger. The panel believes that effective implementation of these recommendations requires understanding on the part of all who are associated with the grain industry (i.e., managers, workers, federal and state employees, legislators, labor officials, insurance underwriters, and equipment manufacturers). Therefore, this report is intended for an audience with widely varied interests in and experience with grain and grain-handling facilities. Detailed technical information is presented in appendixes.

The term "grain-handling industry" is used throughout this report and encompasses both grain elevators and the various grain processing mills. Mills not located next to grain elevators elevate and store grain and other commodities in the same manner as grain elevators (with one exception, dust pelletizing mills); consequently, they have the same problems as grain elevators except for dust disposal. Each mill also has additional explosion problems particular to the processing performed, and these unique problems are discussed in an appendix to this report.

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PREFACE

Agricultural dust explosions have an extensive history. The earliest recorded explosion in a grain-handling facility occurred in a flour mill in Turin, Italy, in 1785.* The U.S. government first took official notice of such explosions in 1913 following one in a feed grinding plant in Buffalo, New York. During and immediately following World War I, the United States Grain Corporation conducted a program to investigate grain elevator explosions and to recommend measures to prevent them. The National Fire Protection Association (NFPA) recently published a list of important dust explosions, excluding those in coal mining, occurring in the United States and Canada since 1960. These and other reports and investigations, however, have done little to reduce the frequency or severity of explosions.

As in the past, a flurry of activity followed a series of disastrous explosions in late 1977. Industry, labor, and government all increased their explosion prevention efforts. The federal government, through the Occupational Safety and Health Administration (OSHA), the Department of Agriculture and the National Institute of Occupational Safety and Health (NIOSH), requested that the National Academy of Sciences' National Materials Advisory Board (NMAB)** through its existing Committee on Evaluation of Industrial Hazards establish a panel to study the grain-handling industry and to recommend measures to reduce the explosion hazard. Therefore, the Panel on Causes and Prevention of Grain Elevator Explosions was formed, composed of experts in many fields related to explosions, the grain industry, and systems analysis.

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* Count Morozzo, Repertory of Arts and Manufacturers 2 (1795):416-432 (referred to in K. N. Palmer, Dust Explosions and Fires, pp. 7-8. 1973).

** The National Materials Advisory Board is a unit of the Commission on Engineering and Technical Systems of the National Research Council. Its general purpose is the advancement of materials science and engineering in the national interest. It fulfills that purpose by providing advice and assistance to government agencies and private organizations on matters of materials science and technology affecting the national interest, by focusing attention on the materials aspects of problems and opportunities, and by making appropriate recommendations for the solution of such problems and the exploitation of the opportunities.

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Chapter 1

INTRODUCTION

BACKGROUND

Explosions in grain elevators and mills have been documented for over 100 years but probably have occurred ever since structures for handling grain in large quantities were developed. Although long recognized as an industrial hazard, elevator explosions received wide national attention recently when during an eight day period in 1977 beginning on December 21 and ending on December 28, five explosions occurred resulting in 59 deaths and 48 injuries (U.S. Department of Agriculture 1980).

In the past, explosion prevention efforts in the grain processing industry were concentrated on mills, mainly flour and starch. The federal government first gave attention to the dangers of grain dust explosions following the explosion of a feed mill in 1913, and the continuing emphasis on mills may have been due to the very large number of fatalities that occurred in early mill explosions (e.g., 43 fatalities and 30 injuries in a starch mill explosion in Cedar Rapids, Iowa, in 1919). However, the danger of explosions due to collections of grain dust in elevators had not been totally ignored (U.S. Department of Agriculture 1918, U.S. Grain Corporation 1920a and b).

In July 1978, at the request of the Department of Agriculture, the National Academy of Sciences conducted an international symposium on grain elevator explosions (National Materials Advisory Board 1978). Shortly after the symposium the Occupational Safety and Health Administration (OSHA) of the Department of Labor requested that the National Academy of Sciences form a group to study the causes and make recommendations for the prevention of grain elevator explosions. In November 1978, the Panel on Causes and Prevention of Grain Elevator Explosions was formed under the Academy's National Materials Advisory Board. The panel is part of the Board's Committee on Evaluation of Industrial Hazards. The 10-member panel is composed of experts in systems analysis, explosion dynamics, investigations and prevention, instrumentation, grain handling and processing, agricultural insurance practices, employee relations, dust control methods, and aerodynamics. Its objectives were to:

1. Study the federal government's investigation of grain elevator explosions and make recommendations for improvement,

2. Investigate grain elevator explosions selected by OSHA occurring during the panel's tenure and determine their causes,

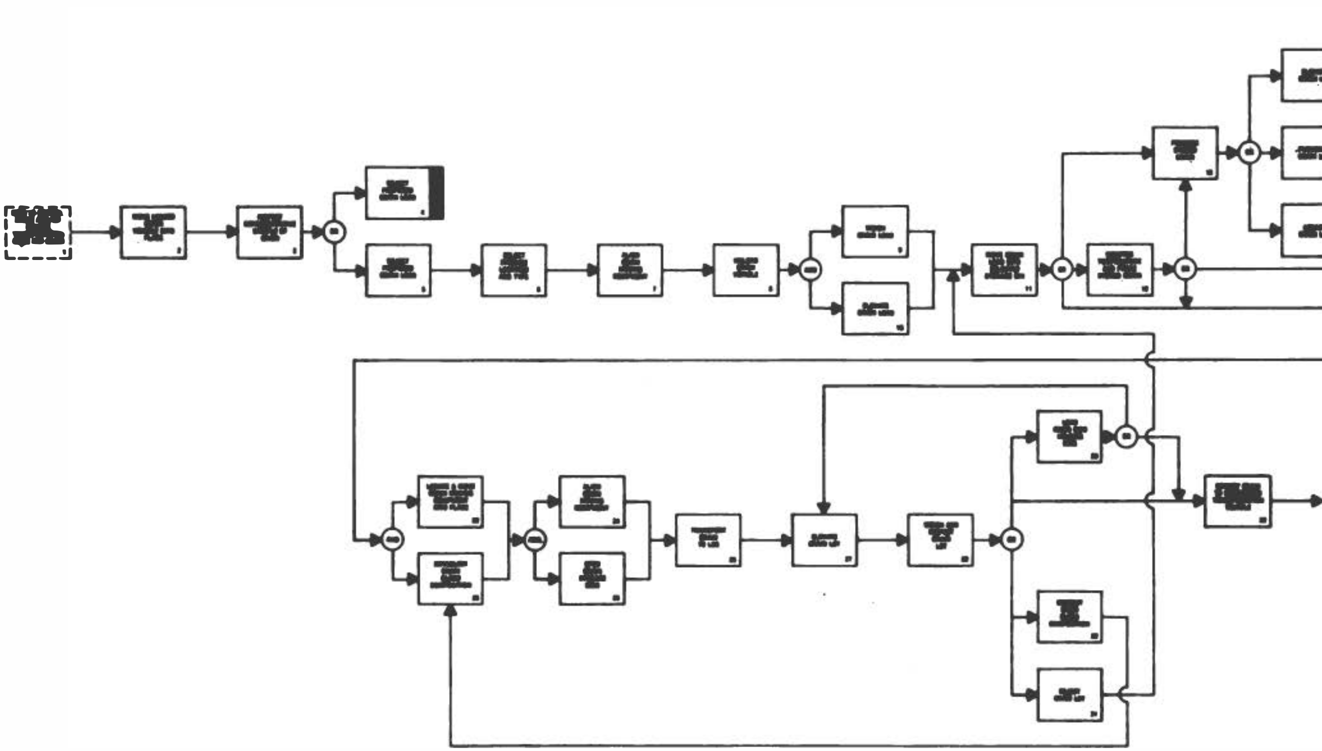

FIGURE 2 Grain elevator operations. The devices that perform the functions shown in the blocks of this diagram are illustrated in Figure 3 and described on pages 15 and 17.

on the left and the outputs appear on the right. Thus, the FFBD shows graphically the interdependence of all tasks or activities taking place in the facility. Since it is one single and complete display of all essential functions, the probability of overlooking any factor related to an explosion is vastly reduced.

Identification of Risk Exposure

The primary mechanism used by the panel to identify the causes of grain dust explosions was the hazard scenario. Every accident is comprised of many elements--not just some singular, isolated event, and the hazard scenario is a brief description of the combined causative factors that could lead to an explosion. Hazard scenarios are not an end in themselves in that they identify only facets of exposure to risk (Grose 1982). However, one of the major values of hazard scenarios is that they can describe explosions that have not yet occurred but that are possible. Thus, they serve to emphasize the need for preventive or corrective actions.

Appendix A presents a representative sample of the more than 150 scenarios that were prepared by the panel. Some of them describe actual occurrences investigated by panel members while others are hypothetical possibilities proposed by employees of the grain-handling industry experienced in elevator operations.

Early in their attempt to identify causal factors for grain elevator explosions, the panel concluded that existing data were insufficient to permit the identification of needed preventive actions. Therefore, a team of panel members was formed to investigate significant explosions that occurred during the panel's tenure. The primary function of the investigation team was to obtain data that identified the hazards leading to a grain elevator explosion. A secondary function was to establish and refine investigative techniques for identifying and analyzing causal factors at the scene of an explosion.* The team was staffed with panel members and liaison representatives who had diversified professional specialties.

Evaluation of Identified Risk

Identifying the many and varied explosions risks in a grain elevator, whether by means of hazard scenarios or on-site investigations of explosions, is a difficult process. It is especially important that hazard identification not be inhibited by any initial concern for the significance of an individual identified hazard; if it is, many subtle hazards probably will be overlooked.

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* A report entitled, "The Investigation of Grain Elevator Explosions," NMAB 367-1, 1980, National Academy of Sciences, Washington, D.C., was issued.

Ultimately, however, all identified hazards must be evaluated for their significance because there are never enough resources available to prevent or correct every hazard that can be identified. The panel ranked all identified hazards into a hierarchy of importance using three measures--the severity of the hazard, its frequency or probability of oocurrence, and the amount of resources required to control it. Each scenario was assigned three letters--one for severity, one for probability, and one for control resources as described in Appendix A. Since historical data for many of the scenarios did not exist, the panel's judgment was important in this ranking.

Once the three letters were assigned to each scenario, all the scenarios could be evaluated by the panel to determine their relative hazard significance.

This ranking procedure can be used in the future by grain elevator owners and operators. Using this decision-making tool, they can judge the significance of all identified hazards on the same basis and efficiently allocate resources for the reduction or control of explosions.

Control of Significant Risk

Once the evaluation of all identified risks revealed those that were most significant, the panel sought expert counsel on how such hazards might be best controlled. This counsel was of several types. Knowledgeable experts in grain dust control, elevator design, environmental protection, grain economics, and grain handling were invited to address the panel on dust explosion prevention. Other groups and spokesmen met with the panel to offer control measures. (See Preface for a list of those contributing to this effort.) Individual panel members also visited selected grain-handling sites to review specific preventive actions for explosion scenarios.

Financing of Uncontrolled Risk

There are three classes of uncontrolled hazards: (a) those for which there is no effective preventive action, (b) those considered insignificant but which turn out to be consequential, and (c) those that were unforeseen. While the panel has made no recommendations regarding the various options for financial coverage of losses due to these three classes of risk, the economic impact due to dust explosions was of constant concern. Among the options discussed were loss write-off, assumption of debt, self-insurance, and other means of transferring the risk of loss.

REFERENCES

Grose, V.L., Converting health hazard control from moralism to management, Professional Safety 25(3) March (1980):31-40.

Grose, V.L., Managing medical malpractice risk via system science, Journal of Medical Systems 6(1)(1982):89-103.

Maritime Transportation Research Board, Research needs to reduce maritime collisions, rammings, and groundings, National Academy Press, Washington, D.C., May 1981.

National Materials Advisory Board, Internationsl Symposium on Grain Elevator Explosions, Proceedings, Volume 2, Report NMAB 353-2, Washington, D.C., July 11-12, 1978.

U.S. Department of Agriculture, Prevent grain dust explosions and fires, USDA Circular, 1918.

U.S. Department of Agriculture, Prevention of Dust Explosions in Grain Elevators--An Achievable Goal, USDA, Washington, D.C., 1980.

U.S. Grain Corporation, Grain dust explosion prevention, (in cooperation with the Bureau of Chemistry, U.S. Department of Agriculture), New York, 1920a.

U.S. Grain Corporation, Proceedings of Conference of Men Engaged in Grain Dust Explosion and Fire Prevention Campaign, (in cooperation with the Bureau of Chemistry, U.S. Department of Agriculture), July 1920b.

Chapter 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Numerous reports on explosion prevention in the grain-handling industry have been published over the past 60 years. Many present long lists of actions to be taken with little or no assessment of their feasibility or potential effectiveness or explanation of why they were needed. These reports generally do not consider the influence of human characteristics on explosion prevention, questions requiring research, or methods for disseminating widely the available information on explosions and their prevention. In addition, the existence of these reports appears to be little known.

2. Recent compilations would make it appear that the number of grain-handling facility explosions occurring annually in the United States has increased during the past 20 to 25 years but that much of this apparent increase could be due to better reporting procedures. Nonetheless, it appears that the problem of grain elevator explosions is greater than generally realized.

3. The elevator leg is the most dangerous location with respect to initial or the primary dust explosions.

4. Grain dust is generated in many places in elevators and mills. Of particular concern is the dust in confined spaces that, without proper housekeeping, will accumulate in layers on all surfaces and present a potential for secondary dust explosions.

5. There is a considerable body of documented evidence indicating that electrostatic discharge can ignite dust clouds under the right conditions; however, the panel found no evidence of ignition due to electrostatic discharge in its investigations of explosions.

6. The contribution of human operatives and external factors other than the immediate physical aspects (e.g., people's attitudes, insurance practices, and government regulation) often are a major part of the problem and often are overlooked.

RECOMMENDATIONS

Given these conclusions, the information obtained during its study and the expertise of its members, the panel identified a number of actions that can reduce the frequency and severity of explosions in grain-handling facilities. It assessed each of these actions in terms of:

1. The efficacy or degree to which the explosion hazard would be eliminated or controlled by the action;

2. The feasibility or acceptability of implementing the action in light of economic, legal, cultural, political, social, and technical considerations; and

3. The efficiency or cost-effectiveness of the action (i.e., the cost of the action versus the potential dollar loss if no action is taken).

On the basis of this assessment, the panel grouped its recommended actions in terms of priority--first, second, and third. The panel believes that the first-priority actions should be implemented in all facilities and that the second- and third-priority actions should be implemented to the extent possible depending on the specific facility. There is no internal ranking within each category.

Some of these recommended actions must be implemented by the grain-handling industry and others by government; still others require cooperative efforts. Further, some of these recommended actions are more appropriate for large facilities and others for small--both existing and new. Recommendations peculiar to mills are given here and discussed in Appendix C.

First Priority Actions

- Continue research on methods for reducing the dust concentration in legs to a level below the lower explosive limit.*

- Establish a housekeeping program involving a mechanical dust collection system supplemented by manual or other means.

- Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

- Use a pre-established and enforced permit procedure whenever welding, cutting, or other open flame work is to be done.

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* Lower explosive limit used throughout this report is synonymous with minimum explosive concentration.

- Incorporate a system to indicate belt slippage and misalignment.
- Incorporate a method to check frequently the temperature and vibration of critical bearings.
- Use devices to extract foreign materials from the incoming grain stream.
- Ground all conveying and electrical equipment.

Second Priority Actions

- Examine the overall functions of mills and elevators to develop a totally new system less subject to the hazards of dust explosions.
- Control dust generation and airborne dust at all grain transfer and discharge points.
- Notify all plant managers that safety is their responsibility. If authority is delegated it must be to an employee who reports directly to the plant manager.
- Apply state-of-the-art techniques to reduce the concentration of airborne dust in and emanating from elevator legs.
- Establish an information center to distribute actively all available information on elevator and mill dust explosions and their causes and prevention.
- Establish a fire and explosion prevention training program at each facility.
- Conduct research to develop economic uses for collected grain dust.
- Locate hammer mills, other grinding equipment, and their dust collection systems separate from the main facility.
- Eliminate all nonessential horizontal surfaces.
- Treat the avoidance of dust explosion hazards as an initial design criteria in the construction of new mills and elevators and the modification of existing structures.
- Continue research on methods for reducing dust concentrations below the lower explosive limit in enclosures other than legs.
- Investigate and report on explosions in a manner that reflects the recommendations made by the panel in its report, "The Investigation of Grain Elevator Explosions," Report NMAB 367-1.

Third Priority Actions

- Follow, to the extent practical, the National Fire Protection Association's standard on explosion venting (No. 68) for all enclosures. Concrete structures should be vented by windows or other openings of the size dictated by this standard.

- Establish a government and industry group to aid in developing and updating explosion prevention regulations for elevators and mills.

- Quantify housekeeping standards for cleanliness in grain-handling facilities that will prevent fires and explosions.

- Coat all nonhorizontal surfaces exposed to airborne dust with a material that will prevent the build-up of layered dust.

- Investigate the effect of electrostatics and absolute humidity on the explosion hazard, including an examination of conveyor belt conductivity and the charging of ungrounded conductive structures.

- Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosive limit where possible in enclosures other than legs.

- If dust is returned to the grain stream do it in the least hazardous manner.

- Use only equipment and installation standards meeting National Electrical Code requirements.

Chapter 3

THE EXPLOSION PROBLEM

Grain dust suspended in air at a concentration above a certain lower limit* burns rapidly when ignited. When this occurs in an enclosed space, explosive pressures are generated and detonation may even occur. The panel found that the potential for grain dust explosions existed in every elevator and mill it visited. An extrapolation to the approximately 15,000** elevators existing in this country at present indicates the potential magnitude of the problem. Data on recorded explosions are presented in Table 1.***

Any movement or handling of grain produces grain dust, and this occurs at each point in the grain-handling system from farm to ultimate consumer. In the past 20 to 25 years the grain-handling industry has processed a continuously increasing amount of grain from U.S. farms. Between 1964 and 1979, for example, grain production increased from 160.7 to 280.7 million metric tons and the amount of grain exported (U.S. Department of Agriculture 1979a) exhibited an even greater increase from 41 to 113 million metric tons. Corn accounted for the greatest portion of both of these increases. Although it is difficult to obtain exact figures for the amount entering the grain-handling system (i.e., total production minus on-farm use), there is no doubt that it has increased approximately 150 to 200 percent. This increase indicates that the velocity of flow through the grain-handling system has increased, that the units of the grain-handling system have increased in size, or that both have occurred. These changes have increased the explosion hazard since the amount of dust generated in a facility increases with the total amount of grain handled and with increased operating equipment speed.

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* The lower explosive limit (LEL) range according to U.S. Bureau of Mines 1961 data for some common agricultural dusts is from 35 to 300 g/m^3 (0.035 to 0.29 oz/ft^3) (See Table B-1 of Appendix B). See Appendix B for a detailed discussion of the explosive properties of grain dust.

** Includes all installations involving the elevation of grain (i.e., conventional elevators and elevators attached to mills).

*** In addition to explosions, over 29,000 grain elevator fires occurred in the U.S. from 1964 through 1973 or an average of more than 2900 fires per year. This is reported to be more than 300 times greater than the average number of grain elevator dust explosions in the same period (Verkade and Chiotti 1976).

TABLE 1 Number of Explosions in Grain-Handling Facilities.

Year	Grain Elevator Explosions (GAO 1979)	Grain Elevator Explosions (USDA 1979a)	Feed Mill Explosions (USDA 1979a)	Grain-Handling Facilities Explosions[a]
1958	8	8	2	-
1959	7	8	2	-
1960	7	8	4	-
1961	9	8	2	-
1962	8	8	1	-
1963	9	8	6	-
1964	3	2	6	-
1965	7	6	3	-
1966	10	9	5	-
1967	13	12	5	-
1968	10	9	7	-
1969	1	1	5	15
1970	12	10	0	21
1971	10	9	1	17
1972	4	2	6	14
1973	7	6	2	22
1974	8	10	5	25
1975	6	6	3	9
1976	13	18	4	28
1977	10	13	8	31
1978	-	7	5	20
1979	-	-	-	29
1980	-	-	-	45

NOTE: The Grain Elevator and Processing Society (1977) reports that 203 explosions occurred between 1860 and 1956; 151 occurred between 1925 and 1956, and 137 occurred between 1958 and 1975. Hall (1978) reports that 490 explosions occurred between 1900 and 1957.

[a]Data supplied by the U.S. Department of Agriculture, Office of Special Coordinator for Grain Elevator Safety and Security. Figures obtained by extensive survey of literature and personal contacts by a member of that Office. Data supplied to panel includes actual dates and locations. A few incidents prior to 1979 were not completely verifiable. The last column does not represent the sum of columns 3 and 4.

Other innovations or changes also have tended to increase the amount of dust in the system. The rapid drying of grain on the farm or at elevators by the application of external heat leads to differential shrinkage, which increases the tendency for the kernel to break. The increased foreign demand for corn and soybeans has changed the mix of grains passing through the system, and although there is no definite proof, it is thought that these grains are considerably dustier than wheat, which was the main export grain prior to 1960. Minimizing the handling of grain will reduce the overall hazard because dust is generated every time grain is moved.

The movement of grain through the handling system is much less seasonal than in prior years due to the large increase in on-farm storage facilities. Available data do not support a correlation between the incidence of explosions and any of these factors. In addition, extrapolation to predict any future hazard due to external causes is next to impossible since the characteristics of each seasonal year (i.e., weather, crop quality, export market, etc.) are unique.

The panel, as well as others who have studied the problem as far back as 1918, is of the opinion that the underlying and by far the most important hazard is grain dust itself. In an operating elevator or mill, grain dust is generated and handled in confined spaces, and without proper housekeeping it will accumulate in layers on interior as well as exterior surfaces. Although there are a number of other factors (such as presence of ignition sources), which contribute to the degree of hazard, the panel feels that they are secondary compared to the hazard imposed by the accumulation of layered grain dust on interior surfaces. This is because the layered dust is the fuel for secondary explosions that occur.

GRAIN-HANDLING FACILITIES

Figure 3 illustrates the physical construction of an elevator (see Figure 2 for a flow diagram of the functions performed in a grain elevator). Not all elevators contain every feature shown but the illustration is a general representation of most of the activities that are performed. One must realize, however, that even with a minimum amount of handling between input and output there are a number of places where the grain is subject to mechanical stress leading to the production of grain dust.

Grain is delivered to an elevator by truck, rail, or barge and is dumped into a pit that feeds a conveyor belt leading to the bottom of the leg, which is called the boot. The leg is an enclosed, vertical, endless-belt, bucket conveyor that elevates the grain and discharges it into the top of a garner. Grain is discharged from the bottom of the garner into a scale bin in batch lots and is weighed. The grain then flows out the bottom of the scale bin onto a belt conveyor that moves the grain to the top of a bin or silo. The first grain dumped into an empty silo may drop as much as 100 feet or more. Grain is unloaded from the bottom of the silo onto a conveyor belt that feeds into the boot of the leg. After being elevated, the

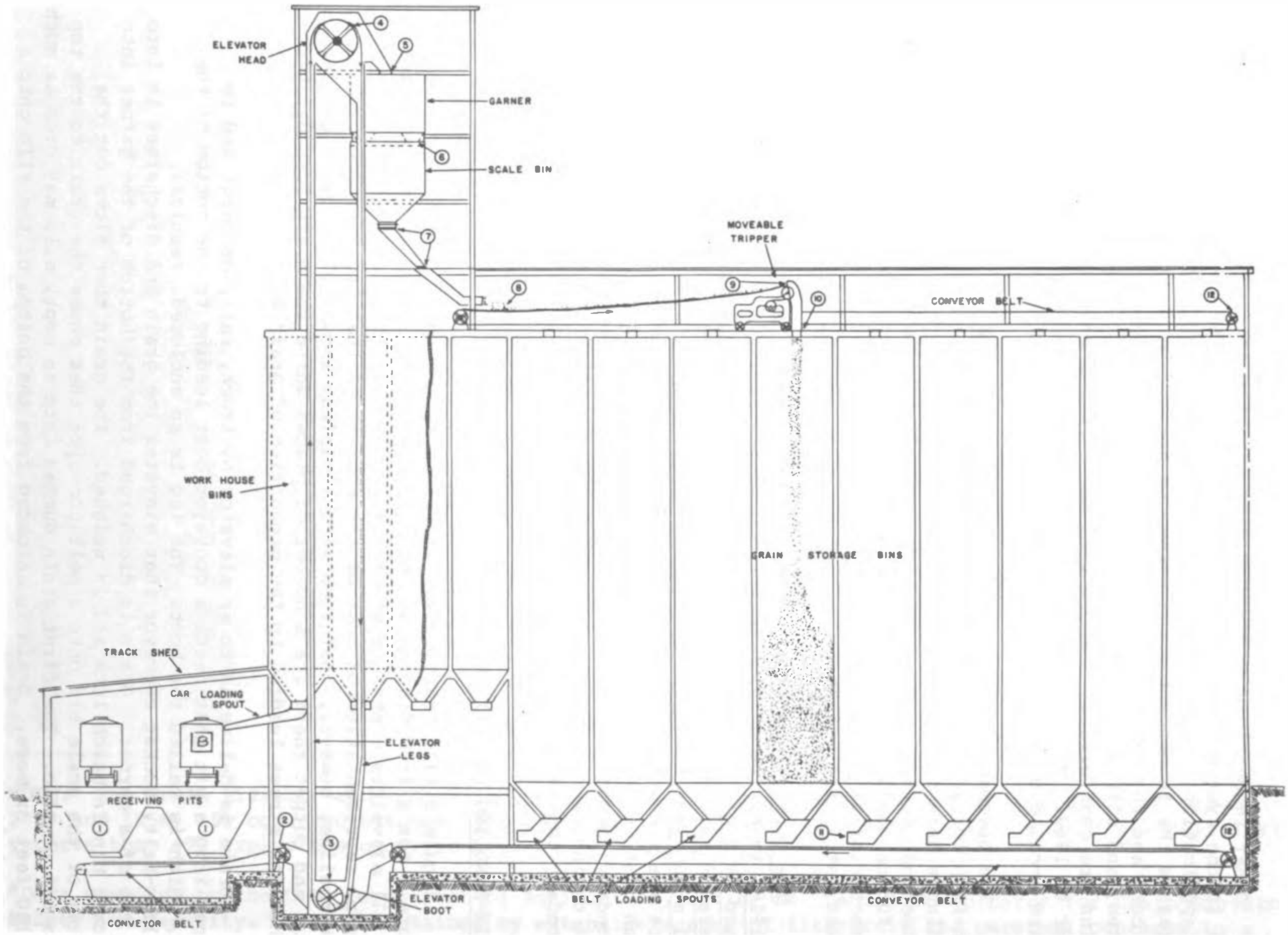

FIGURE 3 Diagrammatic section view of a terminal type grain elevator. Circled numbers indicate points at which dust clouds are likely to be emitted (Verkade and Chiotti 1976.

grain may take one of several different paths (e.g., it may go through the weighing process again and be loaded into a truck, rail car, or barge; it may be blended with grain from other silos and returned to a silo; or it may go to a drier). It should be noted that, except in rare instances, the grain is elevated in the leg at least twice during the time it is in the elevator and the leg is always operating when grain is being moved within the elevator.

Elevators vary in size from 400,000 to 800,000 bushels for the average storage capacity of country elevators (some may be smaller or considerably larger) (T. E. Stivers Organization, Inc. 1980) to an average of about 4 million for those terminal elevators registered under the Uniform Storage Agreement in 1978 (Development Planning and Research Associates, Inc. 1980). Eighty-seven percent of export elevators have a storage capacity greater than 2 million bushels, with some exceeding a 10 million bushel capacity (U.S. Department of Agriculture 1980).

Newer elevators are of slip-form concrete construction whereas older elevators are usually of wood construction, the latter being mostly limited to country elevators. The geometry of elevators and the method of distributing the grain within the elevator also vary widely. Some elevators have legs external to the structure; some use inclined conveyor belts in place of legs, some distribute grain from a leg or inclined belt into a system of pipes (a distributor) leading to silos, thereby eliminating the gallery on top of the bins; some group the bins in a circle around the headhouse instead of placing them in a row as shown in Figure 3; some extend bins on each side of the headhouse; and some have combinations of two or more of these and other features even to the extent of having wood and concrete structures together in the same installation.

In addition to the grain-moving system in an elevator, most newer and some older elevators have a pneumatic dust control system. Airborne dust is collected at various points in the elevator to improve the working environment, to reduce the hazard of dust explosions, and to meet Environmental Protection Agency (EPA) requirements concerning ambient air quality. In some elevators, the dust is collected in a separate bin and offered for sale; in others, the dust is returned to the grain. The efficiency, construction, and safety of dust control systems vary widely throughout the industry.

Some mills for the processing of grain are attached to large elevators and milling is only a small part of the total elevator operation. The operation of those mills that are not adjuncts to grain elevators can be divided into two parts: the elevation and storage of grain and the processing of grain. The elevation and storage portion of the facility has the same problems with dust generation and control as any ordinary elevator. In both types of mill, grain processing (which can include grinding, milling, mixing, pelletizing, etc.) introduces additional explosion hazards. A discussion of the hazards peculiar to mills is given in Appendix C.

Proposals for reducing the explosion hazard must take into account the great variation in types and sizes of elevators and mills, in dust control systems, in types and amount of grain handled, and in the treatment the grain receives in the elevator or mill.

DUST GENERATION

Grain dust is generated initially during the harvesting process, and grain delivered directly to an elevator from harvesting contains an amount of dust that reflects harvesting conditions. Although all grain dust can be considered to present a hazard, the most hazardous is that which can become airborne. There is no particular standard defining the size of airborne dust particles; however, for purposes of comparing ignition and burning characteristics, the U.S. Bureau of Mines (1961) used samples of various dusts, including agricultural dusts, that would pass a 200-mesh screen (maximum particle size 74 μm). The degree of explosion hazard for a unit mass of dust is dependent on the total surface area of the dust, which, of course, is inversely proportional to the square of the size of the particles. The ease by which dust becomes airborne also is inversely proportional to the size of the particles for dusts of equal density.

Dust suspended in air represents the initial hazard since dust clouds can explode. A detailed discussion of dust cloud explosion phenomena is contained in Appendix B and an overview of explosions in grain-handling facilities is presented below. It should be noted, however, that the fuel for the dangerous secondary explosions is the layered dust that has settled on various surfaces in the elevator or mill. Dust on some surfaces such as floors, walls, beams, and ductwork is readily visible and can be removed easily.

Neglected or delayed housekeeping will result in the accumulation of layered dust in an elevator or mill and poor housekeeping methods or an initial explosion can result in the creation of a dust cloud sufficient to be an explosion hazard. Unfortunately, housekeeping and maintenance often are given very low priority and usually are the first tasks postponed when there is a rush of business (e.g., elevators operating continuously during harvest season). Hidden layers on walls and floors of enclosed areas such as bins and ducts, however, have fueled serious explosions in apparently (superficially) clean elevators. Horizontal surfaces inside of equipment should be eliminated through design.

The points at which dust is generated and suspended in air can be identified by following the path of grain through an elevator as was done above. The panel has found that the dust concentration in operating elevator legs, even with currently designed dust control systems, is frequently above the lower explosive limit just above the boot on the up-side of the leg. Dust concentrations ranging from 27 to 500 g/m^3 were measured in this location in four elevators. Only slightly less hazardous concentrations were found to exist at other points in the leg. Panel investigators and others have found that numerous explosions have resulted from the ignition of suspended dust in legs. Thus, the panel considers elevator legs to be the most dangerous location with respect to initial dust explosions. The same conclusion has been expressed in numerous previous reports (e.g., Wade et al. 1980).

At the top of the leg or the inclined conveyor where the grain is discharged into a distributor or onto a conveyor belt, some of the dust entrained in the grain stream will be released when the grain falls through the air and additional dust will be generated when the grain impacts at the bottom of its fall either onto the upper conveyor belt or into an enclosure such as a bin or silo. Silos, bins, and garners are particularly hazardous locations since they are enclosed structures and, while being filled, contain high concentrations of airborne dust in a large volume. After being emptied, a layer of dust will usually cling to the walls.

When grain is moved out of the elevator, it usually is discharged from a bin onto a moving belt at the bottom of the bin in a tunnel, another site for the generation of dust and the release of small particles that become airborne. Layered dust is particularly prevalent in tunnels below bins. The grain is conveyed to the boot of the leg and repeats the process of being elevated and distributed with the attendant opportunities for the generation of additional dust and the suspension of the finer particles. Other processes in the elevator such as drying, cleaning, and blending all require movement of grain through the leg and various amounts of conveying to and from the leg, again with the generation and suspension of dust.

Thus, there are numerous places in an elevator where dust can be generated by mechanical stress on the grain kernels and where fine dust can become airborne and eventually settle as a layer on surfaces. Although the amount of dust that can become airborne at any one time is only a small fraction of a percent of the grain, over a period of time the total quantity accumulating on surfaces can be quite large.* A dust control system is the only method for preventing most of the airborne dust from settling on elevator floors, beams, duct work, etc. and clinging to such surfaces as walls, bin sides, and ceilings.

DUST EXPLOSIONS**

Dynamics

Discussions of dust explosions begin with the concept of an "explosion pentagon" whose sides represent the needed elements. The five sides are ignition, fuel (the dust), air (oxygen), mixing, and confinement. Although these are necessary requirements for a dust explosion, they are not sufficient. Explosions will not occur unless the dust is suspended in an enclosure in air at a concentration exceeding the lower explosive limit. These conditions must occur simultaneously and at one point--an enclosure containing dust suspended in air in the proper concentration with an ignition source.

Therefore, there are four events that must take place before a grain elevator will explode:

- Grain dust must collect in the elevator.
- Grain dust must be suspended in air inside the elevator at a concentration above the lower explosive limit.
- Suspended grain dust must be ignited.
- Sufficient grain dust to sustain rapid combustion must be in the vicinity of the initially-ignited grain dust.

The explosibility of dust under these conditions has been well documented (Bartknecht 1981, Palmer 1973, U.S. Bureau of Mines 1961).

These four events are shown in the fault tree analysis of Figure 4. In this type of analysis, which is widely used to determine and estimate risks, all subordinate events leading to a major undesired event (in this case, "grain dust explosion in elevator") are arranged to show their interrelationship and sequence (Rowe 1977). These subordinate causative events may be independent or dependent. Independent events; e.g., "grain dust is blown down (by an air gun during housekeeping) by airstream," lead into an OR gate, indicating that any one of such events can cause the next higher event. Dependent events; e.g., "grain dust is produced in elevator," require at least one other event to occur before the next higher event can happen. They are shown as leading into an AND gate.

A peculiarity of explosions occurring in dusty structures is the phenomenon of secondary or subsequent explosions following a primary or initial explosion. The secondary explosion can be orders of magnitude greater and more destructive than the initial explosion. If the interior of a facility is dusty, an initial explosion that causes only relatively slight damage can produce a large, suspended dust cloud. Ignition of this cloud by hot particles of dust or flame from the initial explosion (or by any other ignition source) then causes the secondary explosion. Secondary explosions have been known to occur many seconds after an initial explosion. There also have been cases where a series of secondary explosions occurred, one after the other.

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* At a large export elevator during 11-1/2 months of operation 13,000 tons of dust had been removed from 1.8×10^8 bushels (equivalent to 4.5×10^6 tons assuming a bushel weighs 50 lb) of grain.

** See Appendix B for a more complete discussion of dust explosions.

Three conditions for explosions--air, dust, and confinement--always exist in contemporary elevators and mills. The incidents described below illustrate how a sequence of events led to the simultaneous occurrence of all of the conditions required to produce an explosion:

1. During construction work welding was being done on a conduit near an elevator leg that was built external to the headhouse. Some hot welding slag fell, unnoticed, into grain carried in an open screw auger to the leg. The hot slag was carried into the leg boot where it ignited the grain, which in turn, ignited the dust in the leg and caused an explosion. Because the leg was exterior to the elevator structure, no secondary explosions occurred.

2. During the operation of an elevator the bucket conveyor in the leg became jammed by an excess of grain in the boot. An employee began jogging the leg,* a procedure in which the leg conveyor driving motor is repeatedly started and stopped in an effort to free the conveyor belt. Heat generated by friction between the head driving pulley and the jammed belt ignited the belt, which subsequently burned through. When the burning belt dropped, the metal casing split. Flaming material was discharged into the dust cloud in the basement and there was an explosion in the basement and legwell shaft. Hot gases and burning particles were blown through a distributor system into various bins where they caused secondary explosions fueled by dust that was shaken loose from the walls by the initial explosion.

3. In an elevator like that shown in Figure 3, with silos extending out on each side of the headhouse, an initial explosion occurred in a load-out bin (also called a transfer or workhouse bin; see Figure 3). Explosions followed in the three legs in the headhouse and severely damaged the floors and interior partitions. The explosion vented out both sides of the headhouse at the top, across a catwalk, and into the galleries on each side. Dust that had settled on the floor of the galleries below the sides of the conveyor belts propagated a flame, with little pressure rise, down the length of both galleries. The flame travelled the full length of one gallery to an open silo at the end where a secondary explosion occurred. In the other gallery, the flame reached an interstice that was used as a ventilating shaft that extended from the gallery to the tunnel below the silos. An explosion occurred in this space when dust that had been shaken loose from the walls by the explosion in the headhouse was ignited. This explosion then travelled down the tunnel with unusual violence, destroying the conveyor in the tunnel and the loading spouts, and vented out the far end of the tunnel.

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* Jogging the leg, although a practice prohibited in most companies, probably occurs more often than industry is aware of or willing to admit.

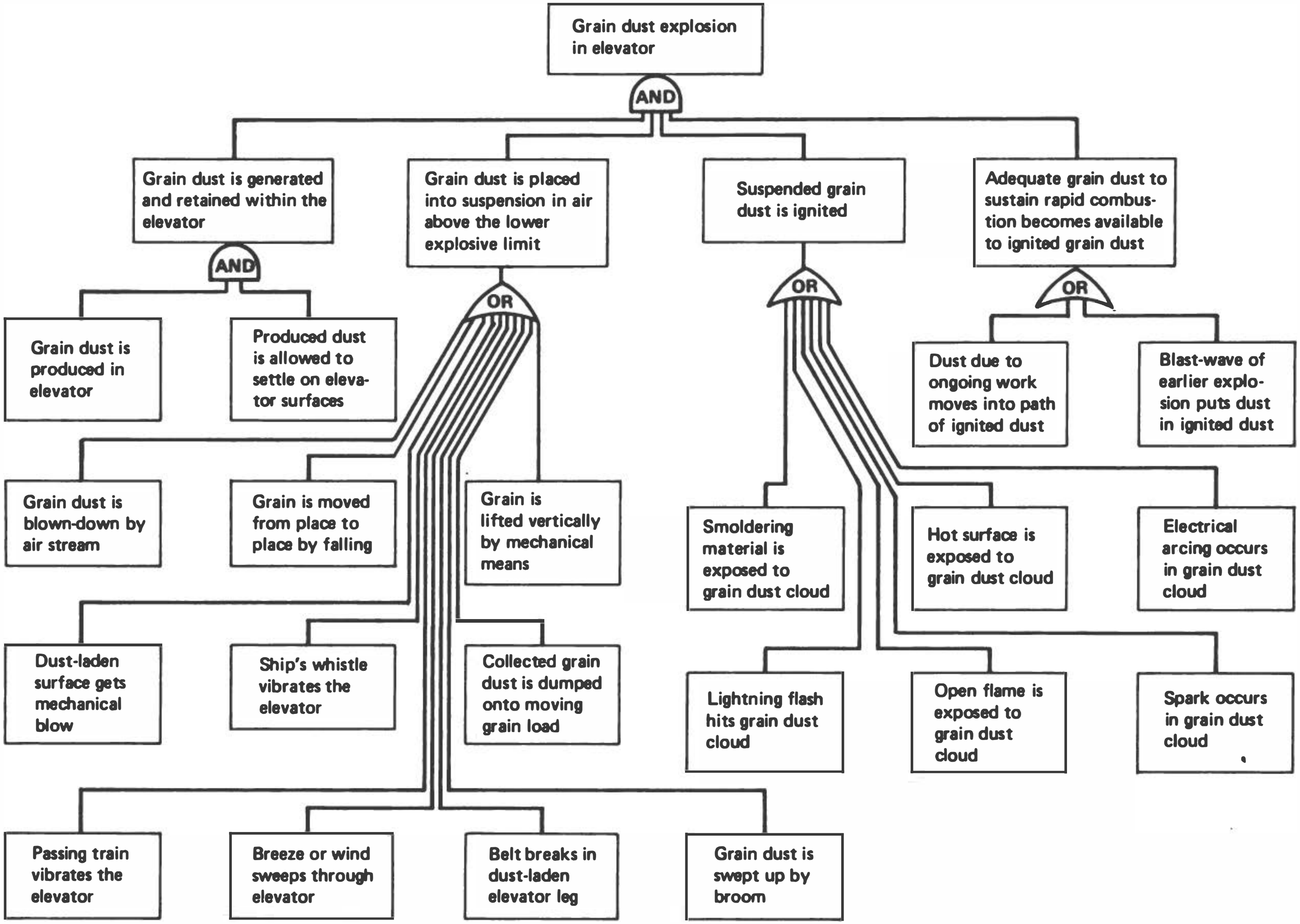

FIGURE 4 Fault tree analysis.

The latter two examples also illustrate the difference between initial and secondary explosions. Even though all of the conditions for explosion may exist at only one place at one time in an elevator or mill, an initial explosion can easily create these conditions at other points. The examples also identify the locations of the initial explosions.

In some cases, secondary explosions have been triggered by ignition of a dust cloud created within the conveying equipment by layered dust being disturbed and set in suspension in air. This hidden hazard of layered dust was illustrated by an explosion, investigated by the panel, that occurred in an elevator with remarkably clean working areas. In this case, the explosion was propagated mainly through hooded conveyors in the tunnels below the silos. Although the work areas had been kept clean by a combination of dust collection and manual housekeeping, quantities of dust sufficient to propagate an explosion had accumulated on interior surfaces of the covered conveyors. The explosion was violent enough to blow out the walls of the tunnel above ground and to initiate subsequent explosions wherever the explosion reached areas where layered dust had been shaken loose or scoured from interior surfaces by the pressure wave.

The secondary explosion hazard due to layered dust cannot be overemphasized. LEL values from U.S. Department of Agriculture 1980 data for grain dust clouds range from 20 to 55 g/m^3 . Using an LEL of 40 g/m^3 and an average density of 18.5 lb/ft^3 for grain dust, a dust layer on the floor of 1/64 in. or more in depth in an enclosure 10 ft in height, can create a dust cloud above the LEL when uniformly dispersed throughout the enclosure. It also should be noted that an explosive concentration in a volume a few inches or feet above the floor (i.e., less than the full volume of the enclosure) can easily be created from a 1/64 in. layer by a slight breeze or other disturbance. Ignition of a small cloud such as this could disperse the remaining dust and result in an explosion throughout the volume.

Ignition

The initial explosion can be ignited by a multitude of sources. A recently published compilation of actual explosions lists 26 different ignition sources for 147 explosions and lists an additional 103 explosions as having unidentified sources (see Table B-2, Appendix B). Other publications show a similar multitude of sources and a large percentage of unidentified sources (for example, Bartknecht 1981, Palmer 1973). Although the panel believes that adequate investigation of the explosions attributed to unidentified ignition sources would have identified most of the sources (National Materials Advisory Board 1980), a valid ranking of the danger due to particular ignition sources based on present data of frequency of occurrence cannot be made because of the large number of unknown sources and because of the relatively large number of unreported explosions. Considering how easy it is to ignite grain dust, either through careless action or circumstances beyond reasonable human control, the potential for ignition exists in numerous locations and at many times in an elevator or mill.

The use of motors, junction and switch boxes, lighting, and other electrical equipment not designed for dusty locations can be extremely hazardous. Lack of (or improper) grounding of electrical equipment can result in electrical sparks sufficient to ignite grain dust, either layered or in a cloud. The lack of a mechanism to prevent the introduction of foreign objects into the grain stream can result in sparking, rubbing, or jamming, and the lack of means to indicate belt slippage and misalignment can result in friction fires or electrical arcing. Poor maintenance of equipment such as motors, bearings, and conveying systems easily can result in hot surfaces capable of igniting dust. Hot work such as welding or torch cutting and electrical work done during facility operation is particularly dangerous. Nonadherence to smoking regulations is an obvious danger.

The effect of relative and absolute humidity and electrostatic phenomena on the ignition of dust clouds is a very controversial subject. Although the data relative to electrostatics are inconclusive, some believe that low relative humidity can contribute to the dust explosion hazard because the potential for electrostatic sparking increases as relative humidity drops and low relative humidity reduces the moisture content of grain dust, thereby lowering the ignition temperature and energy (Palmer 1973). As a consequence, employees of the Federal Grain Inspection Service (FGIS) now are advised to leave an elevator whenever the relative humidity falls below a certain percent and air-suspended dust is above a certain density (Federal Grain Inspection Service 1980). The panel believes, however, that the present basis for evacuation of an elevator needs re-examination. For example, a very serious explosion occurred at the Farmers Export Company elevator in Galveston, Texas, at 8:30 p.m. on December 27, 1977, when a relative humidity of 100 percent was recorded. The major difficulty with accepting data on past explosions is the fact that many of the values of humidity were obtained from readings taken anywhere from 5 to 100 miles distant from the elevator. Also, even assuming that local outdoor temperature and humidity readings could be obtained, the temperature in an elevator during winter may be high enough above the outdoor temperature to create a condition of very low relative humidity even though the outdoor relative humidity is high (e.g., air at 40°F and 100 percent relative humidity, when heated to 70°F, has a relative humidity of only 33 percent).

During periods of low relative humidity there is a tendency for static charges to build up on nonconductive materials and this increases the possibility of electrostatic discharges. Admittedly, the potential for sparking exists in systems employing moving, poorly conducting belts, and electrostatic discharges are observed frequently in elevator legs. However, the panel questions whether the energy in electrostatic sparks generated in elevators or mills is released in a manner that ignites grain dust.

The error of basing safety on high relative humidity is well expressed by the National Fire Protection Association (1978):

> ....moisture cannot be considered an effective explosive preventive since ignition sources provide more than enough heat to vaporize and heat the moisture and ignite the dust.

There is a considerable body of documented laboratory evidence that electrostatic discharge can ignite dust clouds; however, in its investigations of explosions, the panel found no evidence of ignition due to an electrostatic discharge in an actual elevator. The panel therefore recommends continued research to elucidate better the role of electrostatic discharge and absolute humidity in grain dust explosions.

CONTRIBUTING FACTORS

In considering accidents, including grain dust explosions, there is a tendency to focus on immediate physical aspect even though accidents may be recognized as resulting from a combination of causative factors. Thus, the contribution of human operatives and external factors, singularly or collectively, often is overlooked.

The panel believes that the grain dust explosion problem in part results from people's attitudes and other seemingly unrelated factors. The attitudes of owners, operators, and employees that may contribute to the explosion hazard are discussed below. It must be noted, however, that the panel does not mean to imply that these attitudes are universal or that other equally dangerous attitudes do not exist; it only wishes to emphasize that the potential contribution of human attitudes must be recognized.

Attitudes

Owners. It may not always be in the best economic interest of a mill or elevator owner to protect his facility against explosion if it would require a capital outlay that is large with respect to the original cost of the facility. For example, an old facility may be insured for its replacement cost, which is several times its original cost; if it were to explode or burn (without injuring or killing anyone), it would be an advantageous method of replacement.

Some owners of facilities with long explosion-free histories believe they have no need for concern. They may view government concern about explosions as an unwarranted intrusion into their business.

Operators-Managers. The attitudes that elevator and mill operators may have about dust explosions are not unique and are held by some involved in other hazardous operations. Most prevalent is a slowly developed complacency. Even though a manager may intellectually acknowledge the danger of a dust explosion, heavy work schedules, emergencies due to equipment breakdown, worker absences, and other managerial pressures can mitigate his continuous sensitivity to the hazard.

Even when operators hear of an elevator explosion elsewhere, they may believe that the accident was due to some extraneous or stupid action they would never commit. This is a difficult attitude to change without a method for properly investigating and reporting on elevator explosions, and the panel believes that operators informed of the results of thorough investigations would readily identify hazards in their operations that were similar to those contributing to explosions in other facilities, e.g., propane leaks during drier installation.

Operators also tend to assume that their employees are aware of hazards even though they themselves may have only a slight understanding of the mechanisms of grain elevator explosions. Many employees interviewed following the explosions investigated by the panel showed amazing ignorance about how dust explosions occur. Insufficient training of new or temporary employees in safety procedures and fire and explosion hazards can lead to a false sense of security. Lack of standards and procedures for fighting fires in elevators also has led to explosions.*

Many mill and elevator operators use outside contractors for a variety of functions such as welding and equipment installation. If the operator, as the person responsible for facility safety, dces not acquaint the contractors and their employees with the fire and explosion hazards, he is endangering the facility and its employees as well as the contract workers. Ample evidence for this is given by the high percentage of explosions stemming from welding operations (see Appendix B).

Personnel. It is conceivable that an explosion can occur in a grain elevator without an overt act by some person; however, in almost every case, someone, generally an employee, dces something that contributes directly to the occurrence of the explosion. It is highly unlikely that these actions are deliberate attempts to cause an explosion; quite the contrary, the personnel probably were unaware that they were in any way responsible for a disaster.

Government Interaction

The establishment and enforcement of environmental air pollution control regulations in response to the Clean Air Act of 1970 may have had an effect on the dust explosion hazard. The management of grain-handling facilities responded to these regulations in a variety of ways, some of which may have increased the probability of explosions. Prior to the establishment of these regulations some of the airborne dust escaped to the outside ambient air through windows, doors, cyclone collectors, and other openings. Following the establishment of these regulations dust could not be allowed to escape from the structure and it became necessary to install

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* One of the explosions the panel investigated resulted when firemen created a dust cloud while attempting to extinquish a fire in a smoldering dust pile. In another investigation, the fire chief of a large metropolitan area admitted that his fire service did not know how to fight fires in elevators.

dust collection systems to keep the air in the work space tolerably clean. Some managers viewed dust collection systems primarily as a means for meeting ambient air quality standards and only secondarily as a means for reducing the explosion hazard. It should be noted that Environmental Protection Agency regulations apply only to new elevators (1978) with a capacity of 2.5 million bushels or more but that these regulations have been applied by some states to existing facilities without regard to the federal limits on size or age. In older elevators, especially country elevators, little or no attention was given to dust control in the original design. Consequently, any dust collection system added was installed under retrofit conditions and most were installed by local sheet metal companies without reference to the engineering principles of dust control.

The whole subject of dust control versus government regulation has oscillated back and forth in the past 60 to 80 years. Originally some state bureaus of weights and measures prohibited any collection of dust on the assumption that the receiver would be short-weighing the received grain. This restriction eventually was lifted but was partially re-instituted by one state (Iowa) in 1979 and is being considered in another (Nebraska). The purported reason for reintroducing the restriction is that dust collection leads to or enhances dust explosions.

Economics

It is not unexpected that economic factors influence the incidence of dust explosions. Under ideal dust control conditions, all dust, wherever generated, would be collected and only dust-free grain would be delivered from an elevator to the next receiver regardless of the amount of dust in the grain when originally received. In practical situations, however, it is very unlikely that this could happen. First, the costs, both capital and operating, of cleaning the grain are not negligible. Second, the collected material has a sale value of only a fraction of that of grain. Even the removal of only the airborne dust involves high capital and operating costs and represents a loss in salable product. Returning the dust to the grain when it leaves the elevator permits the full grain value for the dust to be received and is one method used to reduce these costs. This, of course, increases the amount of dust to the receiver and thereby increases his hazard especially for the case of export elevators where the grain may have passed through as many as 3 or 4 elevators.

Even customers of grain elevators--those whose grain is processed, stored, or transferred from one transportation mode to another by means of an elevator--indirectly influence the probability of dust explosions through economic pressure. Users, including mills, are the source of many economic pressures on elevator management that in turn cause housekeeping to be ignored, machinery to be operated beyond its performance limits, welding to be done while operations are under way, and employees to be overworked. Additionally, customers always seek the lowest price for elevator services and thereby influence elevator owners and operators to cut corners and not implement all the actions that could prevent explosions. However, customers should also realize that they too bear the cost of explosions.

Insurance

Segments of the insurance industry have obstructed solution of the explosion problem by promulgating recommendations and requirements that have little or no real relationship to the dust explosion hazard. For example, although devices such as motion switches on elevator leg belts and thermocouples on bearings are useful in certain applications as control measures for ignition sources, they are not the substitute for adequate housekeeping that some insurance organizations have implied.

Miscellaneous

One factor over which there is no control is the effect of weather on a season's grain crop. Certain growing and harvesting conditions and certain grain types produce grain that is more susceptible to breakage in handling, and this results in a higher than normal amount of dust. For example, the harvesting of wet corn and subsequent forced drying at the elevator in place of natural drying results in increased kernel breakage.

Finally, specific information on the causes of actual explosions and actions that can be taken to reduce the hazards has not been made available to most grain facility managers. This in itself is a contribution to the explosion problem. For example, five symposia devoted almost entirely to discussion of elevator explosion problems were held between October 1977 and October 1979, but the proceedings of these meetings (Grain Elevator and Processing Society 1977, National Academy of Sciences 1978, National Grain Feed Association 1979, Texas Agricultural Extension Service et al. 1978, U.S. Department of Agriculture et al. 1979b) have not been translated into user terminology and widely distributed.

REFERENCES

Bartknecht, W., Explosions, cause prevention protection. Springer-Verlag, Berlin, 1981.

Development Planning and Research Associates, Inc., Preliminary Benefit Analysis--Cancellation of Carbon Tetrachloride in Fumigants for Stored Grain, for the U.S. Environmental Protection Agency, p. viii-18, April 1980.

Federal Grain Inspection Service, Policy and Procedures Upon Encountering "Unduly Hazardous Conditions" in Grain Elevators, Instruction 370-3, Revision 2, FGIS, Washington, D.C., 1980.

General Accounting Office, Grain Dust Explosions--An Unsolved Problem, GAO, Washington, D.C., 1979.

Grain Elevator and Processing Society, Proceedings of the International Symposium on Grain Dust Explosions, Minneapolis, Minnesota, 1977.

Hall, Leland L., Insurance industry's view, in Proceedings of the International Symposium on Grain Elevator Explosions, National Academy of Sciences, Washington, D.C., 1978.

National Academy of Sciences, Proceedings of the International Symposium on Grain Elevator Explosions, NAS, Washington, D.C., 1978.

National Fire Protection Association, Guide for Explosion Venting, NFPA No. 68, NFPA, Boston, Massachusetts, 1978.

National Grain and Feed Association, Proceedings of the Elevator Design Conference, National Grain and Feed Association, Kansas City, Missouri, 1979.

National Materials Advisory Board, The Investigation of Grain Elevator Explosions, Report NMAB 367-1, National Academy of Sciences, Washington, D.C., 1980.

Palmer, K.N., Dust Explosions and Fires, Chapman and Hall Ltd., London, 1973.

Rowe, W.D., An Anatomy of Risk, John Wiley and Sons, New York City, p. 28-33, 1977.

T. E. Stivers Organization, Inc., An Economic Impact Study of Proposed OSHA Electrical Standards in the Grain Elevator Industry, for National Grain and Feed Association, p. 37, May 1980.

Texas Agriculture Extension Service, Texas A&M University and Texas Grain and Feed Association, Causes and Prevention of Grain Elevator Fires and Explosions, Texas A&M University, College Station, 1978.

U.S. Bureau of Mines, Explosibility of Agricultural Dusts, Report of Investigation 5753, USBM, Washington, D.C., 1961.

U.S. Department of Agriculture, Handbook of Agricultural Charts, Handbook 561, USDA, Washington, D.C., 1979a.

U.S. Department of Agriculture, National Grain and Feed Association, and Kansas State University, Proceedings of the International Symposium on Grain Dust, Manhattan, Kansas, 1979b.

U.S. Department of Agriculture, Prevention of Dust Explosions in Grain Elevators--An Achievable Goal, USDA, Washington, D.C., 1980.

Verkade, M. and Chiotti, P., Literature Survey of Dust Explosions in Grain-Handling Facilities; Causes and Prevention, Energy and Mineral Resources Research Institute, Iowa State University, Ames, March 25, 1976.

Wade, F.J., Hawk, A.L. and Watson, C.A., Investigations to Determine Dust Concentrations and Characteristics Inside Enclosed Work Areas and Equipment at Large Grain Terminals, final report, USDA/Cargill Cooperative Agreement No. 12-25-A-2957, 1980.

Chapter 4

PREVENTIVE MEASURES

To forestall a dust explosion it is necessary to prevent the sequence of events that can lead to the simultaneous occurrence of the conditions for an explosion identified in Chapter 3 (see Figure 4). Some of these conditions are always present and some occur from time to time and their frequency of occurrence can be reduced; however, none can be totally eliminated. The reason that there are not more explosions is that the simultaneous occurrence of these conditions is relatively rare in any single elevator or mill. (The 1980 data indicating that explosions occurred in 45 of 15,000 facilities can be interpreted to mean that the chances of simultaneous occurrence of the conditions is one in 333 per year.)

Since none of these conditions can be totally eliminated there is no single, simple process for preventing explosions. On the other hand, applying what is known about the hazard can reduce the risk to a more tolerable level.

As stated many times in this report, dust will be present wherever grain is handled. The amount of dust can be reduced but never totally eliminated. Operating in an inert atmosphere has been proposed but the cost would be so great as to make it completely beyond reason. Totally eliminating suspended dust in enclosures may be extremely difficult if not impossible, especially in enclosures such as elevator legs, but the amount can be reduced. The possibility of dust suspension in concentrations above the lower explosive limit in open areas of an elevator cannot be ignored but can be reduced with relative ease. Layered dust in open work areas and hidden spaces can be reduced to a less hazardous amount through proper housekeeping. Ignition sources cannot be eliminated totally but the probability of their causing an explosion can be reduced.

DUST CONTROL*

Since grain dust is the fuel for an explosion, decreasing the amount of dust present at all points in a grain-handling structure is the most important "mechanical" step to be taken and will produce the greatest results. The installation of poorly designed dust control systems has fostered a false sense of security and frequently has led to an inappropriate reduction in manual housekeeping. The disappointing performance of many improperly designed systems has generated skepticism concerning pneumatic dust collection in the grain-handling industry.

*The term "dust collection" refers only to the mechanical collection system whereas "dust control" includes collection, housekeeping, and any other actions or equipment used to remove or prevent the generation of dust.

Dust collection should begin at the point grain is received and should continue at every grain transfer point in the elevator. It is particularly important that suspended dust concentrations in enclosures be kept below the lower explosive limit and that layered dust, the main fuel for secondary explosions, not be allowed to accumulate at any location.

As stated in Chapter 3, the panel considers the leg to be the most dangerous location in an elevator for an initial explosion for a number of reasons. First, buckets moving through grain in the boot generate and suspend more dust than any other process in the elevator. Second, most dust collection systems are designed solely to keep the interior of enclosures under negative pressure so as to prevent the escape of dust into the exterior working space; they presently do not reduce the dust concentrations in the leg below the lower explosive limit. Therefore, in many cases the presence of an operating dust collection system produces a false sense of security. The presence in the leg of moving equipment that may act as an ignition source makes the leg a doubly hazardous location. And, of course, the leg casing serves as a confining enclosure.

A mechanical dust collection system must be supported by manual housekeeping to prevent the accumulation of dust in layers in open areas of the facility. Secondary explosions almost always have resulted from the ignition of the cloud created from layered dust. In addition, layered dust can lead directly and indirectly to primary explosions (e.g., in one explosion investigated by the panel a fire in a heavy layer of dust around the top of the leg enclosure was sufficiently hot to ignite the leg belt, which dropped and resulted in an explosion that destroyed the leg and damaged the elevator).

Dust control should be an integral part of the design of new facilities. These designs should incorporate dust control systems and should minimize the work required for manual housekeeping. In addition, the design should minimize grain movement that creates or releases dust.

IGNITION SOURCES

Reducing the number of ignition sources to a minimum is the second most important method of prevention. Like dust, sources of ignition always will exist in or be brought into an elevator.

The use of electrical equipment complying with National Electrical Code standards should be mandatory. Well designed electrical grounding should be used not only to prevent sparking due to isolation of electrical equipment but also to prevent the accumulation of static charges. It is probably helpful if conveyor belts and head pulley lagging are conductive though present knowledge of the contribution of these sources to explosions is very limited.

Systems to check heat, motion, and alignment should be used on leg belts, bearings, and other enclosed grain-handling equipment. Where practical, the systems should be incorporated into an interlock system thatwill halt the grain-handling machinery before these types of malfunctions cause ignition of suspended grain dust and an explosion.

Mechanisms to prevent the introduction of foreign objects into leg boots and mills should be placed so as to screen all entering grain. The introduction of miscellaneous ignition sources such as cigarettes and other burning material and control of welding and cutting operations should, of course, be prevented by rigidly enforced work rules.

VENTING AND SUPPRESSION

Explosion venting is a mixed blessing. The venting of a dust explosion results in an initial high-pressure discharge of hot gases and burning particles followed by a low-pressure discharge of burning particles lasting many times longer than the initial discharge. It is obvious that an explosion in a leg vented within a headhouse can lead to a secondary explosion in a dirty headhouse as easily as an explosion in a nonvented leg, and the danger to employees in the headhouse is lessened only slightly. Some legs have a blow-out panel at the top to vent an explosion upwards, out of the headhouse; however, the panel has seen cases where the blow-out panel remained undisturbed after an explosion but the leg casing had blown open within the headhouse. The venting of other enclosed volumes in an elevator is subject to these same conditions. The proper venting of enclosures with geometries as complex as those found in elevators requires an understanding of explosion dynamics beyond that obtained from the study of simple structures such as cylinders and spheres. Indiscriminate venting should be avoided in order not to increase (instead of lessening) the hazard. Venting, of course, will not prevent a primary explosion but, properly applied, may reduce the possibility of a secondary explosion. Venting involving the use of numerous windows, corrugated metal siding, and other easily blown-out panels is preferred to the construction of solid concrete structures from which an explosion can distribute large pieces of solid masonary rubble over a wide area.

Venting, even via retrofit, is particularly desirable for totally enclosed sections of the leg that are constructed of reinforced concrete and cannot be cleaned readily. These spaces become bombs when ignition sources, including falling and burning belts, enter the wells, and the venting of the exterior walls of these wells will prevent destructive rupture of the enclosure. In addition, efforts to keep these spaces clean of dangerous quantities of layered dust should be made.

Active explosion suppression devices (the event triggers the release of a massive quantity of a suppressant such as Halon 1301) also are a mixed blessing. Such devices represent a large capital investment; therefore, their protective action should be evaluated against the consequences of potential explosion (i.e., the amount at risk) and the probability of their success in preventing that explosion. They are subject to "false releases;" therefore, the probability of this action times the cost of recharging and lost operating time must be added to the initial capital costs. A comparison of these costs versus use of these funds in other, possibly more beneficial activities should be made. Explosion suppression devices are more valuable when used in elevator legs and dust collection systems than in other areas of the elevator facility.

PERSONNEL

To this point, only mechanical prevention has been discussed, but in the great majority of explosions investigated by the panel, the chain of events leading to the simultaneous occurrence of the conditions needed for an explosion was initiated by an action or a lack of action by one or more persons. (All explosions other than those caused by "an act of God" ultimately can be traced to a human cause.) As stated above, the reduction of dust in the grain-handling structure is the most important "mechanical" method of prevention, and the proper actions of persons associated in any manner with grain elevators or mills is equally important. These actions can range from something as immediate as the timely lubrication of a bearing to something as far removed as the teaching of the correct method for fighting dust fires.

The nature of the hazard of dust explosions intrinsic to grain elevators and mills should be made known to all who work within them or are in any way responsible for their operation. The proper and complete education of management in the grain industry on the hazard of dust explosions should be the first step of an explosion prevention program. Although by no means prevalent in the industry, there are still some who either do not believe grain dust explodes or that an inordinate amount of dust is required for an explosion. This was evidenced in a few of the conversations panel members had with grain industry employees and management at symposia on grain dust explosions. Another fatalistic attitude detected by the panel was that work in an elevator or mill is a dangerous occupation and that nothing can be done about the danger.

Employee education programs on the hazards of dust explosions should be part of standard operating procedures in all facilities. It is not sufficient to have merely a short discussion and slide presentation on previous explosions. A demonstration of the explosion potential of dust should be made, preferably with dust gathered from within the facility elevator in the presence of the employees. (The demonstration should be carefully planned and performed by a person knowledgeable about the explosion hazard.)

One employee on each shift, assisted by a safety committee in larger installations, should be given the responsibility and authority for safety in the facility. He should report directly and only to the senior manager of the elevator or mill. His duties should include the development and use of a safety checklist (an example of such a list appears in U.S. Department of Agriculture 1980). The safety officer should be cognizant of the proper method of fighting dust fires and should assure himself that the local fire service is proficient in this matter.

Elevator and mill managers should treat housekeeping and maintenance as major functions of elevator operation. There is, however, a great tendency to postpone these functions during those periods when the elevator is operating at maximum capacity. However, this is the period of greatest risk, and a prearranged schedule of periodic preventive maintenance and housekeeping should be adhered to regardless of the press of business.

INDUSTRY INFORMATION

In the grain-handling industry, large corporations tend to be more knowledgeable about the technical details of grain dust explosions than small companies or the operators of individual country elevators. With respect to elevators, the amount at risk, including elevator personnel, is much greater in larger elevators, but this is offset by the much larger number of smaller elevators, approximately 14,000 versus 1,000. Although efforts to prevent explosions in large elevators should not be neglected, a reduction of the hazard in small elevators would yield a greater result (i.e., the cumulative number of injuries and fatalities in small elevators is greater than that in large elevators). Unfortunately, protection of small elevators is the most difficult to accomplish because less capital is available.

Employee awareness of actual grain dust explosions is important, and this can be accomplished by circulating information on actual explosions and their investigation to all elevators and mills, down to the "grass roots" level, through media such as the Department of Agriculture, state agriculture schools, The Cooperative Extension Service, and trade publications. The details of each explosion plus a report on its causes should be supplemented by recommendations concerning prevention. Unfortunately, however, obtaining and distributing such information is difficult because of legal constraints.

Cooperation among industry, government, educational institutions, and trade and professional organizations in generating and disseminating such information is needed to dispel some of the explosion myths revealed to the panel during its visits to various facilities.

In its investigations of explosions, the panel encountered some resistance from elevator managers in its attempts to determine the cause of explosions. Even in those cases where reluctance to discuss the circumstances surrounding the explosion was not experienced, further investigation often was hindered by legal actions instituted by representatives of injured employees. In a few instances elevator managers and others, who could have provided detailed information, associated the panel's intentions with those of government investigators who were seeking information on which to base personal or corporate blame. Requests to the panel for depositions or actual courtroom testimony placed the investigators in a compromising position with respect to their main concern, which was to determine the sequence of events leading to an explosion. The ultimate purpose was to determine the cause of the explosion as background information for this report and to inform others of means for preventing similar explosions in the future.

Seminars, symposia, and other open meetings on grain elevator safety sponsored by government, industry, educational institutions, and trade and professional organizations have been held in the recent past with increasing frequency, and some have been devoted solely to explosion prevention while others have devoted only a few sessions to the subject. One annual meeting sponsored by a consortium of organizations and devoted solely to grain dust explosions probably would be more effective and efficient than a number of smaller meetings or larger meetings with only a session or two devoted to the problem. It is hoped that the need for meetings dedicated solely to grain dust explosions will not continue indefinitely.

RESEARCH AND DEVELOPMENT

Research concerning dust collection in elevators and mills is needed. A variety of commercial equipment is available but its effectiveness and correct use is not well understood. (The panel has prepared a report on this subject, NMAB Report 367-3.) This research can borrow heavily from the information and experience gained in other industries handling explosive dusts (e.g., coal and flour).

Also needed is an industry-wide study of the grain-handling system from farm to ultimate consumer with emphasis on reducing dust generation. The handling methods now used evolved over a long period during which little if any attention was given to the dust explosion hazard. This research should be aimed at identifying general modifications that can be made in the present system to increase safety. Included in this study should be the design of mills and new elevators in a complete range of sizes from roughly 100,000 to 10,000,000 bushels.

As mentioned before, questions concerning electrostatic phenomena and relative humidity are part of dust explosion lore. There is a need for research on these topics that will relate theory to practice. Considerable information is available on the effect of relative humidity on the build-up of electrostatic charges and the ignition of dust by electrostatic discharges (Palmer 1973), but this information is rarely applied to determine the degree of hazard in an actual elevator or mill environment. For example, the manufacturers of conveyor belts claim that conductive belts reduce the possibility of static charge generation and storage on belts conveying nonconductive materials such as coal and grain. Research is needed to relate the electrical characteristics of conveyor belts to their contribution to the explosion hazard in real situations. The relationship between the conductivity of a belt and its ability to cause ignition is not well understood.

The generation of electrostatic charges during the pneumatic conveying of grain dust under conditions of low absolute humidity also has received little if any attention. Typical elevators and mills should be studied to determine if there are points where hazardous electrostatic conditions can occur due either to basic design or malfunction. If such points are found, the elimination of the hazard will not be difficult; the problem at the moment is recognition.

Research to discover new and more valuable uses for grain dust would encourage the installation of dust collection systems. The pelletizing of dust for use as animal feed is one step in this direction. At present, pelletizing operations use only a small percentage of the available grain dust, but the competition for dust among a few plants relatively close to one another has raised the price at times to almost one-half that of grain. An important factor in the development of a large pelletizing industry is the transportation costs after collecting the large amount of dust dispersed over a wide geographic area. A complete assessment study of the cost-effectiveness of converting grain dust to pellets for animal feed, including the safety benefits resulting from increased dust collection, is needed and would be a suitable project for the U.S. Department of Agriculture or an industry trade organization. The search for additional uses for grain dust also should be increased.

REFERENCES

Palmer, K.N., Dust Explosions and Fires, Chapman and Hall Ltd., London, 1973.

U.S. Department of Agriculture, Safety Operations Plans, A Self-Evaluation Checklist for Operators of Grain Elevators, U.S.D.A., Washington, D.C., 1980.

Chapter 5

CONSTRAINTS

The implementation of safety measures to prevent dust explosions requires consideration of a number of contraints, some that can be overcome and others that can be overcome only with some difficulty or not at all.

COST OF DUST CONTROL

The economics of dust control can be divided into two categories; that applying to new design and that applying to existing facilities. The cost of a dust control system generally will be much less if it is incorporated into the design for a new elevator than if it has to be added to an existing facility; however, the cost for existing facilities will vary greatly (e.g., some equipped with dust control systems may require only a few modifications in equipment and practices whereas others, in which little attention was given during design to the hazard of dust explosions, may require a considerable amount of new equipment and additional labor). The cost of a dust control system also will depend partially on the size of the facility, whether new or existing. For example, operators and designers of small facilities may find that greater cost benefits are derived from a different balance between manual housekeeping efforts and the installation and use of mechanical dust collection systems or other dust control systems.

In all cases, measures to reduce the explosion hazard will generate capital and operating costs that cannot be ignored but may lead to a decrease in insurance costs. New equipment, when required, and the labor involved in its installation can represent a considerable expenditure. Even when only modification of an existing system is required, labor costs cannot be ignored. The cost of down-time while modifications are being made or new equipment is being installed also may be a factor, although this work usually can be done in off-shift time. The cost of operating and maintaining dust control equipment will be a continuing business expense, and additional labor for manual housekeeping may be required. The loss that results from the low market value of dust also must be considered. Although collected dust represents only a small percentage of the received grain (0.1 percent of the total volume of grain handled (U.S. Department of Agriculture 1980)) discarding it or selling it at a sacrifice represents a much larger percentage loss in the elevator's income.

Balanced against these costs are the benefits to be derived. If a facility has no dust collection system, it must do some manual housekeeping. This labor cost will be considerably reduced if a dust collection system is installed. The re-introduction of collected dust into the grain stream and its subsequent sale as grain adds an additional burden and hazard downstream if the grain is delivered to a second elevator. However, if the dust is used, for example, to make pelletized animal feed, part of the collection cost is offset. Portable pelletizing equipment may permit even the smallest country elevator to recover some of the costs of dust collection.

Although no specific mention has been made in this report of occupational safety, it was, of course, a major stimulus for the panel's study. Thus, the panel notes that hospitalization costs, insurance costs, and costs of damage suits resulting from deaths and injuries occurring in explosions must be considered in any assessment of the costs and benefits of measures required to reduce the explosion hazard.

INSURANCE

The panel's study has indicated that insurance is a mixed blessing to the grain-handling industry. Insuring against accidental loss and injury is a legitimate business practice; however, there is little incentive for improving safety when the losses due to explosions in high-risk facilities are absorbed by the insurance premiums of well run, low-risk facilities. The panel has found that the insurance industry, in general, has scant knowledge of the type or degree of explosive hazard found in elevators and mills as evidenced by the fact that dirty (dusty) facilities seem to have little difficulty obtaining insurance, although in some cases they must pay increased rates. This is due mainly to a lack of standards for defining grain dust explosion hazards. As long as this situation exists there will always be some members of the grain-handling industry who will consider insurance as a safeguard in place of adequate safety measures that no one has either bothered or been able to define.

GOVERNMENT-INDUSTRY RELATIONS

Cooperation between government regulatory agencies and industry to increase safety in elevators and mills is something that has yet to be fully developed. Regulatory agencies, both federal and local, are viewed with suspicion by both industry and labor. In general, labor feels that there is not enough regulatory activity and industry feels that most regulatory activity is unnecessary. This is especially true with respect to the Occupational Safety and Health Administration, Federal Grain Inspection Service, and Environmental Protection Agency. The reluctance of elevator management to cooperate with the panel was evident during its investigation of one explosion because of an imagined association between the work of the panel and a regulatory agency investigation. This same general attitude was noted in the panel's previous report (National Materials Advisory Board 1980). On the other hand, too close an association between those responsible for what is inspected and those doing the inspecting can lead to problems as well. The panel believes that a greater dependence by regulatory agencies on performance standards in place of inspections "by the book" would alleviate the feelings of animosity and better serve the goal of increased safety.

Air pollution regulations have already been mentioned in this report. It is interesting to note that some representatives of labor and industry are on the same side of the fence with regard to EPA's emission air quality regulations. Both feel that the regulation preventing the discharge of dust to the outside of the elevator has increased the explosion hazard. The panel determined that improper response to the regulation is the problem.

The actions of state governments with respect to dust control have already been discussed in this report. Education as to the explosive hazard represented by grain dust must not be limited to the industry and its employees.

LEGAL ENVIRONMENT

The current litigious environment significantly affects the prevention of grain dust explosion accidents in that owners, operators, workers, designers, suppliers, witnesses, and investigators may either be held responsible for an accident with attendant civil and criminal penalties, or be harassed outside and inside the court room. An insurance firm may indicate to an insured that dangerous conditions exist within a facility and that such conditions should be corrected. If an accident occurs before the correction is made the company may be held responsible in that it knew of the dangerous condition or failed to notify the responsible public authorities. If a governmental agency fails to detect a hazardous condition that is then involved in the chain of events leading to an accident, it may be deemed that they should have detected such a fault. New design data may be developed as well as unconventional equipment; however, significant risk accompanies its introduction because any accident that subsequently occurs can be blamed on this limited precedent technology. Witnesses are reluctant to provide information relating to accidents since they fear they will jeopardize a possible financial settlement if they have been injured or been served with a subpoena to provide testimony. The results of accident investigations, which should be released immediately to prevent the repetition of similar hazardous conditions leading to an explosion, must be suppressed to avoid their citation.

HOUSEKEEPING

Because housekeeping is the easiest part of elevator operation to ignore, it is usually assigned the lowest priority. If the press of business is great, e.g., three-shift operation, there is a tendency to postpone clean-up operations. This, of course, is exactly the worst time to delay housekeeping. It is looked upon as an expense without an immediate economic return. Those times when it is most needed are also the periods when there is the greatest chance that temporary help will be employed. Inexperienced and untrained temporary help, as a group, are those least likely to realize the hazards of dust explosions, and if they are employed in housekeeping work the situation is doubly hazardous.

PSYCHOLOGICAL FACTORS

The influence of human factors has already been discussed at some length as part of the dust explosion problem. However, because human attitudes, unlike the actions of mechanical devices, are not susceptible to rigorous control, they are a constraint to reduction of the hazard of dust explosions.

Personnel can contribute subtly to the explosion hazard. There are those who realize the hazard but have a fatalistic attitude in that they accept a certain amount of danger as a fact of life. Others feel that there is no danger, either because they do not know or do not believe dust can explode. These same attitudes once prevailed in other fields such as mining, aviation, and the chemical industry but have since been corrected through education and employee-management communication. Since total elimination of the human factor is never possible, it is an ever present hazard that management must guard against.

Employees are not the only group whose attitudes affect safety. Owners and operators-managers, even though they usually are aware of the danger, tend to procrastinate concerning actions to improve safety, especially if they can rationalize a delay on the basis of economics or on the press of additional immediate business. In this context, peer pressure can have either a negative or a positive effect.

Some owners and operators-managers also have the same opinions as employees and this is especially true of those who recognize that an explosion is more remote a possibility than the 100-year flood. Finally, there is the universal human characteristic that responds to a pressure by resisting.

REFERENCES

National Materials Advisory Board, Panel on Causes and Prevention of Grain Elevator Explosions, The Investigation of Grain Elevator Explosions, Report NMAB 367-1, National Academy of Sciences, Washington, D.C., 1980.

U.S. Department of Agriculture, Prevention of Dust Explosions in Grain Elevators--An Achievable Goal, USDA, Washington, D.C., p. 40, 1980.

Chapter 6

BASIS FOR RECOMMENDATIONS

Previous reports concerning the prevention of grain dust explosions in grain-handling facilities have presented numerous recommendations. The panel found no major fault with these recommendations except that they were not ranked in terms of priority, value, or economic feasibility. To be of value to an industry composed of facilities as varied in size, construction, and purpose as those handling grain, recommendations must take into account the fact that no single recommendation will suffice to solve the problem in every facility and not every recommendation can be applied to all facilities.

Further, recommendations must address factors beyond technical ones. Figure 5 illustrates the broader perspective taken by the panel to examine subtle but consequential facets of the explosion problem. For example, the personal cosmology of both grain elevator managers and workers (i.e., how they perceive who they are and the meaning of life) influences their attitude in taking action to prevent explosions.

If resources were unlimited, the panel believes that the dust explosion hazard could be reduced to a negligible level in every type of facility. Recognizing, however, that resources are not unlimited, the panel concentrated its study on first determining what could be done and then on assessing each preventive action's potential for hazard control. To accomplish the latter, each preventive action was ranked as high (H), medium (M), or low (L) in terms of:

1. Efficacy - the degree to which the hazard would be eliminated or controlled by the action;

2. Feasibility - the acceptability of implementing the action in light of the economic, legal, cultural, political, social, and technical considerations depicted in Figure 5;

3. Efficiency - the cost-effectiveness of the action in terms of potential dollar loss if no action is taken versus the cost of the proposed action.

The panel's recommendations fall into two main groups: (1) recommendations to the grain-handling industry and its trade associations concerning hazard reduction in existing facilities, needed research, and the design of future facilities and (2) recommendations to the government concerning more effective regulations. In the following discussion, the recommendations on a specific subject are presented first and then the need

FIGURE 5 Facets of a systems approach to grain elevator explosions.

for them is explained. The panel also realizes that some recommendations may already be in effect and that the cost of implementing these recommended actions will be different for different facilities. The panel hopes that its presentation of the recommendations in this manner will convince owners and managers to examine the list, to determine where their operation is deficient, and to take remedial action within the limits of their economic and administrative capability. The same procedure should apply to those recommendations aimed primarily at labor organizations, trade and professional organizations, and federal, state and local governments.

EXISTING FACILITIES

The following recommendations address engineering matters and administrative actions.

Dust Control

Recommendations	Efficacy	Feasibility	Efficiency
Establish a housekeeping program involving a mechanical dust collection system supplemented by manual or other means.	H	M	H
Apply state-of-the-art techniques to reduce the concentration of airborne dust in and emanating from elevator legs.	H	L	M
Control dust generation and airborne dust at all grain transfer and discharge points.	M	M	M
Eliminate all nonessential horizontal surfaces.	M	M	M
Coat all nonhorizontal surfaces exposed to airborne dust with materials that will prevent the build-up of layered dust.	L	L	M
Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosive limit where possible in enclosures other than legs.	L	L	L

There can be no doubt that overall dust control is the most important action that can be taken to reduce the explosion hazard. It also is the step that will be the most cost-effective. The panel's own investigation of explosions and studies of past explosions indicate that a preventable accumulation and suspension of dust was the basic feature of every explosion. There is no question that dust explodes; the important point is that the accumulation or suspension was preventable.

Of all of the locations in an elevator where dust can exist in suspension, the leg is by far the most hazardous. This has been recognized time and again by groups studying elevator explosions. It is the one piece of equipment with an environment of suspended dust that is continually subject to "choking" (boot fills with grain and buckets will not turn), electrical faults, bearing failures, mechanical misalignments, ingestion of foreign material, etc. The most effective remedy for this situation is use of a dust collection system in the leg sufficient to reduce the concentration of suspended dust. A means for preventing the accumulation of dust on the walls of the leg or a means for periodically removing any accumulated dust also must be provided. A particularly difficult problem is presented by those legs in which the middle portion of the enclosure consists of only the concrete walls of a headhouse. Manual cleaning or enclosing of the belt and buckets in a close fitting, dust-tight metal casing appear to be the only solutions.

Suspensions of dust in enclosed volumes other than legs present a danger second only to that of legs. Silos, bins, garners, enclosed conveyors, etc., contain little if any equipment that can serve as an ignition source and are therefore only rarely the point of an initial explosion. However, ignition of dust concentrations in these enclosures, whose volume can be much larger than that of legs, can result in an explosion of much greater magnitude than that in a leg. These enclosures present two hazard conditions: first, the air-suspended dust that is present when they are being filled and, second, the dust clinging to the walls and ceilings that can be loosened by the shock of an initial explosion. The removal of the airborne dust can be accomplished using the same methods as in the leg. The dust problem in silos and the generation of additional dust can be lessened somewhat if dead boxes, grain ladders, and filling spouts that entrain a large portion of the dust in the grain stream are used.

The movement of grain from one point to another results in the creation of dust and in the suspension of some airborne dust at transfer points. A dust collection system should be used at every point where grain falls through the air (e.g., when it is transferred from one belt to another or from a spout onto a belt). There is little danger of an initial explosion occurring at these points, but without use of a dust collection system, most of the dust will settle on the floors, walls, ledges, ducts, etc., in the work space. This dust then can become the fuel for secondary explosions in tunnels, galleries, headhouses, and other work spaces. Thick layered dust around working equipment presents the ideal conditions for initiation and concealment of smoldering dust fires that can serve as the ignition source for an explosion.

Even if dust control is applied as indicated above, there will be a need for manual housekeeping. The manual vacuuming of all exposed surfaces is recommended over blow down or sweeping, which tends to raise dust clouds and usually does nothing more than redistribute most of the dust. (See, for example, National Fire Protection Association's NFPA No. 618, Code for the Prevention of Dust Explosions in Terminal Grain Elevators.) As mentioned earlier in this report, the danger of layered dust in the work space was vividly exhibited to the panel in one of its explosion investigations. An initial explosion in a headhouse was followed by an explosion in a silo. This secondary explosion was initiated by a flame that propagated near the gallery floor due to a layer of dust until it came to an open empty silo. In numerous other explosions, headhouses, galleries, and tunnels have contained enough layered dust on exposed surfaces to fuel secondary explosions within these structures.

As a complement to manual housekeeping, the panel recommends that all unnecessary horizontal surfaces be eliminated and all nonhorizontal surfaces, both those in enclosures and those in the working areas, be coated with a material that will inhibit the layering of dust. Rough concrete and wood surfaces are particularly susceptible to a buildup of layered dust. Surface coatings over metal should be somewhat conductive.

In summary, dust control is most important in reducing the dust explosion hazard in grain-handling facilities. Some aspects of the dust control recommendations are relatively more expensive than others and some may already be in effect. The value of each of the recommended actions depends, of course, on how well they are applied or performed (e.g., dust control systems that do not keep the dust concentrations below the lower explosive limit or manual housekeeping poorly performed are dangerous since they instill a false sense of security). The total dust control efforts should be based on a performance standard and not merely on the application of the recommended actions.

Every elevator having interior legs should utilize an adequate dust collection system in the leg because of the extremely hazardous condition resulting from suspended dust in proximity to potential ignition sources. The other dust control recommendations will contribute to a reduction of the hazard and are, to some degree, interdependent. For example, the application of surface coatings reduces clinging to vertical surfaces but does not eliminate the need for dust collection from enclosures other than legs; without dust collection at transfer points, the need for manual housekeeping increases greatly. Adequate manual housekeeping is possible only when there is easy access to hidden spaces and all surfaces that can support layered dust. Hence, special attention needs to be paid to providing access ports to dust-containing enclosures to facilitate cleaning. Easy access to large expanses of walls and ceilings, such as occur in many headhouses, must be provided. The panel, of course, advises that all of these recommendations be implemented.

Ignition Control

Recommendations	Efficacy	Feasibility	Efficiency
Use a pre-established and enforced permit procedure whenever welding, cutting, or other open flame work is to be done.	H	H	H
Incorporate a system to indicate belt slippage and misalignment.	H	M	H
Incorporate a method to check frequently the temperature and vibration of critical bearings.	H	M	H
Use devices to extract foreign materials from theincoming grain stream.	M	H	H
Ground all conveying and electrical equipment.	L	H	H
Use only equipment and installation standards meeting National Electrical Code requirements.	L	L	L

Next to the control of dust, the control of ignition sources is the most effective means for reducing the explosion hazard. Since the data on ignition in actual explosions are poor, it is not possible to give a meaningful ranking to ignition sources; therefore, the panel arbitrarily divided the sources into the eight categories shown in Table 2 and then assessed the probability of their occurrence and the ease of their elimination.

The major deterrent to spontaneous ignition of stored grain as a likely source of ignition is the necessity of preserving the commercial value of the grain. In modern operating practice, if the grain is to be in residence for more than a few weeks, the temperature is closely monitored. A rise of a few degrees in grain temperature indicates insect infestation and fungus, which reduce the grain's value and mandates countermeasures, cooling of the grain by pulling air through it or by turning it. Thus, spontaneous ignition is not considered a probable source.

The probability that electrical apparatus and wiring selected and installed in accordance with the provisions of the National Electrical Code (NEC) will be a source of ignition is extremely low under either normal or fault conditions. The code provisions and apparatus standards place limits on temperature of exposed surfaces and mandate enclosures that exclude dust that could contact energized parts.

TABLE 2 Ignition Sources

Source	Probability of Occurrence	Ease of Elimination
Spontaneous ignition	Low	Easy
Arcing from electrical apparatus		
• Normal operation	Low	Easy
• Fault operation	Low	Easy
Sparks from foreign materials		
• Elevators, ferrous metals	Low	Easy
• Elevators, nonferrous metal	Low	Easy
• Elevators, other	Low	Easy
• Mills	High	Moderate
Static electricity		
• Moving belts	High	Moderate
• Moving grain/dust	Low	Difficult
Hot Surfaces		
• Lamps	Low	Easy
• Bearings	High	Moderate
• Radiators/Pipes	Low	Moderate
Friction		
• Rubbing head pulleys	Moderate	Easy
• Slipping belts	High	Easy
• Scraping buckets (misaligned belts)	Moderate	Moderate
Open flame	High	Moderate
Welding and cutting	High	Easy

If the installation is not in accordance with the NEC, the probability of the electrical apparatus or wiring becoming a source of ignition is higher, but in itself such an installation is not likely to be a source of ignition unless open contact switches or other arcing parts are exposed directly to accumulated dust. However, if NEC guidelines are not followed there is a much higher probability that there is also little control of the use of portable equipment such as drills, hand lamps, and grinders that may be ignition sources. Failure to observe NEC requirements often can be an indication of more serious problems rather than an imminent danger itself.

Even in an installation that does not strictly reflect NEC requirements, the immediate hazard may be only moderate if the equipment is nonsparking, enclosures are dust-tight, and a good standard of housekeeping is observed. This does not obviate the need, however, to follow NEC rules because a conforming installation is forgiving of other problems whereas a nonconforming installation in combination with other bad practice may become a hazard.

Most investigations of the production of sparks between combinations of ferrous, nonferrous, and rocky materials have been concerned with the ignition of methane. Although there have been many investigations, no simple picture of the conditions required for dust ignition has emerged. It generally is agreed that the thermite reaction between aluminum and rusty steel under some conditions can ignite methane. Investigators differ on whether impact or friction is the important parameter and whether steel-steel or rock-metal impacts are ignition capable.

The range of energy reported for methane ignition by sparks generated by impact is wide, ranging from 10 to 400 ft-lb, but in most reports above 200 ft-lb. It seems unlikely that a piece of tramp metal or a rock small enough to pass through a 1-1/2 in. grate would result in enough impact energy to ignite grain dust. The weight of a piece of foreign material that could pass a 1-1/2 in. grate could be as high as 1 lb for the case of a steel object. A 1 lb. object would have to fall 200 ft to have an impact energy of 200 ft-lb. Although it is not impossible, it does not seem likely that a piece would fall from a bucket and drop that distance without first striking another bucket or the leg enclosure. The above numbers are for methane. Spark ignition energies for grain dust are at least twenty times higher than that required for methane. Even if one takes into account that slower release of energy accompanies a friction spark (a hot particle) and that dust is more easily ignitable by long-duration electrical sparks (Eckhoff 1975), one concludes that sparks from tramp material falling in an elevator leg are not likely to be a prime ignition source.

The potential for tramp metal to cause a primary explosion does exist in a hammer mill. The energy released when a small piece of metal is struck by hammers in a mill is more than sufficient to ignite grain dust. Pieces of metal as well as other hard objects also can damage hammers in mills and metal buckets in an elevator. Although the objects themselves may not produce sparks sufficient to ignite dust, the damage they cause may lead to an explosion through friction heating or spark generation by the damaged hammers or buckets.

It has been suggested that the use of plastic buckets instead of metal buckets would eliminate the possibility of sparking and reduce friction heating resulting from damaged buckets striking or rubbing against the leg enclosure. More study of this is needed since it is not certain that plastic buckets will not introduce new and equally dangerous conditions.

The literature on ignition by static electricity under conditions found in a grain elevator is sparse. Palmer (1973) offers qualitative guidance only and advises the grounding of all ducts and metal. The Canadian Grain Handling Association (1979) concluded, primarily based on the work of Morse of the National Research Council of Canada, that static electricity generated in moving grain is not likely to be a source of ignition. A more recent study (Safety Consulting Engineers, Inc. 1980) of electrostatic properties of grain cites the need for further investigation of the properties in conjunction with grain-handling facilities. Static discharges from belting have, in conventional wisdom, been presumed to be ignition capable (University of Southhampton 1980). Industry practice has been to bond the metal framework of conveyors to ground to eliminate build-up of static charges, and this should be considered standard practice. Although the presence of large charges has not been conclusively shown to be an ignition source, it seems likely that arcing between parts of metal framework not bonded together could release sufficient energy to ignite a dust cloud or layer. Additional experimental data on ignition by discharges from belting, the presence of static charges in the leg, and the likelihood of static induced ignition in dust collection system are needed.

The ignition temperature of grain dust layers exceeds 200°C. Hot lamp surfaces can serve as ignition sources if they do not meet NEC requirements for use in dusty locations. If lighting fixtures are selected and installed in accordance with the NEC, they should not be considered an ignition source <u>except</u> if installed in a position that permits dust to accumulate on the hot, glass surface in a way that impedes heat transfer.

Fires due to hot bearings have been reported, and one must conclude that bearings are a likely ignition source if only because they are so numerous in an installation using conveyors. Boot and head pulley bearing failure is especially hazardous. Two methods for reducing the hazard due to hot bearings have been proposed: locating the bearings outside of conveyor and leg enclosures so that overheating will not cause ignition of surrounding dust and monitoring the temperature of the bearings. The application of these methods will be inexpensive in new construction but only the second is applicable to an existing facility. Both still require a relatively high standard of housekeeping to keep dust layers from accumulating on external bearing surfaces.

Slipping belts, especially at the head pulley of a leg, have been blamed for grain elevator explosions, in many cases because friction ignited the belt, which then parted and dropped down the leg. The universal application of underspeed devices that prevent operation of the elevator under this condition can eliminate this source of ignition. A somewhat more remote hazard, though it has occurred, is friction heating of the belt due to a slipping or locked boot pulley; therefore, the underspeed device should monitor the speed of the belt as well as that of the head pulley. (In one explosion (Finn 1976), the pulley speed was maintained but the belt slipped because the lagging was worn off and caught fire and dropped down the leg.) This remedy is applicable to existing as well as new facilities. Interlocks to shut down moving systems when part of the system fails or when dangerous choke conditions occur should be standard features.

Venting

Recommendation	Efficacy	Feasibility	Efficiency
Follow, to the extent practical The National Fire Protection Association's Standard on explosion venting (No. 68) for all enclosures. Concrete structures should be vented by windows or other openings of the size dictated by this standard.	L	M	H

Venting can be considered to be the third most important area (following dust and ignition source control), but its effectiveness is limited since it is effective only during the occurrence of an explosion. Many also have reservations about the effectiveness of venting. The American Insurance Association (1978), for example, states: "When the rate of pressure rise exceeds 3,300 psi/s, it apparently becomes impossible to design an effective explosion relieving system." Nevertheless, since the greatest amount of damage and human injury usually is caused by secondary explosions, venting should be considered if it can reduce the connection between primary and secondary explosions.

Many locations within a grain-handling facility can be regarded literally as "loaded cannons" when they contain sufficient dust (either in layers, in a cloud, or both) to support an explosion. Examples are legs, empty bins, tunnels, duct work, headhouses, enclosed conveyors, and galleries. If there is sufficient fuel, an explosion in any of these enclosures will propagate through it until sufficient pressure is built up to rupture the walls or until the pressure is relieved at the end of the enclosure. (If the end of the enclosure is strong enough to withstand the pressure, the reflection of the pressure wave back down the enclosure adds to the magnitude of the already existing pressure.) The bursting strength of existing structures is small compared to the maximum pressures generated by most well-fueled grain dust explosions.

Technical information on the merits of venting grain-handling structures is practically nonexistent. Particularly hazardous is the formulation of size of vent openings based only on the total volume enclosed, without giving consideration to the effect due to the length/diameter (L/D) ratio of the enclosure, or roughness. When the ratio, L/D, equals or exceeds 10 the equivalent diameter of the vent opening exceeds D. Numerous elevator legs have a vent panel only at the top. A well-fueled explosion, initiated at the bottom of the leg, will generate enough pressure to rupture the leg casing as it progresses up the leg long before the pressure wave reaches the vent. Indeed, the panel has investigated explosions in which the leg casing ruptured and the vent, in operable condition, was still closed.

For those cases where L/D is less than 10 (e.g., garners, scales, and bag houses), venting can provide some protection against rupture of the enclosure but a flame will propagate through the normal or vent openings of the enclosure. In addition, the vents must release to the outside of the facility if they are to protect employees in the working areas from exposure to flames.

Examples of incidental venting have been noted in a number of explosions. Headhouses having numerous windows or steel sheathing walls suffer much less damage than those constructed of concrete with only a few windows or none at all. Relieving explosive pressure by blowing out windows or frangible sheathing is preferable to spraying the landscape with large pieces of concrete from a concrete headhouse that has contained the explosion until the pressure becomes sufficient to rupture its walls.

The modification of existing structures to provide venting is often impossible and always very expensive. For example, nothing can be done about venting tunnels that are already completely below grade (e.g, those below silos). Thus, venting should be applied to exterior structures (e.g., bag houses, exterior legs or other conveyors, and exterior ductwork).

Suppression

Recommendation

Impractical for the workplace.
Possibly feasible for the interior of equipment.

Devices for the suppression of explosions can be installed in legs, ductwork, and other narrow enclosures. These devices are containers of pressurized dry powder or inert gases, usually Halons, which release the gas when triggered by actuators sensitive to flame (infrared) or pressure rise. They are very effective in suppressing explosions in enclosures, especially legs and dust collection systems, but they have two drawbacks: they are relatively expensive for small facilities and they are not 100 percent safe against false actuation, which adds to their operating cost because recharging is expensive. Research and development being conducted by the manufacturers of these devices should be followed closely to determine if they are becoming more cost-effective for small facilities.

Passive and active barrier systems that have been extensively employed by the coal mining industry for explosion suppression in tunnels (Cybulski 1975, Liebman et al. 1976) must be examined separately. These devices spread an extinguishing agent--water, Purple K, rock dust--across the tunnel ahead of the advancing flame front. The passive devices consist of frames supporting water containers near the tunnel roof. The airflow behind the pressure wave created by the explosion dumps the water. With the active devices, a sensor detects the explosion and actuates the dispersion devices. Extensive testing has led to optimum designs for these barriers and they may be applicable in elevator galleries and tunnels. Specifically, the water barriers are relatively inexpensive to construct, require little maintenance, and are reliably triggered.

Fire suppression by use of automatic sprinkler systems has only marginal value in the prevention of explosions. (The protection of the physical plant from damage due to fire alone is not the subject of this report.) The initiation of a number of explosions can be traced back to smoldering dust that could never have triggered an automatic sprinkler system.

Inerting

Recommendation

Do not use inerting because it is too expensive and is dangerous to personnel.

Operating a grain-handling facility in an inert atmosphere to prevent explosions has been considered in the past. It has been judged to be completely impracticable from both a mechanical and economic point of view. In addition, the inerting of large volumes is dangerous because workers can be asphyxiated.

Education

Recommendations	Efficacy	Feasibility	Efficiency
Establish an information center to distribute actively all available information on elevator and mill dust explosions and their causes and prevention.	M	L	H
Investigate and report on explosions in a manner that reflects the recommendations made by the panel in its report, Report NMAB 367-1.	L	M	L

As noted many times in this report, ignorance of the explosion hazard is very prevalent and reflects both poor dissemination of what is known and lack of knowledge concerning hazardous factors or situations. The degree of ignorance is inversely proportional to the unit size in the industry (i.e., the management of large grain-handling corporations is much better informed than the management of small mills and country elevators); therefore, given the preponderence of small facilities, lack of information is an important factor. The degree of ignorance also increases in going from overall management to the lowest paid employee.

Ignorance of the dust explosion hazard can be alleviated by collecting available information in a central repository, a relatively simple but laborious task and by distributing the available information. Numerous organizations now are engaged in disseminating information (e.g., the National Grain and Feed Association, the Grain Elevator and Processing Society, the Department of Agriculture, NIOSH, OSHA, the trade and union press, and various university and private research organizations), but it does not seem to reach the "grass roots" of the industry. Regardless of the reason for this, it is a problem that should be overcome. The panel suggests that information be channeled through the Department of Agriculture to the state Directors of Agriculture down to the county agents of the Cooperative Extension Services. The aim is to ensure that each grain-processing facility is informed without having to request information. Organizations such as the U.S. Fire Administration, OSHA, NIOSH, trade and professional associations, unions, insurance groups, and trade publications also should receive all available information.

Operating Procedures

Recommendations	Efficacy	Feasibility	Efficiency
Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.	H	H	H
Notify all facility managers that safety is a non-delegable responsibility. If authority is delegated it must be to an employee who reports directly to the plant manager.	L	H	H
Establish a fire and explosion prevention training program in each facility.	M	L	H
If dust is returned to the grain stream do it in the least hazardous manner.	M	L	L

The manager of each facility is ultimately responsibile for the safety of his plant. Either the manager or a designated employee who reports directly to the manager should be responsible for the day-to-day safety. This person should be completely familiar with all of the plant operations and should perform a system safety analysis of the whole plant. It is important that he understand that all explosions are preceded by a sequence of events that may have begun quite some time before actual ignition of a dust cloud.

Operating procedures affecting safety are numerous and varied but can be classified into a few categories. The diversity of sizes and types of elevators and mills dictates that the details of these procedures be left to each plant or facility; numerous examples for each overall subject are readily available.

The first and most important action is to insure that every employee, visitor, contract employee, local firefighter, and any others who may be in the facility are aware of the hazard of dust explosions and the means for their prevention. Numerous examples of explosions resulting from welding operations appear in the literature and the panel is aware of a number of instances when ignorance of the proper method of fighting a dust fire led directly to an explosion.

Housekeeping, including continuous surveillance for dust emissions and deposits, must be treated as a first priority activity in plant operations. The panel has seen two instances where several feet of dust had collected in boot pits and ultimately led to explosions. It was said that the pits were cleaned out regularly every few months! The importance and degree of housekeeping should be directly proportional to the degree of activity of the facility, not inversely proportional.

Maintenance is related to ignition sources in the same fashion as housekeeping is related to dust control. It is assumed that any normal plant operation should include preventive maintenance; however, in facilities where flammable dust is a problem, maintenance to prevent ignition sources assumes greater importance. Problem sites are bearings, belts, buckets, augers, pulleys (including lagging), trippers, motors, dryers, and dust collection systems. Because of poor design, however, it frequently is difficult to conduct effective maintenance. Head pulley gear boxes may have no work platform around them, tail pulley bearings may be in an unlighted boot pit next to a wall, and legs and enclosed conveyors may not have inspection ports at critical locations. Recognized problem sites and maintenance areas must be made accessible through the use of platforms, removable sections, and hinged ports that can be used by a mechanic (and possibly a helper) who may have tools in both hands. Dryers fueled by propane or butane, which are heavier-than-air gases at room temperature, can be particularly hazardous. Leaks in fuel lines can spread a layer of highly flammable, transparent gas throughout the lowest points in a plant.

Recommendations for the disposal of collected dust are certain to create vigorous responses from industry, labor, and government. As has been noted before, the question of returning the dust to the grain stream is the point at which safety and economics can come directly into conflict. Several aspects of the economic problem were considered by the panel, ranging from total cleaning of the grain to re-introduction of the collected dust into the grain stream. A properly designed and operated dust collection system collects only those dust granules that become airborne. The amount of dust of this size per bushel of grain, although a small percentage, can change radically from crop to crop, season to season, and grain type to grain type. It therefore is difficult to predict the economic impact of discarding the collected dust other than that there is some loss involved. After considering and weighing all factors, the panel has concluded that much more attention must be given to the method by which dust is re-introduced into the grain stream and its effect on downstream elevators. (The panel has seen one particularly bad example in which dust collected on the upside was delivered directly into the downside of an elevator leg!)

This conflict between safety and economics can be resolved if the industry will assume the responsibility for developing and demonstrating a method for re-introducing collected dust that will not increase the explosion hazard above that resulting from disposal of the dust. Methods of re-introducing dust and possible alternative uses of dust that would lessen the incentive to return it to the grain stream are discussed below.

RESEARCH

Dust Control

Recommendations	Efficacy	Feasibility	Efficiency
Continue research on methods for reducing the dust concentration in legs to a level below the lower explosive limit.	M	H	H
Continue research on methods of reducing dust concentrations below the lower explosive limit in enclosures other than legs.	L	M	M
Conduct research to develop economic uses for collected grain dust.	L	M	H

In conformance with some of its other recommendations, the panel believes that research aimed at reducing the dust concentration in enclosed areas will produce the greatest decrease in the explosion hazard. Thus, it believes that research should be directed at developing thorough understanding of the movement of grain from the boot to the discharge spout and of the airflow needed in the enclosure for an effective dust control system. Other topics such as bucket material and design, belt material and design, and placement of input and output openings also should be examined. The aim of the research should be twofold: to identify reasonable modifications that can be made in existing elevator legs and to develop the optimum design for legs in new facilities. Inclined belt conveyors, because of their length, are not always suitable replacements for legs. Their capital and operating costs are greater than those of legs and they require a horizontal space that may not be available.

The problem with other enclosures is different from that with legs since it involves the release of dust from a falling grain stream. This was amply demonstrated to panel members who observed barge loading. When the end of the loading spout was kept level with the surface of the grain no dust appeared; when the spout was a few feet above the grain considerable dust was released into the air. Research in this area should focus on identifying methods for preventing dust from becoming airborne when filling an enclosure and collecting the dust that may become airborne. The latter task is complicated by the fact that most dust collection systems can serve as "sneak paths" for transmitting explosions from one enclosure to another. Hence, several smaller dust control systems may be preferable to a large system.

The use of grain dust for pelletized animal feed does not require additional research, only economic development. The few pellet mills already in existence can sell all they produce and portable mills can service small elevators having only relatively small amounts of dust. If the economic value of dust can be increased, the costs of dust collection will become much more acceptable and the tendency to return dust to the grain will decrease. Information on the present disposition of collected dust, the amounts collected by elevators of various sizes and locations, and the cost of transporting dust is needed.

Research also should be conducted to answer such questions as: How clean is clean? Is it dangerous if the dust layer on the floor is deep enough to show footprints? Will a primary explosion disperse enough dust to cause a secondary explosion if the floor layer is 1/8 in. thick or 1/16 in. thick or even smaller? How much dust will adhere to concrete walls? How well will various thicknesses of dust propagate a flame? No single answer to these questions will be applicable to all enclosures in elevators and mills. However, experiments conducted under rigorous, well defined conditions can establish meaningful reasonable upper or lower bounds.

As noted previously, the burden of research on safe ways to re-introduce dust into the grain stream and the proof of their efficacy should fall upon the industry. Using the values previously mentioned in this report of 13,000 tons of dust collected from a large elevator in a year's time, with the value of grain about $150/ton and the value of dust (for pellets) of about $50/ton, it is easy to see that there is a difference of about $1,000,000 involved. This should provide some incentive for the research. On the other hand, it does seem inconsistent to place a large elevator in jeopardy to recover two thirds the grain value of airborne dust, which may amount to only a fraction of a percent of the grain handled. (A recommendation applying to this topic has already been made. See page 55.)

Research on the application of a substance to grain to inhibit the formation of dust is now in progress. The results are too preliminary for the panel to make any recommendation on the subject.

Ignition Sources

Recommendation	Efficacy	Feasibility	Efficiency
Investigate the effect of electrostatics and humidity on the explosion hazard, including an examination of conveyor belt conductivity and the charging of ungrounded conductive structures.	L	M	L

Most of the ignition sources in elevators and mills are self-evident and the reasons for their occurrence are not mysterious. The one exception is electrostatic discharge. Two research topics are involved: the build-up of electrostatic charges on conveyor belts and other poorly conducting materials and the accumulation of static charges on grain and grain dust.

This work should encompass a number of different topics. Those readily apparent are: (1) the static charging and release characteristics of conveying belts of various materials and various conductivities; (2) the potential for build-up of charges in dust clouds in silos, bins, garners, and other enclosures; (3) electrostatic phenomena occurring in pneumatic systems conveying dust and grain; (4) electrostatic conditions in legs using metal buckets and using plastic buckets of various conductivities; and (5) the effect of atmospheric conditions on the buildup of charges and on the energy needed to ignite grain dust.

Among the aims of work done concerning topic 5 should be to establish the facts concerning the danger of low relative humidity and low absolute humidity. (The effect on the explosion hazard due to agglutination of layered dust resulting from high humidity has never been examined.) Other factors to be considered are differences in electrostatic properties for different types of dust and the basic electrostatic characteristics of grain-handling machinery (i.e., when the machinery is operating but no grain is being handled). Considerable thought and care should be given to the design of experiments in this area since electrostatic phenomena in industrial locations are so elusive and ephemeral. The results of this research obviously should be accompanied by recommendations for the elimination of any electrostatic hazards uncovered.

FUTURE FACILITIES

Recommendations	Efficacy	Feasibility	Efficiency
Treat the avoidance of dust explosion hazards as an initial design criteria in the construction of new mills and elevators and the modification of existing structures.	L	M	M
Examine the overall functions of mills and elevators to develop a totally new system less subject to the hazards of dust explosions.	L	H	H

The first recommendation on the design of future facilities requires little discussion. New facilities should be designed to incorporate adequate dust control, to avoid dust generating operations, to facilitate housekeeping, and to be well vented. Design criteria should reflect these concerns so they are not considered only after the final design is completed when any changes become expensive.

One problem to be considered in the design of elevators and mills is the "response" of the facility if, for some reason, there is a primary explosion. Thus, design criteria should consider the isolation of sites where primary explosions may occur from those that may produce secondary explosions. The use of outside legs, pressurized electrical vaults, and isolated dryers are examples that readily come to mind.

Conservative design has been the rule in the grain-handling industry and although most new elevators and mills incorporate advances in technology (e.g., television surveillance, electrical interlocks, and dust collection systems), they still handle and process grain in fundamentally the same manner as has been used for the past 100 years. A study of the functions of elevators and mills (e.g., grinding, blending, and storing of grain) is needed to serve as the basis for totally new elevator and mill designs that will reduce the explosion hazard without decreasing efficiency or increasing costs, both capital and operating. This study should be limited only by the fact that grain must be transported from the farm to the ultimate consumer with various processing operations occurring along the way. The rapid increase in grain production in the past 20 to 25 years, in a broad sense, changed the function of elevators from storage facilities to surge tanks in a pipeline. The gradual evolution of elevators to accommodate this change unfortunately carried along the hazardous features and, in some cases, intensified them. Considering that the grain-handling industry accounts for more explosions than any other single industry, it would seem worthwhile to re-examine the entire grain-handling process.

GOVERNMENT REGULATIONS

Recommendations for actions by governments at any level--federal, state, or local--in matters of hazard reduction cannot be ignored, especially in cases pertaining to employee safety. Government regulations applying to grain-handling facilities are no different in purpose than those applying to other industries having safety problems: they are intended to point out state-of-the-art practices that will provide a safe working environment and they serve as "laws" whose willful violation will result in punishment that, in turn, will convince other possible violators not to follow the same path.

Grain industry and government understanding of safe operating practices in elevators and mills is minimal. Although large grain corporations will disagree vigorously with this point, there are literally thousands of elevators and mills operating as independent entities whose understanding of the hazard is at best limited to a knowledge that elevator explosions are fueled by grain dust. The federal, state, and local occupational safety enforcement agencies are in no better position to decrease the dust explosion hazard for a number of reasons. First, there are no regulations that apply specifically to elevators and mills. Second, the protection of elevators and mills from explosions is only a small portion of their responsibility and, consequently, they have allocated only a small portion of their staff's time and effort to the problem. (The majority of contacts between industry and safety enforcement agencies occur either after the fact--following an explosion--or during infrequent safety inspections. The panel was privately advised that in one state the available manpower was such that only about 2 percent of the elevators and mills could be inspected each year.) Third, animosity exists between industry and regulatory agencies and, whether for real or imagined causes, it is a hindrance to safety.

Fortunately, some progress is being made in alleviating the contentious situation between industry and government (OSHA). This may result in progress in reducing the explosion hazard. Since this panel's formation, OSHA has taken two positive steps. First, it has developed a training program for its explosion investigators to enable them to determine better the "causes" of explosions. If these investigators consider their primary task to be a determination of cause, the mystery attached to explosions should be reduced and better relations with industry may result. Second, it conducted a series of meetings (New Orleans, Superior, and Kansas City) in 1980 on hazards in grain-handling facilities that demonstrated its willingness to accept industry's input. Industry, itself, cited the need for performance standards at these meetings. It is, however, too early to assess the results of this effort.

Appendix D consists of a report on recommended standards prepared by this panel's Subpanel on Recommended Standards and Regulations. That report should be considered as a beginning step in formulating standards by a cooperative action between industry and government.

Changing the grain grading system so as to penalize for the amount of dust, with the objective of decreasing the explosion hazard, has often been mentioned. The panel is of the opinion that, besides meeting considerable objection from sellers, buyers, and handlers of grain, the definition of a standard solely for this purpose is impractical. The only effect would be to pass part of the hazard cost back to the deliverer of the grain since the grain would be accepted, clean or dusty. It is recognized that the return of dust to the grain stream places a heavier burden on the downstream handlers of grain and their dust control systems. A standard, based on the assumption that the degree of cleanliness of the grain (as now delivered to elevators and mills) is directly proportional to the safety of the facility, ignores the hazard due to dust generation in the facility.

REFERENCES

American Insurance Association, Special Loss Control Bulletin, New York City, N.Y., 1978.

Canadian Grain Handling Association, Fire and Explosion Task Force Report No. 1, Winnepeg, 1979.

Cybulski, W., Coal Dust Explosions and Their Suppressions, NTIS TT 73-57001, National Technical Information Service, Springfield, Virginia, 1975.

Eckhoff, R.K., Towards absolute minimum ignition energies for dust clouds, Combustion and Flame 24 (1975):53-64.

Finn, W.D., Report of the Commission on Health and Safety in Grain Elevators--Burrard Terminal Fire and Explosion of October 3, 1975, University of British Columbia, Vancouver, 1976.

Liebman, I., Carry, J., and Richmond, K., H_2O Barriers for Suppressing Coal Dust Explosions, U.S. Bureau of Mines, Washington, D.C., 1976.

Safety Consulting Engineers, Inc., Rosemont, Illinois, Electrostatic Characterization of Grain Products, prepared for the National Grain and Feed Association, Washington, D.C., October 1, 1980.

Palmer, K.N., Dust Explosions and Fires, Chapman and Hall Ltd., London, 1973.

University of Southhampton, England, Study of Static Electricity on Grain Conveying Belts, prepared for the National Grain and Feed Association, Washington, D.C., November, 1980.

Appendix A

RANKING GRAIN ELEVATOR HAZARDS

The panel, together with its liaison representatives and other specialists from the grain-handling industry, prepared over 150 hazard scenarios as the primary mechanism to identify grain elevator explosion hazards. A representative group of those scenarios is presented so that the method used by the panel for systematically ranking their recommendations can be described.

The systems approach to hazard control, as shown in Figure A-1, requires two things--that all possible hazards be identified and that those identified hazards be ranked for significance. The panel realized that there are more than 150 explosion hazards in a grain elevator. However, by assuring that scenarios were written for every function or block in the FFBD (Figure 2), the panel was confident that they had a low probability of overlooking any major hazard and thereby had a realistic base for preventive action recommendations. Over half the scenarios included here represent actual accidents, and every recommendation by the panel is related to one or more of these scenarios. Therefore, the ranking method is based on a high degree of realism.

Each scenario was reviewed for appropriate preventive actions (PA) by experts in the grain-handling industry, using the 35 different codes in Figure A-2 as a stimulus to consider a wide range of possibilities. The applicable code for each preventive action is shown under the PA CODE Column for each scenario (for example, see Scenario No. 11 with its four proposed preventive actions). A cost was then estimated for each preventive action. Even though several preventive actions were proposed for each hazard scenario, the panel did not always elect to approve all such actions for implementation. Those actions shown with an "X" in the APPROVED PA column were chosen for implementation, and the cumulative costs of those actions are listed as CUMULATIVE PA COSTS. The panel then judged the hazard control potential for each scenario as described in Chapter 6 by averaging only those preventive actions approved for implementation.

Once these steps were completed, every scenario could then be judged against the three criteria in Figure A-3: severity (codes A through D), probability (codes J through M), and control resources (codes P through S).

Once each scenario had its 3-letter code, it was placed in the Hazard Totem Pole of Figure A-4 to determine its significance among all other scenarios. The hazard significance code is the number opposite each 3-letter code in the Pole; e.g., the code for CKP is 19. (For an explanation on the construction of the ordering of the 3-letter code in the Totem Pole, see Grose 1972.)

To illustrate the process, Hazard Scenario No. 11 in this appendix has four proposed preventive actions. The panel selected only 2 of the 4 for implementation. The cumulative cost of these two was $7,000. The overall potential for controlling that particular scenario when only implementing preventive actions 1 and 4 was judged to be "medium." Even though this scenario is ranked high on the Hazard Totem Pole (significance code 6), the panel did not consider it reasonable to implement preventive action 3 (which would have raised the control potential to "high") for an additional $100,000 in an old country elevator. This should clearly show that hazard control potential and hazard significance are totally independent of one another.

When all the scenarios had been ranked in the Pole, the panel determined which preventive actions should be recommended, based on the most cost-effective use of resources to eliminate or control explosions. Starting with those scenarios at the top of the Pole, the specified preventive actions became the panel's highest recommendations. Proceeding downward in the Pole, there is a point where it is no longer prudent to continue investment--either because control resources may have been expended or the remaining risk is acceptable. That point is shown in Figure A-4 as a cutoff.

The panel's recommendations for preventive actions were governed by this approach, and it can be used by those responsible for safety in elevators and mills in developing, evaluating, and implementing corrective actions.

REFERENCES

Grose, V. L. Systems Safety in Rapid Transit, American Society of Safety Engineers Journal, 17(8) (1972):18-26

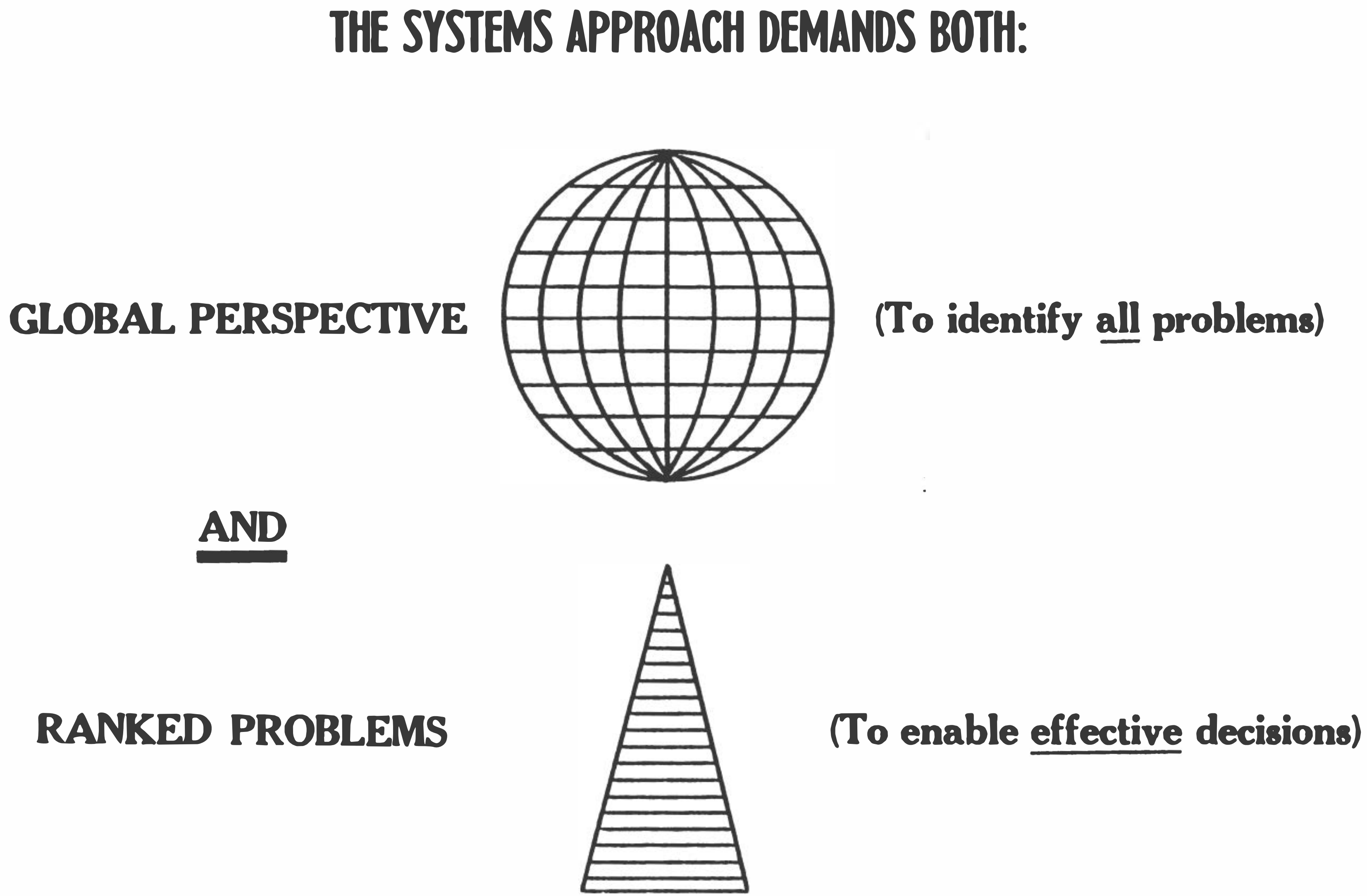

FIGURE A-1 Systems approach management.

PA Code	
1	PERSONNEL Selection - Criteria
2	PERSONNEL Selection - Methods
3	PERSONNEL Training - New Employee Indoctrination
4	PERSONNEL Training - In-Service Courses, Hazard Education
5	PERSONNEL Qualification Validation - Formal Examination
6	PERSONNEL Qualification Validation - Informal Periodic Review
7	PERSONNEL Supervision - Job Assignment Versus Skill Level
8	PERSONNEL Supervision - Assurance of Work Effectiveness
9	PHYSICAL FACILITIES Design - Layout/Arrangement/Modification
10	PHYSICAL FACILITIES Design - Functional Capacity
11	PHYSICAL FACILITIES Operations - Reliability/Operability of Functions
12	PHYSICAL FACILITIES Operations - Sequencing/Scheduling of Functions
13	PHYSICAL FACILITIES Maintenance - Techniques
14	PHYSICAL FACILITIES Maintenance - Inspection
15	ADMINISTRATION Policies - Non-Existent or Inadequate
16	ADMINISTRATION Policies - Restrictive Scope
17	ADMINISTRATION Procedures - Operational
18	ADMINISTRATION Procedures - Jurisdictional
19	EQUIPMENT Function or Design - Utility or Physical Characteristics
20	EQUIPMENT Function or Design - Functional Capability
21	EQUIPMENT Operational Parameters - Functional Reliability
22	EQUIPMENT Operational Parameters - Human Operator Factors
23	EQUIPMENT Maintenance - Availability of Function (downtime factors)
24	EQUIPMENT Maintenance - Calibration
25	ENVIRONMENTAL ASPECTS Government Requirements - OSHA
26	ENVIRONMENTAL ASPECTS Government Requirements - DoA
27	ENVIRONMENTAL ASPECTS Government Requirements - EPA
28	ENVIRONMENTAL ASPECTS Social - Local Community
29	ENVIRONMENTAL ASPECTS Social - Grain Industry Organizations
30	ENVIRONMENTAL ASPECTS Legal - Tort Law
31	ENVIRONMENTAL ASPECTS Legal - International Agreements
32	ENVIRONMENTAL ASPECTS Political - Legislative Action
33	TECHNOLOGICAL ASPECTS Research
34	TECHNOLOGICAL ASPECTS Development
35	ECONOMIC ASPECTS Grain Dust

FIGURE A-2 Hazard preventive action codes.

Hazard Severity

Code	Hazard Severity	Effect on Elevator Objectives	Effect on Functional Capability	Effect on Personnel Safety
A	Catastrophic	Total loss of product with no salvage. All customer services terminated	Physical plant is destroyed or damaged beyond effective use.	Elevator employees, bystanders, or others are killed.
B	Critical	Majority of product lost. Only partial salavge possible. Customer services reduced to low level.	Two or more functions are disabled; elevator must be shut down.	Major injuries occur to employees or bystanders.
C	Marginal	Only 75% of product is salvagable. Grain services are possible by improvisation.	Temporary disruption of elevator functions; normal operations can be restored in 1 day.	Minor injuries occur to employees or bystanders.
D	Negligible	No significant effect on product or service to customers.	No apparent damage to elevator operation.	No apparent harm to employees or others.

Hazard Probability

Code	Description of Situation
J	The identified hazard scenario could occur on the average of once a week.
K	The identified hazard scenario could occur on the average of once a month.
L	The identified hazard scenario could occur on the average of once a year.
M	The identified hazard scenario could occur on the average of once a decade.

Hazard Elimination Control Resources

Code	Calculated Dollar Equivalence (Value of all resources required to either eliminate or control the identified hazard scenario; revision of policy, procedures, manpower, dollars, technology, facilities, materials, and schedule.)
P	Preventive action for the identified hazard will require less than $2,500.
Q	Preventive action for the identified hazard will require between $2,500 and $50,000.
R	Preventive action for the identified hazard will require between $50,000 and $250,000.
S	Preventive action for the identified hazard will require more than $250,000.

FIGURE A-3 Hazard scenario ranking criteria.

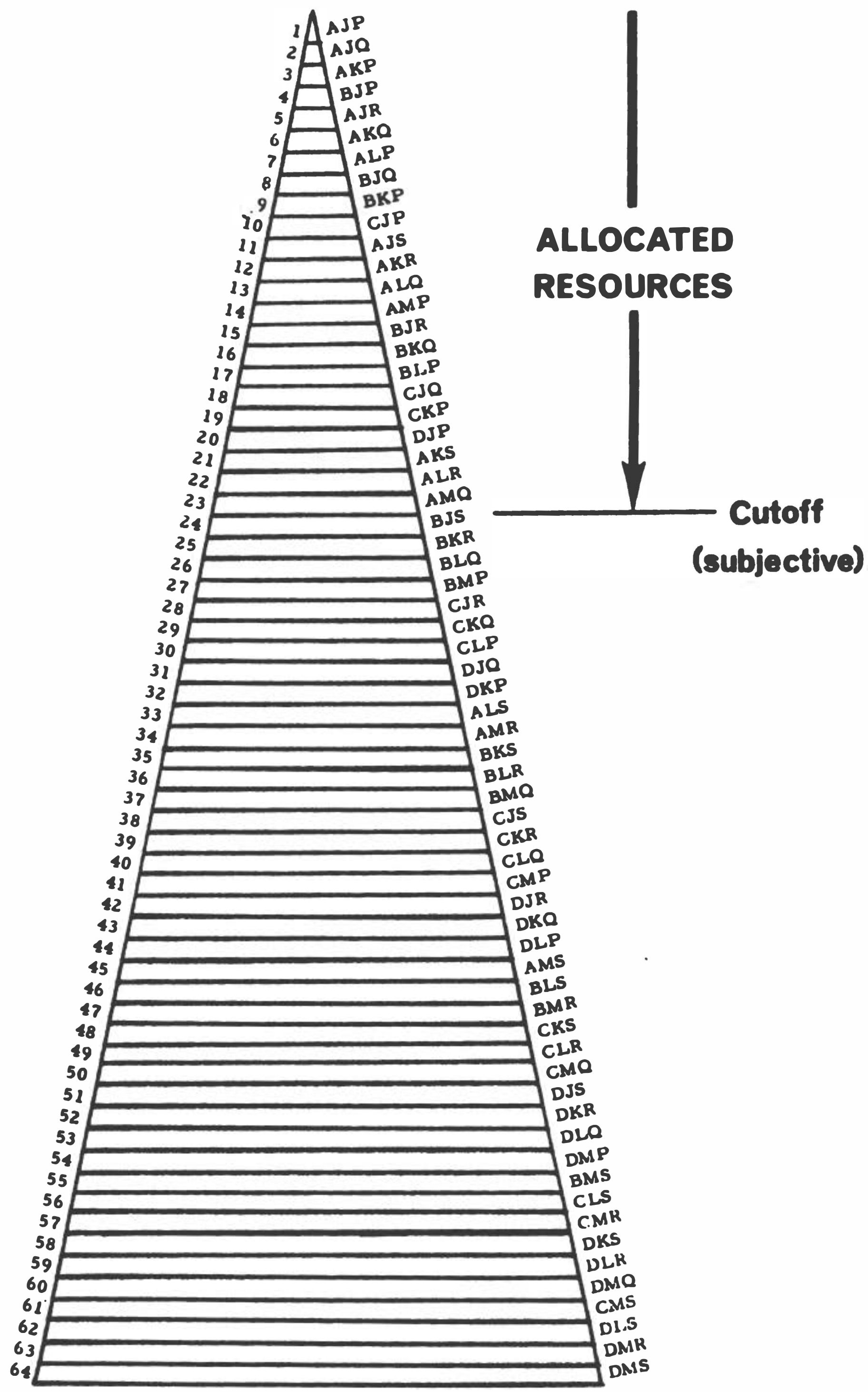

FIGURE A-4 Hazard totem pole.

SCENARIO NO. 1
FFBD NO. 10,
14, 20, 27

FUNCTION: Elevate Grain Load

HAZARD SCENARIO DESCRIPTION:

At a small country elevator a piece of tramp metal in a grain load is dumped into the pit and to a metal bucket leg. The metal becomes wedged in the boot area and the metal buckets rub against it. The buckets heat the tramp metal by friction and this ignites the dust in suspension in the leg. The explosion ruptures the leg casing but it is not sustained for lack of fuel in the surrounding environment.

PROPOSED PREVENTIVE ACTIONS:

1. Install magnet at point where all tramp metal would be picked up before entering the leg.

2. Install heavy screening in conjunction with the grate to halt the flow of tramp metal.

3. Install plastic buckets on the leg belt.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	9	$ 2,000	X
2	9	1,500	X
3	9	10,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$3,500	B	M	Q	37

SCENARIO NO. 2
FFBD NO. 26

FUNCTION: Transport Grain to Leg

HAZARD SCENARIO DESCRIPTION:

At a dirty interior sub-terminal elevator, the head pulley on belt conveyor works loose on shaft and moves over against the side of the casing creating a shower of sparks that ignites a dust cloud over the conveyor discharge. This initial ignition propagates self throughout headhouse and gallery. Elevator virtually destroyed, several casualties and complete loss of grains.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a preventive maintenance program designed to police equipment for proper functioning. (new function)

2. Establish periodic housekeeping inspection parameters. (new function)

3. Establish housekeeping system involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13		X
2	14	$ 15,000 (total cost of PA nos. 1, 2, 3)	X
3	17		X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$15,000	A	L	Q	13

SCENARIO NO. 3
FFBD NO. 11

FUNCTION: Move Grain Load into Selected Storage Bin

HAZARD SCENARIO DESCRIPTION:

This is a dirty export elevator. A new conveyor was added to service new storage bins. The frame of new conveyor not attached to existing system thereby not grounded. As tripper fills bin, a billow of dust reaches the ignition level which is ignited by static electricity from ungrounded frame, arcing to grounded frame. The primary explosion propagates self throughout headhouse and gallery. Elevator destroyed, casualties result and inventory lost.

PROPOSED PREVENTIVE ACTIONS:

1. Ground all conveying and electrical equipment.
2. Inspect system during construction.
3. Install dust collection system on trippers.
4. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	19	$ 500	X
2	14	600	X
3	10	35,000	X
4	13	165,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$201,100	A	L	R	22

SCENARIO NO. 4
FFBD NO. 11

FUNCTION: Move Grain Load into Selected Storage Bin

HAZARD SCENARIO DESCRIPTION:

This is a clean export house. Dust accumulated under conveyor belt produces a friction fire. Burning dust ignites dust cloud. As elevator is clean, damage is isolated. Dust source traced to inadequate dust collection on tripper.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

2. Install reclaiming device at tail pulley.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 20,000	X
2	19	2,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$22,000	C	L	Q	40

SCENARIO NO. 5
FFBD NO. 10,
14, 20, 27

FUNCTION: Elevate Grain Load

HAZARD SCENARIO DESCRIPTION:

In a large, clean interior sub-terminal elevator, a bucket on the leg rubs against leg casing causing friction and heating which ignites dust cloud, blowing out casing. No further damage.

PROPOSED PREVENTIVE ACTIONS:

1. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

2. Install plastic buckets.

3. Use motion sensors to indicate belt slippage and misalignment.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 6,000	X
2	9	10,000	X
3	20	4,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$16,000	C	L	Q	40

SCENARIO NO. 6
FFBD NO. 26

FUNCTION: Transport Grain to Leg

HAZARD SCENARIO DESCRIPTION:

This is a small, dirty country elevator. Contractor working in tunnel. Molten metal falls into dust. Personnel leave for lunch. Molten metal in grain dust produces flame resulting in dust explosions (no dust control) propagating throughout facility. Elevator substantially destroyed, no injuries and total loss of inventory.

PROPOSED PREVENTIVE ACTIONS:

1. Use a pre-established and enforced permit procedure whenever welding, cutting, or other open flame work is to be done.

2. Quantify housekeeping standards for cleanliness in grain-handling facilities to prevent fires and explosions.

3. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 500	X
2	34	5,000	X
3	13	100,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$5,500	A	L	Q	13

SCENARIO NO. 7
FFBD NO. 8

FUNCTION: Unload Grain Vehicle

HAZARD SCENARIO DESCRIPTION:

This is a small, dirty country elevator. A truck has completed unloading. In dusty environment, the truck backfires when started and ignites grain dust and produces explosions throughout the elevator. Total destruction, several casualties and complete loss of inventory.

PROPOSED PREVENTIVE ACTIONS:

1. Establish and enforce a procedure whereby trucks are started only after signal is given to indicate that dust concentration is abated.
2. Quantify housekeeping standards for cleanliness in grain-handling facilities to prevent fires and explosions.
3. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 500	X
2	34	5,000	X
3	13	100,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$ 5,500	A	L	Q	13

SCENARIO NO. 8
FFBD NO. 8

FUNCTION: Unloading Grain

HAZARD SCENARIO DESCRIPTION:

Welding is being done on a new truck dumping hoist in a 2,000,000 bushel country elevator dump pit shed. Brackets are added and removed, but welding is stopped when trucks are dumped. In the meantime, the pit is protected with a tarp. A truck is dumped shortly after several brackets are cut with a torch. One piece is jolted off a beam where it was placed by the welder. It falls into the truck unnoticed and is carried to the boot. A smoldering fire starts and is carried up the leg, starting a spreading flame. Explosion occurs in the leg. The leg is destroyed but no secondary explosions occur. The elevator was noted for being exceptionally clean and virtually free of layered dust. Damage was limited to replacing the leg casing. One employee received minor burns.

PROPOSED PREVENTIVE ACTIONS:

1. Use a pre-established and enforced permit procedure whenever welding, cutting, or other open flame work is to be done.

2. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 500	X
2	13	6,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$500	C	M	P	41

SCENARIO NO. 9
FFBD NO. 18

FUNCTION: Clean Grain Lot

HAZARD SCENARIO DESCRIPTION:

This is a clean export elevator. Tramp metal in grain sent to cleaner causes spark which ignites grain dust, resulting in an explosion. Shaker materially destroyed but no further damage.

PROPOSED PREVENTIVE ACTIONS:

1. Use devices to extract foreign materials from the incoming grain stream.

2. Control dust generation and airborne dust at all grain transfer and discharge points.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	9	$ 2,000	X
2	20	1,500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$ 3,500	D	M	Q	60

SCENARIO NO. 10
FFBD NO. 18

FUNCTION: Clean Grain Lot

HAZARD SCENARIO DESCRIPTION:

This is a dirty export elevator. Painting in the cleaning gallery using a high vapor pressure solvent produces flammable vapor cloud which is ignited by static electric spark. Reverberations produce additional explosions which destroy complex. Several casualties and significant loss of inventory.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

2. Establish procedure to ensure dissipation of vapor cloud.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 45,000	X
2	17	500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$45,500	A	L	Q	13

SCENARIO NO. 11
FFBD NO. 10,
14, 20, 27

FUNCTION: Elevate Grain Load

HAZARD SCENARIO DESCRIPTION:

This is an old, dirty country elevator. Leg belt elevating grain becomes overloaded and comes to a complete stop. Head pulley continues to rotate. The mechanic jogs the elevator attempting to restart the leg. A dust cloud is generated and ignited by the arcing of old, non-Class II Group G switches, motors, etc. Subsequent explosion destroys all. Three casualties and complete loss of inventory.

PROPOSED PREVENTIVE ACTIONS:

1. Use motion sensors to indicate belt slippage and misalignment.

2. Use only equipment and standards meeting National Electrical Code requirements.

3. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

4. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	20	$ 1,000	X
2	16	50,000	-
3	13	100,000	-
4	13	6,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$7,000	A	K	Q	6

SCENARIO NO. 12
FFBD NO. 10,
14, 20, 27

FUNCTION: Elevate Grain Load

HAZARD SCENARIO DESCRIPTION:

This is a small, clean country elevator. A small non-Class II Group G motor is coupled to head pulley shaft to move leg slowly while inspecting buckets. Motor not sized properly and of wrong class which produces arcing and ignition of dust which is jolted into position by mechanical shock. Because of lack of fuel, fire burns self out in short period with minimal damage.

PROPOSED PREVENTIVE ACTIONS:

1. Use only equipment and installation standards meeting National Electrical Code requirements.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	16	$ 1,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$1,000	D	M	P	54

SCENARIO NO. 13
FFBD NO. 10,
14, 20, 27

FUNCTION: Elevate Grain Load

HAZARD SCENARIO DESCRIPTION:

This is a relatively new, but dirty, sub-terminal elevator. Elevator leg stops. Tripped circuit breaker reset. Breaker trips again after a few minutes. Although a malfunctioning motor is suspected, the electrician removes circuit breaker enclosure cover to observe the circuit breaker itself. The breaker is reset and manually held in place momentarily. Meanwhile, flashover occurs in a dust laden area which produces subsequent explosion destroying the bulk of the complex. Several casualties and significant inventory loss.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

2. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$150,000	X
2	13	8,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$158,000	A	L	R	22

SCENARIO NO. 14
FFBD NO. 8

FUNCTION: Unload Grain Vehicle

HAZARD SCENARIO DESCRIPTION:

This is an old but clean sub-terminal elevator. Car receiving belt is overloaded and stalled. Slowdown device fails to operate and does not shut down the belt. The head pulley spins in belt causing burning rubber to drop into leg boot which in turn causes an explosion in the leg. Leg explosion blows several casing panels off as well as the explosion vent and disables leg. No further damage.

PROPOSED PREVENTIVE ACTIONS:

1. Use motion sensors to indicate belt slippage and misalignment.

2. Use heat sensors on critical bearings and pulleys.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	20	$ 4,000	X
2	20	5,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$9,000	C	L	Q	40

SCENARIO NO. 15
FFBD NO. 26

FUNCTION: Transport Grain to Leg

HAZARD SCENARIO DESCRIPTION:

This is an old, large, dirty country elevator. Roof leak causes grain to heat. Monitoring system indicates non-critical temperature, but cable fails to pick up core heat. Spontaneous combustion takes place. To save some grain, operator pulls the bin. Burning grain also gets on the belt. Fire propagates to tunnel and legboot. Legwell blows and destroys headhouse. Two casualties and some inventory loss.

PROPOSED PREVENTIVE ACTIONS:

1. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 5,000	X
2	13	150,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$155,000	A	L	R	22

SCENARIO NO. 16
FFBD NO. 8

FUNCTION: Unload Grain Vehicle

HAZARD SCENARIO DESCRIPTION:

This is a modern, sub-terminal elevator. Dust collection system becomes inoperative. Explosive suspension of dust develops in truck receiving tunnel and throughout rest of elevator. Worker enters truck receiving tunnel, turns on light switch which activates an arc in broken light fixture. Suspended dust is ignited and subsequent explosions propagate throughout complex. Several casualties and significant loss of inventory.

PROPOSED PREVENTIVE ACTIONS:

1. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

3. Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosive limit where possible in enclosures other than legs.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 8,000	X
2	13	135,000	X
3	19	5,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$148,000	A	K	R	12

SCENARIO NO. 17
FFBD NO. 9

FUNCTION: Weigh Grain Load

HAZARD SCENARIO DESCRIPTION:

This is a rather new export elevator. Scale is vented to surrounding atmosphere in scale room producing dust concentrations in suspension as well as a large accumulation in scale room. New employee enters this area with lighted cigarette setting off series of explosions throughout the complex. Several casualties and a significant inventory loss.

PROPOSED PREVENTIVE ACTIONS:

1. Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosive limit where possible in enclosures other than legs.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

3. Establish and enforce "no smoking" rule.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	19	$ 5,000	X
2	13	185,000	X
3	8	500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$190,500	A	L	R	22

SCENARIO NO. 18
FFBD NO. 26

FUNCTION: Transport Grain to Leg

HAZARD SCENARIO DESCRIPTION:

This is a small, old, clean country elevator. A non-pressurized control room has an electric heater. An adjacent spout has several leaks causing dust in suspension. Static dust is removed periodically. The door of the control room remains open and the heater ignites the dust cloud. No secondary explosions occur. Minimal damage sustained in the area.

PROPOSED PREVENTIVE ACTIONS:

1. Pressurize control room.
2. Install self-closing door in all rooms having electric heaters.
3. Redesign and re-route spouts.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	9	$ 1,500	X
2	9	500	X
3	9	10,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$2,000	D	M	P	54

SCENARIO NO. 19
FFBD NO. 19

FUNCTION: Store Grain Lot

HAZARD SCENARIO DESCRIPTION:

In a small country elevator, employee is sent to measure bin. To check grain type and level, he drops unguarded extension light bulb down into the bin. He leaves the light bulb in the bin when he is called away. Additional grain is then dumped into the bin and breaks the bulb which arcs and ignites dust cloud in the bin. This initial explosion triggers a series of explosions which destroy the elevator.

PROPOSED PREVENTIVE ACTIONS:

1. Replace all drop cords with approved fixtures for Class II, Group G, Division I operations.
2. Enforce grain inspection procedure prohibiting use of unattended drop cords.
3. Require visual inspection of all bins for extraneous equipment prior to loading the bins.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	19	$ 500	X
2	17	200	X
3	12	500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$1,200	A	J	P	1

SCENARIO NO. 20
FFBD NO. 32

FUNCTION: Convey Grain to Designated Transportation Vehicle

HAZARD SCENARIO DESCRIPTION:

As grain is being conveyed into a ship, dust accumulates under the loading belt of an export elevator. As the dust increases, it prevents the return roller from turning, thereby developing friction between the roller and belt. The friction starts a small fire. Employee smells smoke, searches for fire, but does not shut down conveyor. Fire eventually ignites dust cloud at discharge end of conveyor. This explosion destroys the loading gallery and kills two employees.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

2. Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosive limit where possible in enclosures other than legs.

3. Redesign conveyor to reduce vulnerability to dust accumulation.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$100,000	X
2	19	15,000	X
3	20	50,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$165,000	A	L	R	22

SCENARIO NO. 21
FFBD NO. 17

FUNCTION: Dry Grain Lot

HAZARD SCENARIO DESCRIPTION:

In a large country elevator, employee uses a jumper on the dryer controls to main burner to start the burner without the blower running because he cannot start it while the blower is on. Dryer catches fire and flame travels up spout to leg feeding the dryer. Because a fire door in the leg head is blocked open, flame enters the leg and ignites dust cloud. Resulting explosion destroys the leg and dryer. No one is injured.

PROPOSED PREVENTIVE ACTIONS:

1. Replace or redesign dryer controls to allow burner start with blower on.
2. Issue and enforce operating procedure which prohibits shunting of controls.
3. Enforce codes on fire door operation.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	21	$ 3,000	X
2	17	500	X
3	17	200	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$3,700	C	L	Q	40

SCENARIO NO. 22
FFBD NO. 17

FUNCTION: Dry Grain Lot

HAZARD SCENARIO DESCRIPTION:

A dryer in a medium-size country elevator discharges grain by an enclosed auger onto an open belt conveyor to an inhouse leg. Dryer overheats, allowing smouldering grain to be carried to the leg. Employee sees burning grain on conveyor, seizes ABC fire extinguisher, and sprays hot grain on the belt. This extinguisher discharge raises a grain dust cloud which is ignited by smouldering grain. Resulting explosion destroys tunnel and propagates up the elevator leg. The elevator is destroyed and two employees are killed.

PROPOSED PREVENTIVE ACTIONS:

1. Couple dryer temperature sensor to auger control to shut down conveyor when dryer is overheated.
2. Quantify and enforce housekeeping standards for cleanliness.
3. Establish procedure for and train employees in handling burning grain including shutdown and handling of fire extinguishers.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	20	$ 2,000	X
2	34	6,000	X
3	17	1,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$9,000	A	K	Q	6

SCENARIO NO. 23
FFBD NO. 32

FUNCTION: Convey Grain to Designated Transportation Vehicle

HAZARD SCENARIO DESCRIPTION:

Rail cars are being loaded at a large terminal elevator with grain that has been processed with equipment that is malfunctioning, making the grain suspect of containing fire. The fire department has responded to the location of the processing equipment. As the bin empties, an updraft enters the bin and creates a dust cloud that is ignited by residual burning grain in the bin. The resulting explosion destroys the bin and triggers additional explosions that destroy the elevator. Four firemen and six employees are killed.

PROPOSED PREVENTIVE ACTIONS:

1. Develop fire procedure for inerting bins with suspected fire.
2. Establish emergency procedures and training for evacuation of personnel and removal of burning grain.
3. Issue procedures for processing equipment that include shutdown instructions and methods of handling hot products.
4. Institute preventive maintenance for processing equipment.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 2,000	X
2	17	1,000	X
3	22	500	X
4	24	5,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$8,500	A	L	Q	13

SCENARIO NO. 24
FFBD NO. 2

FUNCTION: Move Loaded Grain Vehicle into Place

HAZARD SCENARIO DESCRIPTION:

A truck is bringing grain into a large country elevator. As it moves into the dump area, its engine catches fire. The driver jumps out and attempts to extinguish the fire. Burning material from engine drops into the pit where the conveyor carries it to the elevator boot. Dust in the leg is ignited, producing an initial explosion that propagates additional explosions due to dust accumulated through poor housekeeping in the gallery. The elevator is destroyed and there are 10 casualties.

PROPOSED PREVENTIVE ACTIONS:

1. Establish procedure to close dump pit gate whenever grain is not being dumped.

2. Issue emergency procedures covering fire in dump area and providing fire equipment.

3. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 500	X
2	17	1,000	X
3	13	95,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$96,500	A	M	R	23

SCENARIO NO. 25
FFBD NO. 9

FUNCTION: Weigh Grain Load

HAZARD SCENARIO DESCRIPTION:

The lower surge bin in a major export elevator that is relatively clean breaks loose from its mounting and falls 20 feet to ground level during a ship loading operation. The impact of the surge bin on the floor violently shakes the entire elevator, setting static grain dust into suspension throughout the elevator. The surge bin breaks several 440-volt conduits when it falls, and these exposed wires arc wildly and ignite grain dust. Numerous subsequent explosions throughout the elevator destroy the headhouse and kill several people.

PROPOSED PREVENTIVE ACTIONS:

1. Redesign and rebuild surge bin structure to sustain anticipated static and dynamic loads.

2. Relocate and recess electrical conduit where it is not vulnerable to mechanical damage.

3. Enforce housekeeping for dust collection.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	10	$ 25,000	X
2	10	20,000	-
3	17	2,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$27,000	A	M	Q	23

SCENARIO NO. 26
FFBD NO. 22

FUNCTION: Locate and Move Grain-Moving Equipment into Place

HAZARD SCENARIO DESCRIPTION:

Two employees are repairing a loose flange and doubler plate on a belt loading spout in a major export elevator tunnel preparatory to loading a ship. Because of poor housekeeping, considerable dust has accumulated. One of the employees inadvertently strikes the spout while the other is drilling with a hand drill, and dust is shaken loose into suspension where it is ignited by the arcing motor brushes. The resulting explosion travels down the tunnel, up the leg and through the gallery. Two employees die and the elevator is destroyed.

PROPOSED PREVENTIVE ACTIONS:

1. Remove all electrical drills and replace with pneumatic.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

3. Establish and enforce a maintenance policy that prohibits major repair of equipment without prior dust cleanup.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	19	$ 1,000	X
2	13	115,000	X
3	15	500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$116,500	A	K	R	12

SCENARIO NO. 27
FFBD NO. 7

FUNCTION: Align Grain Moving Equipment

HAZARD SCENARIO DESCRIPTION:

During harvest, a part-time employee in a small country elevator overhears that, before the next truck can dump into the pit, the tripper will have to be relocated. He knows that such alignment will take at least five minutes, and since he has not had a cigarette for some time, he decides to light up. The elevator is full of dust from the previous truck load. When he strikes a match, dust explodes and destroys the headhouse. Three people are killed.

PROPOSED PREVENTIVE ACTIONS:

1. Institute new employee indoctrination regarding smoking.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	3	$ 500	X
2	13	25,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Low	$500	A	J	P	1

SCENARIO NO. 28
FFBD NO. 28

FUNCTION: Weigh and Inspect Grain Lot

HAZARD SCENARIO DESCRIPTION:

This is a major inland terminal elevator. A welder is repairing a broken metal part in the headhouse above the scale, without a protective shield or enclosure nor is the area cleared of dust. While grain is elevated to weighing on the scale floor, it is creating a dust cloud. Hot metal droppings from the welding ignites the dust cloud as the grain is emptied from the garner into the scale bin. This results in an explosion that destroys the headhouse and propagates down the gallery. Three people are killed.

PROPOSED PREVENTIVE ACTIONS:

1. Use a pre-established and enforced permit procedure whenever welding, cutting, or other open flame work is to be done.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 2,000	X
2	13	150,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$152,000	A	K	R	12

SCENARIO NO. 29
FFBD NO. 8, 31

FUNCTION: Loading and Unloading Grain

HAZARD SCENARIO DESCRIPTION:

A large, 3,000,000-bushel regional terminal elevator is loading corn into railcars and accepting truckloads simultaneously. Three of four legs are operating. The house has substantial quantities of layered dust in all areas. An operator in the basement suddenly sees a ball of fire coming towards him from a corner area. A series of explosions follow that cause major damage throughout the headhouse, Texas galleries, and bins. Post-explosion investigation found a bin level indicator torn from the side of the bin being emptied into the railcars. The electrical leads showed signs of arcing and were considered the probable cause of the initial explosion in the bin that spread fire and hot gases into spouting and legs throughout the structure. Inspection showed that the level device had been improperly secured to the bin wall and the electrical connections were not according to good wiring practice. An inspector and three employees were injured and a fourth was killed in this $5,000,000 loss.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

2. Use only equipment and installation standards meeting National Electrical Code requirements.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$150,000	X
2	16	10,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$160,000	A	L	R	22

SCENARIO NO. 30
FFBD NO. 11

FUNCTION: Move Grain Load into Selected Storage Bin

HAZARD SCENARIO DESCRIPTION:

A new screw conveyor is added to a cracked corn bin in order to feed a new chicken feed line in a mill. The corn grinder is allegedly locked out. However, the electrician/mechanic locks out 4B instead of 4D (mistaking an order yelled to him by a foreman). Shortly after the conveyor chute is welded on, the foreman starts another conveyor in a separate area but mistakes the starters since one is locked out. Ground corn is put into the bin with the fresh weld. Residual sparks from welding have ignited some corn in the bottom of the bin. The fresh ground corn and its dust explodes. Secondary explosions destroy much of the mill and adjoining headhouse. Five people injured; loss $1,400,000.

PROPOSED PREVENTIVE ACTIONS:

1. Use a pre-established and enforced permit procedure whenever welding, cutting, or other open flame work is to be done.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 500	X
2	13	65,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$65,500	A	L	R	22

SCENARIO NO. 31
FFBD NO. N/A

FUNCTION: Housekeeping

HAZARD SCENARIO DESCRIPTION:

While blowing down dust from overhead beams in a very large port terminal elevator gallery, a workman accidentally hits a lighting fixture with his wand and breaks an unguarded lamp. The elevator is quite dirty since it has not been cleaned for three weeks. The dust in suspension exceeds the lower explosive limit due to the blowdown operation. When the lamp breaks, momentary arcing allows hot particles to ignite the dust. The ensuing fireball engulfs the dirty gallery, enters several empty bins causing explosions within the bins. The fireball in the tunnel from the ruptured bins travels to the headhouse through the fuel-laden tunnel creating another explosion in the basement. Four persons were injured, one fatally; loss $2,000,000.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

2. Use only equipment and installation standards meeting National Electrical Code requirements.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$180,000	X
2	16	10,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$190,000	A	K	R	12

SCENARIO NO. 32
FFBD NO. 8

FUNCTION: Unload Grain Vehicle

HAZARD SCENARIO DESCRIPTION:

Soy beans are being unloaded in the truck dump pit at a 400,000-bushel country elevator. The operator is busy taking samples when the leg jams and burns through at the head pulley. The falling belt ignites dust shaken loose in the concrete enclosed legwell, which explodes. The explosion ruptures the well at the dump level, the top metal leg housing, and the concrete legwell. A secondary explosion severely damages the top of the headhouse and causes fire penetration into several bins through spouting holes. Substantial quantities of layered dust contributed to the total damage. Post-explosion investigation revealed faulty lagging on the head pulley of the leg. The blast caused $750,000 damage, injured two employees, and killed the truck driver.

PROPOSED PREVENTIVE ACTIONS:

1. Use motion sensors to indicate belt slippage and misalignment.
2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.
3. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	20	$ 1,000	X
2	13	25,000	X
3	13	4,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$30,000	A	L	Q	13

SCENARIO NO. 33
FFBD NO. 8

FUNCTION: Unload Grain Vehicle

HAZARD SCENARIO DESCRIPTION:

A small wooden country elevator had been receiving soy beans throughout the day. At about 7:30 pm, during the unloading of a truck, an explosion occurred that propagated through a tunnel from the basement of the office to the truck dump pit and into the basement of the headhouse. This was followed by a much larger secondary explosion in the headhouse. The subsequent fire totally destroyed the headhouse and attached silos. Investigation determined that the underground pipeline leading from a propane tank to dryers had developed a leak. Propane flowed into an underground drainage tile leading to the basement of the office. Propane collected in the lower portions of the basement, truck dump, and headhouse until it reached an ignition source, a gas water heater in the basement of the office. The ensuing explosion released layered dust in the headhouse causing a secondary explosion that blew off the top of the headhouse and ignited the wooden interior. Three people killed.

PROPOSED PREVENTIVE ACTIONS:

1. Examine the overall functions of mills and elevators to develop a totally new system less subject to the hazards of dust explosions.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	9	$ 2,000	X
2	13	50,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$2,000	A	M	P	14

SCENARIO NO. 34
FFBD NO. N/A

FUNCTION: Maintenance

HAZARD SCENARIO DESCRIPTION:

A country elevator is down for minor maintenance. A relatively new employee is told to clean up some bearing grease. He cannot find the high flash-point solvent he normally uses and substitutes gasoline instead. A fellow worker starts some minor repairs nearby using an electric drill. The gasoline vapors flash and penetrate cracks in the leg casing that has a heavy coating of layered dust. Fire starts in the leg and sets off an explosion. Secondary explosions destroy much of the headhouse and dump pit. Although floor surfaces were generally kept clean, layered dust on beams, walls, and other surfaces was not removed. Two employees seriously injured and $800,000 loss resulted.

PROPOSED PREVENTIVE ACTIONS:

1. Use a pre-established and enforced permit procedure whenever welding, cutting, drilling, or other open flame work is to be done.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 500	X
2	13	50,000	-

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$500	B	L	P	17

SCENARIO NO. 35
FFBD NO. 6

FUNCTION: Select Storage Location and Type

HAZARD SCENARIO DESCRIPTION:

An employee in a concrete feed mill was using a drop cord light to determine if a bin was empty. He lowered the light into the operating discharge screw conveyor. The resulting electrical arc ignited a dust cloud in the bottom of a bin. Flames erupted from the bottom of this bin and ignited dust on the mill floor and walls. The secondary explosion destroyed the entire mill.

PROPOSED PREVENTIVE ACTIONS:

1. Install grating cover over top of screw conveyor.

2. Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosion limit where possible in enclosures other than legs.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	10	$ 500	X
2	19	1,500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$2,000	A	J	P	1

SCENARIO NO. 36
FFBD NO. 8

FUNCTION: Unload Grain Vehicle

HAZARD SCENARIO DESCRIPTION:

A concrete export elevator was unloading grain from a rail car. Tail pulley bearing on the car receiving leg had failed to the point that when the oiler greased the leg, the lubricant passed through the hot bearing and flamed up inside the leg. The dust cloud in the operating leg exploded and spread to the belt conveyor. Although the working space of the elevator was very clean, the newly covered conveyor contained cross bracings every 10 feet on which dust had accumulated to a depth of 6 inches. The dust fueled an explosion that destroyed the entire elevator, killing at least 10 people.

PROPOSED PREVENTIVE ACTIONS:

1. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means (particularly for concealed areas).

3. Use heat sensors on critical bearings.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 8,000	X
2	13	180,000	X
3	20	5,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$193,000	A	L	R	22

SCENARIO NO. 37
FFBD NO. N/A

FUNCTION: Maintenance

HAZARD SCENARIO DESCRIPTION:

The office of a wooden country elevator was being rebuilt following fire damage. An underground propane line had developed a leak and propane accumulated on the floor of the office after leaking from the line through sandy porous soil. The office basement was directly connected to the basement of the elevator. A painter entered the basement and lit a match to locate the light switch. The propane exploded and caused a secondary explosion throughout the elevator fueled by layers of dust on the walls and floors. The elevator was totally destroyed in the ensuing fire. Two were killed.

PROPOSED PREVENTIVE ACTIONS:

1. Examine the overall functions of mills and elevators to develop a totally new system less subject to the hazards of dust explosions.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	9	$ 2,000	X
2	13	50,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$52,000	A	M	R	34

SCENARIO NO. 38
FFBD NO. 10,
14, 20, 27

FUNCTION: Elevate Grain Lot

HAZARD SCENARIO DESCRIPTION:

Corn was being unloaded from a concrete country elevator. Layered dust coated the walls, floors, and machinery; dust from a limited dust control system was returned continuously back into the leg. The casing was completely concrete to the top of the head pulley. The head pulley became displaced on the shaft and rubbed against the concrete housing. The friction between the pulley and concrete casing developed enough heat to ignite the dust cloud existing in the leg. The explosion broke out of the leg and caused secondary explosions throughout the structure. The elevator was virtually destroyed. Two fatalities resulted.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

2. Use heat sensors on critical bearings.

3. If dust is returned to the grain stream, do it in the least hazardous manner.

4. Follow, to the extent practical, the National Fire Protection Association's standard on explosion venting (No. 68) for all enclosures. Existing concrete structures should be vented by windows or other openings of the size dictated by this standard.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 40,000	X
2	20	3,000	X
3	11	500	X
4	16	500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$44,000	A	J	Q	2

SCENARIO NO. 39
FFBD NO. 19

FUNCTION: Store Grain Lot

HAZARD SCENARIO DESCRIPTION:

Inadequate housekeeping had been practiced in an old wooden elevator used primarily for grain storage. A finned, space heater had been left on after the employees had left for home. During the night a fire broke out in a small, scale office in which the heater was located. Accumulated dust in the headhouse was placed into suspension and ignited by burning debris. Several subsequent explosions destroyed the elevator.

PROPOSED PREVENTIVE ACTIONS:

1. Establish a fire and explosion prevention training program.

2. Quantify and enforce housekeeping standards for cleanliness to prevent fires and explosions.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	4	$ 1,000	X
2	34	1,200	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$2,200	A	J	P	1

SCENARIO NO. 40
FFBD NO. 8, 32

FUNCTION: Unload Grain Vehicle/Convey Grain to Transportation Vehicle

HAZARD SCENARIO DESCRIPTION:

Corn was being unloaded from a truck and rail cars were being loaded. The elevator was reasonably clean and had a good dust control system with the center of the headhouse being pressurized. The leg became plugged and the foreman attempted to clear the plugged boot by jogging the drive motor. After a short period the leg belt parted at the head pulley and dropped down the leg. The dropping belt created a dust cloud in the leg that was ignited by the burning belt. The leg casing broke open and air, because of the pressurization of the headhouse, rushed up the casing and into the handling system, carrying the burning dust with it. The leg and the handling equipment were damaged but no major structural damage occurred. Two people were killed by the explosion.

PROPOSED PREVENTIVE ACTIONS:

1. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

2. Use motion sensors to indicate belt slippage and misalignment.

3. Apply state-of-the-art techniques to reduce the concentration of airborne dust in and emanating from elevator legs.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 3,000	X
2	20	2,000	X
3	19	6,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$11,000	A	J	Q	2

SCENARIO NO. 41
FFBD NO. 8, 32

FUNCTION: Unload Grain Vehicle/Convey-Grain to Transportation Vehicle

HAZARD SCENARIO DESCRIPTION:

Corn from trucks and rail cars was being unloaded and a barge was being loaded at a steel tank and metal-clad river terminal elevator. Housekeeping was fair with dust collection on the legs only. Electricians, installing new wiring in the elevator, had opened some of the junction boxes in the truck receiving tunnel. An electrical arc from one box ignited a dust cloud in the tunnel resulting in a series of explosions. Rupture of the metal sheeting relieved the explosion pressure and structural damage was minimal. All the elevator legs exploded. The most severely damaged was the barge loading leg to which collected dust was being returned. A number of employees were injured but there were no fatalities.

PROPOSED PREVENTIVE ACTIONS:

1. Use a pre-established and enforced permit procedure whenever welding, cutting, wiring hookup, or open flame work is to be done.

2. Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosive limit where possible in enclosures other than legs.

3. If dust is returned to the grain stream, do it in the least hazardous manner.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	17	$ 500	X
2	19	5,000	X
3	11	3,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$8,500	B	L	Q	26

SCENARIO NO. 42
FFBD NO. 32

FUNCTION: Convey Train to Designated Transportation Vehicle

HAZARD SCENARIO DESCRIPTION:

The operation of grinding milo in a small, country elevator had been slowed during the day because of a malfunctioning sifter. Two employees, working overtime, repaired the sifter and then loaded a truck with wheat from two of the elevator bins. About midnight they noticed a light in a small enclosure directly under the leg head. Deciding the light was a fire they called the fire department and then tried to extinguish the fire themselves. After applying the contents of three small fire extinguishers through a window in the enclosure, one of the employees left to get more extinguishers while the other remained at the site of the fire. Sensing that an explosion was about to occur, the employee at the site turned to leave and was blown off the roof to the ground, about 40 feet below. Grain dust in the structure had been ignited by a bare light bulb. The fire burned through the leg belt, which dropped, causing an explosion in the leg, damaging the head and boot areas.

PROPOSED PREVENTIVE ACTIONS:

1. Use only equipment and installation standards meeting National Electrical Code requirements.

2. Establish a fire and explosion prevention training program.

3. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	16	$ 200	X
2	4	500	X
3	13	1,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$1,700	C	J	P	10

SCENARIO NO. 43
FFBD NO. 32

FUNCTION: Convey Grain to Designated Transportation Vehicle

HAZARD SCENARIO DESCRIPTION:

An old, wooden elevator and mill had been converted to handling grain dust. Dust in one of the bins had gone out of condition, resulting in a fire. The fire department responded and apparently extinguished the fire. The elevator resumed loading out dust and when the bin was almost empty some burning dust from the previous fire entered and ignited the dust cloud in the bin. An explosion and fire resulted which completely destroyed the elevator. Three were seriously injured, but no deaths resulted.

PROPOSED PREVENTIVE ACTIONS:

1. Apply state-of-the-art techniques to reduce the concentration of airborne dust below the lower explosive limit where possible in enclosures other than legs.

2. Establish a fire and explosion prevention training program.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	19	$ 1,800	X
2	4	500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Low	$2,300	A	L	P	7

SCENARIO NO. 44
FFBD NO. 10, 14
20, 27

FUNCTION: Elevate Grain Load

HAZARD SCENARIO DESCRIPTION:

An employee in a dusty, small, country elevator smelled smoke and notified the manager. He ordered everyone to evacuate the elevator and called the volunteer fire department, which arrived in about five minutes. Several employees accompanied the firemen into the elevator to locate the fire. Smoke was pouring out from the edges of 3' X 3' door in the floor leading into the leg pit. After opening the door slightly, an employee saw fire in the pit. A fireman adjusted his hoze nozzle to fog and told the employee to open the pit door. When the fog of water was played into the pit, it dislodged a massive amount of dust that exploded. Four men were injured, one seriously, and the elevator sustained major damage. The dust had been ignited by a light bulb that was buried about 7' in a 14' depth of dust that had been allowed to collect in the pit.

PROPOSED PREVENTIVE ACTIONS:

1. Conduct rigorous preventive maintenance, especially on all parts of bucket elevators.

2. Establish a housekeeping program involving a mechanical dust collection system supplemented by manual means.

3. Establish a fire and explosion prevention training program for employees and local fire officials.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	13	$ 800	X
2	13	10,000	X
3	4	500	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
High	$11,300	B	K	Q	16

SCENARIO NO. 45
FFBD NO. 10, 14
20, 27

FUNCTION: Elevate Grain Load

HAZARD SCENARIO DESCRIPTION:

A small elevator of eight bins uses a screw auger to feed the leg boot. Some minor repairs are being done in the tunnel containing the auger. The leg is started and the repair man lays his tools on the tunnel floor. The bin chute on which he was working falls off at the bin exit and the grain falling from the bin sweeps his tools into the auger opening. A pipe wrench is carried up the leg and jams the head pulley. The belt burns through and falls down the leg, the center portion of the leg being a concrete shaft containing 20 years of accumulated dust. The dust, ignited by the burning belt, explodes and destroys the midsection of the headhouse. The top house is damaged beyond repair. Two employees in the top house are blown through the windows. One employee is killed, the other seriously injured. The elevator reopens 18 months later after $1,000,000 of repairs and reconstruction.

PROPOSED PREVENTIVE ACTIONS:

1. Install gratings over the auger openings.

2. Install motion sensors on the leg belt and pulley.

PREVENTIVE ACTION (PA) DISPOSITION:

PA NO.	PA CODE	TOTAL COST OF PA	APPROVED PA
1	10	$ 500	X
2	20	1,000	X

HAZARD CONTROL POTENTIAL	CUMULATIVE PA COSTS	HAZARD SEVERITY CODE	HAZARD PROBABILITY CODE	HAZARD RESOURCE CODE	HAZARD SIGNIFICANCE CODE
Medium	$1,500	A	K	P	3

Appendix B

DUST EXPLOSIONS

EXPLOSIBILITY OF GRAIN DUST

The dusts generated in grain processing are composed of moisture, starch, protein, fat, and ash. The chemical elements are typical of all natural organic substances derived from plants (i.e., carbon, hydrogen, nitrogen, and oxygen) plus traces of various minerals. The grain dusts collected in dust control systems are 60 to 80 percent combustible (the balance is ash and moisture) and have mean diameters of from 17 to 120 μm. The heat of combustion of such dusts ranges from 12,000 to 20,000 J/g (for comparison, a paraffin hydrocarbon, C_nH_{2n+2}, releases at least 45,000 J/g).

When grain dust is suspended in air at a concentration of about 150 g/m^3, the mixture composition is correct for complete combustion of the dust (i.e., the mixture is stoichiometric). However, in actual dust explosion tests, it is found that the energy release and rate of energy release is a maximum at concentrations well above the stoichiometric concentration (usually at least 3 to 4 times that concentration). Additionally, dust explosions, in contrast to gaseous explosions, show a rather flat response in terms of maximum pressure and rate of pressure rise versus concentration. Thus, for a dust-air mixture there is a large range of concentrations from approximately stoichiometric (150 g/m^3) to approximately 10 times stoichiometric (1500 g/m^3) over which the pressure rise in an enclosure is approximately independent of dust concentration. Under these circumstances, an explosion of a dust-air mixture in the enclosure if not relieved by rupture of the enclosure will generate a pressure rise of approximately 6 to 10 atm, which is the same as that generated by a vapor or gaseous fuel explosion (Bartknecht 1981). Thus, once a system contains the minimum amount of dust needed to sustain an explosion, the basic explosion hazard potential has been established; additional amounts of dust increase the damage potential by only a minor amount and even large excesses do not reduce it significantly. The measurable properties pertinent to an understanding of the ignitability and explosibility of a particular dust are the following:

1. Minimum Temperature for Auto-Ignition in a Combustible Cloud--The apparatus typically used to measure this property is the Godbert-Greenwald furnace (Godbert 1952, Godbert and Greenwald 1936). A sample of dust in a dust holder is blown downward through a vertical furnace of specified dimensions and construction that has been heated to some initial temperature. If a sheet of flame appears at the exit of the furnace, the furnace temperature is said to be above the auto-ignition temperature of the dust

cloud. If no flame appears, the furnace temperature is assumed to be below the auto-ignition temperature. The experiment is performed over a range of dust concentrations by varying the amount of dust in the dust holder. The minimum value of the auto-ignition temperature and the concentration at which it occurs are then recorded.

2. Layer Ignition Temperature--A standard experiment has been devised (National Materials Advisory Board 1982) to measure the surface temperature at which a standard thickness of a dust will ignite within a specified time (usually 30 min). In this experiment, a layer of dust of a specified thickness is placed on a thermostated heated metal surface. The ignition temperature is determined by noting the surface temperature at which a glow or flame appears or a thermocouple placed in the dust sample reads a specified higher temperature (usually 50°C) than a thermocouple imbedded in the hot surface.

3. Maximum Pressure and Maximum Rate of Pressure Rise in an Enclosure and Flammability Limits--In the test for maximum pressure rise and maximum rate of pressure rise, a dust sample is dispersed into a vessel by a burst of high-pressure air. After some delay time the dust is ignited with a high-energy electrical spark and the pressure-time curve of the explosion process is recorded. Two types of vessel have been used for these measurements. One is the Hartmann test apparatus that consists of a small (75 $in.^3$) vertical tube approximately 1 ft long. The other consists of a spherical vessel with central ignition. Bartknecht (1981) has used different size spherical vessels and he has found that for a sufficiently large vessel (greater than 20 liter capacity) one can define a constant:

$$k_{st} = (dp/dt)_{max} V^{1/3},$$

based on the maximum rate of pressure rise, $(dp/dt)_{max}$, and the vessel volume, V. The constant, k_{st}, is unique for each dust type. It essentially gives an indication of the combustion rate of that dust and therefore the relative damage due to an explosion associated with that dust. Bartknecht points out that for vessel volumes less than approximately 20 liter, k_{st} ceases to be a constant and becomes smaller as the vessel size decreases. Thus, the rate of pressure rise observed in small vessels is less than the potential rate of pressure rise that one would observe in a large vessel (it is probable that radiative losses to the wall considerably lower the combustion rate in the smaller vessel). In the test for explosibility limits, a bomb is used and the minimum dust concentration that can be ignited by a high-energy spark is determined. The LELs for common grain dusts are shown in Table B-1.

4. Ignition Energy--The ignition energy of a combustible mixture usually is measured by determining the amount of energy required in a capacitance spark to just cause ignition of the combustible mixture. This also is true in the case of dust ignition. Eckhoff (1975) has concluded that the ignition energies of dust are different from those of vapors and gases in

TABLE B-1 Explosive Properties of Common Grain Dusts.

Type of Dust	Maximum Pressure (kPA)	Maximum Rate of Pressure Rise (MPa/s)	Ignition Temperature Cloud (°C)	Ignition Temperature Layer (°)	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	9.0	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

SOURCE: U.S. Bureau of Mines 1961.

that the ignition process is dependent on details of the spark shape and discharge circuitry. The ignition energies of dusts also have been found to be considerably larger than those of typical vapors or gases. However, the panel during its explosion investigations noted that typical ignition sources in grain elevators exceed these values by several orders of magnitude.

The U.S. Bureau of Mines (1961) performed extensive experiments in the 1960s and measured many of these properties for a large number of dusts including many common agricultural dusts (Table B-1). It devised an explosibility index based on these measurements that is used to rank dusts in terms of their explosion hazard. Unfortunately, this index was based on Hartmann bomb measurements and therefore tends to under-rank the most dangerous dusts including certain agricultural dusts. Bartknecht (1981) has taken a different approach. He measures k_{st} and then segregates all dusts into three categories. His approach, which is based only on the rate of pressure rise in a spherical vessel, can be used to determine proper vent areas for dust explosions (National Fire Protection Association 1978).

EXPLOSION DYNAMICS

Combustion explosions of the type that occur in grain elevators take place because a combustible mixture of grain dust (fuel) and air (oxidizer) exists inside an enclosure (e.g., an elevator leg, a garner bin, or even the building itself) (Strehlow 1980). As mentioned above, a mixture of grain dust and air can be combustible if the dust concentration exceeds some minimum value. Combustion of the explosive mixture in an enclosure will release sufficient heat to produce a pressure rise of approximately 6 to 10 atm if the enclosure is strong enough to contain the mixture during the entire combustion process.

For combustion to occur, an ignition source is necessary. This can take many forms (Table B-2). It is important to note, however, that in grain elevator explosions, the ignition source almost invariably is a "soft" one that has an energy considerably above the minimum ignition energy of the dust-air mixture. This means that the ignition source initially causes a low-velocity flame to propagate away from the source region. The subsequent behavior of the flame and the explosion process that occurs after such soft ignition is very strongly dependent on the geometry of the enclosure and the location and size of the various pieces of equipment, etc., that are located inside the enclosure.

Two different flame and explosion process behaviors have been observed and most grain elevator explosions fall somewhere between the two extremes (Bartknecht 1981). First, if the vessel has a very small length to diameter (L/D) ratio (i.e., is almost spherical in shape), the flame will not accelerate to high velocity and the pressure will rise rather slowly in the enclosure (in large vessels the pressure rise may take as long as 10 s). Under these circumstances, all the walls of the vessel will be pressurized uniformly and, if of relatively equal strength, will fall away at about the

TABLE B-2 Probable Ignition Sources

Source		No. of Facilities
USDA Data[a]		
Unknown		103
Welding		43
Electrical failure		10
Tramp metal		10
Fire other than welding		10
Other foreign objects		9
Friction, choked leg		8
Overheated bearings		7
Unidentified spark		7
Friction sparks		7
Lightning		6
Extension cords in legs		4
Faulty motors		4
Static electricity		3
Fire from slipping leg belt		3
Flammable vapor		3
Smoldering grain		2
Smoking material		2
Firecracker		1
Voltatile chemical from soybean processing		1
External cob pile fire		1
Heating system		1
Gas in bin ignited		1
Extinguishing fire		1
Leak in gas pipe ignited		1
Electrical control panel explosion		1
Slipping conveyor belt		1
	TOTAL	250
EMRII Data[b]		
Unknown		85
Welding		14
Friction in elevator leg		12
Fire other than welding		11
Electrical		6
Lightning		4
Motors		3
Spontaneous combustion		2
Other foreign objects		1
Static electricity		1
	TOTAL	139

NOTE: Data probably are not mutually exclusive.
[a] U.S. Department of Agriculture 1980.
[b] Verkade and Chiotti 1976.

same time. Certain headhouse explosions exhibit this behavior. On the other hand, if the vessel has a large L/D ratio (e.g., a Texas house or gallery) or contains many obstacles (e.g., the usual tunnel of a slipped formed facility), an ordinary slow combustion wave can induce gas motion ahead of itself. This causes turbulent eddy shedding and growth of turbulent wall boundary layers. When the flame reaches these, it accelerates and generates a more rapid pressure rise, which causes even more violent eddy shedding and turbulent boundary layer growth. This behavior results in extremely high propagation rates (up to detonation velocities).

A detonation is a stable, supersonic combustion wave that travels at a velocity determined by the amount of heat released in the fuel-air mixture. These velocities can be as high as 2000 m/s. Furthermore, once such a wave is started in a large L/D-ratio vessel, it usually propagates the length of the vessel or until it runs out of fuel. In general, large L/D-ratio regions or spaces with obstacles suffer much more devastating grain dust explosions than low L/D vessels because the supersonic wave nature of the detonation process produces a local pressure rise of about 20 atm with a rise time of less than 0.1 s. Under these circumstances, the walls cannot relieve in time to stop the pressure from rising to its maximum value, the facility is shattered with pieces thrown great distances, and a sizable external blast wave is produced. The missing bins in the Houston incident undoubtedly experienced this type of a combustion explosion.

As was stated above, grain dust and air mixtures can support a propagating flame above a certain concentration limit. This limit is well above the level that is tolerable to man (e.g., grain dust in suspension at the LEL will not transmit light over a distance of about 3 ft) and is not permitted in personnel areas. It is, however, tolerable in process equipment and quite frequently is reached inside pieces of machinery. In general, the internal explosion of a piece of process equipment, particularly if it is of weak construction (e.g., sheet metal walls tack welded or clamped with weak clamps), will not cause extensive external damage because pressure relief allows much of the combustion to occur externally in a much larger vessel (the room) and the pressure never builds to a damaging level.

Given this situation, one might ask why damaging dust explosions occur in the grain-handling industry. The answer is that even though high concentrations of airborne dust are not tolerated in personnel areas, dust accumulates on exposed surfaces (i.e., the layered dust) and constitutes a fuel source for an explosion in the personnel area itself. Two common sequences of events can be used to illustrate what can occur. In the first sequence, a spark is inadvertently generated in a piece of process equipment and the dust concentration is high enough to support combustion. The weak piece of equipment ruptures, as it was designed to, at a very low overpressure. The explosion produces a reasonably large fireball of burning dust near the piece of process equipment and, because of vibration and air motion ahead of the burning region, stirs up dust that was layered in the personnel area and the entire atmosphere of the area becomes combustible. This leads to a major secondary explosion in the facility. In the second sequence, a hot piece of equipment (e.g., a light bulb) in an explosionproof housing or an explosion-proof motor is covered with sufficient layered dust to lead to layer ignition and smoldering. A workman discovers the smoldering pile and either he or a fireman attempts to extinguish it with a water spray or chemical extinguisher spray. This stirs up a considerable amount of dust, some of which already is burning, and causes a primary explosion that can then trigger a secondary explosion if the rest of the area is dirty.

REFERENCES

Bartknecht, W., Explosions--Cause, Prevention, Protection, Springer-Verlag, Berlin, 1981.

Eckhoff, R.K., Towards absolute minimum ignition energies for dust clouds, Combustion and Flame 24 (1975): 53-64.

Godbert, A.L., and Greenwald, H.P., Laboratory Studies of the Inflammability of Dusts, U.S. Bureau of Mines Bulletin 389, U.S. Department of the Interior, Washington, D.C., 1936.

Godbert, A.L., A Standard Apparatus for Determining the Inflammability of Coal Dusts and Mine Dusts, Report 58, Safety in Mines Research Establishment, 1952.

National Fire Protection Association, Guide for Explosion Venting, NFPA No. 68, NFPA, Boston, Massachusetts, 1978.

National Materials Advisory Board, Classification of Dusts Relative to Electrical Equipment in Class II Hazardous Locations, Report NMAB 353-4, National Academy Press, Washington, D.C., 1982.

Strehlow, R.A., Accidental explosions, American Scientist 68 (1980).

U.S. Bureau of Mines, Explosibility of Agricultural Dusts, Investigation 5753, U.S. Department of the Interior, Washington, D.C., 1961.

U.S. Department of Agriculture, Prevention of Dust Explosions in Grain Elevators--An Achievable Goal, USDA, Washington, D.C., 1980.

Verkade, M., and Chiotti, P., Literature Survey of Dust Explosions in Grain-Handling Facilities: Causes and Prevention, Report IS-EMRRI-2, Energy and Mineral Research Institute, Ames, Iowa, 1976.

Appendix C

EXPLOSIONS IN MILLS HANDLING GRAIN PRODUCTS

Mills of any type (feed, flour, soy, rice, etc.) are subject to the same dust explosion hazards as grain elevators since their input is grain and, before processing, it is handled in the same manner as in elevators (e.g., movement in legs and on conveyor belts, drying, storage in silos). Mills, however, are subject to additional dust explosion hazards because of the actual processing of the grain. The hazards arise because, at some point in the processing, the grain is ground into fine particles of dust-like size, and flammable concentrations cannot be avoided. (Exceptions to this processing will be discussed later.)

The first point of danger is the grinding operation, usually a hammer or roller mill, where explosions can occur for two reasons. First, ingestion of tramp metal or stones can produce sparks sufficient to ignite the ground material. Second, the moving parts of the mill can break and produce sparks. Even if such events do not cause an explosion in the mill, they can ignite the ground material that then is transported to a point where a primary explosion can occur.

After the grinding operation the material usually is moved to the next processing point by pneumatic conveyors similar to those used in dust collection systems. Transporting the material by means of bucket conveyors has all of the hazards attendant to an elevator leg without the possibility of dust collection. Augers and drag conveyors are considerably less hazardous.

Further processing in most cases involves treatment with water in some form, either liquid or steam. The explosion hazard at this point is remote except for one factor. Material that escapes from the processing apparatus settles on floors, walls, beams, etc., and, if not removed, eventually dries to form a dangerous layer of dust.

The product next is dried and moved within the mill in the same manner and with the same hazards as grain in an elevator. Fortunately, the product entering this portion of the mill system does not contain fine dust in the same concentration as grain entering an elevator.

Operations such as flour production that do not involve a wet process are extremely hazardous. In the early part of this century it was realized that the explosion potential of flour and corn starch was very great.

Consequently, there is considerable emphasis on housekeeping, reinforced by the hygienic standards required for processing material for human consumption. The one exception noted by the panel while visiting a mill producing flour was in the bagging operation. The bagging machine was located in a separate small building and a layer of flour, inches deep, was on the floor in some places.

Rice mills and pellet mills are somewhat unique and must be discussed separately. The belief that rice mills will not explode is widespread; however, rice mills have exploded in the past (e.g., in Jonesboro, Arkansas, on May 28, 1964) (U.S. Department of Agriculture 1979). Rice dust and corn dust of the same moisture content have similar explosive characteristics. One of the rice mills visited by the panel operated in two ways that contributed greatly to reducing the hazard. The mill shut down operations just prior to the harvesting period to overhaul all of the equipment and to clean the mill totally. The owner-operator also discarded all the dust accumulated by the collection system.

Dust pellet mills are in a class by themselves because their input is the explosive material, grain dust. In the one mill visited by the panel it was obvious that the major hazard existed in the receiving operation. Dust from rail cars or trucks was dumped into a pit and pneumatically conveyed to silos. The introduction of an ignition source at this point would have caused an immediate explosion either in the pneumatic system or in the silo. During the panel's visit dust was being unloaded from a closed-body truck by means of a front-end loader. Ignition sources on the loader were readily apparent--no protection from ignition by the motor exhaust; headlights (on) with only slight protection; standard, battery operated, starting system; and no grounding (rubber tired wheels). Dust from the silos was fed to a hammer mill, wet processed, pelletized, dried, and stored in bins. The operations following the hammer mill were not particularly hazardous and there was little opportunity for dust to accumulate in layers.

A seed plant's material handling equipment operates at slow speeds so as to handle the grain gently. Dust cloud generation and the explosion hazard is therefore considerably lower than in other mills.

Some mills contain explosion and fire hazards greater than those due to dust (e.g., the use of hexane in oil extraction). However, the panel's concern was limited to the hazard due to dust.

Recommendations for the safe operation of the elevator portion of mills are, of course, the same as those discussed in the main text of this report. The principal difference between recommendations applying to the elevator and to the processing system is that dust collection cannot be applied to the processing machinery; manual housekeeping assumes a greater role due to "leaks" from the processing machinery. The one recommendation specific to mills concerns conveying systems and hammer mills.

All mill operators questioned by the panel about what they believed should be designed differently in new mills to improve safety indicated that the hammer mill should be outside the structure containing the general work area. Although the panel believes that this response was influenced greatly by the uncomfortable level of noise produced by a hammer mill, it agrees with the suggestion on a safety basis. Its implementation not only would place a dangerous process outside the general work area but also would increase the employees' awareness of any sounds produced by other malfunctioning equipment.

Because of the prevalent use of pneumatic conveyance in mills, suppression devices assume an important role in explosion prevention. Systems involving pneumatic conveying of large amounts of explosive dusts in high concentrations should always be protected by explosion suppression devices. Although explosion suppression devices are not considered and flour mill safety is emphasized, the Incorporated National Association of British and Irish Millers (1973) general publication on protection against dust explosions is recommended reading for all involved in the operation of elevators and mills.

In summary, although feed mills, flour mills, and grain elevators differ substantially from one another, they share, in varying degrees, the same dust explosion hazards. The emphasis for hazard reduction in each type of facility is therefore on dust control, and the panel recommends that hammer mills, other grinding equipment, and their dust collection systems be isolated physically and pneumatically from the main facility. The efficacy, feasibility, and efficiency of this recommendation were judged to have a medium hazard control potential.

REFERENCES

Incorporated National Association of British and Irish Millers, Ltd, Dust Explosions in Flour Mills and Bulk Flour Containers, Second (Revised) Edition, London, 1973.

U.S. Department of Agriculture, Prevention of Dust Explosions in Grain Elevator--An Achievable Goal, USDA, Washington, D.C., 1979.

Appendix D

REPORT OF THE SUBPANEL ON RECOMMENDED STANDARDS AND REGULATIONS

A subpanel of the Panel on Causes and Prevention of Grain Elevator Explosions was formed to review existing regulations and standards and to make recommendations that will reduce losses. The work was limited to grain elevators and did not include feed mills and processing plants although much of the information is transferable. The recommendations are not of grain elevator design nature, though it was recognized that a need exists, but rather are directed at existing operating grain elevators.

The subpanel accomplished the following:

1. Reviewed existing regulations and standards
2. Established facts about explosions that would be a basis for creditable regulations
3. Made regulation recommendations

REVIEW OF EXISTING REGULATIONS

There does not exist a regulation specifically for grain elevators, but there are some standards, alerts and instructions which have been reviewed. The following matters were reviewed:

1. Occupational Safety and Health Administration Grain Elevator Industry Hazard Alert - January 5, 1978
   Letter 5/19/78
   Letter 7/18/78

2. U.S. Department of Agriculture
   Federal Grain Inspection Service
   FGIS Instruction 370-3 Rev. 1
   Alert Guideline Procedures and Policies upon Encountering "Hazardous Conditions" in Grain Elevators.

3. National Fire Protection Association Grain Elevators Bulk Handling Facilities 1973
   NFPA 61B

4. Industry Safety Standards
   - Continental Grain Company
   - Bunge Corporation
   - Cargill, Inc.

5. State of Michigan Department of Labor
   Occupational Safety Standards Commission
   Part 77 Grain Elevators and Mills

6. Occupational Safety and Health Administration
   Hazardous Materials Fire Protection

7. Occupational Safety and Health Administration
   Longshoring - Draft

8. National Electrical Code - Article 500 - Hazardous Locations
   Panel 14 - Review draft

The majority of the regulations reviewed were either interim in concept or are being reviewed at this time. For this reason, the subpanel opted to avoid specific review of individual documents, but make general comments only and move on to the positive work of recommendations for effective regulations.

Regulations are too lengthy, containing support data, opinions, statistics and design criteria in addition to the regulations. More than half of all grain elevators have two or less employees who must handle all the management functions including loss control, and they require a simple clear regulation. When part of the regulation is based on controversial opinion, the entire regulation loses credibility and results in a low level of compliance and court cost, dissipating capital that should be employed in loss control. Efficient regulation focuses on reduction in loss of life, limb and property.

BASIC FACTS

To draft an efficient regulation it is first required to establish the basic facts to support the regulation. At present, statistics in the industry are poor and some additional research is needed to eliminate the controversy over such questions as the role of metal sparks in dust cloud ignition. The following are facts on which an efficient, creditable regulation can be written and enforced today.

1. The leg or bucket elevator is the number one location for primary grain dust explosion.

2. Poor housekeeping and inadequate dust control leads to disastrous secondary explosions with high loss of personnel and property.

3. There is little record of primary explosion in working spaces of the elevator and none in large bins, flat warehouses or ship holds.

4. Dust cloud ignition sources may be divided into high and low incidence:

High	Low
- Hot Bearings	- Electrical
- Welding and cutting	- Static electricity
- Belt slippage and misalignment	- Lightning
- Open flames	- Metal and stone sparks
- Foreign objects caught in machinery	- Spontaneous combustion

REGULATION RECOMMENDATION

A simple regulation aimed at the bucket elevator and the high incidence ignition sources should eliminate 90 percent of the primary explosions. Regulation of the dust systems and housekeeping will reduce the loss resulting from the few remaining dust cloud ignitions and the secondary explosions.

1. Legs (bucket elevator) within closed elevator spaces

   a. Should be equipped with motion switches that sound an alarm when belt speed falls 10 percent and shut the leg down if the condition is not corrected in 30 seconds.

   b. Bearings should not be mounted inside the leg casing.

   c. A method must be provided to check bearing temperatures each operating day and a record maintained. In small elevators a simple log will suffice.

   d. The leg discharge should have a plug switch to shut down leg feed or sound an alarm when discharge becomes plugged.

   e. Receiving leg feeds should 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.

   f. Leg should have explosion vents to the outside. The vent should be at least the full size of the head. Vent as near vertical as possible. It is not implied that venting of the head pulley area will be effective for explosions other than those originating in or near the head.

   g. A written maintenance program including a work log dating belt inspection, cup inspection, pulley lagging inspection, motion and plug switch checks should be undertaken.

2. Electrical

a. All closed areas of the grain elevator housing grain-handling equipment should have dust control and housekeeping so as to qualify as Class II, Division 2 locations. This will include loading and unloading sheds with two or more walls.

b. The following will be considered ordinary locations (not as hazardous as Division 2 locations):

- Open roof, dock, and yard areas
- Buildings containing no grain-handling equipment and separated from those containing grain-handling equipment by fire walls and fire doors
- Pressurized rooms

c. Electrical equipment located within conveyor housing or other containers where dust concentrations may reach the lower explosive limit during normal operation shall be suitable for Class II, Division 1.

d. All replacement belts and pulley lagging should be conductive having 15 megohm or less resistance to ground.

e. All motors should be grounded in accordance with National Electrical Code.

3. Dust Control

a. Within closed elevator spaces, transfer points and free-fall areas should be dust tight or dust control should be provided. All interior legs should have dust control.

b. A maintenance program and work log should be kept on all dust systems within the elevator closed spaces.

c. Performance of the dust control system should be continuously monitored.

4. Housekeeping in work areas of the building:

a. Housekeeping schedules and logs should be kept on all closed areas containing grain-handling equipment. Each gallery, each tunnel, each headhouse shall be deemed an area.

b. As a guideline, layered dust in each area should not exceed 1/64" 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 are not considered here; only that material that will pass through a 200-mesh screen (74 μ or smaller in diameter).

5. Procedures

   a. Welding and cutting should not be permitted in the elevator when operating and a permit system should be in effect.

   b. Electrical and air tools should not be used on grain-handling equipment while running, and a method of control should be in place.

   c. An emergency signal system should be in place.

   d. Emergency procedures should be written and posted.

   e. Outside contractors working in the elevator should be required to observe the above procedures.

6. The following training will be documented:

   a. Emergency procedure drill

   b. Explanation of dust explosion pentagon

   c. Explanation of this regulation

   d. Annual meeting with local fire department

This regulation will be acceptable to responsible grain men, can be enforced, and will eliminate more than 90 percent of the grain elevator dust explosion problem.

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BIBLIOGRAPHIC DATA SHEET

1. Report No.	NMAB 367-2
2.	
3. Recipient's Accession No.	
4. Title and Subtitle	Prevention of Grain Elevator and Mill Explosions
5. Report Date	June 1982
6.	
7. Author(s)	Panel on Causes and Prevention of Grain Elevator Explosions
8. Performing Organization Rept. No.	NMAB 367
9. Performing Organization Name and Address	National Materials Advisory Board National Academy of Sciences 2101 Constitution Avenue, N.W. Washington, D.C. 20418
10. Project/Task/Work Unit No.	
11. Contract/Grant No.	J-9-F-8-0137
12. Sponsoring Organization Name and Address *	U.S. Department of Labor Occupational Safety and Health Administration 200 Constitution Avenue, N.W. Washington, D.C. 20210
13. Type of Report & Period Covered	Final
14.	

15. Supplementary Notes *With additional funding from: National Institute for Occupational Safety and Health (NIOSH) and U.S. Department of Agriculture.

16. Abstracts The panel, in this second report of the causes and prevention of grain elevator explosions, presents an overview of the dust explosion problem in grain handling facilities. Recommendations are made that could reduce the present danger of explosions.

A systems approach to risk management was employed that permits all aspects of a situation to be considered simultaneously rather than separately or sequentially. An attempt was made to identify every possible hazard that contributes to grain dust explosions in elevators and mills. Each identified hazard was evaluated in terms of its significance to explosion potential--the most consequential having the highest ranking the the least consequential the lowest. Based on these ratings, the panel formulated its recommendations, balancing those actions that address the most significant hazards with those that cost the least to implement.

Discussed in some detail are preventive measures to forestall a dust explosion, constraints imposed by the cost of dust control measures, insurance against loss and injury, cooperation between government regulatory agencies and industry, the legal environment, elevator operator housekeeping practices, and the psychological factors involved.

17. Key Words and Document Analysis. 17a. Descriptors

Grain-handling facilities
Grain dust
Dust explosions
Ignition sources
Dust control
Venting
Risk management

17b. Identifiers/Open-Ended Terms

17c. COSATI Field/Group

18. Availability Statement: This report is for sale by the National Technical Information Services, Springfield, Va. 22151	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 138
	20. Security Class (This Page) UNCLASSIFIED	22. Price