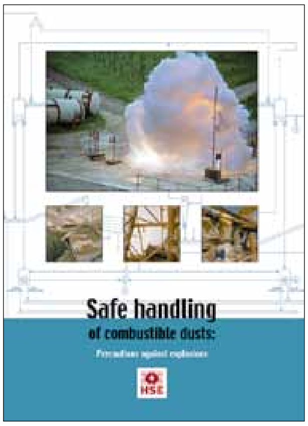
Safe handling of combustible dusts:

Precautions against explosions



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This publication provides practical advice on the prevention and mitigation of dust explosions and fires. The guidance is intended for employers, managers, foremen and safety representatives working in the many industries where combustible dusts may be present. A number of materials used in everyday business can produce dusts that are flammable and can explode if ignited, they include sugar, coal, wood, grain, certain metals and many synthetic organic chemicals.

The publication outlines the relevant legislation and illustrates the effects that dust explosions can have. It also provides advice on how to prevent dust explosions, explains how to protect plant and equipment if an explosion occurs and covers the particular hazards of fires within dust handling plants.

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This guidance is issued by the Health and Safety Executive. Following the guidance is not compulsory and you are free to take other action. But if you do follow the guidance you will normally be doing enough to comply with the law. Health and safety inspectors seek to secure compliance with the law and may refer to this guidance as illustrating good practice.

Contents

Introduction

1 This guidance document provides advice on the prevention and mitigation of dust explosions and fires. Many materials we use everyday produce dusts that are flammable and in the form of a cloud can explode, if ignited. Examples are:

- sugar;
- coal;
- wood;
- grain;
- certain metals; and
- many synthetic organic chemicals.

Quite generally, the advice applies to anything which can burn, and which exists in a fine powdered form, unless tests show that particular hazards are not present. In some cases, a very simple knowledge of chemistry can rule out the explosion risk, eg in the case of sand, cement and sodium carbonate (soda ash).

2 Dust explosions are not new and records from over 100 years ago exist of incidents that have resulted in large loss of life and considerable and costly damage to plant and buildings.

3 The objectives of this book are to:

- outline legislation;
- illustrate the effects of dust explosions;
- show how to prevent dust explosions;
- explain how to protect plant and equipment if an explosion occurs; and
- give advice on the particular hazards of fires within dust handling plants.

Who is this booklet for?

4 This guidance is intended for employers, managers, foremen and safety representatives working in the many industries where combustible dusts may be present. It describes in non-specialist terms the hazards from dust explosions and common means to control the risk.

5 The guidance also describes common ways you can achieve an adequate standard of safety. You may use alternative designs or precautions to meet particular circumstances, so long as they provide an equivalent standard of safety. The guidance contains basic advice and you should not use it as a design guide. Information for design purposes can be found in reference 1.

6 The guidance does not apply to mines, where special considerations apply. The guidance is not applicable to the handling of loose explosive or pyrotechnic compositions in licensed explosives factories. The general principles are, however, applicable to handling individual components of such compositions that are not in themselves explosive (eg sulphur dust or aluminium powder). Powders which can decompose energetically in the absence of air (eg some organic peroxides and blowing agents) are also out of scope. These are covered in reference 25 booklet *Energetic and spontaneously combustible substances.*

Legal framework

7 The Health and Safety at Work etc Act 1974 (HSW Act)[2] places a general duty on employers to ensure the safety of both employees and other people from the risks arising from work activity, so far as is reasonably practicable.

8 The Dangerous Substances and Explosive Atmospheres Regulations[3] require employers to make an assessment of the health and safety risks arising from dangerous substances, and this specifically includes dusts which can explode. Where the employer has more than five employees, the significant findings of the risk assessment must be written down. Precautions to control any risks associated with dust fires and explosions are then needed (see below.) Specific requirements relating to classification of hazardous areas within a plant, and marking of points of entry into such areas are covered in paragraphs 32-34 and 98. These regulations also require that information about the risks and emergency procedures is made available for the fire authorities. It is not necessary to send the written risk assessment to the fire authority in every case, but where contact is made, the particular risks and precautions associated with dust explosions should be identified.

9 In addition to this a number of regulations are relevant where flammable dusts may occur. These are:

- The Fire Precautions (Workplace) Regulations 1997[4]
- The Provision and Use of Work Equipment Regulations 1998[5]
- The Workplace (Health, Safety and Welfare) Regulations 1992[6]
- The Control of Substances Hazardous to Health Regulations 1999[7]
- The Equipment and Protective Systems for Use in Potentially Explosive Atmospheres Regulations 1996[8]

Appendix B contains further information.

Why does dust explode?

10 A dust explosion involves the rapid combustion of dust particles that releases energy and usually generates gaseous reaction products. A mass of solid combustible material as a heap or pile will burn relatively slowly owing to the limited surface area exposed to the oxygen of the air.

> In 1981 an explosion at a plant in Banbury which manufactured custard powder injured nine men and caused substantial damage to an external wall of the building[9]. A fault in a pneumatic conveying system caused a holding bin to overfill and the air pressure caused the bin to fail. The released custard powder ignited as a dust cloud within the building.

11 If you have the same solid in the form of a fine powder and you suspend it in air as a dust cloud the result will be quite different. In this case the surface area exposed to the air is much larger, and if ignition occurs, the whole of the cloud may burn very rapidly. This results in a rapid release of heat and gaseous products and in the case of a contained dust cloud will cause the pressure to rise to levels which most industrial plant is not designed to withstand.

12 Although a cloud of flammable dust in air may explode violently, not all mixtures will do so. The concentration of dust and air must be within the upper and lower explosive limits for the dust involved.

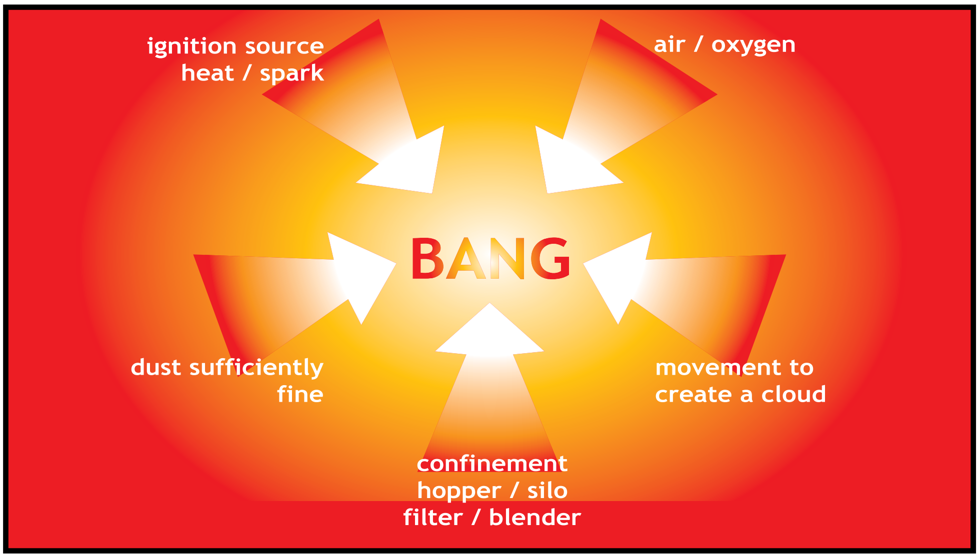
13 Measurements of the lower explosive limits of many materials are available, and for many organic materials the limit is in the range 10 - 50g/m^3. A dust cloud of this concentration resembles a very dense fog. Upper explosive limits are difficult to measure accurately, and have little practical importance.

14 The most violent explosions usually result from dust/air mixtures that are fuel rich. This means that the oxygen available in the air cannot burn all the dust, and partly burnt, glowing material often remains after the explosion. This can reignite if more air becomes available. The shape and size of the dust particles, and other factors, strongly affects the force of the explosion and the explosive limits. Only weak explosions are likely where the mean particle size of the dust exceeds 200 microns, or the moisture content exceeds 16%. Appendix A contains information about methods of testing dusts.

What are the effects of a dust explosion?

15 A dust explosion can result in:

- death or serious injury to workers;
- destruction of plant and buildings;
- a large fireball;
- secondary explosions; and
- fire.



When a dust cloud ignites in an enclosed volume it results in a very rapid rise in pressure within the container. The container may be an item of plant or a room of a building. Typical peak pressures in laboratory apparatus are in the range 8 - 10 bar. In normal circumstances the plant or building will not be strong enough to withstand the pressure from the explosion and it will fail in a sudden and uncontrolled manner. Anyone close to exploding plant, or inside a room where an explosion occurs is likely to be killed or seriously injured. The plant or building will only survive if the design or other protective measures deliberately allows for the high pressures.

16 Where an item of plant fails, or an explosion vent opens as a result of a dust explosion, a fireball and shockwave will emerge. The fireball is usually much larger than the vessel from which it came, and is likely to spread burning particles a substantial distance. A person engulfed in such a fireball is likely to receive serious burn injuries.

17 An explosion within a piece of plant may also stir up dust deposits within the building. The failed plant may also release as a cloud a large quantity of unburnt material. Burning particles from the primary explosion can then ignite the dust cloud within the building causing a secondary explosion that is generally more destructive than the primary explosion.

An explosion initiated in the dust collector of a grain storage facility at Blaye in France. The towers contained elevators and the gallery over the 44 silos contained belt conveyors. All the areas were open allowing the spread of dust clouds and flames. Both towers, the gallery and 28 silos were completely wrecked with the loss of 11 lives.

What can I do to prevent or mitigate the effect of a dust explosion?

Assessing the risk

18 This task should be your starting point, and it can be addressed under a series of questions. Is my dust capable of exploding? Where could dense dust clouds form? What could ignite them? How likely is this? What would be the consequences? Who would be at risk? Can we prevent the risk of an explosion altogether? If this is not possible, what can be done to protect people, and minimise the consequences of an explosion?

Records show where explosions are most likely to start.

19 Following the risk assessment the options should be considered in this order:

- Eliminate the risk.
- Provide controls to minimise the risk.
- Provide supplementary controls to mitigate the consequences.

20 Many products have to be handled as fine powders, and the risk cannot be eliminated, but there are occasions where granular or pasty products can be used with advantage. The risk of an explosion may also be effectively eliminated if the quantity of dust present is sufficiently small.

The great majority of dust explosions start inside the process plant, and most of the control measures concern conditions inside the dust handling system. They can be grouped under the headings of:

- controls over dust cloud formation;
- preventing the explosive atmosphere by inerting;
- avoiding ignition sources; and
- plant controls, which may have various purposes.

Very simple plant

21 In many cases the plant to be assessed is a dust extraction system, with ductwork drawing from a single point of release, and a filter to collect the dust. Key points to consider are then:

- Does the system catch all the dust effectively, so that deposits do not form around the workroom? How do you make sure the fan is always running when needed?
- Was the filter designed to handle dusts that could explode? Explosion vents are normally needed in this case.
- Is it located where it would cause no danger if it exploded? eg on the roof
- How would you know if the filter became blocked, or the fan performance dropped off?
- Do dust deposits in the ductwork need clearing out from time to time? Are there access hatches for this?
- Can you empty the filter without creating a dust cloud?

If you can provide satisfactory answers to these questions, there may be nothing more to do.

Control over the formation of dust clouds

22 Sometimes the process can be designed to prevent or minimise the formation of a dust cloud inside the equipment. If your product is available as a paste, in dampened or pelletised form instead of fine powder the explosion risk may be avoided completely. Any movement of pelletised or granular material is likely, however, to produce dust by attrition.

23 Many types of process plant inevitably contain explosible clouds of dust. Cyclones or dust filters provided as part of a ventilation system concentrate the dust and are likely to contain an explosive atmosphere somewhere within them, even if the dust concentration in the extract ducting is well below the lower explosive limit. In some cases there are alternatives. For example, tray driers create a smaller dust cloud than fluid bed driers. Wet dust collectors avoid the cloud that is formed regularly inside a reverse jet dry filter.

24 Completely enclosed plant should be used whenever practicable for handling fine dusts. This will reduce or prevent significant dust clouds within the building, reduce the extent of any hazardous areas, reduce the need for cleaning, and reduce the exposure of employees to dust, which might have a health risk. Features that should be particularly avoided are: conveyors that tip into open topped plant; discharge of bulk quantities from big bags into process vessels where the air displaced comes direct into the workroom, and filters that have to be regularly emptied releasing large amounts of dust into the building.

Inerting

25 This is a way you can prevent explosions by preventing the formation of an explosive atmosphere. In a substantially closed system the oxygen content of the atmosphere within the plant can be controlled at a safe level. You will normally need to determine the maximum safe oxygen content experimentally. This will vary with the type of inert gas and the chemical reactivity of the material being processed.

> One man died following an explosion in a plant that manufactured powdered aluminium. Part of the process used nitrogen to maintain an inert atmosphere but system controls were rudimentary and inadequate to detect blockages caused by powder collecting in the nitrogen supply pipework.

26 Inerting is only likely to be effective in a system that is fully enclosed, with a minimum number of places where air can enter. You need to consider how process materials will be added to or removed from the system. If air enters at this point, a purge cycle is likely to be needed before the process restarts. Calculations to determine the times and gas flows needed for purging and other design recommendations are given in reference 1.

27 Many factors will influence the overall reliability of an inerting system. For example,

- the location and number of atmospheric sampling points;
- type of sensor head;
- frequency of calibration of the sensor;
- contaminants in the system that interfere with sensor readings;
- provision of safe means of control or shutdown, if the oxygen concentration exceeds a predetermined level;
- adequate supplies of inert gas for all foreseeable needs;
- the number of locations where air may enter the plant;
- the safety margin allowed when setting control levels for oxygen;
- the reliability of any electronic control system;

Where inerting is used as a means of preventing explosions, the overall reliability of the system should be assessed.

28 If the plant is held at a pressure slightly above atmospheric, air leaks into the system can be avoided, but you then need to consider the risk that inert gas could accumulate in the general atmosphere of the workroom. In an extreme case this could lead to asphyxiation.

29 The supply of inert gas should be reliable, and sufficient reserve is needed to shut the plant down safely if a seal failure or similar unexpected leak occurs. This could cause the required flow of inert gas to increase suddenly.

Control over sources of ignition

30 Careless use of welding, flame-cutting equipment or other hot work has caused many incidents. It is essential that before hot work begins you isolate the plant effectively to prevent fresh material entering, and clean it thoroughly. After the work is complete, the site should be watched for at least an hour, for signs that fire is growing from a smouldering deposit.

31 Sparks from hot work may travel a considerable distance, particularly if you carry out the work at a high level. You can greatly reduce the risk of ignition by adopting cold cutting methods. Commonly accepted best practice for hot work requires a permit-to-work system, with the permit issued by a responsible person before work commences.

Such permits need to set out clearly:

- your arrangements for handover,
- the allowable range of work,
- time limits on when the work may be done; and
- the precautions required.

The ACOP to the DSEAR regulations gives further information.[14-18]

Area classification where dusts are handled

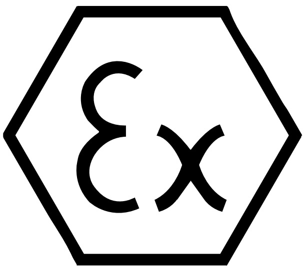
32 Area classification is a technique intended to help people decide where specific controls over all sources of ignition are needed. It was originally developed to help with the selection of fixed electrical equipment, but its use has now been extended to any equipment that has hot surfaces or generates other possible ignition sources. Parts of buildings or process plant may be described as zone 20, 21 or 22, depending on the amount of time that an explosible dust cloud may be present. Equipment installed in a zoned area should then be built to an appropriate standard.

33 The zone definitions are contained in regulations, and are repeated in appendix D. These regulations bring in a new legal requirement to carry out area classification, where dusts are handled in quantity. In most plant handling dusts the inside of the dust equipment will be zone 20 or 21. Rooms within the building, if they need to be zoned, should only be the less onerous zone 22. A few very small areas where dust escapes in quantity in normal operation might need to be zone 21. In the open air, dust clouds are unlikely to persist for more than a brief period, and any zoning is likely to be very limited in extent.

34 Where dust layers are often present, explosible dust clouds can be formed by any sudden movement of air, except with products like sugar, which quickly absorb moisture from the air. Experience shows however, that while fires may easily start in dust layers on hot surfaces, very few explosions are caused by hot surfaces outside the dust containment system. Further advice on zoning is given in reference 11.

Equipment used in classified areas

35 Electrical and non electrical equipment supplied after June 2003 that creates a potential ignition risk and is designed for use in explosive dust atmospheres, is subject to specific regulations. Such equipment should be marked with the sign of explosion protection (see below), a category number (1,2, or 3) followed by the letter D for dust, a temperature rating and other codified identifying marks. The temperature rating may be expressed as a T class (eg T4 or T6) or an actual temperature. Details of the marking scheme are contained in standards.



36 There is rarely any need to site power-consuming electrical equipment inside an area classified as zone 20. If you need to install electrical equipment where it will be buried in dust (eg inside a storage bin) you should consult the equipment supplier.

37 It is preferable to site electrical equipment away from dusty areas, but where you install equipment close to sack tipping points, sanding machines, sampling points or similar foreseeable dusty areas that are classified as zone 21, new equipment should meet the requirements for ATEX category 2D. Existing equipment made to older standards such as BS 6467, or with a dust tight enclosure made to IP6X (see BS EN 60529) is still likely to be suitable.

38 You are likely to need ignition protected equipment in areas inside buildings around process plant handling flammable dusts which are classified as zone 22. In this situation new equipment built to ATEX category 3D requirements will be suitable. Older equipment made with a dust resistant enclosure to IP5X may remain in service.

39 BS EN 50281-1-2 (1999)[10] gives additional advice on the selection, installation and maintenance of electrical equipment for use in the presence of combustible dusts. Anyone familiar with the requirements for protected electrical equipment for use in the presence of flammable gases should note that the requirements for atmospheres of flammable dusts are not the same.

40 Dusty areas may extend well away from sources of release of dust unless you install local dust extraction to prevent this. Air currents will carry the finest dust particles a considerable distance and allow them to settle at high levels within a building. Dust deposits on beams and ledges at high level create a secondary explosion risk, but you should also be aware that surface deposits of dust might ignite on equipment that is designed to run hot, or may block ventilation holes or otherwise interfere with the cooling of electrical equipment.

41 To prevent fires, you should ensure that the maximum surface temperature produced by an item of electrical equipment exposed to dust is below the temperature required to ignite the dust either as a layer or as a cloud. BS EN 50281-1-2 contains a formula for maximum temperatures, which includes a safety margin. You can find tables of measured values of ignition temperatures in reference 12, and as a rough indication the layer ignition temperatures of many natural products exceed 300 deg C and cloud ignition temperatures are usually higher. Thicker dust layers can ignite at much lower temperatures.

42 Where the interior of a plant item requires regular illumination, you can almost always do this with the light source outside the plant. Mains powered portable lights should not be lowered into storage bins. Even if the light unit is designed for an explosive atmosphere, the cable might be easily damaged, and the risk is high. If illumination from the inside is needed, and a dust certified lamp is not available, battery-powered lamps certified for use in gaseous flammable atmospheres are unlikely to cause ignition. If, however, they are dropped and buried in a heap of dust some high powered types could overheat and start a fire.

43 Frictional heating of moving parts of process plant may raise the temperature locally to the point where ignition of a dust occurs without any spark or flame. Bucket elevators have proved vulnerable to this problem, as have hammer mills and rotary atomisers on milk spray driers. Modern plant may have features designed to prevent or detect such problems eg ammeters on motors to indicate overloading. Inadequate maintenance can negate the effectiveness of these features.

44 Impact sparks are likely to arise where tramp metal or stones enter process plant. A magnetic separator to catch ferrous tramp metal is a very widely used precaution that helps minimise this problem. For the separator to remain effective, you need to remove the caught fragments on a regular basis. If you find fragments regularly, it is better to identify the source and then take steps to reduce contamination rather than depend on the magnet. Sieves, pneumatic separators and other methods allow you to remove stones and other extraneous matter from a lighter feedstock. Where you are handling loose materials eg open floor storage of grain, bulk handling in ships' holds etc, such separators are particularly useful.

45 Electrostatic charging of plant items or process materials is likely when moving dusty materials in quantity. It is necessary to take precautions to prevent discharges that are powerful enough to cause ignition of a dust cloud. A conducting (metal) item isolated from earth produces the most energetic discharges when it becomes charged by contact with a stream of charged dust particles. You should prevent this by earthing all metalwork that may be in contact with the dust. The least electrically conducting dusts, such as polyethylene, cause the most problems as the charge is retained within the bulk and additional precautions may be needed.

46 Experience from the chemical industry suggests that explosions are most likely with dusts that have a low minimum ignition energy (MIE). Certainly electrostatic hazards need more careful control with the most easily ignited dusts. For example the use of highly insulating parts may need to be avoided. The test methods used strongly influence measured values of minimum ignition energy, and care should be taken in interpreting data from old sources. Usually the test houses that can measure MIE will be able to advise on the significance of the results.

47 Typical precautions required are earthing of delivery tankers, electrical bonding across sight glasses in transfer lines, earthing of plant items that stand on non-conducting floors and avoiding the use of non-conducting fastenings to join metal components together. Checking the earthing arrangements before the plant is first brought into use might form part of the verifications required by the Dangerous Substances and Explosive Atmosphere Regulations[3]. BS PD CLC/TR50404[19] also recommends the checking of earthing arrangements at scheduled maintenance and after other maintenance or modification.

Common ignition sources include:

- hot surfaces;
- naked flames;
- faulty or unsuitable equipment;
- overheating of moving mechanical plant eg by friction;
- impact sparks;
- electrostatic discharges;
- spontaneous heating; and
- smoking materials.

48 You may require additional precautions where combustible dusts and flammable solvent vapours are present together, eg in some drying or mixing processes in the chemical industry. Reference 20 includes discussion of precautions required in this situation and other circumstances where dust and vapour are present together.

49 Exothermic decomposition, air oxidation or biological action may cause spontaneous heating in many materials. Careful control of maximum temperatures is necessary when you handle such materials in a hot process, such as drying. You may use small-scale tests to identify unstable materials, but large-scale processes should usually operate at temperatures well below the onset temperatures shown in these tests. See reference 20 for information on suitable small-scale tests.

50 When storing such materials for long periods in large bulk containers, periodic temperature checks within the interior of the pile may help you to detect the onset of overheating; alternatively regular transfer of the powder from one silo to another will help dissipate localised build up of heat. Materials known to be prone to spontaneous heating include fishmeal, corn meal, dried sewage sludge and milk powder.

51 Combined gas/dust explosions have also occurred where dust smouldering in a restricted air supply has given off carbon monoxide. In an essentially closed plant, the carbon monoxide can build up to the point where introduction of a fresh air supply causes an explosion.

Plant design and controls

52 Various types of plant design and control may be important in controlling the risk or consequences of a dust explosion. This section cannot be comprehensive but highlights the type of process deviations that you need to control, preferably by continuously monitoring the plant. Examples are:

- Extensive centralised dust collection systems create many links through which burning material can spread following an explosion in the filter. This can be controlled, but filters drawing dust from just one or two locations reduce the risk more simply.
- Overloading or blockage of the feed system may cause some process plant to overheat. If this is possible, reliance on visual indication may not be adequate.
- Large volumes of dust may escape if filters fail, relief panels become loose or sacks being filled fall off a collection point. You may need to monitor the air pressure at appropriate points within the plant to identify such an event promptly.
- Where you provide local exhaust ventilation to control the release of dust from an operation you may find it necessary to interlock the process so that it can only run with the ventilation operating properly.
- Detectors are available which continuously monitor the product from a grinding plant or similar unit for sparks or glowing material. They can then activate a water spray downstream from the detector and extinguish potential ignition sources before they reach a large dust cloud in other parts of the plant.
- High-level alarms on bins or hoppers may be useful in preventing material being spilt. Many reliable types are now available.
- Deviations from a safe condition should cause automatic plant shut-down or the raising of an alarm. In the latter case the follow up action needs to be pre-planned.

Magnesium Grinding and Polishing

Magnesium is rated as an St 3 dust, which means that any explosion will be very severe. If you are involved in the special case of grinding or polishing Magnesium you should ensure that:

- None of the equipment has been used previously for abrading iron or other ferrous material.
- There is a dust extraction system leading to a scrubber where the dust-laden air is drenched with water. It is usual to provide a separate scrubber for each grinding or polishing device. The scrubber will need cleaning out at least once a week and tools containing iron or ferrous material should not be used. The scrubber should have a high level vent to avoid accumulations of hydrogen.
- Duct work carrying grinding or polishing dust is kept as short as possible, with few crevices to retain dust. It should also be possible to inspect and clean the inside surfaces.
- You dispose of any dust collected by removing from site or by burning in a controlled manner.
- Wet sludge is stored outside where gas evolved may disperse safely.

Mitigation measures

53 **The most important mitigation measure is maintaining the process buildings in a clean condition**. If you allow dust deposits to accumulate, they can provide the fuel for a secondary explosion. Dust deposits shaken into suspension from all the ledges within a room by a small primary explosion may then ignite. You only need comparatively small amounts, and a layer of flour 0.3mm thick on the floor can in principle fill a room with an explosible dust cloud up to 3m above floor level.

54 The first step towards preventing dust accumulations within a building is to maintain a plant in a leak-tight condition. Loosely bolted flanged joints, damaged flexible seals and ill-fitting or propped open access hatches are common sources of leaks. Some processes can be operated at slightly below atmospheric pressure to reduce the escape of dust.

55 Despite this, the building will require regular cleaning, and the preferred method is a vacuum system rather than brushes and shovels, which tend to raise dust clouds. You should avoid the use of compressed air lines to dislodge dust deposits, as this will cause unnecessary dangers by creating dust clouds. There is no general preference between mobile vacuum cleaners and a centralised system. Depending on the design of the building, both may have their place.

56 You can reduce the labour involved in cleaning by designing plants and buildings with the minimum number of horizontal ledges on which dust can settle, and sufficient access platforms to avoid the need for temporary platforms. Do not neglect the highest parts of buildings as these are the areas where the finest and most hazardous dust can be found.

57 Electrical apparatus may be particularly prone to overheating if dust deposits accumulate and the standards[10] assume that dust deposits will never be more than 5mm thick. If you cannot control dust accumulations to this thickness, you should obtain special advice from the equipment supplier.

58 Where filtered dusty air is returned to a workroom, it is important to ensure that this does not significantly increase the exposure of an individual employee to the dust. Health limits for dusts are typically a thousand times less than explosion limits, and you should, therefore, consider the effect of recirculation in any assessment made under the Control of Substances Hazardous to Health Regulations[7]. The failure or partial failure of a filter may greatly increase exposure to dust unless there is prompt detection of the fault. Dust filters may not remove volatile materials and where these are present a further assessment of the health risks is needed. A badly designed air recirculation system may also adversely affect worker comfort.

59 We can group more technical measures to mitigate an explosion into the following main categories:

- explosion relief venting;
- explosion suppression and containment; and
- plant siting and construction.

Explosion relief venting

60 A simple and common method of protecting process plant against the consequences of an internal dust explosion is to provide one or more deliberate points of weakness. We call these explosion relief vents. If they are of suitable size and in the right place, they will safely vent an explosion within the plant. The intention is to prevent injuries to persons nearby by avoiding uncontrolled failure of equipment.

61 Extensive research over the last 20 years has provided soundly based calculation methods to determine the vent area required. To design an explosion vent you require:

- the volume of the equipment to be protected;
- the properties of the dust measured in a 20-litre or larger apparatus;
- an estimate of the strength of the plant involved; and
- the opening pressure of the relief panels.

The plant user supplies information about the properties of the dust whilst the equipment manufacturer or installer supplies the calculation of relief areas. Some manufacturers test a complete assembly of, for example, a filter, with its vent panels. Others may calculate the equipment strength and fit vent panels from a specialist supplier that have been separately tested.

62 Different design equations are used for different circumstances. For example a tall thin silo may need more vents than a short squat vessel with the same volume. Full details are given in reference 1.

63 When an explosion vent opens as a result of a dust explosion, a fireball or jet of flame must be expected. This can carry out a mass of burning and unburnt dust. In addition there will be a pressure wave associated with the explosion. If the vent opens inside the building the burning dust may start further fires, and the blast may damage nearby plant. Anyone inside the room or building may be at serious risk. For these reasons explosion vents which discharge inside a building will give people inside the building little protection from the explosion. The usual solution is to fit a duct to lead the explosion products to a safe place in the open air. You may need to keep personnel away from an area around the end of a vent duct. Proprietary flameless venting devices, which quench flames and catch burning dust are also available. The suppliers' advice concerning installation must be followed carefully. See also paragraphs 68 and 69.

64 Bucket elevators may have an explosible cloud of dust within both legs during normal operation. Frictional heating within the elevator has caused a number of explosions. Explosion relief vents at the top and as close to the boot as is practicable (this generally means within 6m of the boot) will usually provide adequate protection for dusts with a K_{St} of 150 or less although long elevators may require additional vents. See appendix A for an explanation of K_{St}

This assumes the vent panels have an area equal to the cross-section of the leg, or for any panel at the top, both legs. Reference 1 contains additional guidance for dusts with a K_{St} of more than 150.

Note: *It is often difficult to locate relief panels at the elevator boot where they can open safely.*

65 Because of the difficulty of ducting vents from bucket elevators sited in buildings to the open air, it is preferable to locate such elevators outside buildings.

66 Screw conveyors do not generate large dust clouds within the casing, and experience has shown that explosion relief on such items is not normally necessary. Drag link (en masse) conveyors may contain a substantial void above the powder level in horizontal sections, and can be damaged by, or transmit explosions. Malfunction of either type of conveyor may cause frictional heating and ignition of the dust.

67 The dangers of a dust explosion will depend, among other factors, on the size of the ignited cloud. There is no simple answer to the common question: My plant has a size of only *x* do I still need an explosion vent? It will depend on the risks to people for any given plant. Factors you should consider are: the explosibility of the dust, whether existing openings will provide adequate protection, the cleanliness of the building, the likelihood of an ignition source being present, and the number of people who would be at risk.

68 To operate successfully an explosion vent must open reliably at a pressure well below that which the plant it is protecting can withstand, and must open fully almost instantaneously. Vents normally take the form of bursting panels or explosion doors. From 30 June 2003 newly supplied vent covers should conform to the EPS Regulations[8], be tested by one of the recognised independent test houses (notified bodies) and CE marked.

69 Where you site explosion vents is important because, if they are close to a wall or other obstruction, it can inhibit the release of combustion products and make the vent ineffective. Normally you should leave a minimum space of 1 panel diameter or diagonal between a vent panel and an obstruction. A larger distance will be needed to prevent damage to masonry walls from the pressure wave.

70 Where panels could become dangerous missiles in the event of an explosion, you should attach them to the plant by a strong chain, cable, or other restraint. The chain/cable must be long enough to allow the panel to open fully. Normally explosion vent doors and panels are not strong enough to stand on, and where necessary you should provide a suitable barrier to prevent access. A less satisfactory alternative is a widely spaced wire grill on the inner side.

71 Explosion doors are heavier than panels and will take longer to open than the lightest vents available. For this reason doors are likely to need to be bigger than the area calculated for panels. New doors made and tested to the EPS Regulations will come with a quoted figure of effective vent area. All types of explosion vent need occasional maintenance, to ensure that seals remain in good condition, there is no accumulation of dirt or corrosion products and hinges operate easily etc.

Explosion suppression and containment

72 Although the provision of explosion relief vents is the most widely used technique for protecting process plant from dust explosions, suppression and containment are equally valid alternatives. The choice of technique will depend not only on safety considerations, but also issues like cost, reliability, continuity of operation and keeping a plant free from contamination. Explosion venting will be inappropriate if the material is too toxic or environmentally harmful to release to atmosphere, or if there is no safe place to locate the vent outlet.

73 Dust explosions typically produce maximum overpressures in the range 8 to 10 bar. It is not generally practicable to produce plant capable of withstanding such pressures unless it is of small volume and simple circular or spherical shape. Hammer mills and certain other grinding equipment are however, often strong enough to contain an explosion; you will need to consider protection of the ductwork leading to and from them unless it is of similar strength. Plant operating under a vacuum, eg some types of drier, may also be strong enough to withstand the low explosion pressures that would result.

74 Explosion suppression systems allow the control of a developing explosion by the rapid injection of a suitable suppressing medium into the flame front. They have been developed into reliable systems over years of testing and operating experience. They are classed as autonomous protective systems and need certification and appropriate marking under the EPS regulations.

75 Such systems combine, in their simplest form, a rapid-acting pressure sensor with a number of pressurised containers of suppressant designed for rapid injection into the protected vessel. The suppressant is commonly a dry powder similar to those used in fire extinguishers, but in certain circumstances it may be water. The few specialist manufacturers of explosion suppression equipment are the best source of advice if you are considering this method of explosion protection.

Plant siting and construction

76 Where some risk of a dust explosion remains despite a high standard of control over sources of ignition, and provision of protective measures, the siting of unit(s) in the open air may minimise the consequences of an explosion. The intention of the risk assessment mentioned in paragraph 8 is to consider such factors.

Open air siting of dust handling process plant is strongly recomended

- where the scale of the operation is large, such as large silos;
- where substantial sized plant, such as a dust filter, has a flammable, dust cloud inside it constantly during normal operation; or
- where a particularly severe explosion is possible, as with metal powders.

77 When you install plant handling flammable dusts within a building, ducting the relief vents direct to the outside will reduce the risk to the building and people within it. To function correctly such ducts must have at least the same cross-sectional area as the vent panel or door. Any duct will provide some restriction to the flow of gases through it and, in consequence, both relief panels and ducts need to have a larger cross-section than for a freely discharging vent. You can minimise this problem if you locate such plant items close to an outside wall and ducts are straight and of minimum length. Vent ducts should be designed to direct any burning material safely away from anywhere people regularly go. Reference 1 contains detailed advice on the design requirements for the use of ducts.

78 Sometimes you may not be able to site explosion-prone plant where it can relieve to a safe place in the open air. In this case you should give careful consideration to the consequences of an explosion within the building. Explosion vents should not relieve to regularly occupied areas. The use of suitable plant automation may remove the need for personnel to visit vulnerable areas while the plant is running.

79 The building itself may be vulnerable to a pressure rise from either a primary or secondary explosion. In the past buildings with load bearing brick or stonewalls have collapsed following dust explosions, with much loss of life. A suitable choice of building design will allow a building to relieve a pressure wave without major damage. You may achieve this by fitting areas of open louvres, roof or wall panels of light construction lightly attached, or plastic glazing weakly secured to its frames. Methods are available for estimating the required area of weakness in a building (see reference 1).

Interconnected plant

80 Many processes involving flammable dusts use a series of interconnected units of plant, such as grinders, elevators, cyclones, silos and filters. Unless you take appropriate precautions, an explosion occurring in any one unit of plant may spread from unit to unit causing extensive damage.

81 Methods to separate items of plant and so restrict this possibility include the use of:

- rotary valves;
- a choke of material in an intermediate hopper;
- screw conveyors with a missing flight and baffle plate;
- explosion suppression barriers; and
- explosion isolation valves.

The aim is to prevent both the spread of burning particles, and the pressure wave associated with the initial explosion. Equipment newly installed after June 2003, intended specifically to act as an explosion barrier device needs to be tested and certified under the EPS Regulations[8]. Detailed standardised test arrangements are not available for any types of barrier device at the time of going to print.

82 The transfer system of the plant will continue to spread burning material with potentially serious consequences unless it shuts down immediately in the event of a fire or explosion. You can achieve this by providing trip switches activated by explosion relief panels to cut the power to elevators, conveyors, rotary valves etc.

83 Rotary valves are commonly provided to control powder flow, or to act as an air lock. If they are also intended to act as explosion chokes, they need rigid blades eg of metal, that will not deform under a pressure wave, and which have as small a clearance as practicable from the casing. Both the gap width and gap length affect the ability of the valve to extinguish a flame front. See figure 3 rotary valve diagram

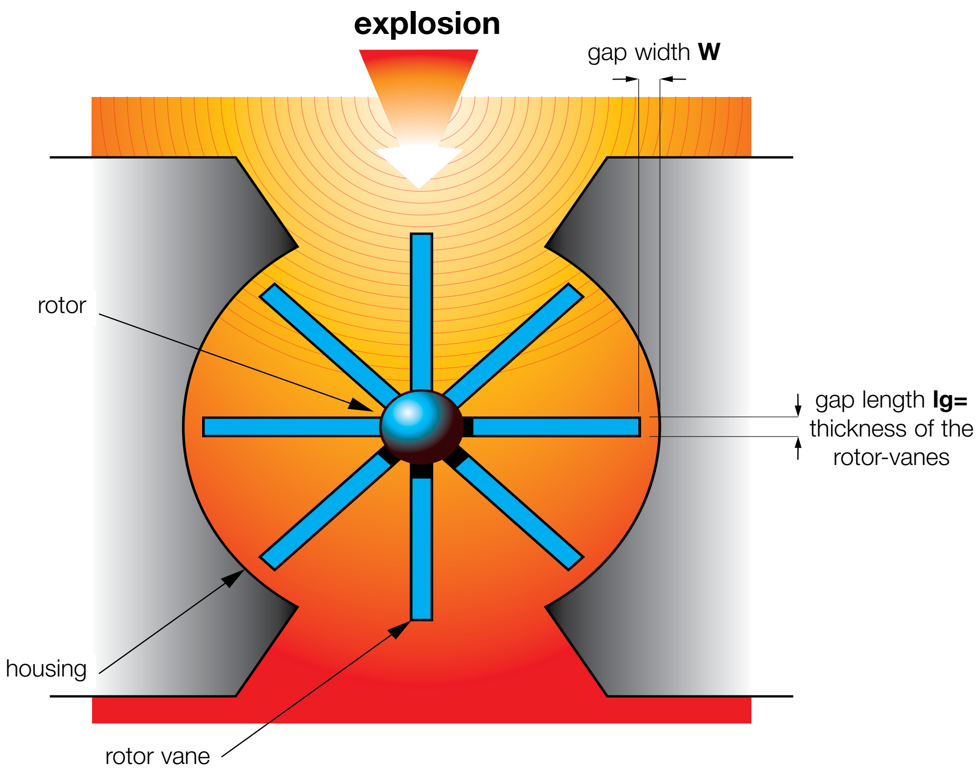


Figure 3 Important dimensions of rotary values used as chokes

84 If you omit one turn of the flight, a screw conveyor will act as a choke to a dust explosion. On an inclined conveyor the screw will not normally empty itself below the missing flight even when the supply of feed to the lower end stops. A horizontal conveyor with a trough casing needs an adjustable baffle plate to complete the seal of dust with the upper side of the casing. See figure 4

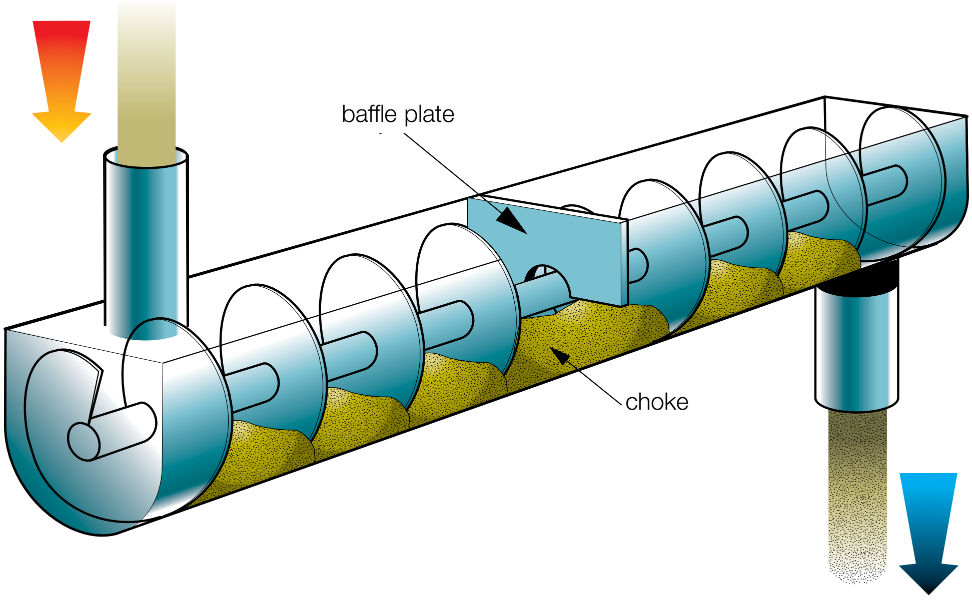


Figure 4 Use of a screw conveyor as an explosion choke

85 Explosion suppression barriers, also called advanced inerting systems are similar to suppressors used for major items of plant. A suppression barrier involves linking a pressure or optical detector to a rapid-acting device designed to inject an inerting or suppressing material into a duct. See figure 5.

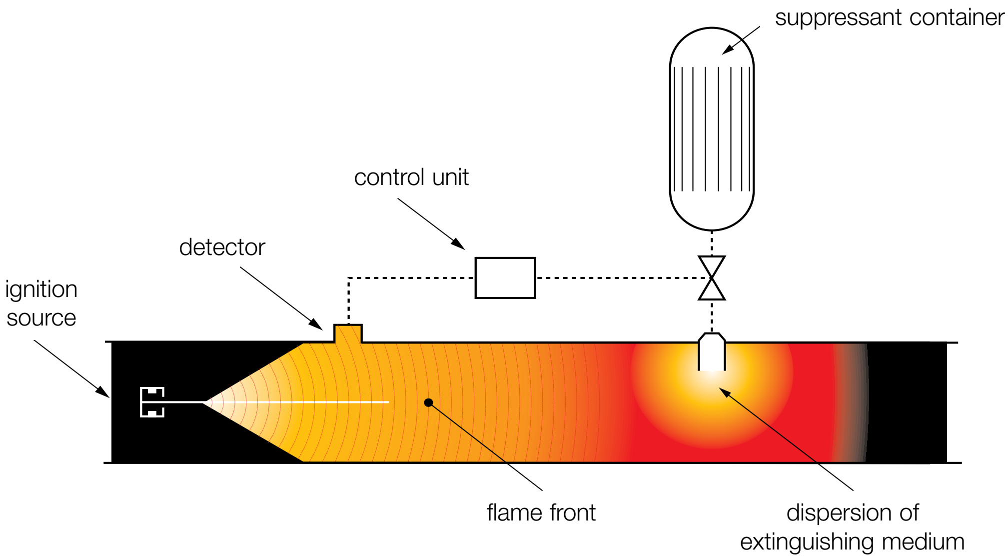


Figure 5 Suppressant barrier

86 Explosion isolation valves act by closing in milliseconds, following detection of a flame or pressure rise by a sensor situated an appropriate distance towards the anticipated source of the explosion. They have particular advantages where you want to avoid a hold up of material within the plant. See figure 6

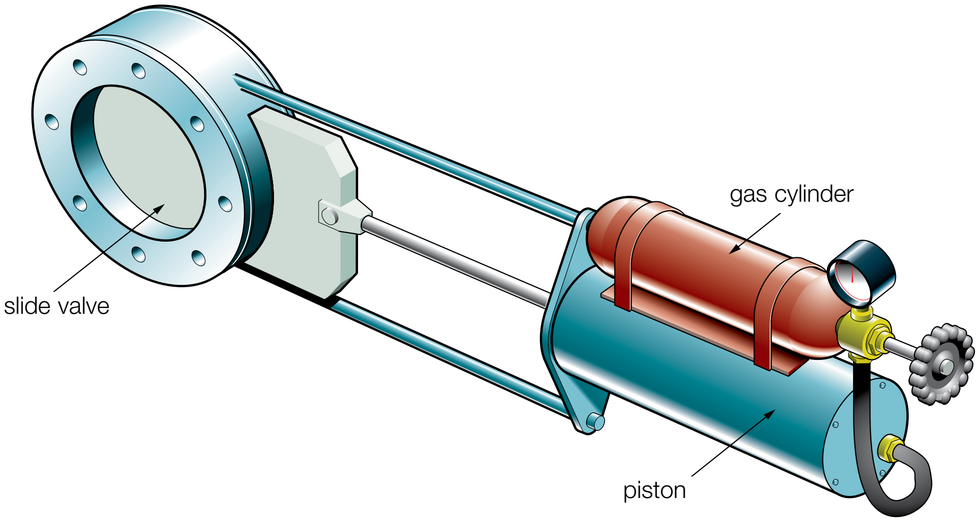


Figure 6 High speed isolaion valve

87 Your choice between these methods will depend on the particular plant or process concerned, but on any substantial system of interconnected plant that is vulnerable to dust explosions you will certainly need to take some effective steps to prevent propagation of any explosion to other plant items.

Verification before first use

88 Regulations require that any explosion protection measures included in plant newly brought into use after 30 June 2003 should be verified by a competent person. This might include: checks of the design of vent panels; checks that electrical equipment actually installed is suitable where necessary for use in dusty areas; a review of the zoning diagram; and checks of earthing arrangements, measurements of air flows in extract ducts etc. The objective is to see that the plant is installed correctly, and will perform to its intended design. This work may be done by someone working for the installer, user or an independent company.

Fires involving explosible dusts

89 Some dusts are capable of self heating, when they are held in quantity, deposited on a heated surface, or deliberately heated as part of a process. Depending on the conditions, the product may rise in temperature until it starts to smoulder or burn. Dusts which demonstrate this hazard can be identified by a variety of tests, which try to mimic on a small scale the conditions found in a full scale plant. Details are given in reference 20

90 Small smouldering fires may develop in dust accumulations not only from self heating but also from any of the common sources of ignition. If you suspect a fire inside a dust handling plant, it may be dangerous to open up any of the inspection points to look inside. A sudden rush of air into the plant could cause a smouldering deposit to flare up, or a dust cloud to form, followed by an explosion that vents out through the inspection point. It is preferable first to try and cool the affected plant from the outside, or where practicable to apply a water spray into the plant through a small opening. See also paragraph 39.

91 If you try to extinguish a fire using water, it is important that you apply it as a fine spray or fog. Using high-pressure water jets on a smouldering fire is dangerous, as you can raise dust clouds. Attempts to restrict the spread of fire by removing dust from adjacent plant have also resulted in the unintentional formation of dust clouds with disastrous consequences.

92 When tackling fires involving powdered metals or coal you should not use water as it may cause a violent reaction or the formation of flammable gases. Dry sand applied cautiously to a small burning heap on the floor from long-handled shovels may be effective, but special proprietary powder fire extinguishers are better. If a fire certificate is in force for the premises it will specify the types and numbers of fire extinguishers required.

93 You may tackle deep-seated fires inside a dust handling plant by applying an inert atmosphere. It is likely to take a considerable time for displacement of all the air from the centre of a large volume of powder and it may take days or even weeks to dissipate the residual heat from a fire in a large silo.

Examples of protection in two plants

94 To illustrate the application of the precautions already described, paragraphs 95 and 96 describe the safety features of two simple plants.

95 The first plant is a grinding operation that involves the tipping of granular material from intermediate bulk containers (IBCs) into a feed hopper. This leads to a small hammer mill and from this a blower transfers the ground material to one of two product bins. See Figure 7.

- The IBC tipping point has local exhaust ventilation. This draws escaping dust to a filter located outside the building. The filter has explosion relief.
- The feedstock flows from the hopper through a rotary valve to the mill. The rotary valve serves not only to control the flow of product, but also prevents an explosion in the mill venting out through the hopper.
- A magnetic separator before the mill catches tramp metal.
- The mill itself can withstand an explosion and needs no explosion relief. The inlet and outlet ductwork and associated joints are capable of withstanding over pressures of up to 9 barg without distorting enough to allow flames to emerge.
- A pressure sensor on the conveying system detects blockages. This allows the mill to be turned off before material in the mill overheats and catches fire
- Slide valves control what bins the product will enter. Interlocking ensures that only one valve is open at any time. This will prevent an explosion propagating from one bin to another.
- The bins are outside the building and have explosion relief.
- The bins have integral filter socks to permit the escape of air displaced during filling. The dusty side of the filter is effectively part of the bin; the calculation of the explosion relief area required depends on the bin volume alone.

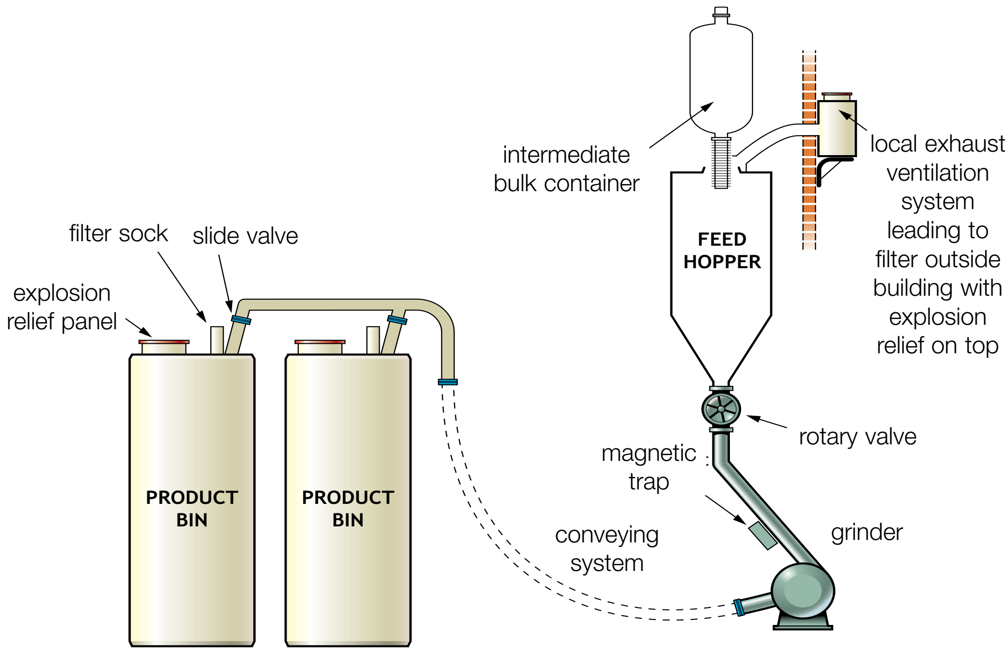


Figure 7 Simple grinding installation diagram

96 The second plant takes bulk powder deliveries from a road tanker and stores it in a single silo inside the factory. See Figure 8.

- The road tanker is earthed to the plant before delivery starts. The pneumatic filling line uses some plastic sections, but the earth continuity of all metal parts of the plant has been checked.
- The bin has explosion relief, and a duct directs any relieving explosion to a safe place outside the building.
- The airstream from the bin goes to a cyclone outside the building. This cyclone has explosion relief. An alternative to the cyclone would be a filter unit. A filter would separate fine particles more effectively.
- The bin has a high level alarm to warn against overfilling and so prevent the escape of material. Omission of this is possible by ensuring a high standard of supervision of the transfer.

Human factors

97 Fires and explosions can occur even in the best designed plant if the people involved do not understand the hazards of the dust and the controls provided. The Dangerous Substances and Explosive Atmospheres Regulations require you to provide information for employees about risks and safety measures provided, together with adequate health and safety training. You should give all people involved in plants handling explosible dusts training in general terms about the nature and hazards of dust explosions, typical sources of ignition, safeguards provided, precautions to take and any emergency procedures on their plant. Particular points you should cover in such training are: the importance of good housekeeping, the need to report promptly any substantial release of material, or any equipment malfunction that could be a source of ignition.

98 You may need to restrict access to some areas while the plant is operating. This is easier to achieve where there is clear marking of the areas concerned. This type of arrangement is sometimes used for areas at the top of storage bins, where it has not proved possible to duct explosion vents to the outside. DSEAR[3] also requires the access points to zoned areas to be marked with a yellow and black triangular Ex sign (see below), where the risk assessment shows it will have some benefit. Signs might help remind employees where special rules apply, for example on the use of portable electrical equipment, or define parts of the premises where office staff are not intended to have access because they have not been trained.

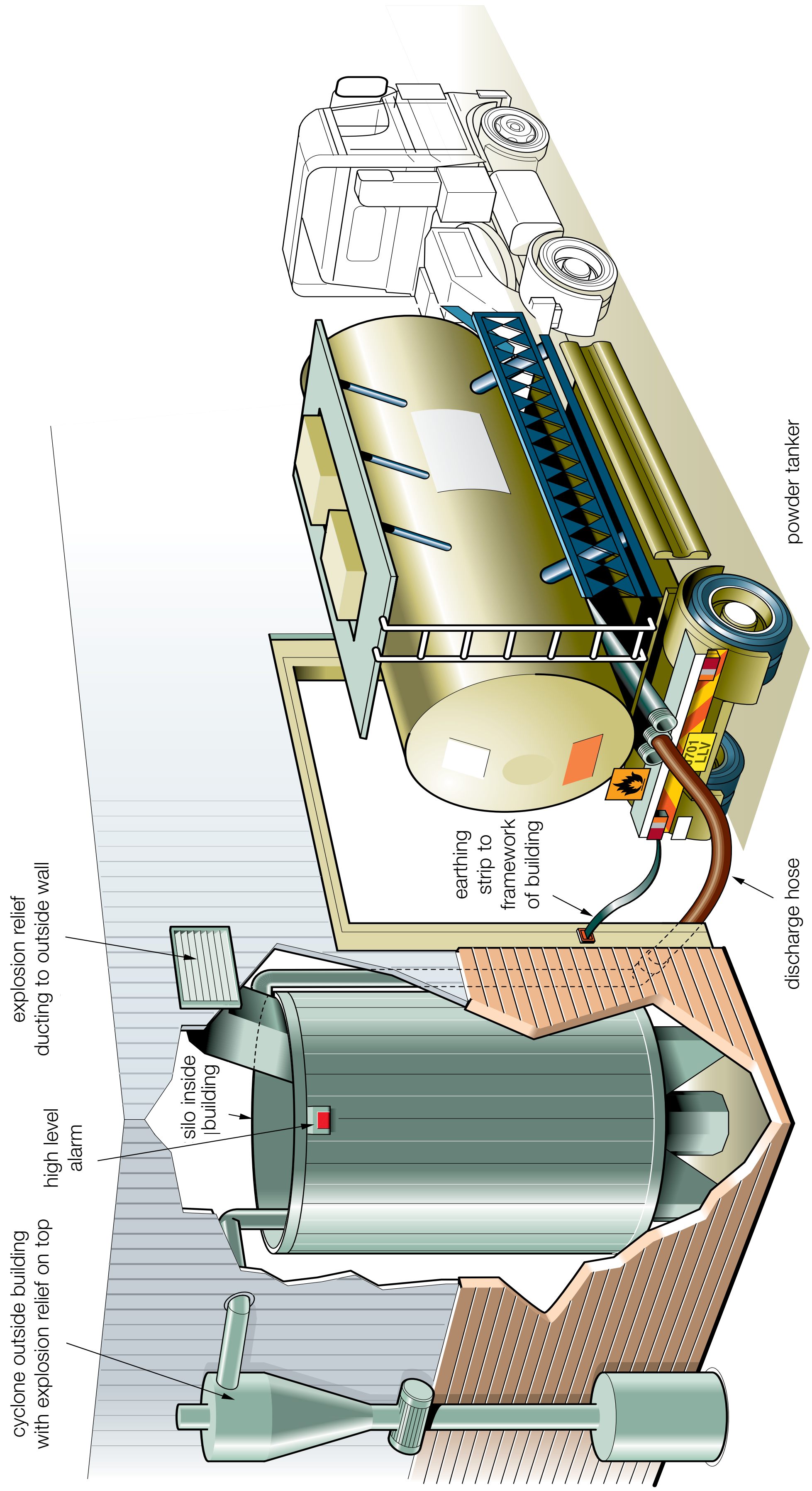


Figure 8 Pneumatic delivery diagram

Appendix A: Dust testing for fire and explosion properties

A1 A wide range of tests have been developed for use where combustible dusts are used or stored. The results may be useful in plant design, or setting safe operating conditions. You should be clear how the results will be used, before carrying out the work.

A2 Tests may be needed to answer the questions:

Question 1 **How could a dust be ignited in this process?**

Question 2 **What would be the consequences?**

Question 3 **How do I design the plant and process to preventor minimise the consequences of an explosion?**

Question 1	**Test**	**Main Purpose**
Hot surface	Layer ignition test Cloud ignition test	Used to specify equipment surface temperature limits
Self heating	Various	Used to specify processing and storage temperatures and volumes
Electrostatic spark	Minimum ignition energy	Safe use of highly insulating materials, and other precautions, against static electricity.
Question 2	**Test**	**Main Purpose**
Can the dust explode?	Vertical tube test Particle size analysis	Are precautions against an explosion risk needed?
Can fire spread across a layer of dust?	Train fire test	Limited application
Question 3	**Test**	**Main Purpose**
Can I avoid dust clouds capable of exploding	Minimum explosible concentrate	May demonstrate the risk is minimal in some applications
How violent would an explosion be?	20 litre sphere, KST, Pmax measurement	Design of explosion vents or suppression system
Can the explosion risk be prevented by excluding air?	Limiting oxygen concentration	Used in the design of plants protected by inerting

Other tests may be needed in particular circumstances

A3 The vertical tube apparatus is a small-scale method, which gives a visual result only. It is used as a quick screening test to determine whether a particular dust has any potential for exploding. Dusts that do not explode on initial testing may be dried and/or sieved, then retested. See figure 9

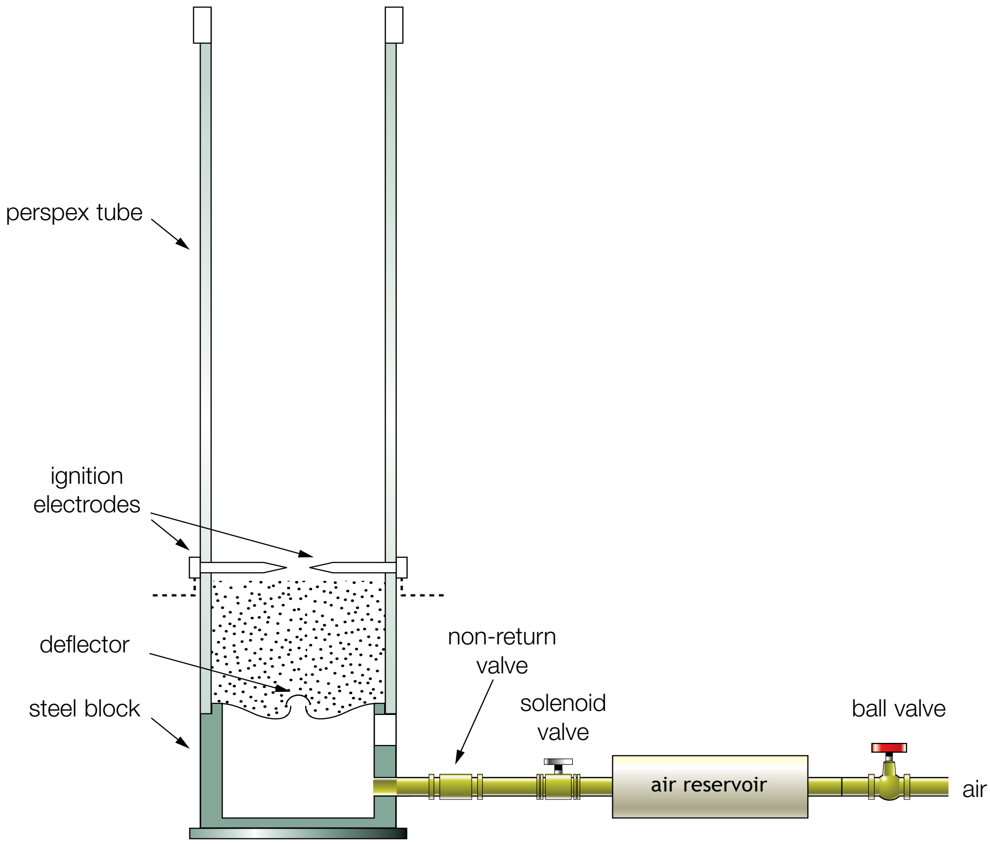


Figure 9 Vertical tube apparatus

A4 Numerical data obtained from the 20-litre sphere test apparatus (figure 10) is used in the design equations for explosion vents and suppression systems and in the design of pressure resistant plant. The apparatus allows a well-distributed dust cloud to be ignited with a powerful ignition source and the pressure time trace to be recorded. Tests are normally run at a range of concentrations repeated and averaged to determine the most vigorous conditions.

A5 The most significant figure from this test is the maximum rate of pressure rise. This is because test work on vessels of up to 600m^3 capacity has shown that the following relationship holds for a given dust:

$$V^{1/3.} \left(\frac{dP}{dt} \right)_{max} = K_{St}$$

where K_{St} is a constant with units of bar. m. sec^{-1}, and V is the volume in m^3 of the vessel. The meaning of $(dP/dt)_{max}$ is indicated (figure 11) by a graph of a typical pressure-time trace from an explosion. The test is run at a range of concentrations, and the K_{St} value calculated from the most vigorous explosion.

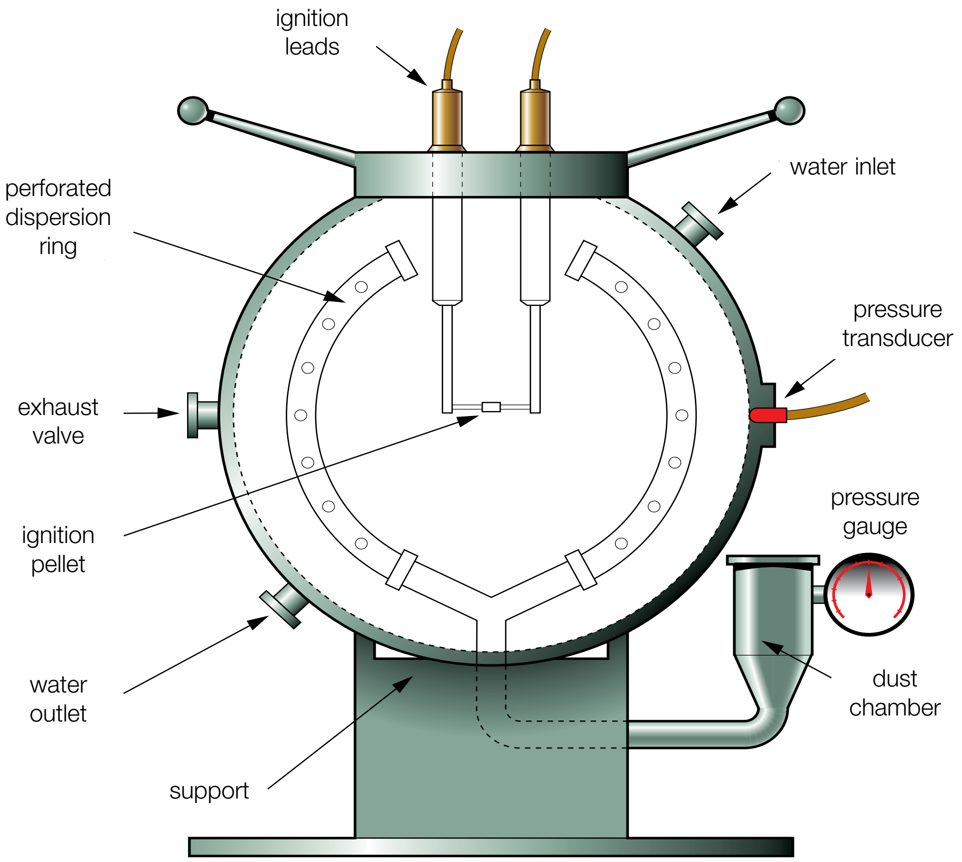


Figure 10 Sphere test apparatus

A6 Values of K_{St} are used in one generally useful method of calculating the size of explosion relief vents. Dusts are commonly classified into broad groups as an indication of their explosion properties. The dust groups are given below and examples of measurements are given in Table 1.

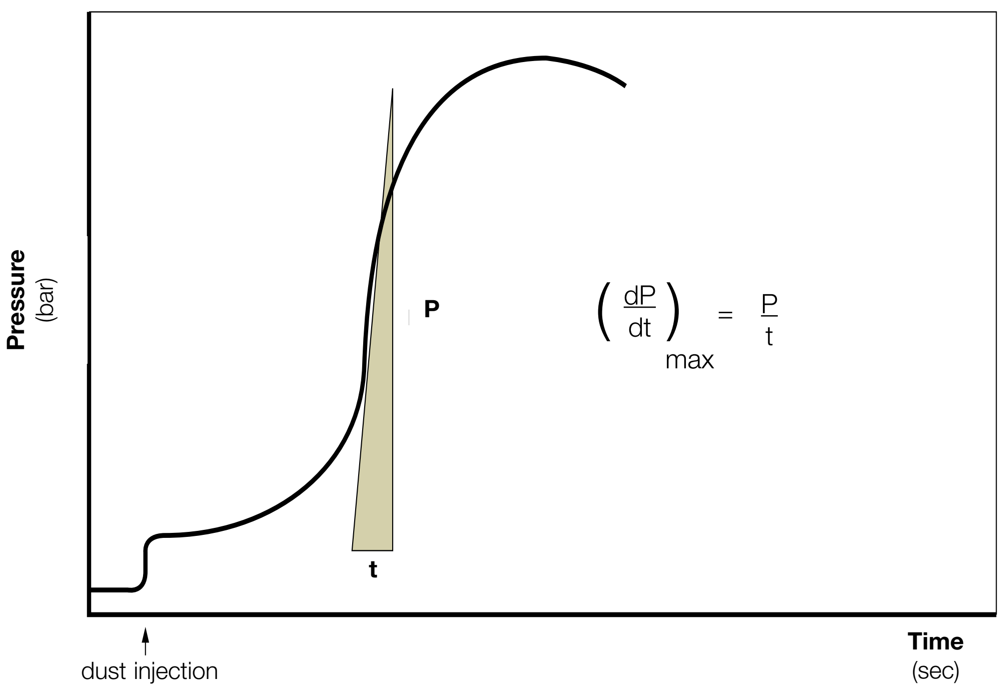


Figure 11 Typical trace from a dust explosion test

Explosion class	K_{St} bar.m.sec^{-1}	
St 0	0	No explosion
St 1	> 0 ≤ 200	Increasing severity of explosion
St 2	> 200 ≤ 300	
St 3	> 300 ≤ 600	

A7 A range of wheat dust and wheat flour samples have been tested with moisture contents in the range 4-14% and median particle sizes in the range 21-72 microns. The range of K_{St} values were from 53-137 bar.m/sec, with a value of 146 for a sample of wheat gluten at 7% moisture, ie all were St1 class. See reference 22

A8 The results of tests on a large number of samples of different materials are given in reference 13. For some natural products, where a scatter of results is to be expected, this reference gives records of substantial numbers of earlier tests. In this case, cautious assumptions about the properties of a particular product based on the set of tests, may be as reliable as testing a further single sample. In other cases, however, it is strongly recommended that process equipment is designed using test results on samples representative of the finest and driest material likely to be found in the process, and not just data drawn from other sources.

Table 1 Dust groups and examples of measurements

Dust tested	Median particle size µm	Minimum explosible concentration g/m³	Maximum explosion overpressure bar	K_{St} valve bar.m/s	St class
Paper tissue	54	30	8.6	52	1
Glucose	30	60	9.2	123	1
Wheat	80	60	9.3	112	1
Polyethylene low density	62	15	8.5	131	1
Polymethyl methacrylate	21	30	9.4	269	2
Calcium stearate	12	30	9.1	132	1
Wood flour-various samples	65	60	7.7-10.5	83-192	1
Magnesium	28	30	17.5	508	3

Warning: *these results are not intended to be used directly for plant design*

Appendix B: Legal

B1 The Health and Safety at Work etc Act 1974 (HSW Act)[2] places a general duty on employers to ensure the safety of both employees and other people from the risks arising from the work activity, so far as is reasonably practicable. Suppliers or manufacturers of flammable dusts that can explode, particularly where these are new substances, have a duty under section 6 to inform anyone to whom the substance is supplied about its properties. This may include the results of tests for explosibility.

B2 The Dangerous Substances and Explosive Atmosphere Regulations 2002[3] requires that risk should be eliminated or reduced as far as is reasonably practicable and that substitution of the dangerous substance should be considered as the first option. The requirements are set out in more detail in supporting approved codes of practice.[14-18]

B3 The Provision and Use of Work Equipment Regulations 1998[5] requires every employer to take measures to prevent work equipment catching fire or exploding. Where it is not reasonably practicable to prevent all fires and explosions, measures to reduce the likelihood and minimise the consequences of a fire or explosion are required. Any new equipment provided at a workplace must comply with relevant European product safety legislation.

B4 The Workplace (Health, Safety and Welfare) Regulations 1992[6] and the associated Approved Code of Practice sets out the requirement to maintain plant in a clean condition. The importance of cleanliness in plants handling flammable dusts is highlighted elsewhere in this guidance.

B5 The Control of Substances Hazardous to Health Regulations 1999[7] will usually apply where fine dusts are present as many cause health risks where they can be breathed in. Precautions taken to reduce the dust levels in the workroom for health reasons will help reduce the need for regular cleaning of the room. Knowledge of the particle size of the dust will be useful in assessing both the health and potential explosion risks.

B6 The Equipment and Protective Systems for Use in Potentially Explosive Atmospheres Regulations 1996[8] (EPS) introduce requirements relating to equipment placed on the market that are intended for use in potentially explosive atmospheres. Any equipment, protective system or device within the scope of the regulations is required to satisfy the relevant essential health and safety requirements, and have undergone an appropriate conformity assessment procedure. It will carry the CE mark and symbol of explosion protection, Ex in a hexagon. Such equipment may be described as ATEX equipment. A substantial guide to these regulations is published on the EU website. The regulations describe 3 categories of equipment, with the different categories intended for use in the different zones. In addition equipment classed as an autonomous protective system must comply with detailed essential health and safety requirements.

B7 The Fire Precautions (Workplace) Regulations 1997 as amended by SI 1999/1877 apply very widely, and require employers to take precautions to safeguard employees in case of fire. These include adequate emergency escape routes from buildings, fire alarm systems and fire extinguishers. The precautions selected will need to take account of any explosible dust that is present.

Appendix C: Laboratories undertaking testing of flammable dusts

C1 FRS, Building Research Establishment Ltd, Garston, Watford, WD2 7JR

C2 Chilworth Technology Ltd, Beta House, Chilworth Science Park, Southampton, SO16 7NS

C3 Syngenta Technology, Process Hazards Section, South Bank, Huddersfield Manufacturing Centre, PO Box A38, Huddersfield, HD2 1FF

C4 Hazard Evaluation Laboratory, 50 Moxon Street, Barnet, Hertfordshire, EN5 5TS

C5 Burgoyne Consultants Ltd, Burgoyne House, Chantry Drive, Ilkley, West Yorkshire, LS29 9HU

C6 Health and Safety Laboratory, Harpur Hill, Buxton, Derbyshire, SK17 9JN

Appendix D: Area classification, Zones definitions

Zone 20

A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is present continuously, or for long periods or frequently.

Zone 21

A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is likely to occur in normal operation occasionally.

Zone 22

A place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation, but if it does occur, will persist for a short period only.

Layers, deposits and heaps of combustible dust must be considered as any other source which can form an explosive atmosphere.

Reference 14 describes the transitional arrangements for implementing the requirement for area classification of dust handling plant

Different equipment categories are specified under the EPS regulations. Category 3D is designed for use in zone 22, category 2D in zone 21, and category 1D in zone 20.

References

1 *Dust explosion prevention and protection: A practical guide* Institution of Chemical Engineers 2002 ISBN 0 85295 410 7

2 *Health and Safety at Work etc Act 1974* chapter 37 The Stationery Office ISBN 0 10 543774 3

3 *Dangerous Substances and Explosive Atmospheres Regulations 2002* SI 2002/2776 The Stationery Office ISBN 0 11042957 5

4 *Fire Precautions (Workplace) Regulations 1997 SI 1997/1840* as amended by SI 1999/1877 The Stationery Office ISBN 0 11 082882 8

5 *Provision and Use of Work Equipment Regulations 1998 SI 1998/2306* The Stationery Office ISBN 0 11 079599 7

6 *Workplace (Health, Safety and Welfare) Regulations 1992* SI 1992/ 3004 The Stationery Office ISBN 0 11 025804 5

7 *Control of Substances Hazardous to Health Regulations 1999* SI 1999/437 The Stationery Office ISBN 0 11 082087 8

8 *The Equipment and Protective Systems for Use in Potentially Explosive Atmospheres Regulations 1996*, implementing the ATEX 95 directive SI 1996/192 as amended by SI 2001/3766 The Stationery Office ISBN 0 11 038961 1

9 *Corn starch dust explosion at General Foods Ltd, Banbury Oxfordshire, 1981* The Stationery Office ISBN 0 11 8836730

10 BS EN 50281-1-2 1999 *Electrical apparatus for use in the presence of combustible dust; selection installation and maintenance* British Standards Institution

11 BS EN 50281 -3 2002 *Electrical apparatus for use in the presence of combustible dust. Classification of areas where combustible dusts are or may be present* British Standards Institution

12 *Combustion and Explosion Parameters of Dusts (Brenn- und Explosionskenngroessen von Stauben)*, published in English by the HVBG (statutory accident insurance organisation) Sankt Augustin, Germany ISBN 3 88383 468 8

13 BSEN 60529 1992 Specification for classification of degrees of protection provided by enclosures British Standards Institution

14 *Dangerous Substances and Explosive Atmospheres. Dangerous Substances and Explosive Atmospheres Regulations. Approved Code of Practice and guidance* L138 HSE Books 2003 ISBN 0 7176 2203 7

15 *Design of plant, equipment and workplaces. Dangerous Substances and Explosive Atmoshperes Regulations 2002. Approved Code of Practice and guidance* L134 HSE Books 2003 ISBN 0 7176 2199 5

16 *Storage of dangerous substances. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved Code of Practice and guidance* L135 HSE Books 2003 ISBN 0 7176 2200 2

17 *Control and mitigation measures. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved Code of Practice and guidance* L136 HSE Books 2003 ISBN 0 7176 2201 0

18 *Safe maintenance, repair and cleaning procedures. Dangerous Substances and Explosive Atmospheres Regulations 2002. Approved Code of Practice and guidance* L137 HSE Books 2003 ISBN 0 7176 2202 9

19 PD CLC/TR50404: 2003 *Electrostatics. Code of Practice for the avoidance of hazards due to static electricity* British Standards Institution

20 *Prevention of fires and explosions in dryers* Institution of Chemical Engineers 2nd ed 1990 ISBN 085295 257 0

21 *The explosibility of dispersed flour dust*, Incorporated National Association of British and Irish Millers Ltd.

22 BS EN 1127 *Explosive atmospheres, explosion prevention and protection, part 1 basic concepts and methodology*. British Standards Institution
This contains further information on many of the issues covered in this booklet, and in particular, a discussion of all the potential sourcces of ignition.

23 BS EN 13463 part 1 *Non electrical equipment for use in potentially explosive atmospheres, basic method and requirements* British Standards Institution

24 *Guide to the ATEX 95 (equipment) directive*
http://europa.eu.int/comm/enterprise/atex/index.htm

25 *Energetic and spontaneously combustable substances: Identification and safe handling* HSG131 HSE Books 1995 ISBN 0 7176 0893 X

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