Information document (ID) on Risks from Sewage Sludge Drying Plants

INTRODUCTION

1 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.

2 This guidance covers thermal dryers for sewage sludge's; however the guidance is likely to be applicable to other organic wastes with similar properties to sewage sludge.

Dried sludge, usually in the form of granules/pellets, has the advantage of being easily stored and has reduced transportation costs. Sewage sludge after mechanical dewatering contains around 25% dry solids as compared to dried sludge, normally 85-95% dry solids. Thermal dryers can also be used as pre-treatment for other processes, and elements of this guidance will be applicable to those where the dry solids may be up to 45%.

TREATMENT PROCESS

3 Sewage sludge is primarily derived from municipal wastewater, which also contains fibres, fats, oils and detergents. A variety of other substances from industrial wastes can also be present that may affect both the safety and operational performance of the drying plant. The water company or those with delegated responsibility (Local Authorities) regulate industrial wastewater discharges to sewers. These bodies permit the discharges of wastewater from most industries. Regulations ensure that those contaminants, which would reduce the effectiveness of the waste treatment processes, are removed before discharge but the same discharges may contain substances that can cause problems when the resulting sludge is treated in a sludge drying plant. Examples of these could be an increase in fibre content from a paper works discharge, fibre from wool scouring and cloth dyeing plants, animal hair from slaughter houses, fats and fibres from food processing, trace metals and trace organics from chemical works and metal processing plants. There may also be accidental contamination such as from fuel spills. Other chemicals may be introduced as part of the sewage treatment process, which in turn may affect the drying plant.

4 Sewage treatment typically consists of three basic processes: preliminary treatment, primary settlement and secondary treatment. Preliminary treatment involves grit removal and screening to remove larger material such as rags, towels, etc. In primary settlement the sewage flows through large tanks where the smaller organic material is allowed to drop out. Metal or stones should not normally get through this stage and should be prevented from entering the sludge train destined for the dryer where they could cause sparking. During the secondary treatment stage, the mixed liquor is aerated to aid bacteria in breaking down its mass, after which the resulting secondary sludge is allowed to settle. The sludge produced by the primary settlement process and the secondary oxidation process is combined to form the untreated sludge often known as `raw sludge'. If raw sludge is stored it will putrefy, become acidic, producing hydrogen sulphide and other volatile sulphur compounds. Raw sludge can be fed directly to a dryer or to a digester for further digestion by anaerobic or aerobic bacteria after which it can also be fed to a dryer. The digestion process produces methane and carbon dioxide.

5 Prior to drying the sludge may be dewatered by mechanical means, aided by the addition of a polymer to bind the sludge together. Free water is removed to achieve around 25% dry solids. The material produced is referred to as “sludge cake”, which may be stored for later transportation to another site for drying. Hydrogen sulphide and ammonia may be released during this process, which may require local exhaust ventilation.

6 The sludge can now be passed to a thermal dryer for removal of the remaining water to produce the finished product, normally 85-95% dry solids. Drying plants can operate on digested, raw or mixed sludge.. The physical characteristics of the final dry product will be different depending on the sludge used. A variety of factors are involved such as total organic matter, primary/secondary sludge ratios, the type of mechanical dewatering and the type of polymer. Beyond approximately 40% dry solids the sludge becomes thixotropic (known as the “sticky phase”). Beyond approximately 65% dry solids the sludge begins to flow again. This sticky phase makes the sludge difficult to handle through the dryer. Some processes overcome this by directing a proportion of the dried granules and the fines (under sized material) to be recycled and mixed with the dewatered cake.

7 Where the dryer is used as a pre-treatment process, the objective is to raise the dry solids of the sludge without reaching the sticky phase. Under normal operating conditions the risks associated with the partially dried sludge are not the same. However under abnormal conditions risks do arise for which this guidance may be relevant.

8 The amount of dust produced in the dryer and later processing plant will be affected by the type of dryer installed. Sewage dust is typically an St1explosion class dust. The St system is a classification system for combustible dusts based on the explosion constant for the dust (Kst). For a dust to be classified as St1 the Kst constant falls in the range of 0-200 bar.m.sec^{-1}. Sewage sludge dust has a similar range of figures to wood flour (90-190 bar.m.sec^{-1}). Depending on the design of plant there is the potential for a dust explosion to occur in the main dryer, dust collection and handling plant, pelletiser and final product discharge plant. The material can also self heat leading to ignition and a slow burn which may be accelerated with the ingress of additional air into the plant.. Explosions and fires in dryers and associated processing plant have occurred in the UK.

SLUDGE SPECIFICATION

9 There can be considerable variation in the physical and chemical properties of sewage sludge, which will affect processing. Therefore, the sludge must be assessed for those properties, which could affect the safety of the drying plant and the stability of the dried product. Such an assessment should include seasonal variations and reasonably foreseeable contamination. The specification for these safety critical properties must be agreed between the plant supplier and user at the design stage and reviewed during plant commissioning. The specifications may indicate a safe operating range or set figures, which should not be exceeded without being considered as part of a plant modification scheme. Appendix A contains information to help identify appropriate safety critical properties of sewage sludge.

10 Reasonable precautions should be taken to prevent the ingress of tramp metal into the drying process. Tramp metal may provide an ignition source.

11 Once the plant is in operation the user should ensure that quality control procedures are in place to pick up any variations in the sewage sludge being fed to the dryer, which could adversely affect its safe operation. A further assessment will be required if there is a significant change to the sludge composition. Personnel controlling the sewage network, e.g. trade effluent inspectors, should be aware that any significant changes affecting the chemical composition of the sewage sludge should be discussed with the dryer plant management prior to implementation.

RISK ASSESSMENT

12 A risk assessment should involve identifying the hazards present in the working environment or arising out of the work activities and evaluating the extent of the risks involved, taking into account existing precautions and their effectiveness. Risk assessments are required under various UK legislation, the more significant health and safety regulations are listed in Appendix B. The risk assessment should be reviewed and if necessary modified since risk assessment should not be a once only activity. As the nature of the work changes, the appreciation of hazards and risk may develop. In most cases, it is prudent to plan to review the risk assessments at key stages throughout the feasibility, design, commissioning and operation for the whole plant, including both pre and post-dryer plant. Safety critical properties (see Appendix A) for the sludge must be identified sufficiently early in the project to enable them to be incorporated into the design features. These should be measured and regularly checked during plant commissioning and operation. Once operational the risk assessment should be reviewed on a regular basis dependent on the nature of the risks and the degree of change likely in the work activity.

13 A risk assessment needs to be carried out for reasonably foreseeable contaminants, which could enter the plant. For example fuel spills entering a sewage treatment works are quite foreseeable; however, the assessment may indicate that the dilution factor is such that they pose no risk to the plant. However, a large accidental discharge of a specific chemical from a nearby chemical/industrial plant may be a risk. Any procedures put in place to deal with such an event should be reliable and regularly checked.

14 The risk assessment needs to identify the relevant hazards from the material given its likely condition in different parts of the plant. Various combinations of prevention and protection will be required for specific parts of the plant. Once the plant is operational a review of the original risk assessment should be carried out with particular emphasis on likely operator interventions, e.g. blockage removal.

ELECTRICAL/MECHANICAL EQUIPMENT

15 The Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR) require plant operators to undertake an assessment of where explosive atmospheres may form within a plant, as one part of the risk assessment described above. This assessment is called hazardous area classification, and the objective is first to allocate zones, which depend on the probability that an explosive atmosphere may form, and then to use these zones as a basis for selecting electrical and other equipment.

16 In a sludge drying plant, explosive atmospheres may arise from clouds of dust, carbon monoxide, methane, or contaminants like petrol. Standards give a framework for undertaking an area classification, see BS EN 60079-10-1:2009 for gases and vapours, and BS EN 60079-10-2;2009 for dusts. Good plant design can minimise the extent of any hazardous areas. For example good ventilation can prevent accumulations of methane in sludge storage tanks.

17 The extent of zones arising from dusts depends on the amount of dust, which leaks out, either in normal operation, or as a result of some equipment fault or operating error. If the amount of dust liable to be released is minimal, and what is released is promptly cleaned up, the extent of any zoned areas outside the containment system of the plant will be very small or non-existent. However as the plant ages dust leaks may increase requiring increased maintenance and cleaning to ensure the classification is still correct. Accumulation of dust through poor housekeeping can result in risks being generated in areas which otherwise would not be zoned. Appropriate design to avoid dust accumulation and housekeeping are crucial to risk limitation.

18 Once zones have been allocated, new equipment that could create an ignition hazard installed in these zones should be built to the appropriate ATEX standard. See the Approved Code of Practice to DSEAR for details. Until recently, whilst equipment could be built to the standards for dust zones, little was actually produced as the zone definitions were different, however weather proof equipment often met the requirements for preventing dust ingress. Provided existing equipment meeting the enclosure standard IP5X (BS EN 60529:1992) can be shown not to develop surfaces hot enough to ignite dust as a layer or cloud the risk assessment may conclude it can continue to be used safely in zone 22. See BS EN 60079-10-2;2009 for advice on selection of electrical equipment for use in areas zoned for dust hazards.

19 Similar considerations apply to mechanical equipment that may form hot surfaces, perhaps as the result of some equipment fault. BS EN13463-1: 2009 gives advice on an ignition hazard assessment for non-electrical equipment, which may be useful for older equipment as well as new equipment.

20 The installation as a whole should comply with BS 7671:2008 Requirements for Electrical Installations.

PRE-DRYER STORAGE

21 A specific risk assessment is required together with appropriate measures to prevent contamination entering the dryer for example:

1) methane, where the plant is processing anaerobically digested sludge or where it could be generated as a result of long periods of storage;

2) petrol, diesel and oil are possible contaminants of sludge, however dilution effects may substantially reduce the potential risk. If such a dilution effect cannot be demonstrated then a hydrocarbon detector will be required. If this is standardised on pentane it will identify both methane and petrol in any pre-dryer storage. It should be connected to a suitable alarm;

3) stones or pieces of metal which could cause an ignition source or jam moving machinery need to be removed, e.g. by sieves, strain presses, narrow aperture pump feeds, extruders, passage through a digester etc.

DRYER DESIGN

22 Drying is achieved either by convection drying when hot gas/air is blown through the sludge or by conduction drying whereby the sludge is brought into contact with a heated surface.

23 In the case of convection drying, the gas (air) flowing through the dryer can be heated directly or indirectly. With direct heating the hot waste gas (oxygen depleted) from a combustion chamber is fed into the dryer, while with indirect heating air is heated via a heat exchanger.

24 With conduction drying, heat is usually provided by either steam or from a hot oil system. The dryer will have various combinations of heated jackets and hollow paddles/discs through which the heating medium flows.

25 Rotary dryers consist of a horizontal drum, which rotates around its axis. The sludge to be dried is moved through the drum by internal fittings (paddles/blades) or taken up by the drying gas flowing axially through the drum. In the case of convection dryers gas input temperatures can be as high as 750^{0}C. Mechanically dewatered sludge is mixed with dried product (normally under/over sized) to achieve a product that is above sticky phase before it is fed into the drying drum.

26 In a paddle dryer, heated paddles rotate in a mass of sludge held in a heated stationary chamber with dried material cascading from the end of the dryer. Paddle dryers can operate without back mix using mechanical energy to maintain movement through the sticky phase.

27 Horizontal disc dryers operate in a manner similar to a paddle dryer with heated discs or rings rotating in a mass of sludge, a proportion of which is recycled product to avoid the sticky phase.

28 With a thin film dryer sludge is spread onto the outer heated wall of the dryer by a rotor. The dryer can be used to dry sludge to over 90% dry solids but its main advantage is that it can handle the sticky phase without back mixing. A single stage thin film unit may be used in conjunction with a paddle dryer.

29 In a vertical tray dryer, re-circulated granules coated with sludge are rolled over heated trays by a slow ploughing movement and transported by gravity from one tray to the next, until they reach the outlet at the bottom of the dryer.

30 In a belt dryer, the material is transported on a slow-moving belt through a heated environment.

31 In a plate press, heat can be added to supplement the mechanical dewatering to achieve a higher % dry solids.

PRINCIPLES OF DRYING PLANT SAFETY AND INHERENT SAFETY

32 All suppliers of sludge drying plant must comply with the essential health and safety requirements contained in the Supply of Machinery Regulations 2008. It is a requirement of any operator of a sludge drying plant to carry out a suitable and sufficient risk assessment as required by the Management of Health and Safety at Work Regulations 1999 together with the operational requirements found in the Provision and Use of Work Equipment 1998. In addition the DSEAR 2002 requires that employers classify areas where accumulations of combustible dust and gases may occur and justify their selection of equipment used in classified areas.

Regulation 6 of DSEAR requires that the process selection should include risk minimisation starting with the choice of a least-risk design. For example, if the sludge properties show that a strong exotherm occurs at temperatures in excess of 130^{o}C then a dryer that uses steam at 105^{o}C will be inherently safe in contrast to a dryer that uses hot oil at temperatures in excess of 130^{o}C.

A qualitative risk analysis, e.g. HAZOP should be carried out on the drying plant.

33 The risk of a fire/explosion can be further reduced by the following preventative measures:

(1) avoiding a flammable atmosphere;

(2) inerting;

(3) avoidance of ignition sources.

34 If the above measures cannot eliminate or sufficiently reduce the risk then protective measures will also be needed such as:

(1) explosion relief venting;

(2) suppression systems;

(3) containment;

(4) safe location;

(5) explosion isolation between sections of plant.

35 Manufacturers and designers must first identify where a flammable atmosphere could occur, taking into account all likely operating scenarios, i.e. start up, running, emergency shut down, restart. They must then select the most appropriate `Basis of Safety' for each part of the plant also taking into account various modes of operation e.g. manual, fully automatic. Should a specific plant be modified by the manufacture then the "basis of safety" will need to be reviewed.

DRYER BODY

36 The most likely options for the dryer body will be a combination of:

(1) avoidance of ignition sources;

(2) inerting;

(3) venting;

(4) suppression.

37 Normal operating conditions for the plant must be specified, the basis of safety defined and risk assessments prepared for all operations. Starting and stopping a dryer are both normal operations and hence the basis of safety and risk assessments must cover these cases as well as routine maintenance activities. All documentation should use terminology clearly. Documents should refer to the "running condition" if only the running condition is being noted and be clear that the term "normal operation" be used to cover starting, running and stopping the dryer as a normal activity.

38 Whilst measures should be taken for the avoidance of ignition sources such as metal and stones capable of causing sparking, the fact that smouldering sludge is an ignition source means that removal of ignition sources alone is unlikely to provide an appropriate level of prevention. If plant operators wish to use removal of ignition sources as the sole basis of safety for the dryer they will have to conclusively demonstrate that all such ignition sources had been removed in accordance with BS EN 1127-1 2011 Explosive Atmospheres - Explosion Prevention and Protection.

39 **Inerting** appears to be the most common basis of safety to avoid dust cloud explosions used by the UK plants. Under running conditions a depleted oxygen atmosphere is generated and maintained by steam driven off by the drying process. In the case of direct convection dryers, burner flue gases depleted in oxygen also pass through the dryer.

40 A depleted oxygen atmosphere (inert) should be maintained at all times when there could be a dust cloud present inside the dryer together with a foreseeable ignition source. The minimum oxygen level that will support an explosion is referred to as the `limiting oxygen concentration' (LOC) (see Appendix A). It is important that this is correctly measured if it is the basis of safety for the dryer. There is typically a variation in LOCs, these are often

in the range 8-14%v/v.. It is important that laboratory measurements are undertaken on a representative sample of the sludge and correctly equated to normal operating conditions within the dryer.

41 A 'maximum permissible oxygen concentration' (MPOC) that is 2% below the measured LOC is recommended. However, this safety margin may need to be increased, if for instance the speed of response of oxygen sensors is slow, the accuracy of the measurement is insufficient, or because the detector head is remote from the place where oxygen content starts to rise. Consideration also needs to be given to how quickly oxygen levels will increase, such as during an emergency shut down, in relationship to the deployment of any preventative measures. Once in operation dryers usually run at oxygen levels well below the MPOC.

42 Incidents have occurred during shut down and start up, in particular after a short shut down with hot material still present, when the LOC is likely to have been exceeded. For dryers whose basis of safety relies on depleted oxygen levels this appears to be the most hazardous part of their operation. It is important that the risk assessment addresses such foreseeable situations, which may affect the safe operation of the plant.

43 If the MPOC is exceeded then corrective action must be initiated. This may include progressive measures such as water sprays, inert gas injection and heat reduction/cooling. Intermediate alarm settings may be used to initiate specific corrective action.

44 Manufacturers/operators of equipment should establish how oxygen levels are to be controlled during all modes of operation and in particular during start up. During start up, an inert atmosphere should be established before there is a possibility of an explosive dust cloud being generated in the dryer. If necessary during start up and shut down there are a variety of ways in which an inert atmosphere could be maintained such as water sprays, steam injection, combustion gas, and nitrogen. Consideration needs to be given to whether air/gas movements and drum rotation, which could lift a dust cloud, should be restricted until an inert atmosphere is established. The risk of explosion is likely to be highest during a start up after a recent shutdown as smouldering material may provide an ignition source. Depending on the type of dryer, during shut down ambient air may be drawn in as the dryer cools thus exceeding the LOC.

45 If the dryer is stopped, the inert atmosphere will reduce smouldering. As well as providing an ignition source smouldering could produce carbon monoxide that could lead to further fire/explosion risks,. Suitable procedures should be in place to prevent smouldering in the event of the dryer stopping such as: stabilising by the addition of water or fresh sludge; removal of dried material; or cooling using the drum heating systems. Smouldering was probably the ignition source in some dryer incidents. Of particular concern are places inside the dryer where dry material is left to build up. Over time such material absorbs more heat and with an increase in oxygen levels may rapidly start to burn.

46 If inerting is the basis of safety then in order to confirm that an inert atmosphere is being maintained oxygen levels should be monitored. When selecting an oxygen detection system, it is important that the supplier confirms its suitability for use at elevated temperatures, high humidity and with likely contaminants. There are currently several types of sensor, which could be used for the detection of oxygen deficiency in sewage sludge drying plant.

47 The dryer manufacturer/operators should demonstrate that the type and location of any oxygen detector(s) is measuring the actual oxygen levels within the dryer. Locations will range from inside the dryer, to steam leaving the top of the dryer or the exit for dried product. Monitoring for an unexpected decrease in oxygen levels, which may be quite small, may also be beneficial in identifying a smouldering fire. Further reliability may be achieved, if

necessary, by using duplicate detectors. The reliability of such a detector(s) should also be confirmed by regular calibration and if necessary cleaning, also it should be designed to fail to safety, such as by giving increasingly high readings.

48 Explosion relief **venting** is currently only feasible for a fixed dryer body. The vents must be correctly positioned, sized and installed. An explosion will produce both a pressure wave and a fire ball requiring venting to a safe place, such as outside the building, by means of suitable ducting. If this is not possible, quench pipes can be used. These devices consist of a bursting disc and packing matrix. Whilst substantially reducing both the pressure and thermal energy of the explosion their outlet should be placed away from easily accessible areas such as walk ways. Consideration may also have to be given to the outlet proximity to parts of the building which could still be damaged by the reduced pressure wave exiting the quench pipe e.g. wall cladding. The manufacturers advice should be sought on suitable separation distances. It should be appreciated that that once used the quench pipe will require replacing before the plant can again become operational. Both explosion vent panels and quench pipes are ATEX equipment. They should have been 3rd party tested, and be Ex and CE marked. The basis for the design size should be documented.

49 An explosion could propagate to other parts of the plant before the vent system was able to relieve the pressure. Consideration may also have to be given to the use of partial containment measures such as explosion suppression barriers and explosion isolation valves. Pressure wave piling between vessels should also be considered.

50 Immediately after an explosion there is unlikely to be sufficient oxygen to support a fire. However as the hot gases inside the dryer cool air will be sucked in which could support a smouldering fire. Consideration will therefore have to be given to additional fire precautions.

51 Whilst the use of an oxygen detector is not required in a dryer protected by explosion relief venting one still is recommended to monitor for any unexpected decrease in oxygen levels caused by a smouldering fire. It will also provide useful information in managing any potential fire immediately after an explosion.

52 **Suppression** involves injecting a powder capable of suppressing the growing fireball into an area where an explosion has started. Expert guidance from the suppliers should be sought on the location and design of such systems. Suppression equipment is within scope of DSEAR. Suppliers of new systems should provide documentation to show they have been 3rd party assessed to comply with this Directive. They will be Ex and CE marked. Consideration will also have to be given to the means for dealing with any smouldering fires, which may arise after the explosion as most suppression systems are a single event protection.

53 When selecting safety systems designers should consider the risks arising from fires as well as dust explosions. An inert atmosphere will prevent fires as well as dust explosions (prevention) and can be used in conjunction with either relief panels or chemical suppression (mitigation). Chemical suppression, on its own, may not always cater for fire risks. Inert atmosphere safety systems will require training of operators and technicians covering working safely with inert atmospheres.

54 Failure to accurately control the process temperature may result in smouldering material passing into downstream plant. Over drying may also affect the thermal stability of the final product. Accurate and reliable temperature measurement is therefore essential.

55 Where outlet temperature is a critical control parameter consideration should be given to providing a duplicate temperature probe for initiating appropriate alarms and trips. Intermediate temperature alarm settings should

initiate control actions such as water sprays. With some dryer designs it is not practical to obtain a reliable measurement of product temperature on discharge as the material does not flow smoothly over the temperature probe. It may be appropriate to use other means such as measuring air/gas exit temperatures providing that a clear relationship has been established with product temperatures. Each type of dryer will need both process and safety instrumentation systems to be assessed for their ability to identify burning material.

56 Water has several uses within drying plant. Water sprays can be used as a means of indirectly controlling oxygen levels, in particular, at start up and during shut down. Increased water flow, through this system or a separate system, may be used for controlling a fire in the dryer. The amount of water for fire fighting will need to be determined by the thermal energy contained within the dryer.

57 A means of identifying a fire inside the dryer is required such as by a) exceeding a safety critical temperature, b) the detection of an increase in combustion gases (carbon monoxide), c) triggering an infrared detector or d) rapid fall in oxygen level. Automatic shut down should then be initiated including appropriate fire fighting systems. Such systems are likely to involve a water deluge system, as other systems such as carbon dioxide will only be effective by continuously maintaining an inert atmosphere. With the loss of the inert atmosphere, self-heating may re-ignite the now over dried sludge. In existing plants, if a deluge system is installed consideration needs to be given to the increased load on the plant and its supporting structures caused by the mass of water. Consideration should be given to the amount of sludge within the system and the potential for re-ignition a considerable time after the initial event especially when using gas deluge systems.

58 An assessment should be made of the consequences of the interruption of the flow of sludge to the dryer and if necessary measures put in place to maintain the plant in a safe condition. A reliable means of monitoring sludge flow into the dryer should be established. Rotational sensors on motors of screw feeds may not be sufficient, as they do not indicate any actual flow. Consideration should be given to whether temporary loss of flow itself should initiate corrective action (e.g. after a defined time period) or whether the system is robust enough to rely on existing controls involving maintaining an inert atmosphere and temperature reduction.

59 Critical instrumentation and systems, which have a safety function, must be identified and their reliability assessed. The standards for critical instrumentation and systems are IEC 61508 and 61511. Similarly, any emergency systems should be designed to have a high degree of reliability. For instance, if a water spray is available to indirectly decrease oxygen levels, then the water should be from a secure source such as a pressurised water system. The spray heads should be located to avoid dust ingress, which could block them. If using final effluent held in a storage vessel, its level must be monitored. If water is pumped, a high degree of reliability will be required of any associated pumping system. If under pressure, the pressure gauges should be checked regularly. The system should also be regularly tested and records of the proof testing maintained. 65 Heating systems, usually hot oil or steam, should be designed to fail to safety. If heat continues to be supplied to the dryer in an uncontrolled manner then a fire could occur, therefore a high degree of reliability is required for the temperature control systems for the heating loop. In the event of a fire, heat input should cease and if practical cooling be applied to the dryer. The type of heating medium will dictate what action can be taken. For example with hot oil system the hot oil could be sent to a dump tank and be replaced by unheated oil. Operators should be aware that the residual heat left in the dryer could lead to sludge left in the dryer self-heating.

60 Where gas burners are used to provide direct or indirect heating, appropriate burner controls will be required. Special start up procedures will be needed for direct convection dryers because of the potential for producing a dust cloud during purging. Air for combustion should be filtered or drawn from an area where dust from the

process will not be present. Guidance on appropriate burner control and operational procedures has not been included in this information document.

61 Control systems should be capable of maintaining the plant in a safe condition in the event of a major power failure. Battery back up can be used to operate the safety critical controls necessary to maintain the plant in a safe condition. A site emergency generator may also be used provided its reliability is regularly tested.

62 Settings for safety critical alarms/trips must not be accessible to unauthorised persons. Any changes may only be done by a responsible person after fully risk assessing the consequences of any such changes using an appropriate plant modification scheme. Expert advice, such as from the plant manufacturer, should be sought when applicable. Appropriate records should be kept of any such changes.

DRIED MATERIAL HANDLING

63 The options available for prevention and protection, which may be used in appropriate combinations for specified handling plant, are:

(1) inerting;

(2) avoiding ignition sources;

(3) suppression;

(4) relief venting;

(5) containment;

(6) control of temperature.

64 If **inerting** is to be the basis of safety in the product handling plant then oxygen levels must be monitored and controlled. It cannot be assumed that because an inert atmosphere is being maintained in the dryer, all connected plant is also inert. Processing plant often runs on a slightly negative pressure to prevent the escape of dust. The movement of solid product will affect airflow. Also, with age seals are likely to deteriorate allowing air ingress. An air leak at one point may be sufficient to allow the localised oxygen level to exceed the LOC. Consideration also needs to be given to start up where smouldering material may provide an ignition source for any dust cloud generated. A thorough risk assessment will be required to confirm that inerting can be used as a basis of safety.

65 **Avoiding ignition sources** in handling plant is unlikely to be acceptable as the only basis of safety, unless conclusive compliance with BS EN 1127-1 2011 can be demonstrated. Burning material may leave the dryer and pass through the plant providing an ignition source. There is therefore, the potential for fire and explosion throughout the solids handling and storage plant.

66 If plant is sited indoors and it is not possible to guarantee inerting or to relieve any explosion to a safe area then explosion **suppression** systems may be appropriate. Expert guidance should be sought on the location and design of such systems.

67 Provision of **relief venting** provides a simple solution to minimise damage. Approved methods should be used for calculating the appropriate opening pressure and size of any relief panels. These should vent to a safe place,

preferably outside the building. Where venting to a safe place is difficult, quench pipes may be used, providing these are correctly designed and sited. Consideration should be given where venting takes place within a building to potential pressure rises on the building fabric and mitigation provided accordingly. Vent openings located on the top of a vessel may require warning signs to prevent access into a hazardous area during plant operation.

68 Where **containment** is chosen then the plant must be designed to withstand the pressures likely to be generated in an explosion (see Appendix A). Containment is the option normally chosen for pelletisers. It may also be an option for other storage vessels and transport systems, which, cannot be easily fitted with relief venting.

69 Measures need to be designed into the plant to prevent the propagation of an explosion into other sections of the plant. Some simple precautions to prevent propagation of explosions though interconnected plant include the use of chokes, e.g. keeping screw conveyors full or partially filled by the removal of a flight, the use of rotary valves at discharge points, though this technique may not be totally effective. It is also possible to use explosion suppression barriers and explosion isolation valves. Where containment is being used as a basis of safety, any such plant should be designed to withstand the pressures that could be produced in the event of an explosion. For vessels relying on containment, the removal of a flight in a screw conveyor may not be adequate to stop such a pressure front passing to connected plant. The choice of which measures are adopted may also be influenced by the need to avoid condensation within the plant.

70 For dryers using fabric filters for dust separation and closed cycle conveying of the drying air, suitable preventative measures could include, a dust-measuring unit, on line differential pressure monitor installed behind the filter to check for damage to the filter, a spark detector to monitor for early signs of fire. If a set limit is exceeded, which is specific to the unit, safety measures are to be automatically activated, e.g. by water injection or inert gas supply. The risk assessment should consider the method and control of any shake down mechanism. If reverse jet filters are installed on plant using inerting as a basis of safety then an inert gas should be used or the volume of air must be kept sufficiently low so as not to exceed the MPOC. Also, automatic shake down must not be initiated when any critical alarm conditions exists in other parts of the plant.

71 As well as avoiding ignition sources designers of new plant should consider means to reduce or prevent dust becoming airborne. For example reducing free fall distances between sections of the plant. This is particularly important for plant, which produces a material that has to be pelletised.

72 Many types of equipment used in solids processing and conveying have moving parts in contact with the material. Examples are screw conveyors, bucket elevators, silo dischargers and fans. In principle such equipment may create an ignition source from frictional heating, either because it continues to turn while the flow of material is blocked, or because the normal clearances between moving parts have been lost as a result of damage, or from tramp stones or metal entering the system.

73 All such mechanical equipment in a sludge drying plant, that may contain a dust/air cloud at any time during operation, should be carefully selected to avoid ignition risks. The ignition hazards associated with the equipment should be systematically analysed. Equipment that moves only slowly, or has a low power input may present no ignition risk, even under fault conditions. 80 Drying plants use elevators for lifting dust, pellets or granules. Where elevators are used, the manufacturer must be able to demonstrate compliance with the requirements of the Supply of Machinery (Safety) Regulations 1992 as regards the avoidance of fire.

74 . 82 Bucket elevators have been the site of explosions when used to convey potentially combustible material The design may include the removal of any sources of ignition in the design of the elevator, however the designers/operators of the whole drying plant need to take into consideration the possibility of smouldering material entering the conveyor. Consideration also needs to be given to an explosion, elsewhere in the plant, propagating into the elevator. Additional protective measures may therefore be required.

75 Explosion relief venting has often been the basis of safety for bucket elevators. Explosion relief vents at the top and as close to the bottom as is practicable will usually provide adequate protection for dusts with a Kst of 150 or less although long elevators may require additional vents. Suppression systems can be used as a basis of safety, providing the elevator casing is gas tight. If inerting is to be the basis of safety, this must be monitored using an oxygen detector. Where the product contains only a small amount of dust, and evidence is provided that this level is well below the Minimum Explosible Concentration (MEC) the need for explosion vents can sometimes be avoided by forced extraction of air from the top of the elevator, appropriate dust and airflow monitoring may then be required.

76 Where the elevators have plastic parts of low electrical conductivity, it is also possible for electrostatic charge to build up if there are any conducting (metal) parts not effectively earthed. All such plant should be designed to avoid the risk of static build up, and plant controls should ensure that it does not continue to turn while the flow of solid product is blocked. Safety can be further improved by using belt-tracking controls and zero speed detection switches, locating bearings outside dust tight casings and mechanical reversing brakes.

77 Inspection windows should not be provided in parts of a plant structure which might fail in an explosion or fire. Such panels encourage operators to stand in a hazardous position. The extent of the risk will depend on the basis of safety adopted for that plant.

78 Measures are required to deal with fires. A variety of fire detectors may be used including carbon monoxide detectors and infrared spark detectors. Opening the plant should be avoided as it may let in more air possibly increasing the fire. Allowing it to burn might generate other flammable material, e.g. carbon monoxide. As any fire may have started slowly, burning material may already have entered other parts of the plant. It is important that the consequences of any fire are understood, suitable equipment is provided, operators are adequately trained and information made available to the emergency services on the risks posed by a plant fire. Any manually initiated fire fighting systems must have control points in a safe location remote from any direct or indirect risk associated with the fire.

PRODUCT STORAGE PLANT

79 If stored above a critical temperature, the product can begin to self-heat caused by a slow burning process. This critical temperature can be calculated by extrapolating the results of isothermal basket tests (see Appendix A). The size of the stored mass and its residence time will affect this temperature. A suite of basket tests has been carried out by the industry. For a 1-metre cube basket test the majority of results are above 60 $^\circ$ C. However when extrapolated to a 27 metre cube the range drops with the majority of results falling between 50-60 $^\circ$ C. The final product will vary and the self-ignition temperature can be reduced by contaminants such as oil and or ferric chloride. For this reason, in general, it is recommended that finished product should be cooled to below 40° C prior to discharge to the final product silo. However for particularly large silos onset temperatures may be even lower requiring a lower final product temperature. The control of product temperature prior to transfer to the storage silo is important in preventing fires along the supply chain due to self heating

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80 Storage silos may be designed to aid cooling and should be sized to allow for thermal dissipation of heat. Tall narrow silos are therefore preferable to short wide silos. This will also make a fire within a silo easier to control. However, if the silo is too narrow it will make the fitting of relief venting impractical. With multiple silos procedures should be in place to ensure cyclical emptying otherwise safe residence times could be exceeded. Also, in the event of prolonged plant shut down or a blockage in the silo, consideration needs to be given to the thermal stability of stored product.

81 Where significant levels of dust are likely to be produced in the storage silos, they should be designed to mitigate the effect of any explosion. The simplest protection is the provision of explosion relief panels venting to a safe area. It is for this reason that silos are better located outside the main building though it is acknowledged that with some products condensation within the silo may affect ease of discharge and the product can be heated due to thermal gain.

82 Water condensing inside a silo can lead to bacterial decomposition of the sludge. This may provide heat, which could promote a slow burn. Wet sludge can become sticky and bridge across the silo. If condensation is a problem the silo may be aspirated with small volumes of dehumidified air or large volumes of atmospheric air.

83 Storage silos should be designed to identify and contain a fire. A slow burning fire in the bulk of material is likely to be starved of oxygen and therefore produce carbon monoxide (CO). Carbon Monoxide is an explosive gas and any explosion venting should take the potential presence of this gas into consideration. A CO detector in the silo may be used as an indication of an incipient fire. The burning material at first only produces small quantities of CO. The detector will have to be set to identify low levels, which may be further diluted due to aspirated air. A rising trend of CO within a silo should be taken as an early indication that combustion may be present and appropriate action taken. The slow initial exothermic reaction is followed by a rapid exothermic reaction producing large quantities of CO. An assessment should be made from which the safety trip set point for CO detection should be set. Alarm values for CO detection are typically of the order of 100 ppm. Multi-point temperature probes can be used to monitor the stored material though it should be appreciated they will only give localised measurement and may miss a hot area.

84 An inert gas can be used to contain a fire. However, it will not necessarily extinguish it. Injection of an inert gas into the mass of stored product may only have a limited effect as thermal currents may divert the gas away from the hottest parts of the stored material though it will prevent further propagation. Immediately after injection there will be a drop in temperature due to the cold gas entering the silo. This does not mean the fire has been extinguished. Temperatures should be monitored for several hours before deciding if the fire has been brought under control. Spraying water into the silo may only produce a surface cake that will prevent further water penetration. Procedures need to be in place for dealing with a silo fire.

OFF LOADING AND BAGGING PLANT

85 All electric equipment in the off loading and/or bagging plant should be designed to appropriate standards in accordance with current UK legislation. New equipment supplied after 30 June 2003 shall comply with DSEAR.

86 A risk assessment and where necessary appropriate protective measures should be provided against the generation of static electricity; in particular, where plastic pipes or trunking, which cannot be earthed, are used to transfer product. Appropriate measures could include earthing, minimising dust levels and using conductive material in the design of the plant.

87 Depending on the levels of dust associated with the finished product, dust extraction may be required at the bagging plant. As well as protecting the operator from inhaled dust such extraction equipment will reduce the likelihood of a dust cloud explosion and can be taken into consideration during the zoning exercise required by DSEAR. Any associated dust extraction plant should have protection against the consequences of a dust explosion e.g. explosion relief venting. Further information can be found in the HSE publication HSG103 'Safe handling of combustible dusts: Precautions against explosions' (ISBN 0-7176-2726-8).

88 Measures should be in place to prevent an explosion when carrying out bulk transfers to and from road tankers. Consideration will need to be given to static discharges within the tanker and pipe work. Incidents have occurred in other industries during the pneumatic discharge of road tankers carrying flammable dusts.

89 The thermal stability of the product varies between sites. As well as the initial silo loading temperature, it is affected by the total mass of the product. Taking these factors into account the time before self-heating causes ignition can be calculated, however it should be appreciated that dried sewage sludge may not completely stabilise and will be subject to a slow temperature increase.

90 Flexible intermediate bulk container (FIBC): Lined bags have the advantage that they prevent the product becoming damp. However, there is an increased static risk during loading and any build up of heat will be more difficult to dissipate. Open weave bags do not provide weather protection for outside storage and depending on the type of product may allow the escape of dust. If the bag is to be stored outside, it should be made from ultra violet resistant material.

91 Fabric will be tensile tested to make sure it is to the correct strength in both warp and weft tapes.
UV tests are made on the fabric prior to producing the bags, tests standard ASTM G53-96. Fabric is exposed to UV Radiation for 8 hrs at 60c using UVB 313 bulbs and then four hrs humidity 50c. This is repeated for 200 hrs removing the a sample every 50 hrs. All four warp and weft samples are tensile tested against the original sample. The fabric should not loose anymore than 50% of its original strength.

A complete bag will be tested to destruction to ensure the SWL (safe working load) This standard is BS EN 21898.

TRANSPORT HAZARDS

92 The relevant legislation is the Carriage of Dangerous Goods and Transportable Pressure Equipment Regulations 2004, enforced by the Department for Transport. To come within scope of the Regulations dried sewage sludge has to be classified as dangerous for carriage. The material is known to be able to self-heat when in a large mass. However to be classified as a Class 4.2 material, that is a substance liable to spontaneous combustion due to self heating, it has to come within the definition contained in ADR. ADR is a European Agreement Concerning the International Carriage of Dangerous Goods by Road. Section 2.2.42 of ADR deals with Class 4.2 materials. Under the heading 'Classification' section 2.2.42.1.5(c) refers to

'Substances with a temperature of spontaneous combustion higher than 50 °C for a volume of 27 m^3 are not to be assigned to Class 4.2.'

93 For sites which have been able to demonstrate their product self combusts above 50 °C, they will not come within the regulations, and this removes any restrictions placed on bulk movements. For materials coming within the scope of the Regulations a packing group will have to be allocated in accordance with the regulations. This is likely to be Packing Group III: this will restrict bulk movements to road tankers.

94 For plants producing product that comes within scope of the Regulations ADR also lays down requirements regarding the nature of packaging and labelling. However there are various exemptions available under Note 1&2 of section 2.2. 42.1.5 of ADR involving testing a 10 cm cube of the material at different temperatures to assess spontaneous combustibility.

95 The industry pooled its information on self-heating property data to decide if dried sewage sludge comes within scope of the Regulations. The majority of samples were around 50 ° C for the theoretical 27 m capacity. Contamination can affect the reaction properties and there is currently no way of monitoring on line as it becomes difficult to guarantee that the product will always remain outside the Regulations. The due diligence defence in the Regulations would allow an operator to claim that they had behaved reasonably by setting up a system of regular testing. The decision as to what would be considered reasonable rests with the Department for Transport who may seek the guidance of a court. Operators must therefore decide whether their product falls, even occasionally, within the Regulations and act accordingly. Alternatively a suitable sampling system shall be in place to demonstrate exclusion from the Regulations.

STORAGE AND HANDLING

96 Adequate information on storage should be given to those storing flexible intermediate bulk containers of the finished product. Information is required on the maximum dimensions of any stack of bagged product to prevent self-heating and allow access for fire fighting. Consideration should also be given to the stack height, as the stability of the product will vary; a soft granule may be more prone to compression leading to stack collapse.

97 If the material is to be stored in bulk in floor piles within buildings suitable handling methods should be used to prevent dust generation. Such bulk storage will also be subject to self-heating similar to silo storage facilities. Segregation may also be required from other incompatible materials. Consideration will also have to be given to any occupational risks from dust produced during handling. If stored in bulk in the open rain may help form a non-load bearing crust on the surface. Depending on public access warning signs and simple barrier fencing may be required, to prevent access to stored materials. Hazard Data Sheets should be available to the end user giving details on handling the product.

SAFE SYSTEMS OF WORK

98 Adequate safe systems of work (e.g. permit to work and competent persons under Confined Space Regulations) are required for entry into any confined spaces in both plant vessels and the plant building due to the possible presence of an inert atmosphere. This is particularly important if nitrogen or carbon dioxide is to be used for inerting and applies not just to obvious structures such as the dryer, dust collector, etc but also any low floor areas such as sumps.

99 Similarly, due to the fire/explosion risk from the dried product any hot work should be carefully controlled by a safe system of work, for example a permit to work as a high risk activity under DSEAR. Plant, which contains dried material, must be thoroughly cleaned prior to hot work such as welding. It must be appreciated that even a small amount of hot charred material may be an ignition source for a fire/explosion further along the plant.

100 Adequate safe systems of work will also be required for maintenance of mechanical and electrical plant. The risk assessment should identify foreseeable risks from accessing mechanical plant and appropriate measures adopted to minimise risk. In particular operators may not be familiar with screw conveyors: locked/secure isolation of electrical power must be achieved before removing the covers of a screw conveyor. Similarly rotary valves are not normally found on water treatment sites and operators may not be familiar with the risk of amputation as the slow moving blades may not be visible. Any work on such rotary valves must be under a strict safe system of work. If either type of plant is opened regularly then consideration should be given to interlocking. Also, screw conveyors often have inspection hatches with an internal mesh panel. Regular checks should be made when the plant is not running to ensure such mesh panels are in place.

TRAINING

101 A high level of training is required for all operators and their supervisors who may conduct work on or around this type of plant and associated equipment. Such training as well as covering the normal operation of the plant should cover emergency situations. Appropriate refresher training and emergency exercises should also be provided. Operators must be able to interpret the information provided by instrumentation and alarms to take the correct remedial measures. A basic understanding of the properties of dried sludge is also necessary in particular when deciding on appropriate action to deal with a fire.

PLANT MODIFICATION PROCEDURES

102 Any changes to the plant or its operating parameters, which might affect its safe operation, should be subject to a plant modification scheme. It is important that all persons who may have a useful input are consulted including the original designers of the plant where possible. All such changes should be recorded. Any modification procedures must take into account DSEAR and the Basis of Safety. A valuable tool to assist in this process is to subject any changes to plant, design or operation to a Hazard and Operability (HAZOP) study

OCCUPATIONAL HEALTH RISKS

103 There is limited information to establish whether there is a health risk from dried sewage sludge dust. However as plants normally pasteurise the sludge some limited biological activity will be present. Dried sewage sludge may contain allergens, which could give rise to respiratory problems.

104 Studies have been carried out on endo-toxins, breakdown products from the cell walls of gram-negative bacteria. Exposure to sufficiently high concentrations can cause a variety of symptoms. The risk is estimated to be low in normal plant operation, however, additional care should be exercised during plant maintenance where there could be exposure to high concentrations of dust. There appears to be little risk from bacteria, viruses and protozoa provided an appropriate temperature and residence time achieves pasteurisation during drying. Finished product can be re-colonised by opportunistic bacteria from the air or from contact with handling plant. Wetting of the finished product may also encourage bacterial growth, however, this will be a different population from that found in the original sludge making it difficult to assess the risk.

105 It is therefore preferable to minimise contact with dried sludge dust by the use of suitable personal protective equipment. Work practices should be adopted which minimise dust generation. Industrial vacuum cleaners with appropriate air filters should be used, in particular, for cleaning down dust-laden plant prior to maintenance. Also

a simple occupational health monitoring system would be appropriate involving a medical questionnaire with the possible use of lung function tests.

106 As moist sludge may grow a range of opportunistic bacteria, operators should be instructed on appropriate standards of personal and plant hygiene. If the hands have been contaminated, operators should avoid rubbing their nose or mouth with their hands. After working with dried sludge, hands and forearms should be thoroughly washed with soap and water. This is particularly important before taking any food or drink, or before smoking. If clothes or boots have become contaminated they should be washed thoroughly. Used protective clothing should be placed in a contaminated clothing container for disposal or laundering. Any cut, scratch, or abrasion of the skin should be washed immediately and covered by an appropriate waterproof dressing.

APPENDIX A

PROPERTIES OF SEWAGE SLUDGE

Current HSE guidance can be found in the publication entitled 'Safe handling of combustible dusts: Precautions against explosions' HSG103 ISBN ref 0-7176-2726-8. Other useful guidance includes the IChemE books, ‘Dust explosion prevention and protection – a practical guide, Edited by John Barton, 2002 ISBN 0 85295 410 7 and Prevention of fires and explosions in dryers. John Abbott, second edition 1990 ISBN 0 85295 257 0.

1 In order to design an adequate level of safety into a plant the critical properties of the material being handled must be identified and then measured. Such measurements are only of benefit if they affect the design and/or operating parameters of the plant.

2 A variety of sludge properties are detailed below. The figures entered have been obtained from various sources. Although some of the measured properties are similar for different sludge there are also significant variations. It is essential to identify the critical ignition properties, which contribute to the determination of the basis of safety selected in different parts of the plant. Most of the tests below are detailed in national and European test standards.

3 **Minimum Explosible Concentrations** (MEC) for sludge has been measured as low as 60g/m^3, which is a typical value for many dusts. It is likely that this figure will be exceeded somewhere within a sludge drying plant. All dried sludge is likely to exceed the explosible concentration in some areas, while in others there may be dust present but not in sufficient quantities to pose a risk of ignition. In these areas calculation of the dust cloud concentration may be useful in helping to determine if a hazardous area zone 22 is necessary. In some parts of the plant dust clouds may only be present following failure of a seal or system, e.g. a tear in a dust filter bag, enabling dust to pass into an area where in normal operating circumstances there would not be any dust present in quantities significant for ignition, again knowledge of the MEC may be useful. MEC figures may be needed by the designers of protection systems for processing plant. Due to the variation of MEC and the likely variation of dust concentrations in different parts of the plant trying to operate below the MEC is unlikely to be an acceptable basis of safety on its own, though may be suitable in specific process areas or plant, depending on the risk assessment.

4 The **explosion constant (K_{st})**, which for a variety of sewage dusts has been measured between 50 and 200 bar m s^{-1}, though a typical range is between 80 – 150 bar m s^{-1}, and classifies the material as a class St1 explosible dust. The variation of K_{st} effects the rate of pressure rise during the explosion and hence is necessary

to be measured where explosion protection systems are required such as suppression, relief venting, containment and explosion isolation involving slam shut valves. Explosion **over pressures (P_{max})** in the range of 6-9 bar have been measured which needs to be known if an explosion is to be contained and also in designing explosion relief venting.

5 The **minimum ignition energy (MIE)** for dusts is known to vary with particle size and moisture content. There will be a variation in particle size between and within plants. Sufficient energy sources in excess of the MIE will be present in the dryer itself but in other areas of the process, such as dust filters, some bagging plants and if pneumatic conveying is undertaken, it is necessary to know the susceptibility of the dust to ignition from static discharges when conducting a risk assessment. Measure MIE values in sewage sludge dust samples vary enormously with some having low MIE values and others not being ignited at these spark energies (<1000mJ) at all.

6 Data for **minimum ignition temperatures (MIT)** ranges from 360-550^{0}C. This parameter measures the temperature at which a dust cloud in contact with a hot surface or gas will ignite. This becomes a relevant factor for plants having high dryer gas inlet temperature where dust clouds may be presen (rotary convection dryers) t.

7 Dust **layer ignition temperatures (LIT)** range from 160-375^{0}C for a 5mm layer. It is a measure of the temperature of ignition where a dust layer has one surface in contact with a hot surface and one in a comparatively cool ambient environment, such as a layer of dust on the outer surface of a dryer or other item of equipment within a process building. Outside the plant dust should not be allowed to accumulate on hot surfaces in order to reduce the risk of ignition and also reduce the possibility of a secondary explosion. Guidance on choosing appropriate electrical equipment can be found in BS EN 60079 – 14 Explosive atmospheres. Electrical installations design, selection and erection . LIT is of use to in undertaking the fire/explosion risk assessment and to aid initial and on-going selection of suitable electrical equipment.

8 The **powder layer test** can be useful in determining the ignition temperature of dust layers inside the dryer, where one surface is in contact with the dryer and one surface has hot gas circulating above it. The test is described in the IChemE dryers guide and may be of use when conducting the risk assessment of a dryer where dust layers are present of a depth of around 15mm thickness.

9 For through-circulation band and fluidised bed dryers the **aerated powder test**, described in the IChemE dryer guide can be used to determine the temperature at which the material ignites inside the dryer which is of use at design stage and also when conducting the risk assessment.

10 **Burning numbers (BZ)** may be of assistance when conducting a risk assessmentas it measures the burning behaviour of a fire in a deposit by measuring the speed of propagation The BZ number would give a feel for the level of risk and it may vary for a given plant due to variations of sewage sludge particle size and moisture content.

11 There appears to be considerable variation in thermal stability data from small-scale **differential scanning calorimetry** and **thermal gravimetric analysis**. There are also doubts as to how representative the figures are for actual plant conditions. It is therefore questionable whether they can provide information, which may be used to determine safe operating limits.

12 Information is available from **isothermal self-heating basket tests**, which will give a more realistic profile of thermal decomposition both inside hot process equipment such as dryers and during bulk storage. Information

from laboratory scale basket tests can be scaled up to consider the heating effects on the material deposits as found in the dryer process. This can be used in the design of conveyors and silos used for cooling and also indicate safe storage volumes and times for material at a given temperature. If the finished material is in granules or pellets it may affect the results of such tests. Site-specific isothermal basket tests are therefore likely to be of value for both the design of the plant and for guidance on the storage of the finished product. Extrapolated basket tests can be used to decide if the material is a self-heating substance as defined within the Carriage of Dangerous Goods and Transportable Pressure Equipment Regulations 2004.

13 The **limiting oxygen concentration (LOC)** determines the level of oxygen required for a dust cloud to ignite. Limiting oxygen levels are used as a safety measure in parts of all sewage sludge dryers . Typical values are between 8 – 14%. For plants using inerting as a basis of safety the LOC should be measured. As particle size affects the LOC (and all other dust cloud ignition tests) care needs to be exercised to obtain a representative sample.

Normally the LOC is measured at ambient temperature using nitrogen as the inerting gas. Past research commissioned by the HSE compared LOC results for steam at 100 ^{0} C, nitrogen at both ambient and 100 ^{0} C, and carbon dioxide at ambient. An increase in temperature to 100 ^{0} C reduced the LOC for nitrogen by about 1.5%.

The inerting media chosen will also give different LOC results. By way of example using the same sample at 100 ^{0} C the following results were found LOC (nitrogen/100 ^{0} C) 6.5% and LOC (steam/100 ^{0} C) 10.5%. This would mean that a laboratory LOC (nitrogen/ambient) 8.0% equates to LOC (steam/100 ^{0} C) 10.5%. This makes steam the best material for inerting purposes, as it will allow a higher oxygen concentration. It should be appreciated that these figures are based on a limited study using sludge from a single plant. Further information would need to be gathered to confirm if these ratios are constant for different sludges.

When quoting LOC figures it is therefore important to specify the temperature and inerting material used in the testing. Where samples from a specific plant can be shown to behave predictably for a given inerting media and up to the maximum temperature they will be exposed to, if any further testing is needed, ambient temperature using nitrogen should be satisfactory as the laboratory figure can be equated to the operating LOC using the relationships discovered in teh research project described above .

Using the example above a laboratory LOC carried out at ambient temperature using nitrogen produces an 8% LOC. If the plant operates at 100 ^{0} C this will reduce the LOC to 6.5%. If steam is the inerting media the expected LOC will increase by 4% to 10.5%. However at start up and shut down if nitrogen is used as an inerting gas a dust cloud explosion is possible at oxygen levels above 6.5% especially if the dryer is still at operating temperature.

For plants using inerting as a basis of safety LOC measurements should be carried out until a clear pattern is established. The LOC figures may be consistent or a seasonal variation may be observed. When considering the frequency for measuring the LOC consideration should be given to:

1) the variation of previous LOC figures;

2) the margin between the LOC (steam) and normal operating conditions, including any inerting gas used at start up and shut down using the appropriate inert gas LOC;

3) any changes in the source or processing of the sludge prior to drying.

14 Equally, the operational safety margin is not consistent with some guidance suggesting that the **maximum permissible oxygen concentration (MPOC)** for an unmonitored plant should be 60% of the LOC and other guidance allowing a reduction of 2% below LOC. HSE currently recommends an MPOC of not less than 2% below the LOC (measured with nitrogen at ambient temperature), with higher risk plants requiring a bigger margin. Higher risk plants are those which during an emergency shut down can experience a rapid rise in oxygen levels, eroding the safety margin between the LOC and the MPOC.

APPENDIX B

RELEVANT LEGISLATION

(Where directive numbers have been given these refer to the principal directive which may have been subsequently amended leading to amendments with UK legislation, also parts from other directives may have been implemented within existing UK legislation. This is not intended as a complete list of relevant UK legislation but only includes legislation mentioned within this Information Document. Commonly used UK abbreviations have also been included in brackets.)

1 **The Health and Safety at Work etc Act 1974 (HSW Act)** 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. In addition, equipment suppliers or manufacturers have a duty under section 6 of the HSW Act to ensure, so far as is reasonably practicable, that the equipment is safe for use at work. Where suppliers or manufacturers know that their equipment will be used for handling flammable dusts, they have a duty to design and construct it with suitable precautionary measures to prevent and protect against explosions. Written advice and warnings about the safe use of the equipment may also be necessary. Similarly, suppliers or manufacturers of flammable dusts that can explode, have a duty to inform anyone to whom the substance is supplied about its properties. This may include the results of tests for explosibility.

2 **The Management of Health and Safety at Work Regulations 1999** (Management Regs)(Framework Directive 89/391/EEC) include provisions that every employer should make an assessment of the health and safety risks arising from the work activity. Where flammable dusts/self heating substances are handled in quantity, the possible causes and consequences of a fire or explosion involving the material are matters to be covered by the assessment.

3 **The Dangerous Substances and Explosive Atmosphere Regulations 2002** (DSEAR)(Safety risks from chemicals at work Directives 98/24 and 99/92) requires that risk should be eliminated or reduced as far as is reasonably practicable. The regulations also require hazardous area classification of plants handling explosible dusts, and that areas where explosive atmospheres may occur should be marked at their points of entry. The requirements are set out in more detail in a supporting approved code of practice.

4 **The Provision and Use of Work Equipment Regulations 1998** (PPE Regs)(Personal Protection Equipment directive 89/686 as amended) 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.

5 **The Workplace (Health, Safety and Welfare) Regulations 1992** (Workplace Regs)(Work Equipment Directive 89/655) 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.

6 **The Control of Substances Hazardous to Health Regulations 2002** (COSHH)(Protection of workers from risks related to the exposure to chemical, physical and biological agents at work Directive 80/1107) controls the health affects that many fine dusts can cause to anyone exposed to them. The COSHH assessment is likely to consider how fine dust can become airborne, and through this identify potential explosion risks.

7 **The Supply of Machinery (Safety) Regulations 2002** (Machinery Supply Regs)(Machinery Directive 89/392). These regulations lay down the essential health and safety requirements, define responsible person, the contents of a technical file and include the different conformity assessment procedures which manufacturers must follow in order to fix a CE mark of conformity to their products.

8 **The Equipment and Protective Systems for Use in Potentially Explosive Atmosphere Regulations 1996 (EPS)**(ATEX Directive 94/9)**.** These regulations 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 to 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. The regulations describe 3 categories of equipment, with the different categories intended for use in the different zones.