DOCUMENT RESUME

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TITLE	Safety in Elevators and Grain Handling Facilities. Module SH-27. Safety and Health.
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DESCRIPTORS	Behavioral Objectives; Equipment Utilization; *Health Education; *Learning Activities; Learning Modules; Postsecondary Education; *Safety Education; Secondary Education; *Vocational Education
IDENTIFIERS	*Grain Silos; Hazards; *Occupational Safety and Health

ABSTRACT

This student module on safety in elevators and grain handling facilities is one of 50 modules concerned with job safety and health. Following the introduction, 5 objectives (each keyed to a page in the text) the student is expected to accomplish are listed (e.g., Explain how explosion suppression works). Then each objective is taught in detail, sometimes accompanied by illustrations. Learning activities are included. A list of references and answers to learning activities complete the module. (CT)

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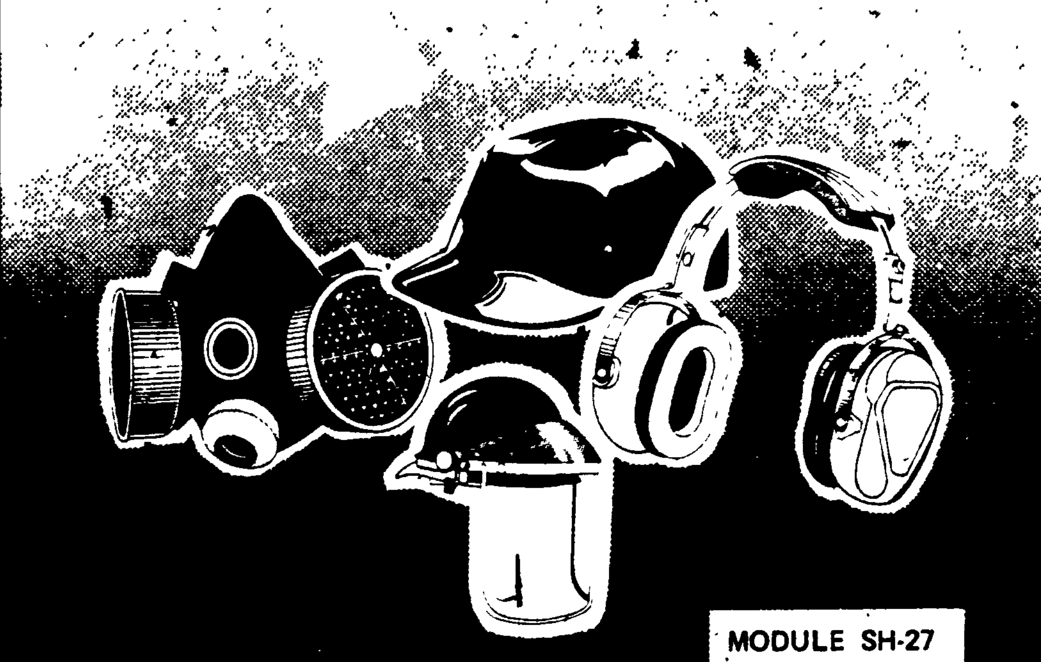
SAFETY AND HEALTH

SAFETY IN ELEVATORS AND GRAIN HANDLING FACILITIES



MODULE SH-27

CORD CENTER FOR OCCUPATIONAL RESEARCH AND DEVELOPMENT

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ORD

The Center for Occupational Research and Development
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Waco, Texas 76710

INTRODUCTION

Over the years, the "agricultural revolution" in the United States has seen the grain and feed industry grow from small country businesses serving local needs to one of the most influential forces affecting world markets.

U.S. grain production annually exceeds 12 million bushels with about 9 million bushels sold other than for replanting, or off-farm, (1977). Nearly all of the grain sold off-farm is handled in the grain marketing system. This system handles, stores, conditions, processes, and markets the grain. The marketing system exports grain valued at over $11 billion, and this is 2/3 of the value of the total U.S. agricultural exports.

The U.S. grain and feed industry includes approximately 9,500 country grain elevators, 400 inland terminal elevators, 80 export terminal elevators, and 7,000 feed mill operations. As grain handling systems grow in size and number, health and safety risks multiply. Today, current grain elevator health and safety hazards are similar to those of many large industrial plants. Of particular concern in recent years has been the increasing loss of lives and property due to grain elevator explosions.

OBJECTIVES

Upon completion of this module, the student should be able to:

1. Summarize the history of grain dust fires and explosions, showing the reasons for the increased frequency and size of explosions beginning in the early 1900s. (Page 3)
2. Identify four basic ingredients of a grain dust explosion. (Page 5)
3. Discuss how dust particle size, concentration in the air, and minimum ignition temperatures affect the possibility of grain dust explosions. (Page 6)
4. List in order the major probable sources of ignition and probable locations of primary grain elevator explosions. (Page 8)
5. Define the terms primary explosion and secondary explosion and discuss their relationship with one another. (Page 12)

6. Explain the terms ignition sensitivity and explosive severity and their role in the calculation of the explosibility index. (Page 14)
7. Explain three general methods of preventing potentially explosive airborne dust clouds. (Page 16)
8. Discuss the major countermeasures used to control the six major sources of ignition in grain handling systems. (Page 19)
9. Explain how inerting prevents ignition of grain dust. (Page 22)
10. Explain how explosion venting works to limit explosion damage. (Page 24)
11. Explain how explosion suppression works. (Page 25)
12. List the three general types of grain driers and the hazards associated with grain driers. (Page 27)
13. List the four levels of service given to equipment in a preventive maintenance program. (Page 29)
14. State the health symptoms related to human exposure to grain dust. (Page 31)
15. List the NFPA standards that apply specifically to grain or agricultural commodity systems. (Page 33)

OBJECTIVE 1: Summarize the history of grain dust fires and grain dust explosions, showing the reasons for the increased frequency and size of explosions beginning in the early 1900s.

Fires and explosions in grain storage areas have been potential hazards for several years. One of the first explosions recorded in which dust was recognized as a contributing factor occurred at a flour mill in Turin, Italy, in 1785. It was not recognized until over one hundred years later that dust alone could cause an explosion.

The earliest reported agricultural dust explosion in the United States was in 1846. From 1846 to 1878, ten explosions were recorded, nine of which occurred in flour mills; one took place in a candy factory where starch was the explosive material. In 1878, the tenth of these dust explosions was the first accident in the United States to record loss of life when eighteen persons were killed.

Agricultural dusts other than flour caused a series of 72 explosions and 60 deaths in U.S. agricultural industries between 1878 and 1913. The last of these explosions involved a loss of 33 lives and 80 injuries in a feed mill explosion in Buffalo, New York.

The most catastrophic agricultural dust explosion ever recorded in the U.S. occurred in a Cedar Rapids, Iowa, starch factory in 1919 when 43 people were killed and 30 injured. Five years later, another starch factory explosion in Pekin, Illinois, killed 42 and injured 22. Although dust explosions have occurred in a number of other industries processing such agricultural products as coffee, spices, powdered milk, and tobacco, in all of the recorded history of agricultural explosions, grain elevators rank first in the number of explosions, people killed, and amount of property damage. From 1846 to 1956, almost twice as many dust explosions occurred in grain elevators than in flour mills, nearly four times as many as in starch processing and utilization, and over one and one-half times as many as in feed and cereal mills.

Another problem for the grain industry has been dust fires. Historically, dust fires have far outnumbered dust explosions, although they have resulted in significantly less damage per fire. Until 1905, grain elevators were built of wood and were powered by nonenclosed machinery. When dust did ignite, the storage spaces were not so tightly enclosed as to allow the buildup of high explosive pressures. Therefore, early dust explosions were generally rapidly spreading fires rather than explosions.

All this changed when the first concrete elevator was built in 1905. Concrete was used to provide strength to allow for very large grain storage capacities and was considered to be fireproof. However, it soon became apparent that fireproof structures were not the same as explosion-proof structures. The strong concrete enclosures prevented the release of pressures built up during rapid burning dust fires and explosions. These pressures were thus able to build up within the concrete enclosures until they resulted in an explosion. Since 1900, over 800 grain dust explosions have been recorded involving over 700 fatalities.

Although grain dust explosions cause the most damage per incident, dust fires also continue to plague the grain industry. Over 29,000 grain elevator fires occurred in the U.S. from 1964 to 1973, an average of more than 2900 per year with an average total annual loss of over $33,000,000. A significant decrease in the number of annual grain elevator fires has occurred since 1969, possibly because of the increased use of fire protection equipment, including the use of automatic detection, alarm, and sprinkler systems.

ACTIVITY 1:*

(Circle the correct answer.)

Increased frequency and size of grain dust explosions, beginning in the early 1900s can be accounted for by:

1. An increase in grain production.

*Answers to Activities begin on Page 35.

2. The building of concrete elevators.

3. The building of wood elevators.

4. The lack of fire prevention equipment.

OBJECTIVE 2: Identify four basic ingredients of a grain dust explosion.

A grain dust explosion is the result of a rapidly burning fire inside an enclosure. Four basic ingredients produce an explosion - fuel, air, an ignition source, and a confined area. These ingredients can be found in any grain or agricultural handling facility. Fuel, in the form of grain dust or powder, is present to various degrees in all types of grain handling and processing facilities. To be explosive, however, a dust must be (1) combustible, (2) finely divided, (3) dispersed in air, and (4) in a concentration within its explosive range. The dust/air concentration is critical; a mixture too "rich" or too "lean" in dust will not ignite. However, in every substantial dust cloud, an explosive concentration exists somewhere.

Before an explosion can take place, there must be oxygen, the second ingredient, to support combustion. The air in all feed mills, grain elevators, and flour mills contains sufficient oxygen to support a fire or explosion.

When fuel and oxygen are present in sufficient quantities, a fire can occur with the addition of a third ingredient - an ignition source. This may be in the form of heat, a spark, a flame or anything that provides energy of a significant amount for a long enough period of time for ignition to occur.

Several things in grain elevators and processing plants can provide a source of ignition: static electricity discharges, friction from moving parts of machinery, spontaneous combustion within stored grain, and welding and cutting operations. Other ignition sources include faulty wiring, heating and lighting equipment, open flames, and sparks caused by metal debris in the grain stream striking process equipment parts.

The fourth ingredient which turns a dust fire into a dust explosion is a confined area. This closed container can be a piece of process equipment, a room enclosing process equipment, or a grain bin. As the fire progresses, tremendous heat is generated which results in a rapid expansion of the air. When the resulting pressure exceeds the structural strength of the confined area, explosion will occur. When all four elements combine, an explosion occurs in milliseconds.

ACTIVITY 2:

(Circle the correct answer.)

Which of the following ingredients, if present at one time and location, have the potential for causing a grain dust explosion?

1. Airborne combustible dust, an overheated motor bearing, oxygen, and a static electrical spark.
2. Static electrical spark, oxygen, a closed container, and a lighted cigarette.
3. A welding arc, a closed container, airborne combustible dust, and friction heat from an improperly adjusted motor belt.
4. Airborne combustible dust, an overheated motor bearing, oxygen, a closed container.

> **OBJECTIVE 3:** Discuss how dust particle size, concentration in the air, and minimum ignition temperatures affect the possibility of a grain dust explosion.

Several factors can help determine how explosive a cloud of dust is. The size of grain dust particles is a major factor in their explosibility. Dust clouds made up of very small particles will most likely ignite at lower temperatures, cause a more powerful explosion, and have a faster rate of pressure increase or rise. The reason for this is the increased surface area of smaller particles; they have more surface area in contact with oxygen in the environment.

The dust particles in most grain elevators have average diameters of approximately 12 microns. One micron is 1/10,000 of a centimeter. Particles less than 100 microns are considered hazardous.

Ignition temperatures have been measured for dust clouds and dust layers. Ignition temperatures for dust layers are less than those for dust clouds due to the increased time exposure of dust layers to hot surfaces as opposed to the relatively shorter time exposure of dust clouds to possible ignition sources.

Like flammable gases, combustible dusts must be within their explosive range in order to support combustion. Just because one can see airborne dust does not mean an explosion hazard exists.

As a "rule of thumb," explosive concentrations of mixed grain dust are within the explosive range when the dust cloud obstructs a 100 watt bulb at a distance of 10 feet. Caution is necessary in applying this informal and inexact measure as only laboratory analysis of air samples provides an accurate measure of concentration, particle size distribution, and other factors of risk.

Appendix A includes two tables; one table shows the minimum explosive concentrations, ignition temperatures, and ignition energies for a number of agricultural dusts. The second table gives the maximum explosive pressure and rate of pressure rise for a sampling of dusts.

ACTIVITY 3:

Which of the following statements about grain dust is false? Grain dust clouds made up of very small particle sizes will most likely ...

1. Ignite at lower temperature.
2. Produce lower explosive pressure.
3. Have a fast rate of pressure rise.
4. Have increased surface area contact.

OBJECTIVE 4: List in order the major probable sources of ignition and probable location of primary grain elevator explosions.

Because of the widespread destruction resulting from a grain dust explosion and the lack of eyewitnesses, investigations that attempt to identify the source and location of initial explosions have generally met with little success. In many cases supposition or a "best guess" has had to replace fact. Table 1 presents the probable ignition sources for 250 incidents of grain dust explosions. In 103 of the 250 incidents studied, probable ignition sources could not be identified.

TABLE 1. PROBABLE IGNITION SOURCES

	Number of Incidents	Percent of Incidents
Unknown	103	41.2
Welding or cutting	43	17.2
Electrical failure	10	4.0
Tramp metal	10	4.0
Fire other than welding or cutting	10	4.0
Unidentified foreign objects causing spark	9	3.6
Friction from choked feed mechanism	8	3.2
Overheated bearings	7	2.8
Unidentified spark	7	2.8
Friction sparks	7	2.8
Lightning	6	2.4
Extension cords caught in feed mechanism	4	1.6
Faulty motors	4	1.6
Static electricity	3	1.2
Fire from friction of slipping drive belt	3	1.2
Leaking flammable vapor	3	1.2

Smoldering grain or meal in feed mechanism	2	0.8
Smoking material (cigarettes, matches, etc.)	2	0.8
Lighted firecracker	1	0.4
Volatile chemical escaping from soybean processing	1	0.4
Fire from cob pile outside facility	1	0.4
Faulty heaing system	1	0.4
Pocket of gas in bin igniting	1	0.4
Extinguishing fire	1	0.4
Leak in gas pipe igniting	1	0.4
Electric control panel exploding	1	0.4
Slipping conveyor belt	1	0.4
Sample Size (Incidents Examined)	250	100.0

Table 2 presents the probable locations of primary explosions. In about 43 percent of the incidents these sites are unknown. Figure 1 illustrates a typical grain elevator and can be used to locate some of the major sites of primary explosions.

TABLE 2. PROBABLE LOCATION OF PRIMARY EXPLOSION.

	Number of Incidents	Percent of Incidents
Unknown	107	42.8
Bucket elevator	58	23.2
Hammer mills, roller mills, or other grinding equipment	17	6.8
Storage bins or tanks	13	5.2
Headhouse	9	3.6
Adjacent or attached feed mill	8	3.2
Basement	4	1.6
Processing equipment	3	1.2
Dust collector	3	1.2
Tunnel	2	0.8

Distributor heads	2	0.8
Passenger elevator or manlift shaft	2	0.8
Grain drier	2	0.8
Outside and adjacent to facility	2	0.8
Pellet collector	2	0.8
Conveyor system	2	0.8
Receiving pit	2	0.8
Other handling equipment	2	0.8
Procesing plant	1	0.4
Down spout	1	0.4
Corn tester	1	0.4
Feed room	1	0.4
Sampler	1	0.4
Storage room	1	0.4
Boiler or feed mill	1	0.4
Electrical switch	1	0.4
Auger conveyor	1	0.4
Electric panel	1	0.4
Sample Size (Incidents Examined)	250	100.0

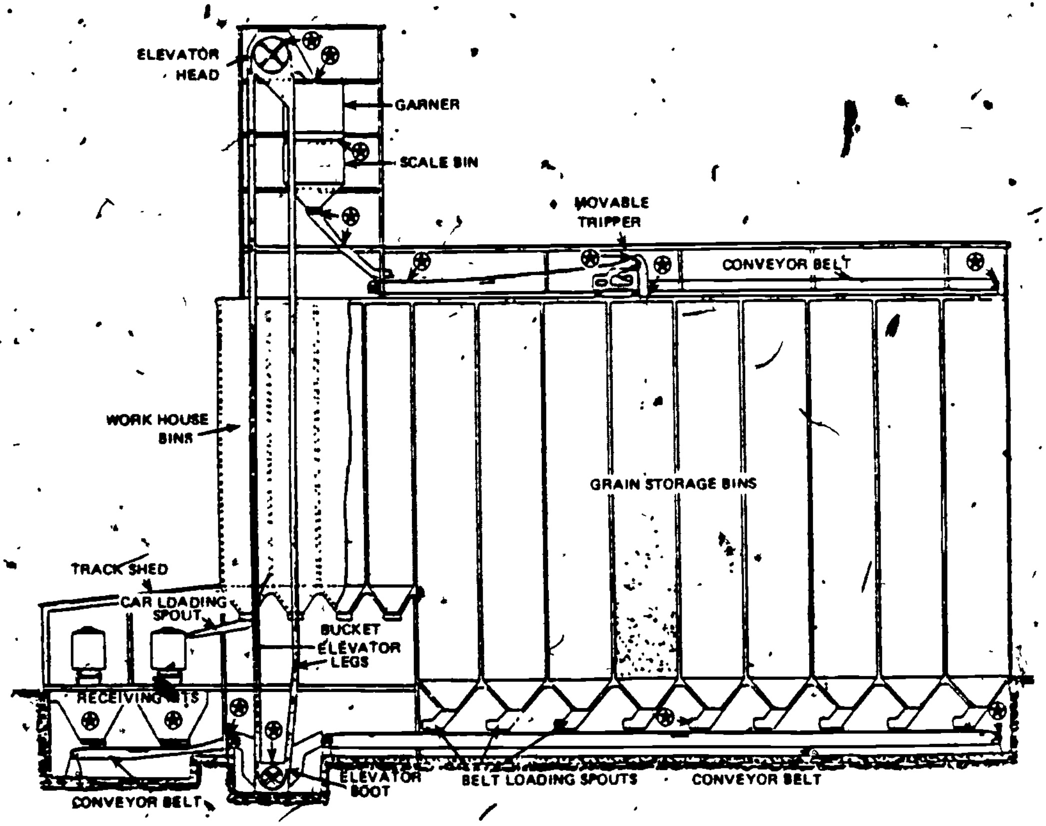

Figure 1. Diagrammatic section view of a terminal type grain elevator with stars identifying potential dust cloud areas.

ACTIVITY 4:

(Circle the best answer.)

1. What is the highest single recorded probable ignition source for grain dust explosions?
   a. Lightning.
   b. Static electricity.
   c. Welding or cutting.
   d. Smoking.

2. Of known locations of primary explosions in grain elevators, the greatest number have taken place in:
   a. The grain storage bins.
   b. The bucket elevator.
   c. The area of the conveyor belt.
   d. The headhouse.

OBJECTIVE 5: Define the terms primary explosion and secondary explosion and discuss their relationship with one another.

When massive destruction results from a grain dust explosion invariably it is because several explosions have occurred in a series. That is, there was one primary explosion and several secondary explosions. Often these explosions move in a series of chain reactions from one end of a grain elevator plant to the other in a matter of seconds.

Primary explosions occur because fuel, oxygen, heat, or a spark, are mixed together in the right proportions within a confined area. When this mixture occurs, a fire ball, high pressures, and a shock wave are produced. The shock wave travels throughout the surrounding physical plant and causes dust at considerable distances from the primary explosion to become airborne. This airborne secondary dust includes dust resting on rafters, process equipment, walls, and floors. Although not normally hazardous, this dust is capable of causing massive explosions when suddenly blown into the air as a result of the shock wave from a primary explosion. A primary explosion may also destroy processing equipment, which can disturb stored grain or grain being processed. All this can produce even greater amounts of airborne dust.

With so much extra dust airborne, secondary explosions may now occur. These are ignited by the heat of the primary explosion, by normally present ignition sources in plant areas not normally subject to dust clouds, and, according to recent research, from the shock wave created by the primary explosion. Secondary explosions are the real threat to grain handling and processing industries. Figures 2a through 2d illustrate the sequence of events which produce primary and secondary explosions.

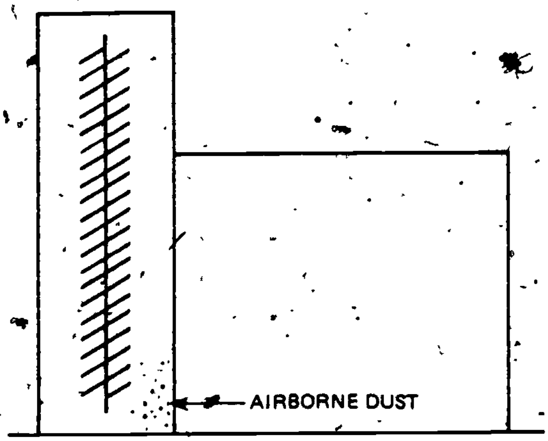

Figure 2a. Grain elevator with explosive airborne dust generated in bottom of elevator leg.

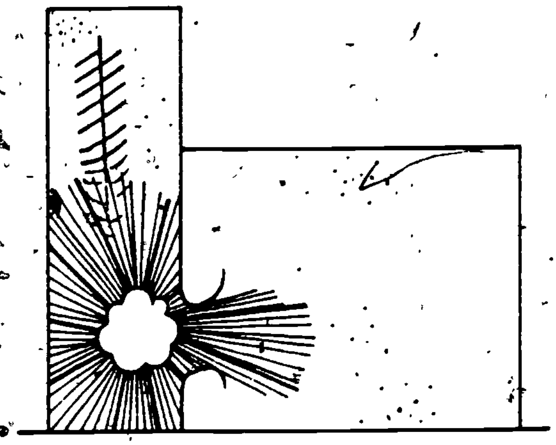

Figure 2b. An ignition source (such as an overheated bearing) plus oxygen causes a primary explosion in the enclosed elevator leg. The explosion sends out a shock wave which causes more dust to become airborne.

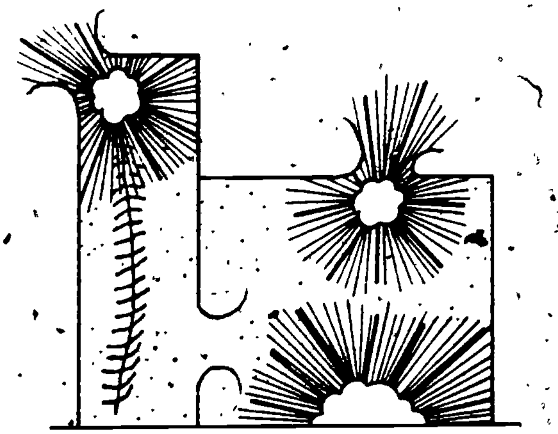

Figure 2c. Secondary explosions occur where secondary dust clouds have been generated. These clouds initiate other clouds and further explosions.

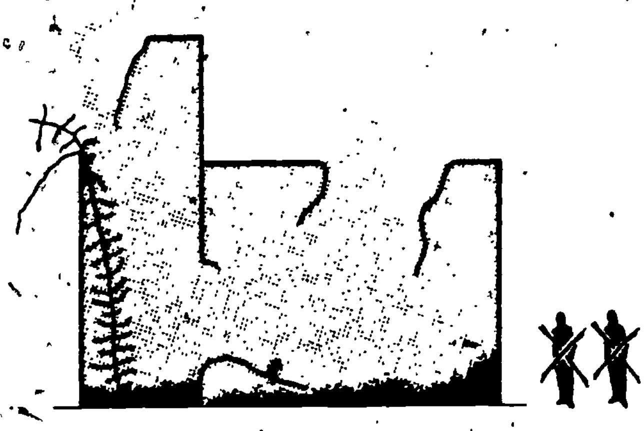

Figure 2d. Elevator is destroyed by secondary explosion.

ACTIVITY 5:

Which statement below is true?

1. Primary explosions produce the greatest damage in grain elevator explosions.
2. A major source of fuel for secondary explosions is the dust that is allowed to accumulate on floors, rafters, and machinery throughout a grain facility.
3. A secondary explosion can occur without a primary explosion.
4. Primary explosions and secondary explosions can be unrelated to each other.

OBJECTIVE 6: Explain the roles of ignition sensitivity and explosive severity in the calculation of the explosibility index.

The potential hazard of any dust is determined by two factors: (1) its ignition sensitivity, or how easy it is to ignite, and (2) its explosive severity or how strong the explosion is after it occurs.

A dust cloud's ignition sensitivity is influenced by its concentration, particle size, moisture content, minimum ignition temperature and minimum ignition energy. Explosive risk is greatest when dust concentration is in the middle of its explosive range, particle size is small, and moisture content, ignition temperature, and ignition energy are low. It is interesting to note that the minimum ignition temperatures for most grain dusts are less than minimum ignition temperatures for propane, which is 842°F.

Strength of combustion, or explosive severity, is measured by how fast the pressure rises within a structure containing an explosion and the maximum pressure that is generated during the course of the explosion. The explosive pressure of a grain dust explosion can exceed that of most fuel gas explosions under similar conditions.

Ignition sensitivity and explosive severity are combined to form an explosibility index to measure the danger of various dusts (Ignition Sensitivity x Explosive Severity = Index of Explosibility). This index was developed by the U.S. Bureau of Mines, and continued by the National Fire Protection Association (NFPA). The index uses Standard Pittsburgh Coal with 37 percent volatiles as the standard for the comparison.

Results of calculations of ignition sensitivity, explosion severity, and the explosibility index for various agricultural dusts are given in Table 3. See Appendix B for actual calculation example.

TABLE 3.- EXPLOSIBILITY INDEX FOR VARIOUS AGRICULTURAL DUSTS.

Dust	Ignition Sensitivity	Explosive Severity	Index of Explosibility
Cinnamon	2.5	2.3	5.8
Corn	2.3	3.0	6.9
Cornstarch	2.8	3.4	9.5
Grain (mixed)	2.8	3.3	9.2
Sugar	4.0	2.4	9.6
Wheat	1.0	2.6	2.6
Wheatflour	1.5	2.7	4.1
Wheatstarch	5.2	3.4	17.1
Coal dust**	1.0	1.0	1.0

**Standard Pittsburgh Coal with 37 percent volatiles.

Note: These figures may vary slightly between references depending on the laboratory apparatus used in analysis.

ACTIVITY 6:

1. State the basic equation for determining the explosibility index. ______________________

____

2. (Circle the best answer.)

The ignition sensitivity index for wheat is 1.0 and its explosive severity index is 2.7. What is the relative hazard associated with the index of explosibility for wheat in terms of the type of explosion it can produce (ignition sensitivity x explosion severity = index of explosibility)?

a. Weak - 0.1.
b. Moderate - 0.1 - 1.0.
c. Strong - 1.0 - 10.
d. Severe - 10+.

OBJECTIVE 7: Explain three general methods of preventing potentially explosive airborne dust clouds.

Efforts to prevent grain dust explosions are based on an understanding of their causes. If all four ingredients (fuel, oxygen, an ignition source, and a confined space) must be present at the same place and time to cause an explosion, then the way to prevent an explosion is to keep all four ingredients from coming together at one place and time. By eliminating any one of the four basic ingredients, an explosion can be prevented. By eliminating any one of the first three ingredients (fuel, oxygen, and an ignition source), a fire can be eliminated.

Obviously, grain itself cannot be eliminated from grain handling operations. However, steps can be taken to reduce and control dust.

Dust is generated whenever grain is moved, handled, or processed. Therefore, the first dust control measure is to enclose the process and the second is to reduce the moving, handling, or processing of the grain to the minimum. For example, this can be done by reducing the distance that the grain must fall at various points in the grain elevator, reducing belt speed, and by providing choke feeds so that grain to be moved flows onto a belt from the bottom of a chute. This chute is placed only a couple of inches above the moving belt so that the grain does not have to fall and hit the belt. Falling grain produces dust.

These methods reduce the amount of dust formation but do not, of course, eliminate it. Therefore, the second recognized necessary step in dust control is exhaust ventilation. The four components of a ventilation system are normally hood, duct, fan, and cleaning or conditioning devices. Ventilation system design must conform to NFPA and other recognized standards.

In process control ventilation, suction ventilation systems are installed at all points in a grain elevator where dust is generated or where it is disturbed enough to become airborne. An example of a dust control ventilation system is illustrated in Figure 3.

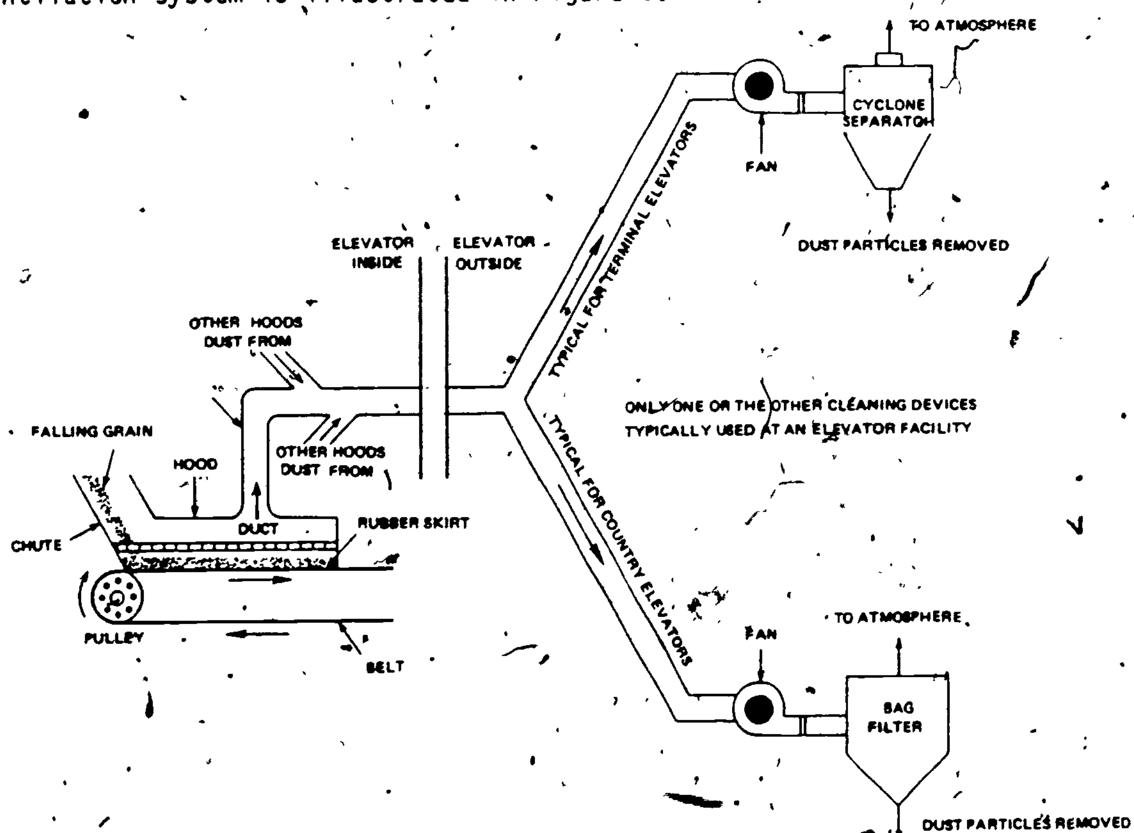

Figure 3. Components of typical grain dust exhaust ventilation system.

By removing dust from the grain stream as it is generated, exhaust ventilation systems prevent the formation of large airborne dust clouds, and prevent airborne dust from coming in contact with ignition sources. The dust is removed from the grain so it can no longer be a hazard elsewhere in the grain elevator, and airborne dust is prevented from settling on floors, rafters, and other surfaces where it can become airborne again by the shock wave of a primary explosion. Also, if dust is allowed to settle on hot surfaces, it can smolder and then burn, thus igniting a primary explosion.

The third method of dust control is simply good housekeeping. This involves the actual brushing of dust from rafters and other horizontal surfaces and removing dust from floors. No matter how efficient the designs of dust control equipment and ventilation systems may be, dust will gradually build up on horizontal surfaces in a grain elevator and must be removed.

IMPORTANT NOTE! It is the slow buildup of dust on floors, rafters, and other horizontal surfaces which provides the fuel for secondary explosions. A dust layer thick enough to leave a clear footprint, if completely airborne, is enough dust to form an explosion. Therefore, dust must be continually removed from floors, rafters, and other surfaces.

ACTIVITY 7:

1. Which of the following is not a good method to control the generation of airborne dust hazards?
   a. Increase the distance grain must fall onto belt systems.
   b. Use exhaust ventilation systems.
   c. Enclose dust-producing processes.
   d. Sweep and clean floors and surfaces regularly.
2. List the four basic components of a typical dust control ventilation system.
   a. ________________
   b. ________________
   c. ________________
   d. ________________

OBJECTIVE 8: Discuss the major countermeasures used to control the six major sources of ignition in grain handling systems.

To prevent the ignition of grain dust and the resultant dust explosions, every possible ignition source in a grain elevator must be kept at a safe level. Six major sources of ignition are cutting and welding, static electricity, friction heat, spontaneous heating and combustion, improper or poorly maintained electrical equipment, open flame, and sparks from metal scraps.

The first major source is cutting and welding. Welding or cutting should not be allowed where grain dust accumulates. Welding or cutting should be allowed only if a "hot work permit" has been approved. A hot work permit is a written form which outlines the policies, regulations, and procedures which must be followed before equipment capable of igniting combustible materials (such as welding equipment) can be used outside of plant areas especially designated for its use. The hot work permit requires that the worker eliminate potential fuel sources before approval for hot work is granted.

The need to weld or cut in plant areas containing dust can be partially eliminated, by using equipment that is easily removed. Such machinery can be unbolted and moved to a central maintenance shop for necessary welding or cutting.

Static electricity, the second source to be discussed, is generated by the contact and separation of dissimilar materials. Although it cannot be prevented, static electricity is controlled by providing a safe path for it to travel to ground. This is done by bonding (electrically connecting) all equipment and by grounding (providing an electrical path for the static-electric charge to travel to ground). All equipment in a grain elevator should be bonded and grounded to prevent the build-up of static electricity. This is especially true of all belt systems.

Friction heat is a third major source. Heat is often generated when motor bearings overheat, when belt roller bearings overheat, and when belt systems become clogged with grain, causing belts to stop while belt pulleys (the belt drive rollers) keep moving against the belts. Most heat-producing friction hazards can be prevented with proper inspection and lubrication of all machinery on a regular or scheduled basis. Clogged belt systems can be detected through the use of electronic motion detectors and prevented from creating friction by automatic shutdown systems.

Spontaneous heating and combustion, a third ignition source, occurs in stored grain when heat is produced by bacterial action within the stored grain at a faster rate than it can be given off. When this heat cannot be dissipated fast enough, spontaneous heating occurs. When the heat level reaches the grain's ignition temperature, spontaneous combustion occurs. Such combustion results in a fire and can be a potential source of ignition for a grain dust explosion.

Spontaneous heating and combustion can be controlled in a number of ways. Monitoring the internal temperature of stored grain, periodically moving grain from one bin to another in order to allow for the dissipation of heat, controlling the moisture content of the grain which controls the bacterial activity, and periodically forcing air through the grain to dissipate the heat (aeration) are some of the possible control methods.

Improper electrical design and inadequate maintenance can create a fourth source of ignition. Elimination of wiring, heating, and lighting equipment sources of ignition requires proper design and proper maintenance.

During initial design, equipment suitable for the location in which it will be used should be chosen. In some cases, special equipment for dust locations should be installed. The type of equipment installed should be selected using a thorough knowledge and understanding of Article 500, Hazardous Locations, of the National Electric Code, NFPA NO. 70. Section 500-5 of this code specifies certain requirements for locations related to combustible dusts.

Special equipment used in some hazardous locations must be "dust-ignition-proof". "Dust-ignition-proof" means equipment enclosed in such a manner that it will prevent the entrance of dust and, at the same time, not permit arcs, sparks, or heat generated inside the enclosure to ignite accumulations or suspensions of dust in the vicinity of the enclosure. Article 500 of the code explains this.

Regardless of the type of electrical equipment installed throughout a grain elevator facility, it must be properly maintained to prevent it from becoming hazardous. Periodic inspection for damage, wear, and deterioration is required.

A fifth source of ignition is open flame. The major sources of open flame (excluding welding and cutting) are cigarette smoking and open burning of trash. Cigarette smoking and open burning must be strictly forbidden in and around a grain elevator.

Sparks from scraps of metal in the grain are a sixth source. To prevent tramp metal in the grain stream from causing sparks by striking other metal surfaces, two major preventive measures may be utilized. First, a small opening grate at rail and truck dump areas will allow the free flow of grain but will trap any large pieces of metal. Second, an electromagnetic cleaning device placed at a point where the grain stream must pass close enough will allow small bits of metal to be removed from the grain. This magnet must be inspected and, if necessary, cleaned daily.

ACTIVITY 8:

(Circle the best answer.)

1. Which of the following is not a method used to control a dust explosion ignition source?
   a. Exhaust ventilation.
   b. Grounding and bonding.
   c. Use of "hot work permit."
   d. Electromagnetic cleaners.

2. Equipment enclosed in such a manner that it will prevent the entrance of dust but not permit arcs, sparks, or heat generated inside the enclosure to cause ignition of dust on or near the enclosure is called ______________________

OBJECTIVE 9: Explain how inerting prevents ignition of grain dust.

Inerting is a method used to prevent the formation of combustible or explosive dust-air mixtures. Inerting involves replacing a portion of the oxygen in the air with an inert gas so that the resulting atmosphere contains too little oxygen to support a fire.

For grain dusts, all of the oxygen would not have to be removed to prevent fire or explosion. Inerting gases which have been used are carbon dioxide and nitrogen. If nitrogen were used, and the oxygen in the atmosphere were reduced from the normal 21% down to approximately 12 to 14%, an explosion of grain elevator dust could not occur even if a source of ignition were present.

Inerting is not a new idea. The Bureau of Chemistry of the U.S. Department of Agriculture was very active during the period 1914 to 1935 in investigating and promoting the use of inert atmospheres to control dust hazards. Although inerting has been adopted in some industries for various grinding and dust handling operations, it was never generally employed by the grain storage and feed mill industries.

Potential benefits of inerting were said to include (1) a reduction of grain spoilage from oxidation and aerobic bacteria, (2) control of sprouting, (3) inhabitation of insects, rodents, and other pests, and (4) a reduction of fire and explosion hazards. Industry practice has shown more cost-effective methods for control of spoilage, sprouting, and pests. Although it was generally agreed that inerting was an effective fire and explosion control in principle, it was felt that the cost of inerting was prohibitive as a general control for several reasons.

In general, inerting was considered unsuitable for use in grain elevators for many reasons: (1) the large volumes involved, (2) the difficulties in providing air-tight storage to allow for the recirculation of inert gas with minimum loss, (3) concrete is porous and allows exchange of gases through the walls, (4) the need for continuous monitoring, (5) existing storage units have openings for ventilation filling, and discharging grain, and (6) the requirement for an inert gas supply of adequate capacity.

Although many of these prohibiting factors may still be valid, some are being re-evaluated in light of new economic incentives, new electronic monitoring and control equipment, and new methods of construction. Inerting may be attractive for special applications in relatively small or critical units. Two of the most vulnerable units for consideration might be bucket elevators and bag filler units.

NFPA No. 69, "Standard for Explosion Prevention Systems," provides a considerable amount of information on inerting materials and methods for installing inerting systems, including basic design data for the guidance of engineers.

Grain elevators and feed mills should study industry experience with the explosive hazards of combustible dusts and their use of inert gas protection. Grinders, pulverizers, mixers, conveying systems, dust collectors, and sacking machines could be operated more safely using the inerting method of explosion control.

ACTIVITY 9:

(Circle the best answer.)

Inerting prevents dust explosions by:

1. Preventing the generation of airborne dust.
2. Preventing static electricity.
3. Preventing the presence of enough oxygen to support combustion.
4. Preventing lint buildup in faulty bearings.

OBJECTIVE 10: Explain how explosion venting works to limit explosion damage.

When a dust cloud is ignited, tremendous heat is produced. As the atmosphere within a closed container is heated, two things will happen. First, as the air is heated, it will expand. Second, if the container is tightly closed and does not allow the heated air inside to expand, pressure will build up inside the container. When this pressure builds to a point that it reaches a force equal to the structural strength of the container, the pressure will burst the enclosure. This is what happens in an explosion and it happens in less time than an eye blink.

The basic theory of explosion venting is to provide panels in the walls and ceilings of rooms, bins, and other enclosures that will blow out at low pressures during the course of an explosion to allow for pressure relief before the pressure in the enclosure reaches the enclosure bursting pressure.

NFPA 61-B-1980, "Standard for the Prevention of Fires and Explosions in Grain Elevators and Facilities Handling Bulk Raw Agricultural Commodities," requires the use of explosion relief venting panels in rooms, buildings, bins, and other enclosures. Specifications are in NFPA 68, "Guide to Explosion Venting."

Although venting can reduce potential damage and injuries from grain dust explosions it is important to understand its limitations. First, venting does not eliminate the explosion but only reduces its effect. Second, vent panels must be placed so as not to present a hazard to people or other equipment should they open and emit a large and forceful amount of flame during an explosion. Third, as room or enclosure size increases, the size of the panel must increase. This presents a problem when the size of the enclosure requires that large wall or ceiling surface areas be used as vent areas. Beyond a certain room or enclosure size, venting becomes impractical due to the lack of enough surface area for proper venting and the effect that venting panels will have on the overall strength of the structure being vented.

ACTIVITY 10:

Which of the following statements is false? Explosion venting:

1. Does not eliminate or reduce the occurrence of dust explosions.
2. Can be installed on any size structure.
3. Prevents the buildup of high explosive pressures.
4. Must be located so as not to present a hazard to people during operation.

OBJECTIVE 11: Explain how explosion suppression works.

Space-age electronics have made it possible to detect an explosion the instant it is ignited and to extinguish it before it does any damage. This is possible because an explosion takes a few thousandths of a second to develop explosive force. The amount of time is less than an eye'blink, but it is enough time to allow electronics to take action.

During the first fraction of a second when an explosive dust or gas is ignited, a relatively weak shock wave travels out from the point of ignition at a speed of about 1,100 feet per second. The flame front, the leading edge of the explosion, comes behind this, traveling about 10 feet per second in an ever-enlarging sphere.

Pressure-sensitive equipment can detect the initial shock wave in 35/1,000 of a second while the flame front is about the size of a baseball (see Figure 4). In another 5/1,000 of a second, the detector activates the extinguisher. At this point, the explosion's flame front is about the size of a softball.

Extinguishing chemicals, under high pressure, are released from cylinders that have been placed strategically around grain handling equipment.

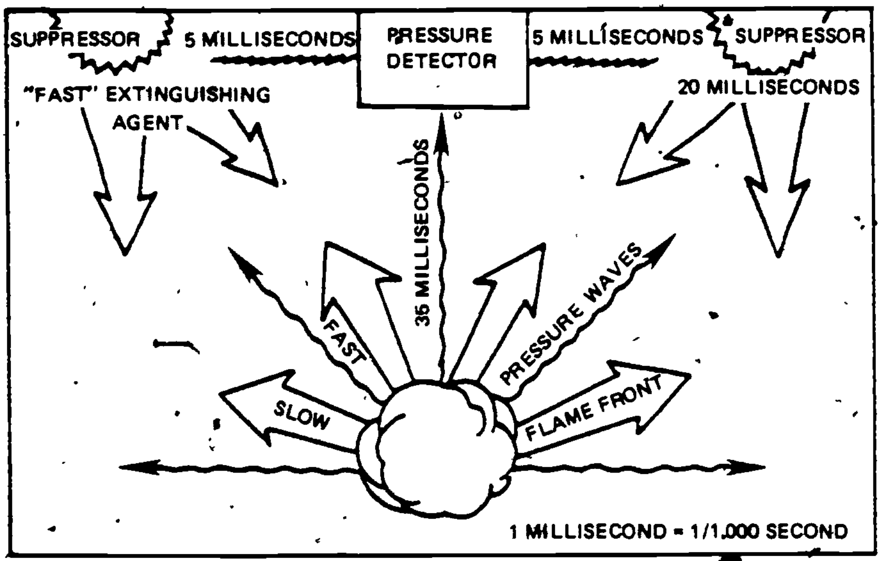

Figure 4. Pressure-sensitive equipment can detect the initial shock wave of ignition within 35 milliseconds. The detector activates extinguishers within 5 milliseconds. The chemical reaches the flame front within 20 milliseconds to extinguish it.

The high pressure causes the chemical to travel at a high speed toward the advancing flame front. Within 20/1,000 of a second of its release, the chemical collides with the advancing flame front - by this time about the size of a basketball - and extinguishes it.

The total elapsed time has been about 60/1,000 of a second. By comparison, an eye blink takes about 100/1,000 of a second. The explosion will not have had time to make any noise; the only sound heard is from the release of the extinguishing chemical.

Explosion suppression devices have been used with great success in the petroleum industry for many years. Use in grain handling facilities has been limited but their value for some applications is being examined.

Limitations of suppression devices are generally of two types. First, the units must be placed approximately four feet apart in a hazardous dust area in order to provide adequate coverage and second, the units are expensive. However, these limitations may be more imaginary than real if their installation prevents the loss of tens of millions of dollars common in large elevator explosions.

ACTIVITY 11:

Explosion suppression equipment can detect and extinguish an explosion:

1. In 5/1,000 of a second.
2. In 20/1,000 of a second.
3. In 60/1,000 of a second.
4. In 100/1,000 of a second.

OBJECTIVE 12: List the three general types of grain driers and the hazards associated with grain driers.

Typically, grain drying is broken down into natural air, supplemental heat, and heated air methods. Natural air and supplemental heat-drying methods are most often used at farm or small commercial storage locations. These methods are low energy users since little to no heat is used to dry the grain. Typically, grain is placed in round metal bins with perforated floors and dried by using fans to force ambient air up through the floor perforations and the grain mass. In humid areas, a heater is added to the system to lower the relative humidity of the drying air by raising the air temperature a few degrees.

The third drying method is the heated air type. This method uses a batch or continuous flow, high capacity drier and involves the drying of thin layers of very moist grain with very hot air.

Driers are useful, but they have certain hazards. Driers should be constructed of noncombustible materials and have access doors to permit inspection, cleaning, maintenance, and the effective use of portable extinguishers or hose streams.

Accident prevention measures for drying systems also include normal recommendations associated with electric and gas equipment. Inasmuch as fans and fan-heater units are typically located outside, adequate grounding is very important. Further, excessive temperature detecting devices should be used to automatically shut down a unit if excessive temperatures are reached. In some cases, fire detection systems are recommended.

Drier operators should be fully instructed on safe operation and how to make periodic inspections of the drier unit. Of particular importance is the care that should be exercised in the use of any portable or stationary augers used to load or unload bins or trucks. Bodily injuries involving augers are usually severe.

Another major hazard associated with bin drying systems is suffocation. There is real danger when someone gets inside a bin to inspect the grain mass. An oxygen deficiency test should be made before entering a grain bin. Cave-ins and grain-slides can also occur. It is recommended that at least one other person be close by to offer assistance to a distressed grain inspector and that the two (or three) should be linked with a safety line.

ACTIVITY 12:

(Circle the best answer.)

1. A design feature of grain driers that prevents fires is:
   a. Automatic temperature detecting devices.
   b. Access doors.
   c. Fire detection systems.
   d. Grounding of electrical components.
2. List three precautions that should be taken by a person who is entering a bin to inspect the grain mass.
   a. ______________________________
   b. ______________________________
   c. ______________________________

OBJECTIVE 13: List the four levels of service given to equipment in a preventive maintenance program.

Consider the following incident: A 6-inch bearing on a grain elevator head pulley failed in such a way as to allow the bearing races to rub together, generating heat. Thus, heat, oxygen, and a closed container (head house) were all together, awaiting only the presence of grain dust for a potential explosion to occur. Later, as a rail car opened over a dump pit, dust was generated and drawn into the elevator. When the dust had risen to the level of the hot bearing, a devastating explosion occurred that spread back to the dump pit and to several other elevator locations.

This incident resulted in thousands of dollars in damages, one minor injury (although the potential for serious or fatal injury was present), and the loss of 30 days production. The cause was an unserviced bearing. Had the bearing been inspected on a periodic basis, this explosion could have been prevented.

The purpose of preventive maintenance is to (1) protect plant investments, (2) permit scheduled shutdown, (3) extend equipment life and reliability, and (4) do all these things at a reasonable cost.

Preventive maintenance is based on the recognition that the expected service life can be reasonably predicted for almost any machine or machine part. It is also recognized that the failure of minor inexpensive machine components or the failure to keep machines in proper adjustment, if left uncorrected, will more than likely cause more extensive future failures.

Equipment which is not maintained and is allowed to break down during operating periods is not only costly to production but also usually more costly to repair. Equipment breakdowns in a grain elevator often produce sources of heat or sparks as sources of ignition, or create conditions which cause dust to become airborne, thus contributing to an increased potential for dust fires or explosions.

All machines will fail if not given proper attention at proper times. The following are four levels of service given to plant equipment for the purposes of preventive maintenance:

Level 1: Equipment operator attention daily, weekly, monthly.

Level 2: Routine periodic scheduled inspection, adjustment, cleaning, replacement of minor parts, and evaluation of operation.

Level 3: Routine partial disassembly, inspection of, and replacement of disassembled defective parts and parts predicted to fail before the next scheduled level 3 inspection.

Level 4: Major equipment service or rebuild.

The basic steps in setting up a preventive maintenance program are as follows:

1. Identify and list all items to be included in the preventive maintenance program. Develop a way to label and classify each piece of equipment.
2. Build an equipment service and information library.
3. Determine what is to be inspected, how often, and what level of service is required.
4. Prepare detailed written inspection work sheets to provide instructions to inspectors and repairmen and a means of reporting equipment status to management.

A good preventive maintenance program will not only reduce operating costs and production delays but will significantly reduce the probability of plant fires and destructive grain dust explosions.

ACTIVITY 13:

1. List the four levels of service given to equipment in a preventive maintenance program.

   a. ______________________________

   b. ______________________________

   c. ______________________________

   d. ______________________________

2. Which of the following statements is false? Preventive maintenance:

   a. Permits scheduled shutdowns for repairs.

   b. Utilizes detailed inspection work sheets.

   c. Extends equipment life and reliability.

   d. Involves the inspection of only expensive major components of machinery.

OBJECTIVE 14: State the health symptoms related to human exposure to grain dust.

Grain dust can injure a worker's health. Grain dust and other such organic materials can provoke in man a variety of pulmonary (lung-related) health disorders. Symptoms of grain dust exposure observed in grain handlers include phlegm production, chronic cough, shortness of breath, chest tightness, wheezing, and grain fever (typical fever symptoms).

In addition to respiratory problems, workers new to grain handling sometimes develop a skin rash that usually goes away in a few days.

When any dust in the air is collected from the breathing zone of workers, it is measured in milligrams of dust per cubic meter of air (mg/M^3). Current health standards suggest a maximum of 15 mg/M^3 total dust to be in the breathing zone of grain workers.

To visualize this small amount consider the following:

$$1 \text{ pound} = 0.4536 \text{ kilograms}$$
$$1 \text{ kilogram} = 1000 \text{ grams}$$
$$1 \text{ gram} = 1000 \text{ milligrams}$$

Therefore,

$$\begin{aligned} 1 \text{ pound of grain dust} &= 0.4536 \text{ kilograms} \\ &= 453.6 \text{ grams} \\ &= 453{,}600 \text{ milligrams} \end{aligned}$$

In the typical five pound bag of flour purchased at a grocery store there are 2,268,000 milligrams of flour. If only 15 of these 2,268,000 milligrams in a five pound bag of flour were to become airborne in one meter of air, the maximum allowable concentration for human exposure will have been reached.

Recent dust concentration measurements obtained during complete work-shifts in a variety of terminal, transfer, and county elevators ranged between 0.18 mg/M^3 (well under the maximum allowable of 15 mg/M^3) to 781 mg/M^3 (well over the maximum allowable of 15 mg/M^3). The highest concentrations measured were found in the receiving tunnels of terminal and transfer elevators.

Federal regulations (OSHA) require that an employer control the work-room airborne dust levels by feasible engineering controls or by other administrative means. The use of respiratory protection (dust filter masks) is primarily used during the period that dust controls are being implemented or where such controls are not feasible. Engineering controls include local exhaust ventilation, process equipment changes to reduce dust generation, and automation.

ACTIVITY 14:

(Circle the best answer.)

1. Which of the following dust concentration levels is acceptable for continuous human exposure?
   a. Five grams per cubic meter of air.
   b. Five pounds per cubic meter of air.
   c. Five kilograms per cubic meter of air.
   d. Five milligrams per cubic meter of air.
2. List three engineering controls and one other control that can be employed to reduce grain dust intake by workers.
   a. ______________________________
   b. ______________________________

c. ____________________

d. ____________________

OBJECTIVE 15: List the NFPA standards that apply specifically to grain or agricultural commodity systems.

Standards that apply to grain handling facilities are many and varied because a grain facility is subject to all industrial standards related to individual machinery components, structural design, and operation and maintenance. Certain standards, however, apply specifically to grain-handling systems. These include:

- NFPA 61B, Prevention of Fires and Explosions in Grain Elevators and Facilities Handling.
- NFPA 61C, Prevention of Fire and Dust Explosions in Feed Mills.
- NFPA 61D, Prevention of Fire and Dust Explosions in the Milling of Agricultural Commodities for Human Consumption.

The content of these standards are similar in some ways and different in others according to the nature of the grain handling systems to which they apply. An outline of NFPA 61B-1980 is provided in Appendix C to illustrate the general content of these standards, much of which has been the content of earlier sections of this module.

ACTIVITY 15:

(Circle True or False.)

Only three standards apply to the design and operation of grain handling facilities?

True False

REFERENCES

Graziano, John V., et al. Prevention of Dust Explosions in Grain Elevators - An Achievable Goal. United States Department of Agriculture, January, 1980.

McKinnon, Gordon P., and Tower, Keith, editors. Fire Protection Handbook. 14th ed. Boston, MA: National Fire Protection Association, 1976.

National Fire Protection Association, various standards, including:

NFPA 61B

NFPA 61C

NFPA 61D

NFPA 70

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

ANSWERS TO ACTIVITIES

ACTIVITY 1

2.

ACTIVITY 2

4.

ACTIVITY 3

2.

ACTIVITY 4

1. c.
2. b.

ACTIVITY 5

2.

ACTIVITY 6

1. Ignition Sensitivity x Explosive Severity = Index of Explosibility
2. c.

ACTIVITY 7

1. a.

2. a. Hood.
   b. Duct.
   c. Fan.
   d. Cleaning or conditioning devices.

ACTIVITY 8

1. a.

2. "Dust-ignition-proof"

ACTIVITY 9

3.

ACTIVITY 10

2.

ACTIVITY 11

4.

ACTIVITY 12

1. a.

2. a. Oxygen deficiency test before entering.
   b. At least one other person should be close by.
   c. The two or three should be linked with a safety line.

ACTIVITY 13

1. a. Level 1: Equipment operator attention daily, weekly, monthly.
   b. Level 2: Routine periodic scheduled inspection, adjustment, cleaning, replacement of minor parts, and evaluation of operation.
   c. Level 3: Routine partial disassembly, inspection of and replacement of disassembled defective parts and parts predicted to fail before the next schedule level 3 inspection.
   d. Level 4: Major equipment service or rebuild.

2. d.

ACTIVITY 14

1. d.

2. a. Local exhaust ventilation.

   b. Process equipment changes.

   c. Automation.

   d. Dust filter masks.

ACTIVITY 15

False.

APPENDIX A

SOME AGRICULTURAL DUSTS AND THEIR MINIMUM EXPLOSIVE CONCENTRATIONS, IGNITION TEMPERATURES, AND IGNITION ENERGIES.

Dust	Minimum Explosive Concentration in oz/cu ft	Minimum Ignition Temperature in °C (°F) Cloud/Layer	Minimum Ignition Energy in millijoules (mJ)
Cinnamon	0.060	440(824)/230(446)	30
Corn	0.055	400(752)/250(482)	40
Cornflour	*	400(752)/ *	*
Cornstarch	0.040	410(770)/350(662)	40
Grain (mixed)	0.055	430(806)/230(446)	45
Sugar	0.045	370(698)/400(752)	30
Rye flour	*	435(815)/ *	*
Wheat	0.055	430(806)/290(554)	43
Wheatflour	0.050	380(716)/360(680)	50
Wheatstarch	0.045	430(806)/ *	25
Coal dust**	0.055	610(1130)/170(338)	60

*Not referenced

**Standard Pittsburgh Coal - 37 percent voltatiles

Note: It may be useful to keep in mind that the typical static discharge from an individual's hand to a door know after crossing certain rugs is approximately 25 millijoules.

MAXIMUM EXPLOSIVE PRESSURE AND RATE OF PRESSURE RISE FOR SOME AGRICULTURAL DUSTS.

Dust	Maximum Exposure Pressure psi	Maximum Rate of Pressure Rise psi/sec
Cinnamon	121	3900
Corn	113	6000
Cornstarch	145	9500
Grain (mixed)	131	7000
Sugar	109	5000
Wheat	103	3600
Wheatflour	95	3700
Wheatstarch	100	6500
Coal dust*	90	2300

*Standard Pittsburgh Coal - 37 percent volatiles

Note: Maximum explosive pressure is actually reached in a fraction of a second. The rate of pressure rise indicates the rate at which the buildup occurs, multiplied as if an entire second was required for maximum explosive pressure to be reached.

APPENDIX B

Ignition Sensitivity =

$$\frac{(\text{Ign. Temp. x Min. Energy x Min. Conc.})\ \text{Pgh. Coal Dust}}{(\text{Ign. Temp. x Min. Energy x Min. Conc.})\ \text{Sample Dust}} \quad [1]$$

Explosion Severity =

$$\frac{(\text{Max. Rate of Pressure Rise})(\text{Max. Explosive Pressure})\ \text{Sample Dust}}{(\text{Max. Rate of Pressure Rise})(\text{Max. Explosive Pressure})\ \text{Coal Dust}} \quad [2]$$

Explosibility Index =

$$(\text{Ignition Sensitivity}) \times (\text{Explosion Severity}) \quad [3]$$

<u>Example calculations</u> for mixed grain dust:

Ignition Sensitivity =

$$\frac{(610\ \text{C x } 0.06\text{J x } 0.055\ \text{oz/cu ft})\ \text{Pgh. Coal Dust}}{(430\ \text{C x } 0.03\text{J x } 0.055\ \text{oz/cu ft})\ \text{Grain Dust, Mixed}} = \quad [4]$$

$$\frac{2.013}{0.7095} = 2.8$$

Explosive Severity =

$$\frac{(115\ \text{psig x } 5{,}500\ \text{psi/sec.})\ \text{Grain Dust, Mixed}}{(83\ \text{psig x } 2300\ \text{psi/sec.})\ \text{Pgh. Coal Dust}} = \quad [5]$$

$$\frac{632{,}500}{190{,}900} = 3.3$$

Ignition Sensitivity x Explosive Severity = <u>Index of Explosibility</u>

Grain Dust, Mixed 2.8 x 3.3 = 9.2 [6]

There are some reasonable cautions that must be recognized in the use of the explosibility index figures. The explosibility index is based on laboratory observations using dusts that have been screened to produce a relatively uniform particle size (less than 74 microns) and concentration (0.50 oz per cu ft) for test purposes and comparisons. Different methods of preparation, treatment, differing ages of the grain and other variables lead to differences from one grain dust sample to another. Therefore, explosibility data may vary from test to test to a small degree and the characteristics of dusts found in various grain processing units may vary to some degree from those used to set up this index. That is they may be slightly less explosive, for example, if larger particle sizes are involved, or more explosive due to less moisture. For this reason, published data is often expressed in terms of maximum values observed over many tests.

APPENDIX C

NFPA 61B-1980, STANDARD FOR THE PREVENTION OF FIRES AND EXPLOSIONS IN GRAIN ELEVATORS AND FACILITIES HANDLING BULK RAW AGRICULTURAL COMMODITIES.

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