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To
AFQ Inspectors
SG Specialist Inspectors

SEWAGE SLUDGE DRYING PLANT

This 2-part OC introduces an **information document (ID)** on the control of risks from sewage sludge drying plants together with information on product handling. The attached ID can be used as a basis for inspecting existing and new plants. Copies can be made available to interested parties outside HSE.

INTRODUCTION

1 There has been a rapid increase in sewage sludge drying plants in the UK over the last few years. Currently there are over 20 fully operational plants and a further 10 pilot plants and commercial forecasts expect this growth to continue. The drying process produces an explosible dust and the finished product can self heat leading to a smouldering fire. Four of these plants have experienced dust cloud explosions, fortunately without causing injury. The attached ID describes the process and gives advice on precautions.

FURTHER GUIDANCE

2 Whilst the hazards associated with this type of plant are not new, the apparent variability of sewage sludges has raised concerns about some of the design criteria for the plants. Given the current rate of growth of new plants, it has been decided not to delay guidance until these matters are fully resolved. Within the ID mention is made of problems currently being researched by HSE. It is expected that the ID will be revised towards the end of 2001 to take account of the research findings. Additional information on fluidised bed dryers and belt dryers will also be included.

BENCHMARK STANDARD

3 The ID identifies hazards common to all types of drum dryers. The actual risk will vary depending on the particular plant design; for instance a dust cloud is likely to exist in the plant at some stage. However, the size of the cloud will vary depending on the vessel in which it occurs. In other lower risk parts of the plant smouldering material may cause a fire which can spread to sections of the plant having high dust concentrations. It is therefore better to assess the plant in sections, eg dryer, dust collector, bucket elevator. Specialist inspector assistance is likely to be needed to provide an assessment of risk to establish the appropriate risk gap for a particular deficiency.

ACTION BY INSPECTORS

4 Inspectors should be aware of the processes and risks described in this OC and the attached ID and provide copies to anyone requiring advice.

5 It is recommended that specialist group assistance be obtained when carrying out inspections of sewage sludge drying plant.

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Health and Safety Executive **Information Document HSE 847/9**

CONTROL OF HEALTH AND SAFETY RISKS AT SEWAGE SLUDGE DRYING PLANTS

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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 The implementation of the EU Urban Wastewater Directive has resulted in an increase in the number of sewage treatment works providing full treatment of sewage. With the cessation of sewage sludge dumping at sea many sewage

undertakings have had to find alternative means for disposal. Whilst landfill for untreated sewage sludge is an option, associated charges make this expensive.

3 Recycling to land is still currently the favoured option as sewage sludge is a valuable fertiliser. Raw liquid sludge and raw dewatered sludge cake can no longer be applied to farmland as a result of an agreement between the British Retail Consortium, the farming industry and the water industry. This takes the form of a matrix which details the type of sludge treatment and the type of crops to which such sludge can be applied.

4 Sewage treatment works without immediate access to agricultural land have to transport treated sludge considerable distances with the associated transport costs. As sludge is only applied to the land at certain times of the year, this would mean sewage treatment works having very large storage facilities.

5 These pressures have led to the rapid increase in the number of sludge drying plants in the UK. Dried sludge in the form of granules/pellets has the advantage of being easily stored and transportation costs, when compared with liquid distribution, are reduced. Sewage sludge after mechanical dewatering contains around 30% dry solids as compared to dried sludge normally 90-95% dry solids. Dried sludge can also be more conveniently handled by farmers and there is considerably less risk of infection when compared to the older methods for handling raw sewage. In the form of granules/pellets other possible disposal routes can be explored such as a fuel in power stations, for fuel gas production and use in building materials.

TREATMENT PROCESS

6 Sewage sludge is primarily derived from human wastewater which also contains paper fibres, waste food, 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. Industrial wastewater discharges to sewers are regulated by the water company or those with responsibilities delegated from the water company such as a local authority. 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 petrol spills. Other materials may be introduced as part of the sewage treatment process, which in turn may affect the drying plant such as ferric chloride which prevents the sludge from becoming septic.

7 Sewage treatment consists of 3 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 get through this stage and must 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.' This raw sludge can then be fed directly to a dryer or to a digester for further digestion by anaerobic or aerobic bacteria after which it can be fed to a dryer. The digestion process produces methane and carbon dioxide. If raw sludge is stored it will putrify become acidic producing hydrogen sulphide and other volatile sulphur compounds.

8 Prior to drying the sludge is dewatered, aided by the addition of a polymer to bind the sludge together. Free water is removed by mechanical means such as a belt press or centrifuge to achieve around 30% dry solids. Hydrogen sulphide and ammonia may be released during this process requiring local exhaust ventilation. The material produced is referred to as sludge cake, which may be stored for later transportation to another site for drying.

9 The sludge now passes to a dryer for removal of the remaining water to produce the finished product, normally 90-95% dry solids. Drying plants can operate on digested, raw or mixed sludge. The choice of which type of sludge to use in a dryer is normally an economic decision usually involving existing plant for example if a digestor is already available on site the dryer can be designed to deal with digested 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. At 30% dry solids the sludge becomes thixotropic (sticky phase). By the time it reaches 60% dry solids the sludge begins to flow again. This sticky phase makes the sludge difficult to handle through the driers. To overcome this a proportion of the dried granules and the fines (under sized material) are recycled and mixed with the dewatered cake. The addition of 90% dry solids material with 30% dry solids cake gives a mixture with dry solids greater than the 60% sticky phase barrier. This process of back mixing has the added benefit of formulating the granular structure. There are drying systems that achieve granulation without such back mixing. Such systems are specially designed to overcome the sticky phase without adjusting the inlet dry solids to greater than 60%.

10 The amount of dust produced in the dryer and later processing plant will be affected by the method of drying. In all the drying processes currently operating in the UK dust can occur within some part of the plant. Sewage dust is classified as an St1 explosible dust. The St system is a classification system for combustible dusts based on the explosion constant for the dust. For a dust be classified as St1 this 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 drier, dust collection and handling plant, pelletiser and final product discharge plant. Once

dried, material in the plant can also self heat leading to ignition and a slow burn which may be accelerated with the ingress of additional air into the plant. Dried product in storage may also self ignite. Dryer explosions/fires and fires in associated processing plant have occurred in UK plants. To date none have caused injury but there has been plant damage.

SLUDGE SPECIFICATION

11 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 must include seasonal variations and reasonably foreseeable contamination. The specification for these safety critical properties must be agreed between the supplier and user at the design stage and reviewed during plant commissioning. The specifications may indicate a safe operating range or set figures, which must not be exceeded without being considered as part of a plant modification scheme. An appendix has been added to this information document to help identify appropriate safety critical properties of sewage sludge.

12 A risk assessment needs to be carried out for reasonably foreseeable contaminants which could enter the plant. For example petrol spills entering a sewage treatment works are quite forseeable, 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 significant risk. Any procedures put in place to deal with such an event should be reliable and regularly checked.

13 Once the plant is in operation the user must ensure that quality control procedures are in place to pick up any variations in the sewage sludge being sent to the plant, which could affect its safe operation. A further assessment will be required if sludge from other sources is to be imported to the plant, such as by tanker. Personnel controlling the sewage network, eg 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. For instance, the connection of an existing sewage network to the sewage treatment works may bring in an industrial contaminant not assessed when the dryer was designed.

14 Some drying plants have the facility to accept sludge cake from other sewage treatment works. Again quality control measures will be required to ensure that such material can be dried safely. For instance, tramp metal and stones can produce sparks within the drying plant. Sludge cake could introduce such material into the dryer if the sewage liquor is not screened at source to the standard required for the drying plant.

INDUSTRIAL STANDARDS

15 Currently no industry standards exist for sewage sludge drying plants. BS EN 12255-8 *Wastewater Treatment Plants*, available in draft, only deals with sludge treatment and storage. However this does not cover in any detail, appropriate safety requirements for sludge drying plant. There is also in existence, a draft DIN standard E DIN 19569-10: 2000-01 *Sewage Treatment Plants*, Part 10: *Specific Principles for Thermal Drying Equipment*. The principals contained in the draft DIN are also covered in this information document.

16 The Explosive Atmospheres Directive 1999/92/EC (Equipment and Protective Systems Intended for Use in Explosive Atmospheres Regulations 1996), on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres (the ATEX User Directive) and, the safety aspects of the Chemical Agents Directive 98/24/EC on minimum requirements for improving the safety and health protection of workers, will both be applicable to the operators of sewage sludge drying plant when implemented in the UK. Suppliers will have to comply with the equivalent ATEX Equipment Directive 94/9/EC as regards new equipment supplied after 30 June 2003. No attempt is made here to detail all existing UK Health & Safety legislation applicable to dryers.

RISK ASSESSMENT

17 Risk assessments need to be completed at key stages throughout the feasibility, design, commissioning and operation of the plant. Safety critical properties 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. 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, eg blockage removal.

ELECTRICAL EQUIPMENT

18 The installation as a whole should comply with the requirements of BS 7671 *Requirements for Electrical Installations*. Electrical equipment should be chosen with appropriate protection against dust entry, and the surface temperature rating should be low enough to prevent the ignition of dust deposits on the equipment.

19 When carrying out a risk assessment to comply with ATEX Directive 1999/92/EC, a potentially flammable area zone classification exercise should be carried out. The selection of electrical equipment is directly related to the outcome of this exercise unless otherwise specified when the risk assessment is recorded. (BS EN 50281-3 *Electrical apparatus for use in the presence of combustible dusts* will soon be available; current advice can be found in IEC 61241-3). Such equipment must be selected on the basis of its maximum operating temperature being compatible with the minimum ignition temperature and layer ignition

temperature of the dust likely to be present. If flammable gas, eg methane could be present, the appropriate parts of BS EN 60079-10 *Classification of Hazardous Areas* provide suitable guidance. In some cases third party certification of equipment by a 'Notified Body' will be necessary to comply with the ATEX Directive. The ATEX Directive also applies to other sources of ignition such as mechanical and hot surfaces.

PRE-DRYER STORAGE

20 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 and diesel 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) iron content - the sludge should be analysed for iron content as part of an ongoing screening programme. Where the levels are abnormally high ignition tests should be carried out to determine if this has reduced the ignition temperature for the dried sludge. Iron can be present for a variety of reasons such as:

(a) where iron salts are used as coagulants at drinking water treatment plants and the resulting sludge is tankered to the sewage treatment works for treatment or discharged to the sewer system;

(b) where iron salts are used to precipitate phosphates from sewage in nutrient removal plants;

(c) where iron salts are used for odour control purposes; and

(d) where industrial effluent discharges to sewer have a high iron content.

Hydrogen sulphide, together with iron, may have to be considered due to the formation of iron sulphide, which is pyrophoric.

(4) major sources of chemical contamination which could come from a leak at a chemical works and may require specific detectors; and

(5) stones or pieces of metal which could cause an ignition source or jam moving machinery and need to be removed, eg by sieves, strain presses, narrow aperture pump feeds, etc

DRYER DESIGN

21 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.

22 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.

23 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.

24 There are various types of thermal dryers operating in the UK including:

(1) horizontal drum dryers (eg rotary dryers, paddle dryers and thin film dryers);

(2) vertical tray dryer-pelletisers;

(3) conveyor belt dryers; and

(4) fluidised bed dryers.

25 At present the information document only deals with horizontal drum dryers and vertical tray dryers. It is hoped to add sections later on conveyor belt dryers and fluidised bed dryers.

26 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 450 ^{0}C. As rotary dryers should not be used for sewage sludge in the adhesive phase (40-60% dry solids) mechanically dewatered sludge is mixed with dried product (normally under/over sized) to achieve fluidity before it is fed into the drying drum.

27 In a paddle dryer a heated paddle or series of discs rotates in a mass of sludge held in a heated stationary chamber with dried material cascading from the end of the dryer.

28 With a thin film dryer sludge is spread onto the outer heated wall of the dryer by a rotor. The drier can be used to dry sludge to over 90% dry solids but its main advantage is that it can handle the difficult sticky phase between 40-60% dry solids

without back mixing. A single stage thin film unit is often used in conjunction with a paddle drier to take the sludge from 60% to over 90% dry solids.

29 In a vertical tray dryer, recirculated 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.

PRINCIPLES OF PLANT SAFETY

30 All suppliers of sludge drying plant must comply with the essential health and safety requirements contained in the Machinery Directive 89/392. It is a requirement of any operator of a sludge drying plant to carry out a suitable and sufficient risk assessment. In addition to existing UK legislation directive 1999/92/EC requires that employers classify areas where accumulations of combustible dust and gases may occur and justify their selection of equipment used in classified areas.

31 The risk of a fire/explosion can be reduced by:

(1) avoiding a flammable atmosphere;

(2) inerting;

(3) avoidance of ignition sources.

32 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.

33 Manufacturers must first identify where a flammable atmosphere could occur, taking into account all likely operating scenarios, ie start up, running, emergency shut down, restart. They must then select the most appropriate 'Basis of Safety' for each part of the plant.

DRYING PLANT SAFETY

34 The most likely options for the dryer will be:

(1) removal of ignition sources;

(2) inerting; and

(3) suppression.

35 This does not preclude the use of containment or venting as a basis of dryer safety. Currently HSE is not aware of any dryers operating on either of these principles.

36 Whilst measures should be taken to remove potential sources of ignition such as metal and stones capable of causing sparking, the fact that smouldering sludge is an ignition source means that removal of ignition sources is unlikely to provide an appropriate level of prevention. If plant operators wish to use removal of ignition sources as a principal of dryer safety they would have to conclusively demonstrate that all such ignition sources had been removed in accordance with BS EN 1127-1 1998 *Explosive Atmospheres - Explosion Prevention and Protection*.

37 Suppression has been put forward as the basis of safety on at least one plant. This involves injecting under pressure, an inerting material into the dryer. It is likely only to be applicable to certain smaller dryers.

38 Inerting appears to be the most common basis of safety to avoid dust cloud explosions used by the UK plants currently known to HSE. Under normal operating conditions the inert atmosphere is generated and maintained by steam driven off by the drying process. In the case of direct convection dryers, burner flue gases also pass through the dryer.

39 A depleted oxygen atmosphere (inert) should be maintained at all times when there could be a dust cloud present inside the dryer. The minimum oxygen level that will support an explosion is referred to as the 'limiting oxygen concentration' (LOC) (see appendix). It is important that this is correctly measured if it is the basis of safety for the dryer. There is currently a wide variation in reported LOCs from 5-15% v/v. These are usually measured in a nitrogen or carbon dioxide atmosphere. HSE has commissioned research work to measure LOCs at the high temperatures and humidity which are more representative of the conditions in dryers.

40 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. Once in operation dryers usually run at oxygen levels well below the MPOC. Some incidents have occurred during start up after a short shut down when the MPOC is likely to have been exceeded. It is important that the risk assessment addresses such foreseeable situations, which may affect the safe operation of the plant.

41 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.

42 Manufacturers of equipment should establish how oxygen levels are to be controlled both during normal and abnormal operation and in particular during start up. During start up, an inert atmosphere should be established before there is a possibility of an explosible dust cloud being generated in the drier. If necessary there are a variety of ways in which an inert atmosphere could be achieved 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 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, ambient air may be drawn in as it cools thus exceeding the LOC (paragraph 39 refers).

43 If the dryer is stopped, the inert atmosphere will reduce smouldering although insufficient information is currently available on minimum oxygen levels required to control smouldering. As well as providing an ignition source smouldering could produce carbon monoxide that could lead to further fire/explosion risks, though this would require a high concentration of gas (125,000-740,000 ppm). 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.

44 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. HSE is currently looking into the reliability of such detectors for use in dryers.

45 The dryer manufacturer must be able to 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. Further reliability may be achieved, if necessary, by using duplicate detectors. The reliability of such a detector(s) must also be confirmed by regular calibration and if necessary cleaning. The detectors used should be designed to fail to safety, such as by giving increasingly high readings.

46 The outlet temperature of the dryer determines the percentage dry solids of the dried sludge and as such may control the sludge inlet flow to the drier and/or the supply of heat. Failure to accurately control the temperature may result in smouldering material passing into downstream plant. Overdrying may also affect the thermal stability of the final product. Accurate and reliable temperature measurement is therefore essential.

47 The simplest means of measuring product outlet temperature is by a thermocouple. Where practical, 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 the 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. Cooling systems in the processing plant can also have alarms fitted to indicate when excessive cooling is required. Each type of dryer will need both process and safety instrumentation systems to be assessed for their ability to identify burning material.

48 Water has several uses within drying plant. Water sprays can be used as a means of 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 fighting a fire in the dryer. The amount of water for fire fighting will be determined by the mass of sludge that needs to be soaked.

49 Means of identifying a fire inside the dryer are required such as by exceeding a safety critical temperature, the detection of combustion gases (not applicable on convection dryers using combustion gases) or an infrared detector. 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 overdried 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

50 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 screw feeds are not sufficient, as they do not indicate any actual flow. Consideration should be given to whether temporary loss of flow itself should initiate corrective action (eg 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.

51 Critical instrumentation, which has a safety function, must be identified and its reliability assessed. Similarly, any emergency systems should be designed to have a high degree of reliability. For instance, if a water spray is available to decrease oxygen levels, then the water should be from a guaranteed 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. Any manual valves used to isolate the system should be locked open with the key kept by a responsible manager. The system should also be regularly tested. A qualitative risk analysis, eg HAZOP should be carried out on such critical systems.

52 Heating systems 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. In the event of a fire, heat input should cease and if practical cooling be applied to the

dryer. Operators should be aware that leaving material in the dryer could lead to self-heating.

53 Where gas burners are used to provide direct or indirect heating , appropriate burner controls will be required. Also purging should be carried out prior to burner ignition. Special start up will be needed for direct convection dryers. Guidance on appropriate burner control and operational procedures has not been included in this information document.

54 Control systems should be capable of bringing the plant into 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 get the plant into a safe condition. A site emergency generator may also be used provided its reliability is regularly tested.

55 Settings for safety critical alarms/trips must not be accessible to plant operators. Any changes may only be done by a responsible manager after fully risk assessing the consequences of any such changes using an appropriate plant modification scheme. Appropriate records should be kept of any such changes. It would also be advisable to discuss any such changes with the plant manufacturer.

PRODUCT HANDLING PLANT SAFETY

56 This section refers to dust collectors, fines storage silos, sieves, pelletisers, conveyor systems, eg screw conveyors and bucket elevators.

57 The options available for prevention and protection in handling plant are:

(1) inerting;

(2) avoiding ignition sources;

(3) suppression;

(4) relief venting; and

(5) containment.

58 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. As a minimum, a further oxygen detector will be required near the exhaust fan. 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 oxygen level to exceed the LOC (paragraph 39). 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 a basis of safety.

59 The avoidance of ignition sources in handling plant is unlikely to be acceptable as the only basis of safety, unless conclusive compliance with BS EN 1127-1 (paragraph 36) 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.

60 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. The design of these systems must ensure that injection of suppressant is activated before the flame front reaches the protected vessel. Expert guidance from the suppliers should be sought on the location and design of such systems

61 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 , special flame arrestors may be used.

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

63 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 , eg keeping screw conveyors full or partially filled by the removal of a flight, the use of rotary valves at discharge points. 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 be influenced by the need to avoid condensation within the plant.

64 For convection dryers using fabric filters for dust separation and closed cycle conveying of the drying air, a dust-measuring unit or on line differential pressure monitor should be installed behind the filter to check for damage to the filter. It would also be appropriate to monitor for the early indications of a fire such as by using a spark detector. If a set limit is exceeded, which is specific to the unit, safety measures are to be automatically activated, eg 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 (paragraph 40). Also, automatic shake down must not be initiated when any critical alarm conditions exists in other parts of the plant.

65 Where bucket elevators are used, the manufacturer must be able to demonstrate they have complied with the requirements of the Machinery Directive 89/392/EEC as regards the avoidance of fire. This section does not apply to chain elevators, which in their vertical position have little free volume. Hybrid elevators using combinations of chains and buckets will have to be assessed individually. Normal bucket elevators have been responsible for explosions when used to convey a potentially combustible dust. Drying plants use them for lifting dust, pellets or granules. Historically in the UK, explosion relief venting has been the basis of safety for bucket elevators. Suppression systems can also be used as a basis of safety. New guidance on appropriate levels of explosion relief for bucket elevators will be available shortly from HSE. 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, 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 also be required. Safety can be further improved by eliminating static discharge, using belt-tracking controls and zero speed detection switches, locating bearings outside dust tight casings and mechanical reversing brakes. However, the risk of ignition from burning material may still remain and therefore the elimination of ignition sources may not be a reliable basis of safety.

66 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. Similar considerations should be given to the position and design of control room windows.

67 Measures are required to deal with fires in any parts of the handling plant. 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, eg carbon monoxide. As any fire may have started slowly, burning material may already have entered other parts of the plant. HSEs primary concern is for the protection of people at work. Plant operators may attempt to deal with such a fire and the emergency services will certainly attempt to contain the fire. 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.

STORAGE PLANT SAFETY

68 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, paragraph 4). The size of the stored mass and its residence time will affect this temperature. Critical temperatures are around 50 ^{0}C. The control of product temperature prior to transfer to the storage silo is important in preventing silo fires.

69 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 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, consideration needs to be given to the thermal stability of stored product.

70 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 amount of dust may be low if the product is within specification and is carefully transferred to the silo. 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.

71 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. To prevent condensation, the silo may be aspirated with small volumes of dehumidified air or large volumes of atmospheric air.

72 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. A carbon monoxide detector in the silo may be used as an indication of an incipient fire. The burning material at first only produces small quantities of carbon monoxide. The detector will have to be set to identify low levels, which may be further diluted by aspirated air. The slow initial exothermic reaction is followed by a rapid exothermic reaction producing large quantities of carbon monoxide. 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.

73 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 will produce a surface cake that will prevent further water penetration. Procedures need to be in place for dealing with a silo fire. This may involve the gradual emptying of the silo to a safe place such as a skip into which water can be sprayed.

OFF LOADING AND BAGGING PLANT SAFETY

74 No sources of ignition should be in a position where a dust cloud could occur. All electric equipment in the off loading and/or bagging plant should be designed to appropriate standards in accordance with current UK legislation and , as regards new equipment supplied after 30 June 2003, the ATEX Directive.

75 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 are used to transfer product. Appropriate measures could include earthing, minimising dust levels and using conductive material in the design of the plant.

76 Any associated dust extraction plant should have protection against the consequences of a dust explosion.

77 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. Loading open lorries can produce a dust cloud which could be ignited as well as causing local contamination.

78 The thermal stability of the product varies between plants. As well as the 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. Silo temperatures should be monitored prior to discharge to ensure that product is below the set critical temperature. There is still considerable debate as to what is an appropriate bagging temperature, typically a figure of less than 50 ^{0}C.

79 There is as yet no clear consensus amongst plant operators of what is the most appropriate type of 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.

TRANSPORT HAZARDS

80 The allocation of an appropriate packing group for dried sewage sludge is based on the ability of the substance to undergo oxidative self-heating as determined by exposure of it to air at temperatures of 100 ^{0}C, 120^{0}C or 140^{0}C in a 25 mm or 100 mm wire mesh cube. These tests are very similar to the isothermal basket test (see appendix, paragraph 4) required to establish product stability. Further information can be found in the HSE publication *Approved Requirements and test methods for the classification and packaging of dangerous goods for carriage* – Approved Requirements ISBN 0-7176-1221-X. These are taken from

Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, published by the United Nations.

81 Early measurements suggest that dried sewage sludge is likely to fall into category 4.2 'spontaneously combustible substances' of which most are likely to be classified in Packing Group III, simply requiring labelling for transport. However, given the current uncertainty all dryer plants should have their product tested to confirm its classification. If product is found that falls into Packing Group II then additional precautions will be required in particular for bulk loads.

INFORMATION FOR SAFE STORAGE

82 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. Information should be provided on how to deal with a bag that has become wet.

83 If the material is to be stored in bulk in floor piles suitable handling methods should be used to prevent dust generation. Rotation of the pile may also be necessary to avoid self-heating. Also, segregation may be required from other incompatible material such as ammonium nitrate fertiliser. Consideration will also have to be given to any occupational risks from dust produced during handling.

SAFE SYSTEMS OF WORK

84 Adequate safe systems of work (eg permit to work) 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 is to be used for inerting. This is not only in obvious structures such as the dryer, dust collector, etc but also any low floor areas such as sumps.

85 Similarly, any hot work should be carefully controlled by a safe system of work.

86 Adequate safe systems of work will also be required for mechanical plant. The risk assessment should identify foreseeable risks from accessing mechanical plant and lead to appropriate measures 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. Rotary valves are not normally found on water treatment sites. Operators may not be familiar with the risk of amputation from them 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

87 A high level of training is required for all operators and their supervisors who may be new to this type of process plant. Such training as well as covering the normal operation of the plant must cover emergency situations. Appropriate refresher training and emergency exercises should also be included. Operators must be able to interpret the information provided by instrumentation and alarms to take the correct remedial measures before the plant trips to a safe condition. A basic understanding of the properties of dried sludge is also necessary. For example, during a fire, allowing air into a plant could increase the fire, putting water on bulk material on fire in a silo may not put out the fire but merely form a layer of damp sludge over the still burning material.

PLANT MODIFICATION PROCEDURES

88 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. All such changes should be recorded.

OCCUPATIONAL HEALTH RISKS

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

90 Studies have been carried out on endo-toxins, which are 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 as low in normal plant operation. However, additional care must 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 is achieved during drying. Finished product can be recolonised by opportunistic bacteria from the air or from contact with handling plant. Wetting of the finished product will encourage bacterial growth. However, this will be a different population from that found in the undried sludge making it difficult to assess the risk.

91 It is therefore preferable to minimise contact with dried sewage 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.

92 As moist sludge will grow a range of opportunistic bacteria operators should be instructed on appropriate standards of personal 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 a waterproof dressing.

APPENDIX
(paragraphs 11, 39, 62, 68 and 80)

PROPERTIES OF SEWAGE SLUDGE

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 properties, which may determine the basis of safety selected in different parts of the plant.

3 Minimum Explosible Concentrations (MEC) for sludge has been measured as low as 60g m^3. It is likely that this figure will be exceeded somewhere within a sludge drying plant. This is unlikely to be worth measuring for a specific plant as all dried sludge is likely to exceed the explosible concentration in some areas. 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.

4 The **explosion constant (K_{st})**, which for a variety of sewage dusts has been measured between 50 and 200 bar m s^{-1} which classifies the material as a class St1 explosible dust. Isothermal basket tests can be used to provide this information. Any variation of K_{st} will only alter the speed of propagation of any explosion, though it will be of use to those designing explosion relief. This information will be needed if a suppression system; explosion venting or explosion isolation methods involving slam shut barriers are used. 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.

5 The **minimum ignition energy (MIE)** for dusts is known to vary with particle size. There will be a variation in particle size between and within plants. It may not be practicable to obtain meaningful information, which can be used in plant design. Sufficient energy sources in excess of the MIE will be present in the dryer and it is therefore not normally necessary to measure the MIE. The only exception would be if information were required to assess the risks from static discharge in particular at bagging plants.

6 Data for **minimum ignition temperatures (MIT)** ranges from 360-550^{0}C. This becomes a relevant factor for plants having high dryer gas inlet temperatures (rotary convection dryers). Whilst MIT is likely to be exceeded during a fire it is unlikely to be of much use as a control parameter.

7 Dust **layer ignition temperatures (LIT)** range from 160-375^{0}C for a 5mm layer. Within some areas of the plant such temperatures may be exceeded through local heating effects. Outside the plant dust must not be allowed to accumulate on hot surfaces to prevent ignition and also reduce the possibility of a secondary explosion. Guidance on choosing appropriate electrical equipment can be found in BS EN 50281-1-2 *Selection, Installation and Maintenance*.

8 Burning numbers (BZ) may be of assistance if long-term storage is proposed. However, the precautions required for monitoring silos are unlikely to change. The BZ number would give a feel for the level of risk but it may vary for a given plant due to variations of sewage sludge.

9 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.

10 Information is available from larger isothermal basket test, which may give a more realistic profile of **thermal decomposition**. Information from laboratory scale basket tests can be scaled up to consider the heating effects on bulk material such as found in storage silos. This can be used in the design of silos used for cooling and also indicate safe storage 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.

11 There are significant differences for the measured **limiting oxygen concentration (LOC)** between samples. Limiting oxygen levels is used in parts of all dryers currently known to HSE. Some LOCs are quoted as high as 15% whereas one source found a figure of only 5%. Currently it is not clear if laboratory measurements of LOC are representative of plant conditions, eg high temperature and high humidity. HSE is currently carrying out a research project to assess the reliability of current methods for measuring LOC. For the present plant operators should follow the advice provided by the plant manufacturers. If HSE is able to develop a more realistic method for the measurement of LOC then operators may be required to retest. If real variation between samples does occur, LOC should be measured for representative samples for each plant where inerting is the basis of safety. As particle size and shape may also affect the LOC care needs to be exercised to obtain a representative sample. It should also be appreciated that an accurate LOC will be devalued if the oxygen detectors within the plant are not giving true readings. Again HSE is looking into the accuracy of such equipment.

12 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, with higher risk plants requiring a bigger margin.

13 It is not known whether there are any critical margins for possible contaminants. Consideration may have to be given to monitoring iron levels as ferrous sulphide is known to cause fire propagation if air enters an inert vessel. Also, iron levels may increase the decomposition rate of the finished product. Potassium permanganate, added to control septicity, may also accelerate decomposition.

13 July 2001