

WASTE STABILISATION AND SOLIDIFICATION

Guide for Regulators and Operators

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Abstract

Solidification and Stabilisation (S/S) treatment of waste involves mixing cement into contaminated media or waste to immobilise contaminants within the treated material. The waste become more solid thereby lowering the solubility of toxic contaminants in the waste. In some cases, such as in stabilisation, the toxicity of the hazardous constituent(s) is lowered.

Waste stabilisation and Solidification (S/S) can be carried out ex-situ or in-situ. Ex-situ mixing involves removing the waste from its location and transferring it to a treatment plant for processing. The waste is mixed with the S/S agents in a fixed or mobile treatment plant. In the case of In-situ mixing, the waste remains in place and the S/S agents are injected or mixed with specialised augers or other equipment.

The standard bulk material handling and mixing equipment used in many Solidification and Stabilisation (S/S) process make the technology appear simple. However, there are significant challenges to the successful application of S/S processes. The morphology or chemistry of S/S treated waste are complex. An understanding of the chemistry and interaction of the waste material, the contaminant(s) and the binder is important if a successful treatment program is to be achieved.

Stabilisation and Solidification has frequently been used for the treatment and immobilisation of soils and sludges containing one or more contaminants. Although there is no standard method of S/S application, selecting an appropriate binder is crucial to a successful treatment program. A well structured testing program guided by an understanding of the mechanisms involved in S/S system will reduce uncertainty in the selection process.

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1. INTRODUCTION

Solidification/stabilisation (S/S) is typically a process that involves the mixing of a waste with a binder to reduce the contaminants leachability by both physical and chemical means and convert the hazardous waste into an environmentally acceptable waste form for land disposal or reuse/recovery. S/S has been widely used to treat and dispose of hazardous and mixed waste streams, as well as remediation of contaminated sites like other immobilisation technologies. S/S does not destroy the waste and contaminant(s) it contains, but tends to prevent its release into the environment.

1.1 Objective

The aims of this Guidance are to:

- provide the regulatory and scientific basis for the use of S/S process
- provide a description of the different S/S systems
- provide a clear structure and methodology for operators to follow in their submission of an application for waste solidification and stabilisation
- minimise the effort by regulators and operators of a waste solidification and stabilisation operation by identifying and expressing what constitute BAT techniques for such an activity, and
- provide a description of the testing and evaluation of the materials before and after treatment

1.2 Definition of Stabilisation and Solidification

Solidification refers to techniques that encapsulate a waste, forming a solid material and does not necessarily involve chemical interaction between the contaminants and the solidifying additives. The waste is normally treated to entrap the waste materials in a solid and/or crystalline matrix. For example, solidification consists of encapsulating the insoluble residue from an air pollution control (APC) washing process with cement to form a monolithic material that reduces the porosity and hydraulic conductivity of the material and hence its leachability.

Stabilisation refers to techniques that chemically reduce the hazard potential of a waste by converting the contaminant to less soluble, mobile or toxic forms. The physical nature and handling characteristics of the waste are not necessarily changed by stabilisation. The waste is treated so as to complex or bind the contaminants into a stable, insoluble form.

Inorganic binders such as cement are effective in immobilising heavy metals through chemical and physical containment mechanisms, but are not as effective in immobilising most organic contaminants. Many substances in the waste significantly affect the setting and hardening characteristics of binders, especially cement-based cementing systems.

The mixing of waste and binders can be carried out through either ex-situ or in-situ processes. A wide range of mixers are available for ex-situ mixing, including pugmills, mortar mixers or concrete mixers. In situ methods are widely used for remediation of contaminated sites and can be classified into the following three categories:-

- backhoe-based methods,
- drilling/jetting/augering/trenching methods and
- shallow area methods.

Selection of the mixing method is based on the depth of the contaminant and the characteristics of the contaminated media.

1.3 Regulatory Framework

Waste, including Hazardous and Non Hazardous waste has the potential to cause particular harm to human health and the environment. It is therefore vital that it is handled and treated in an appropriate way. Both IPPC and the Waste Framework (WFD) (2008/98/EC) Directives require that appropriate measures be taken against pollution and specifically that the production of waste is avoided. Appropriate measures means taking measures that deliver the best overall environmental outcome. It also means that where waste is produced, it should be recovered, re-used or used as a source of energy in preference to disposal.

With regard to waste S/S and its relationship with the principles of BAT and Waste Hierarchy, the question of whether these activities constitute the appropriate means of dealing with the waste and provides opportunities for subsequent use of the treated waste arises. Clearly, where an opportunity to recover waste exists, then disposal may not be the appropriate measure. Although S/S is commonly used to treat industrial waste to make it safe for land disposal, it can also have the added benefit of improving soil conditions for construction of structures and pavements.

One of the six key principles of the Government's strategy for hazardous waste management is to ensure that best available techniques are applied to hazardous organic waste. Although this guidance makes references to the impact of organics and its interferences on waste S/S processes, it is also a viable option for the treatment of organic waste where used correctly.

The strategy provides the foundation for the Government's National Policy Statement (NPS) on Hazardous waste infrastructure in England. The draft NPS states that there is need for a number of nationally significant infrastructures

including "Treatment plant for air pollution control residues (APC)". APC's such as Flyash and ground bottom slags are known to have pozzolanic properties. Their use or recovery within the S/S process is a positive way forward and contributes to the objectives of the National Policy Statement.

Waste treatment is most critical in the case of waste that cannot be destroyed or detoxified and there will always be a need for the safe disposal of waste through landfill or incineration. A thorough understanding of the potential behaviour of S/S waste is therefore necessary to make a judgement as to the long term effectiveness of their containment. The extent to which various contaminants are securely held in S/S waste must also be determined for all S/S processes so that the potential for recovery can be evaluated.

This document assumes that S/S of waste do have important roles to play and tries to identify what constitutes the best practicable environmental option.

1.4 Environmental Permitting Consideration

1.4.1 Treatment of Waste

Waste management is a regulated activity under the Environmental Permitting Regulations 2010. This means the treatment of controlled waste may require an environmental permit. The environmental permit can be either a standard rules permit or a bespoke one depending upon the type of treatment and site location. New standard rules permits for land remediation and waste treatment were introduced on 6 April 2010. They cover a wide range of treatment/remediation activities, including waste solidification and stabilisation. A bespoke permit will be required for operations that do not fit the standard rules. Operators who want to treat waste using S/S technology must therefore apply for an environmental permit.

1.4.2 Disposal of S/S treated waste

All waste activities, other than temporary storage at the place of production, are classified as either disposal or recovery operations. So where waste is not being recovered it is deemed to be part of a disposal operation.

The Landfill Directive (2001) classifies landfills into three distinct types: Inert, Hazardous and Non hazardous Landfills. Before waste can be accepted for disposal into any of these landfills, the operator and holder of the waste must ensure that it meets the waste acceptance criteria (WAC) for that class of landfill. So it is common for waste to be treated by S/S or other means prior to landfill, in order to meet those criteria. For example, the Landfill Directive requires at least 50 kPa for Granular waste or 1 MPa after 28 days curing for Monolithic waste.

1.4.3 Recovery of treated waste

The treatment of waste for the purpose of reclamation, restoration or improvement of land is a recovery operation whereby the treated material replaces other (non waste) materials which would have had to be used for that purpose. Any waste, whether inert, non-hazardous or hazardous is capable of being used in a recovery operation. However, the waste must always be suitable for the purpose it is intended and the operator or holder of the waste must demonstrate the genuineness of the recovery by submitting a waste recovery plan to the Environment Agency.

Where excavated materials are recovered via a treatment operation then their re-use at a site may be dealt with by the Development Industry CoP as detailed below.



Fig.1.1. Slag Boulders, North Gare Sand Dunes

Solidified slag from the ironworks of Teesside and Hartlepool still retaining the shapes of the buckets they cooled down in. All of the South and North Gare breakwaters was constructed from slag from the ironworks as well as providing stabilisation of the sand dunes as exposed here. Seven million tons of slag are estimated to have been used in the construction of the South Gare alone.

1.4.4 Definition of waste (CoP)

This is a voluntary Code of Practice (CoP), which provides a framework for determining whether or not excavated material used in land development is waste. The CoP has been produced by industry and is supported by the Environment Agency. [The Environment Agency's Definition of Waste Position Statement \(PS006\)](#) explains how it will take account of the CoP in regulating development activities.

Excavated material generated by the development of land may be waste and subject to waste regulatory controls, which ensure that waste does not harm human health or the environment.

Whether or not a substance or material is waste depends on whether the holder of a substance or material is discarding it, or intends to or is required to discard it. This must be considered in the light of all the specific circumstances of each case.

The CoP sets out good practice for the development industry to use when assessing:

- whether materials can be classified as waste or not; and
- determining when treated waste can cease to be waste for a particular use.

The CoP applies to excavated material, both uncontaminated and contaminated, from man made and natural sources:

- for re-use on the site from which it has been excavated, either without treatment or after on site treatment, in the development of that land
- for re-use in the development of land other than the site from which the material has been excavated, following treatment at an authorised treatment hub within a defined cluster agreed with the Environment Agency, and used in the development of land at a site within the cluster.

The CoP does **not** apply to wastes that go to and from fixed soil treatment facilities unless it operates as a hub within a defined cluster project.

2. SOLIDIFICATION/STABILISATION

2.1 Scientific basis of S/S

Stabilisation and Solidification (S/S) have different goals. Solidification aims to minimise the spread of pollution by converting the contaminated materials into solid impermeable mass with a low surface to volume ratio. This is often achieved by adding a binder such as cement and quicklime to the waste material. Stabilisation is a form of solidification where reagents are added which converts the contaminant to a less soluble form by chemical reaction or pH adjustment. The combined process of solidification and stabilisation are often termed "waste fixation or encapsulation".

In hazardous waste disposal or contaminated land remediation, treated waste must meet certain standards for either safe land disposal or re-use, by removing the hazardous characteristic of the waste. This usually involves passing concentration-based standards such as the landfill waste acceptance criteria or remediation standards as agreed by the regulator.

A binder is often used to stabilise the contaminants in the waste. Portland cement is a commonly used binder because of its availability and low cost. Supplementary cementing materials such as coal fly ash and ground blast furnace slags are often used to partially replace portland cement to improve the performance of the treated waste and to reduce the cost of the binder.

2.2 Types of binders

2.2.1 Inorganic binders

The two principal types of inorganic binders are Cement binders and Pozzolanic binders (lime, kiln dust, fly ash, etc). A pozzolan is a siliceous or siliceous and aluminous material, i.e containing silica or silica and alumina which in itself possess little or no cementitious value but which will in finely divided form and in the presence of water, reacts chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties. The most common inorganic binders are:

- Portland cement
- Lime/ fly ash
- Kiln dust (lime and cement)
- Portland cement/ fly ash
- Portland cement/ lime
- Portland cement/ sodium silicate

2.2.1.1 Cement Processes

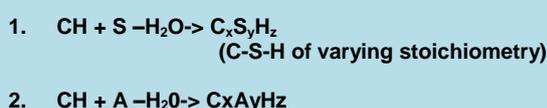
During the cement based S/S process, the reaction forms a granular or monolithic solid that incorporates the waste materials and immobilises the contaminants. The solid matrix forms because of hydration of silicates in the cement, yielding calcium-silicate hydrate (C-S-H). The major crystalline compounds present in portland cement are Tricalcium Dicalcium Silicate (C_3S), while Tricalcium Aluminate (C_3A) and Calcium Aluminoferrite (C_4AF) are present in small quantities. The cementation process binds free water, increases the pH and alters other chemical properties of the mixture, reduces surface area and increases strength. All these mechanisms contribute to the overall performance characteristics of the treated waste.

The hydration of portland cement is a series of simultaneous and consecutive reaction between water and solid cement constituents which occur in the setting and hardening process. Anhydrous portland cement consists of angular particles (usually 1 to 50 μm) with a chemical composition of the primary clinker materials (U.S. EPA, 1993) that correspond approximately to C_3S , C_2S , C_3A and C_4AF , where $C=CaO$, $S=SiO_2$, $A=Al_2O_3$, $F=Fe_2O_3$, $S=SO_3$ and $H=H_2O$.

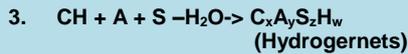
Once the cement powder comes into contact with water, tricalcium aluminate (C_3A) immediately hydrates, causing the rapid setting which produces a rigid structure. In an idealised setting, the water hydrates the calcium silicate and aluminates in the cement to form calcium silicate hydrate (C-S-H). Densely packed fibrils of silicate grows out from the cement grains and interlace to harden the mixture entrapping inert material and unreacted grains of cement. Hydration of tricalcium and dicalcium silicates results in the formation of Tobermorite (C-S-H) and Crystalline Calcium Hydroxide (CH). These compounds account for the strength development after the initial settings. The setting rate is controlled by the amount of gypsum added to the cement. If sufficient gypsum is present, sulfates combine with tricalcium aluminate to form calcium aluminate sulfate which coats the cement particles and retards hydration reactions.

2.2.1.2 Pozzolanic Processes

Pozzolanic reaction, while not identical, are similar to Portland cement reactions.



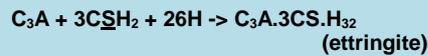
(hexagonal and cubic aluminate hydrates)



The above reaction (Hydrated Lime with Flyashes) yields products whose properties are similar to the reaction products of Portland cement. The difference is that Pozzolanic reactions consume lime rather than produce it, as with portland cement hydration.

2.2.1.3 Ettringite Formation Effects

Ettringite also known as Calcium Aluminate Sulfate Hydrate is a needle like crystal which appears within minutes of cement hydration (see equation)



Its formation is typically required early in the curing process to control setting rate. However the ettringite then dissolves and precipitates as calcium sulfate. Due to the high content of water of hydration, ettringite increases the volume of solids where it forms. If formed while the S/S treated waste is still plastic, the material can accommodate the expansive salt. However, if the ettringite forms after the grout has become rigid, cracking can occur and will reduce the strength of the product. The formation of this salt, with its larger amount of water of crystallisation and consequently larger increase in volume can be destructive to the S/S treated product.

2.2.2 Organic binders

Organic binders are mainly used to solidify radioactive or hazardous organic wastes that cannot be destroyed thermally. Organic binders used for S/S include the following:

- Asphalt (bitumen)
- Polyethylene
- Polyesters
- Polybutadiene
- Epoxide
- Urea Formaldehyde
- Acrylamide Gel
- Polyolefin Encapsulations

There are two basic types of organic S/S processes. These are:

- Thermoplastic, and
- Thermosetting

2.2.2.1 Thermoplastic

Thermoplastic processes involve blending with a polymer such as asphalt, polyethylene or other thermoplastic binders. Thermoplastic is a polymer that becomes pliable or moldable above a specific temperature and returns to solid state upon cooling. Liquid and volatile phases associated with waste are driven off and the waste is contained in a mass of cooled, hardened thermoplastic.

2.2.2.2 Thermosetting

Thermosetting polymers involve mixing waste with reactive monomers which join to form a solid incorporating the waste. Unlike thermoplastics, thermosetting polymers form irreversible chemical bonds during the curing process. Thermoset bonds break down upon melting and do not reform upon cooling, e.g., urea formaldehyde.

Studies have been carried out to investigate the potential of the thermosetting polyester polymer to solidify/stabilise phenol, a primary constituent in many organic hazardous wastes. Most of the polyester polymer solidified phenol specimens showed no measurable amount of phenol in the leachate after the extraction procedure test. Results also showed that compressive and tensile strengths of solidified waste reduce with increasing phenol content. Full details can be found in article by Vipulanandan, C., Krishnan, S., titled: Solidification/stabilization of phenolic waste with cementitious and polymeric materials.

2.2.2.3 Additives

Additives are added to improve the immobilisation of specific contaminants. They can also be incorporated to mitigate the effects of certain inhibitors. It should be noted that many additives may work for one constituent but have the opposite effect for a different constituent.

2.3 Waste/binder compatibility literature

2.3.1 Cement and environmental properties that may affect waste containment

The ability of a stabilised/solidified (S/S) waste product to contain a given hazardous constituent depends primarily upon its resistance to leaching or volatilization of waste constituents and its long term durability. The characteristics of S/S waste that are most important to containment are leachability and durability.

When a solid matrix is in contact with a leachant, some constituents of the matrix may dissolve. S/S treated waste generally constitute a heterogeneous and complex solid phase of a structural point of view. During the contact with the leachant, the matrix undergoes or is subjected to a number of physical and or chemical processes. The scheme below illustrates the main physical and chemical factors that influence the release of elements contained in a porous monolithic solid subjected to leaching.

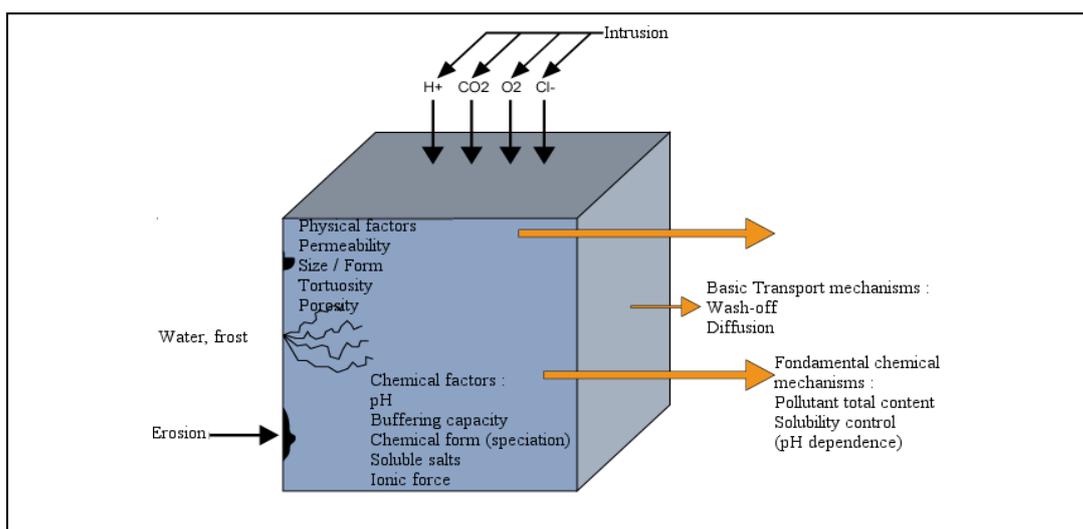


Fig. 2.1. Schematisation of the whole mechanisms that influence the leaching phenomena on solidified or recycled waste.

Internal diffusion of soluble ions or molecules in a solid matrix depends largely upon the relative amount and character of void spaces in the solid matrix, which relates to the permeability of the porous solid and its ultimate strength.

The several kinds of voids in hydrated cement paste have great influence on its final properties of strength, durability and permeability. The smallest voids, which occur within the C-S-H (calcium silicate hydrate) gel structure are 0.5 to 2.5 μm in diameter (US EPA, 1988). They account for about 28% of the porosity in solid C-S-H. These small voids have little effect on the strength and permeability of the final products but appear to be important in drying shrinkage and creep (US EPA, 1988). Capillary voids are larger and in well-hydrated, low-water/cement ratio mixes. The voids range from 10 to 50 μm , but in high ratio mixes, they may be as large as 3000 to 5000 μm . It is generally held that pore size distribution and not total capillary porosity, is a better criterion for evaluating the characteristics of a cementitious product. Capillary voids larger than 50 μm are thought to be harmful to strength and permeability, while those smaller than 50 μm are important in drying shrinkage and creep (US EPA, 1988).

Air voids are generally spherical and usually range from 0.05 to 0.2 mm or up to 3mm in some cases. They are introduced intentionally into the hydrated cement paste to increase resistance of the final product to freeze thaw (frost) damage even though they affect its strength and permeability.

Depending on environmental conditions, the voids are capable of holding large numbers of water. Water in voids greater than 50 μm does not cause shrinkage in the final product while loss of water held by capillary tension in voids from about 5 to 50 μm may cause some shrinkage. Absorbed water, i.e. water close to the surface (probably within 4.5 μm of the surface) is mainly responsible for the shrinkage and cracking of the solidifying mass. Water more tightly bound in the interlayers of calcium silicate will cause considerable drying shrinkage.

2.3.2 Effects of wastes on cement/pozzolan process

Waste, either hazardous or non hazardous may contain a number of substances such as acids, salts, bases and organic materials. Some properties of the waste, such as moisture content, particle size distribution and concentration of contaminants may also be found to have the most significant effects on the properties of the treated

waste. These may be present either singly or in combination thus, these properties need to be monitored and where required, adjusted through pre-treatment.

2.3.2.1 Waste that pose complications for S/S

- Wastes with volatile organics (pretreatment is usually required)
- Wastes that contain a large number of different types of contaminants
- Wastes that are situated such that field S/S will be difficult or expose local receptors to unacceptable risk
- Wastes will large amount of interfering/incompatible constituents
- Wastes that contain organics as the primary contaminants.

2.3.3 Other potential interferences

S/S treatment process can be affected by many different factors, e.g. binder to waste ratio, water content, or ambient temperature. These interferences can affect the stabilisation processes an/or the chemical stabilisation of the treated products. General types of interferences caused by the chemical constituents include:

- Inhibition of bonding of the waste material to the S/S material
- Retardation of setting
- Reduction of stability of the matrix resulting in increased potential for leachability of the waste
- Reduction in physical strength of the final product

2.3.3.1 Interference with Solidification

Many waste constituents affect cementation chemistry by altering the setting rate or the properties of S/S treated waste. The setting rate may increase or decrease depending on the contaminant type. For, e.g. mild accelerators such as chloride or nitrate anions can slow setting at higher concentrations.

Table 2.1 lists substances found to affect cement reactions. Many of these substances can reduce the ultimate mechanical strength of the waste form by producing cracking and spalling. Table 2.1 compiles the characteristics reported to interfere with solidification/stabilisation processes and indicate their potential impacts.

Table 2.1 SUMMARY OF FACTORS THAT INTERFERE WITH SOLIDIFICATION/STABILISATION PROCESSES

Possible Interfering Characteristics	Potential Interference Mechanism	Reference
Semivolatile organics or PAHs	Organics interfere with bonding of waste materials	U.S. EPA, 1988c
Oil and grease	Weakens bonds between waste particles and cement by coating the particles. Decreases in unconfined compressive strength with increased concentrations of oil and greases	U.S. EPA, 1988c; Cullinane and Bricka, 1989.
Phenols	Marked decrease in compressive strength.	U.S. EPA, 1988c; Cullinane and Bricka, 1989.
Nonpolar organics (oil, grease, aromatic hydrocarbons, PCBs)	May impeded setting of cement, pozzolan or organic-polymer S/S. May decrease long-term durability and allow escape of volatiles during mixing. With thermoplastic S/S, organics may vaporise from heat.	U.S. EPA, 1989g
Polar organics (alcohols, phenols, organic acids, glycols)	With cement or pozzolan S/S, phenol retards setting and may decrease short term durability; all may decrease long term durability. With thermoplastic S/S, organics may vaporise. Alcohols may retard setting of pozzolans.	U.S. EPA, 1989g
Solid organics (tars, resins)	Ineffective with urea formaldehyde polymers, may retard setting of other polymers.	U.S. EPA, 1989g; Wiles, 1987
Aliphatic & aromatic hydrocarbons	Increase set time for cement.	U.S. EPA, 1989b
Chlorinated organics	Increase set time and decrease durability of cement.	U.S. EPA, 1989b
Organic acids (hydroxycarboxylic acid, citric acid, tartaric acid, benzoic acids, EDTA)	Retard setting rate.	Dole, 1985
Presence of phenols and nitrates	Cannot be immobilised with lime/fly ash, cement, and soluble silicates; fly ash and cement; or bentonite and cements.	Stegemann et al., 1988
Metals (lead, chromium, cadmium, arsenic, mercury)	May increase setting time of cements.	U.S. EPA, 1989g
Metals salts and complexes	Increase set time and decrease	U.S. EPA, 1989b

	durability for cement or clay/cement.	
Copper, lead, and zinc	Detrimental effect on physical properties of cement-treated waste.	U.S. EPA, 1990
Halides	May retard setting, easily leached from cement and pozzolan S/S treated waste. May dehydrate thermoplastics.	U.S. EPA, 1988c
Soluble salts of manganese, tin, zinc, copper and lead	Reduce physical strength of final product; cause large variations in setting time; reduce dimensional stability of the cured matrix, thereby increasing leachability potential.	U.S. EPA, 1988c
Cyanides	Cyanides interfere with bonding of waste materials	U.S. EPA, 1988c
Arsenates, borates, phosphates, iodates, sulfides, and carbohydrates	Retard setting and curing and weaken strength of final product.	U.S. EPA, 1988c
Sulfates	Retard setting and cause swelling and spalling in cement S/S. With thermoplastic solidification may dehydrate and rehydrate causing splitting.	U.S. EPA, 1988c
Presence of coal or lignite	Coals and lignites can cause problems with setting, curing and strength of the end product.	U.S. EPA, 1988c
Sodium borate, calcium sulfate, potassium dichromate and carbohydrates	Interferes with pozzolanic reactions that depend on formation of calcium silicate and aluminate hydrates.	U.S. EPA, 1988c
Oxidisers (sodium hypochlorite, potassium permanganate, nitric acid, or potassium dichromate)	May cause matrix breakdown or fire with thermoplastic or organic polymer S/S	U.S. EPA, 1989g
Nitrates, cyanides	Increase setting time, decrease durability for cement-based.	Colonna et al., 1990
Soluble salts of magnesium, tin, zinc, copper and lead	May cause swelling and cracking within matrix, exposing more surface area to leaching.	Colonna et al., 1990
Flocculants (e.g. ferric chloride)	Interference with setting of cements and pozzolans.	Colonna et al., 1990 p. 407
Soluble sulfates >0.1% in soil or 150 mg/L in water	Endangerment of cement products due to sulfur attack.	Jones, 1990
Soluble sulfates >0.5% in soil or 2000mg/L in water	Serious effects on cement products from sulfur attack	Jones, 1990
Inorganic acids (HCL, H ₂ SO ₄ , Nitric acid)	Decrease durability for cement (Portland Type I) or clay/cement	U.S. EPA, 1989b
Inorganic bases	Decrease durability for clay/cement; KOH and NaOH decrease durability for Portland cement Type II & IV.	U.S. EPA, 1989b
Sodium hydroxide	Increase early strength at 2 to 5% concentration but decreased early strength at 8% level.	U.S. Army, 1990
Presence of anions in acidic solutions that form soluble calcium salts (e.g., calcium chloride, acetate and bicarbonate)	Cation exchange reactions – leach calcium from solidified/stabilised product, increases permeability of concrete; increase rate of exchange reactions.	Jones, 1990
Low-solids wastes	Large volumes of cement or other reagents required, greatly increasing the volume and weight of the end product. Waste may require reconstitution with water to prepare waste/reagent mix.	U.S. EPA, 1988c
Fine particle size	Insoluble material passing through a No. 200 mesh sieve can delay setting and curing. Small particles can also coat larger particles, weakening bonds between particles and cement or other reagents. Particle size >1/4 inch in diameter not suitable.	U.S. EPA, 1988c
Environmental/waste conditions that lower the pH of matrix	Eventual matrix deterioration.	Colonna et al., 1990 p. 407

2.3.3.2 Interferences with Stabilisation

Some waste characteristics can interfere with the stabilisation process. Table 2.2 summarises the effects of waste constituents on immobilisation mechanisms. Interferences with stabilisation include chemical incompatibilities and undesirable reactions.

Table 2.2: Potential chemical incompatibilities between binder and waste constituents

Characteristics Affecting Process Feasibility	Potential Incompatibilities	Reference
Volatile organics	Volatile not effectively immobilised; driven off by heat of reaction.	U.S. EPA, 1988c
Use of acidic sorbent with metal hydroxide wastes	Solubilises metal.	U.S. EPA, 1986c
Use of acidic sorbent with cyanide wastes	Releases hydrogen cyanide.	U.S. EPA, 1986c
Use of acidic sorbent with sulfide wastes	Releases hydrogen sulfide.	U.S. EPA, 1986c
Use of alkaline sorbent with waste-containing ammonium compounds	Releases ammonia gas.	U.S. EPA, 1986c
Use of alkaline sorbent (containing carbonates such as calcite or dolomite) with acid wastes	Releases carbon dioxide which can cause frothing/foaming.	U.S. EPA, 1986c
Use of carbonaceous sorbent (carbon, cellulose) with oily waste	May create pyrophoric waste. Ignitable (spontaneous)	U.S. EPA, 1986c
Use of siliceous sorbent (soil, fly ash) with hydrofluoric acid waste	May produce soluble fluorosilicates.	U.S. EPA, 1986c

2.4 Pre-treatment

2.4.1 The Need for Pre-treatment

The ability of a stabilised/solidified (S/S) waste product to contain a given hazardous constituent depends primarily upon its resistance to leaching or volatilization of waste constituents and its long term durability. The characteristics of S/S wastes that are most important to waste containment therefore are leachability and durability.

Various factors as shown above affect the immobilising mechanism of stabilisation/solidification of hazardous wastes. These include the type and amount of pozzolanic materials and solidification-aiding reagents and the characteristics of the wastes. Some of the chemical components of the complex waste may interfere with the proposed S/S process and cause undesired results (e.g. flash set, set retardation, spalling, contaminant leaching release, etc). The need for pre-treatment can therefore have both environmental and economic benefits. A typical example is the solidification of air pollution control residues (APC). One of the principle problems with APC residues is the high content of soluble chlorides, so washing is a common first stage in many treatment processes (Open University 2005).

The final properties of a waste-cement mixture are highly dependent upon:

- The constituents of the waste that may interfere with the setting reaction.
- The water/cement ratio is the primary determinant of the size configuration of the void space and permeability of the final product;
- Presence of admixtures such as fly ash or surfactants that may modify setting or final strength parameters of the products; and
- Procedures and conditions used for mixing and curing the treated wastes. The strength and durability of concrete products are directly related to the types and number of voids in the final product. Care should be taken to thoroughly test specific wastes that are candidates for this treatment.

Pretreatment of waste prior to S/S treatment can be very important in the overall treatment process. Improvements can sometimes be made to the physical characteristics of the waste, to alter metal speciation, to improve metal immobilisation, or to remove problematic organics. The presence of large pieces of debris, foreign objects or poor handling characteristics of the waste can interfere with sampling, analysis and S/S processing.

Preliminary waste characterisation should identify the presence of debris. Failure to screen waste samples adequately prior to acceptance and to confirm the composition on arrival at the site has historically led to subsequent problems, which include inappropriate storage and mixing of incompatible substances, accumulation of wastes and unexpected treatment characteristics.

The debris can either be removed by screening and processed separately or can be broken down with size-reduction equipment. Excess free liquid, high viscosity or caking properties can all present problems in material handling. Possible pretreatment methods to improve handling are drying, pelletising or adding sorbents to control liquids. Other available methods for pre-treatment include; dilution with solid or liquid materials, grinding, and adsorption and adsorption with porous substances, e.g., activated carbon.

2.4.2 Pretreatment for Organic and Inorganic Constituents

Both organic and inorganic constituents can complicate stabilisation in both organic and inorganic based S/S treatment systems. A variety of pretreatment options are available to remove organics (volatiles and semi-volatiles) and inorganic materials prior to S/S treatment.

Types of Pre-treatment Options

- Chemical reduction of hexavalent chromium to the less soluble and toxic trivalent state
- Elimination of problem constituents, for example, destruction of cyanide or stripping of ammonia
- Soil washing
- Thermal removal
- Chemical oxidation
- Extraction
- Biodegradation
- Addition of a sorbent (such as limestone, clays, activated carbon or fly-ash) prior to mixing.

Refer to Remediation Position Statement guidance (226-06) for full description of some the above options.

3. S/S TECHNOLOGY SCREENING PROCEDURES

3.1 Application of S/S

S/S process have been applied to a variety of wastes, such as nuclear, municipal ash and wastewater, slurries, contaminated soils and debris, liquid, solid, organic and inorganics. Despite it's flexibility and broad appeal, S/S

treatment is not appropriate for all wastes. It is generally appropriate as a treatment alternative for material containing inorganics, semivolatile and/or non volatile organics.

S/S treatment is typically not the preferred choice for treating waste containing only volatile organics. Where wastes containing VOC contamination are to be treated by S/S processes, the VOCs should not be the prime target. Sites or wastes contaminated with high levels of VOCs require pretreatment prior to S/S treatment. Apart from hindering the stabilisation process, volatile organics can make it necessary to use expensive off-gas collection and treatment systems.

Selection of S/S treatment for waste containing semi-volatile and volatile organics require a site specific treatability study or non site specific treatability study data generated on waste which is very similar (in terms of contaminant type, concentration and waste matrix) to that to be treated. A careful treatability testing program, guided by expert knowledge is typically required to formulate, test and apply an S/S treatment system. The need for treatability study data and the importance of conducting appropriate leachability tests as part of the study are highly important if organics are present in the waste.

3.2 Selection of treatment technology

S/S treatment technology is potentially suitable for most wastes or contaminated sites. In assessing this technique, its effectiveness in reducing hazard and rendering substances suitable for release to other processes must be considered. Due to the variable and complex composition of many waste streams, not only primary hazards but also secondary hazards must be considered.

The technique should be designed and operated to avoid deliberate or inadvertent production and release of substances that may be harmful to the environment and to prevent the transfer of such substances from one environmental medium to another. For the purpose of waste regulation, it is important for operators to show the suitability of each waste stream for treatment by this process, show how the effectiveness of the process has been maximised and ensure that the process does not result in dangerous emissions.

The end use or destination of the treated waste is also a key consideration when selecting the treatment technology. Waste is either treated for disposal or recovery so a clear destination for the S/S treated waste should have been identified. If destined for landfill disposal, the selected technology must ensure that the treated wastes meets the requirements of the Landfill Directive, including the need to meet the relevant landfill Waste Acceptance Criteria (WAC). If destined for recovery/reuse, the technology must be able to achieve established or agreed site specific reuse criteria.

If S/S is chosen as a potential technology, then the general decision flowpath illustrated in figure 1.1 can be followed.



Fig 3.1. SEDA site. Source: Inertec

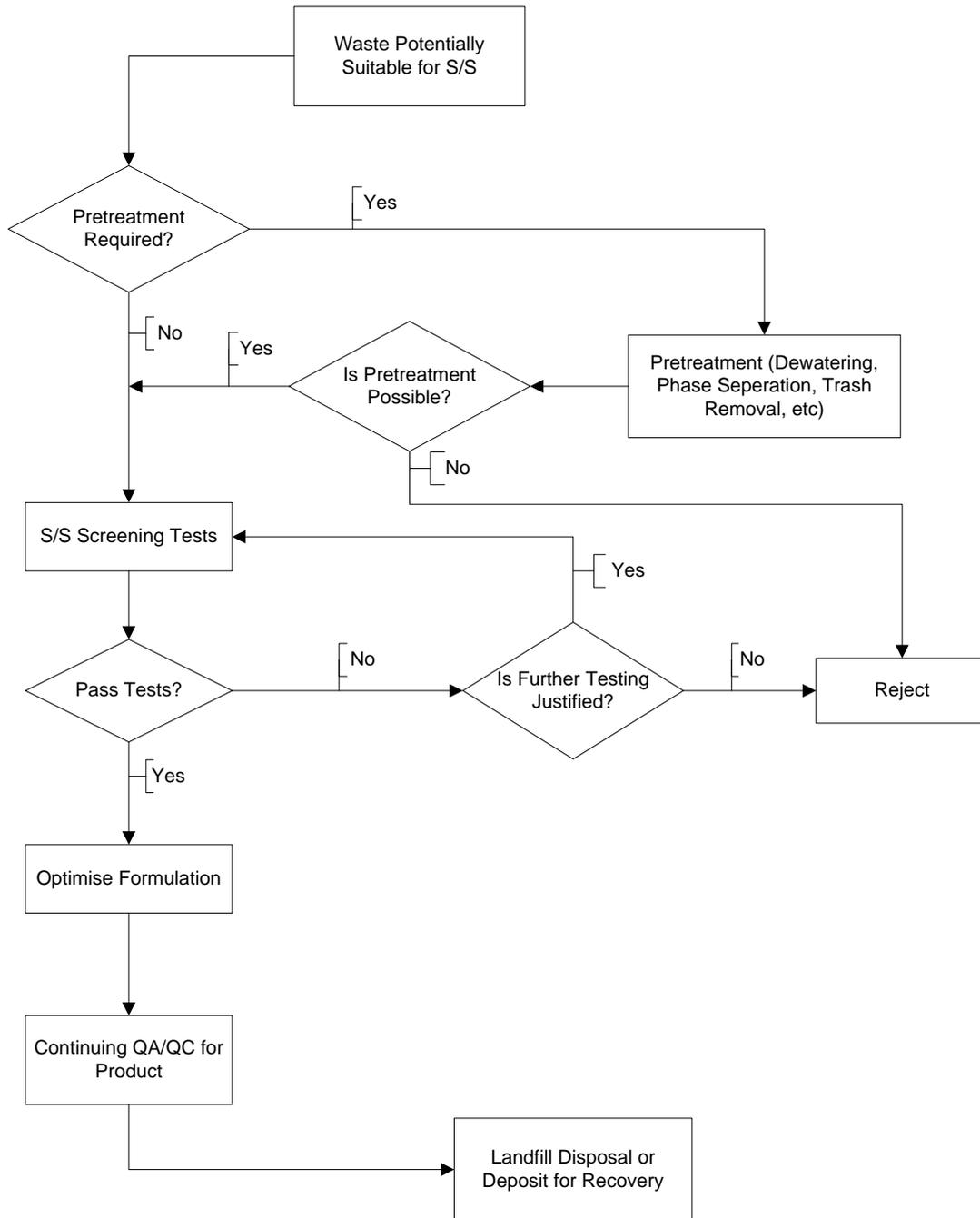


Figure 3.2: S/S decision flowpath

3.3 Technology screening procedure

A treatment technology that has been properly screened prior to full scale implementation has the highest probability of success in the field. Once stabilisation has been selected as a potential treatment technology, a technology screening process should be followed. Based on the characterisation of the waste sample and the site characteristics, performance objectives should be established.

Treatability studies provide valuable site specific data needed to select and implement the appropriate remedy. The following sections explain the major steps in the technology screening process in their order of implementation.

3.3.1 Site specific baseline information requirements

These are information requirements for technology screening and fall into 5 subsections.

- waste pre-acceptance
- Waste sampling
- waste characterisation
- site characterisation and
- quality assurance & quality control

3.3.1.1 Waste Pre-acceptance

Waste pre-acceptance involves analysing a representative sample to determine compliance with the facility permits and to screen waste for unsuitable wastes which may lead to adverse reactions or uncontrolled emissions. Pre-acceptance procedure provides opportunity to assess the various waste types and contaminants and then suitability for treatment with S/S treatment technology.

The waste may come from various types of industries such as manufacturing, mechanical production, petroleum refineries or power stations. These waste typically include materials such as sludges, spent cleaning materials, pickle liquors, plating wastes and combustion residues (APR) many of which contain complex mixtures that cannot be categorised easily and may not all be amenable to S/S treatment. The class of contaminants and/or substances in a waste will influence the type of S/S treatment that can be applied to the waste.

Indicative BAT - Pre-acceptance for on-site treatability study

1 From the waste processing enquiry the Operator should obtain information in writing relating to:

- the type of process producing the waste
- the specific process from which the waste derives
- the quantity of waste;
- chemical analysis of the waste (individual constituents and as a minimum their percentage compositions)
- the form the waste takes (solid, liquid, sludge etc)
- hazards associated with the waste
- sample storage and preservation techniques

2 Unless a sample and analysis has already been completed by a third party and the Operator has sufficient written information from them, then the Operator should in every case obtain representative sample(s) of the waste from the production process/current holder and compare it against the written description to ensure that it is consistent.

3 Other than for pure product chemicals, the chemical analysis should relate to an actual analysis and not simply be based on product data sheets or an extrapolation of information on product data sheets. For example, taking the concentrations as specified and applying a dilution factor is not acceptable.

4 The Operator should ensure that the sample is representative of the waste and has been obtained by a person who is technically competent to undertake the sampling process.

5 Samples should be clearly labelled and any hazard identified.

6 Sample tracking systems within the site should be established and be auditable.

7 Results of analysis should be kept within the tracking system. These details should include:

- check on constituents declared by waste producer/holder to ensure Permit compliance, treatment plant specification and final disposal
- all hazardous characteristics
- physical appearance
- colour
- pH
- presence, strength and description of odour assessment (note COSHH implications)

8 Following characterisation of the waste, a technical assessment should be made of its suitability for treatment or storage to ensure Permit conditions are being met.

9 All records relating to pre-acceptance should be maintained at the installation for cross-reference and verification at the waste acceptance stage. These records should be kept for a minimum of 3 years

3.3.1.2 Waste sampling

The objective is to obtain waste samples for analysis and treatability testing that are representative of the waste as a whole and of the extremes of waste composition (hot spots) which can be used for worst case testing.

Key Note

The key requirement is to obtain a sample(s) that is representative of the load, that is, the sample takes account of the full variation within a bulk load such that "worst-case" scenarios are accounted for.

A sampling plan should be written which should incorporate the sampling regime for waste characterisation and where appropriate, compliance testing and on-site verification. A sampling plan standard has been published as a

British Standard, BS EN 14899. It is supported by 5 technical reports CEN/TR 15310-1, 2, 3, 4 and 5.

For specific ecotoxicity test, there is a standardised process: Preparation of waste sample for ecotoxicity test EN 14735.

3.3.1.3 Waste Characterisation

Waste characterisation phase involves analysing untreated waste samples for chemical, physical and hazardous characteristics. It is important to determine with confidence the primary characteristics that may interfere significantly with the S/S process.

Tests of "basic characterization" aim at obtaining information on characteristic properties of the waste and on their short and long-term behaviours in the conditions specified by the considered scenario. Liquid / Solid ratios (L/S), leachant composition, factors that control the leachability as pH, redox potential, complexation capacity and physical parameters are taken into account in these tests.

Two additional objectives for collecting waste characterisation data are that such data are useful in selecting the most suitable binding agent for the waste and in predicting the ultimate performance of the waste/binder mixture. As a minimum, background information on waste history will allow the subsequent analytical activities to be more focussed, emphasizing target contaminants and problem constituents.

Types of characterisation data that may be required for the waste include chemical, physical, physicochemical (i.e. relating to the form of the contaminant as opposed to its bulk concentration). The collected information will help to:

- a. gather information on substances that interfere with common S/S processes
- b. establish baselines for comparison with chemical data on the treated waste, and
- c. establish the target contaminants and their physicochemical form.

Indicative BAT for Basic Characterisation

The minimum analysis should include leaching data to define the soluble portion of the contaminant in the waste, yielding an understanding of contaminant partitioning in the waste form and to establish the target contaminants whose leachabilities must be reduced during the S/S process. If present, the hazard characteristics for ignitability, reactivity and/or corrosivity may preclude stabilisation or at least indicate need for pretreatment.

Baseline data may include a variety of parameters and by definition, are needed to assess how the parameters change during the S/S treatment. Such data may be either chemical (e.g. pH, Eh, total and leachable contaminants) or physical (e.g. specific gravity, permeability, physical state, total solids, viscosity, etc).

Another characterisation category is constituent that may interfere with the S/S process. These include a great variety of constituents depending on the binding agent contemplated. Examples are oils and grease.

Along with chemical data, there is a need for physical properties and textural characteristic data, because heterogeneous waste containing large blocks or boulders may be difficult to process without pretreatment. Also included in this category are other parameters that will aid in the selection of the binding agent or the design of the S/S process. Examples are particle size and water content.

3.3.1.4 Site Characterisation

Whether carrying out treatment of imported waste or in-situ remediation of contaminated soil, information on site characteristics is an important aspect of the technology screening process. The following types of information are highly important:

- Baseline information on the geology, hydrology, weather, etc may constrain the design of the field treatment system, influence project timing and have other effects.
- Site layout and proximity to needed resources also affect engineering design and therefore project cost.
- Information on site history may provide valuable insight about the waste, including the types of chemicals that were used at the site and provide some information on where they were released or disposed of.
- Proximity to sensitive receptors, including residential homes, playgrounds and sensitive habitats.

Key issues

In some cases, the capacity of the site to provide sufficient area for the expected processing hinders stockpiling and temporary or final waste disposal or onsite re-use may be a problem as some kind of processing require excavation and/or stockpiling of untreated waste along side processed waste and the binder.

This will usually need to be covered to reduce exposure to wind and precipitation. Binders also increase the volume of the treated waste product. One solution to this is to deliver pre-weighed amount of the binder directly to the process site. The binder can then be added directly to the mixing area rather than being stockpiled in bulk containers.

3.3.1.5 QA and QC

Any waste sampling and characterisation activity should be supported with a QA/QC program. The objective of QA/QC program is to assess and identify measurement errors that may enter the data collection and measuring system at various phases of the project during sampling, sampling handling/preparation and analysis. Analysis should be carried out by a laboratory with robust quality assurance and quality control methods and record keeping.

3.4 Waste/binder compatibility screening

3.4.1 Identifying available binder

The next stage after determining that S/S is a potentially applicable technology for a specific waste is to identify appropriate binder type. The objective is to identify those binder types most suited for the waste and its contaminants and for the related waste disposal or recovery scenario. That is, the treated waste should be suitable in terms of risk for the eventual disposal or re-use environment.

The principle criteria for waste/binder compatibility screening include:

- a. interferences and chemical incompatibilities
- b. metal and organic chemistry considerations for target contaminants and
- c. compatibility with the disposal or reuse/recovery environment
- d. cost
- e. process track record

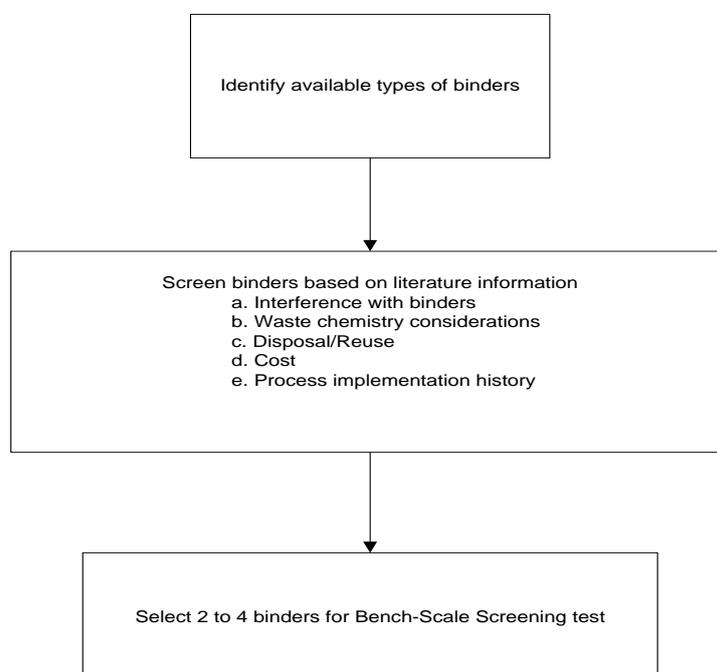


Figure 3.3: Waste/Binder Compatibility Screening

3.4.2 Interference and chemical incompatibility consideration

S/S treatment using pozzolanic binders may be inhibited in the presence of certain constituents such as high concentration of oil, grease and other organics, chlorides and other soluble salts. Certain S/S process will not function properly if the chemical environment is not adequately controlled.

3.4.2.1 Metal Chemistry Consideration

Numerous chemical complexities exist as it pertains to S/S treatment. Chemical condition such as high pH that are favourable for the immobilisation of certain metals e.g. Ni and Zn actually may be detrimental to others. For example, AS and Cr form soluble anionic species at high pH. Also the solubilities of many metal hydroxides is affected by their amphoteric behaviour (solubilities increases at both high and low pH). The minimum solubilities for one metal may be several pH units different from the minimum solubility for another.

3.4.2.2 Organic chemistry considerations for target contaminants

The selection of binders for waste containing organic contaminants must be based upon compatibility with the organic contaminants. Example of binders and additives that are used frequently for immobilising organic

contaminants include such materials as activated carbon and modified clays. In general, generic binders such as portland cement are not effective at immobilising organics, with the exception of high polar compounds (alcohol, phenols, etc) in low to moderate concentrations.

Key Considerations

When evaluating the feasibility of applying S/S technology to waste containing significant concentration of organic contaminants, the operator should consider:

- Whether an alternative treatment i.e. destruction or extraction technology is available and applicable to the waste. Destruction or extraction technologies are preferred as they eliminate or remove the contaminant as opposed to just immobilising it.
- The volatility of the organics and whether an emission may occur during excavation, mixing and/or curing.
- The solubility of the organics in water and the meaningfulness of conducting aqueous leachate tests as a measure of degree of immobilisation of the organics by S/S treatment.
- Whether the organic contaminants may degrade or transform to other by-products during S/S treatment and the toxicity of those by-products.
- The intended re-use or disposal of the treated waste.

3.4.3 Compatibility with the disposal or re-use environment

The end use of the S/S treated waste has a bearing on binder selection. Many treated wastes may be sent to a landfill for disposal and others may be recovered as fill material, road base or construction material. Both waste disposal and recovery options are controlled activities in the United Kingdom. For example, the landfill waste acceptance criteria will have to be met or a waste recovery plan specifying site specific reuse/recovery criteria will be required. Recovery on land proposals are subject to intense scrutiny to demonstrate environmental protection.

3.4.4 Cost

Cost should be used only to screen binders that are significantly less economical or whose benefits clearly do not justify the added cost. The operator will be expected to use an appropriate binder. Where there are several suitable options with varying effectiveness, environmental risks and cost, an "Options Appraisal" should be carried out to support the selected option.

3.4.5 Process Track Record

This may be used as a further screening tool in the selection of binders. Several databases are available that may be referred to as sources of information on successful treatability studies. Data should be sorted as appropriate such as by metal, organics, waste types, binder type or other delineators. It should however be noted that suitable variations in waste chemistry can lead to very different treatability results.

3.5 Performance standards

Performance standards are specified values or parameters of a successfully S/S treated waste as determined by specific tests or measurements. The properties tested are legal/regulatory standards or determined on a site specific basis and considered crucial for predicting the efficacy and long term reliability of S/S. Every waste treatment remedial action project needs a clearly defined set of measurable performance standards. The success or failure of the project depends upon the ability to satisfy these standards.

If treatment by S/S cannot meet these objectives at the bench scale, S/S alone probably cannot provide sufficient treatment to meet waste or site clean up goals. Once test methods and performance standards have been determined, the parameters to be used in interpreting test results can be derived readily. The testing program should not commence without a clear definition of what will constitute success or failure.

3.6 Laboratory bench-scale screening of the waste/binder mixtures

The result of the waste/binder compatibility screening will be a list of binders or binder additive systems that are potentially suitable for S/S treatment. The result of the analysis now needs to be made specific to the actual waste to be treated. In cases where there is a high level of confidence that a given binder will easily satisfy the project's performance standards, the bench-scale screening step may be deemed unnecessary. However, it will improve confidence and the project's credibility where a bench-scale screening is conducted. This is because of the numerous possible subtleties in S/S processes.

The process involves mixing relatively small amounts of waste with binders for testing individual parameters or indicators of S/S technology performance. These tests are usually performed in batch, e.g. jar tests with treatment parameters varied one at a time.

3.6.1 Performance Testing - Water/Cement Ratio (W/C)

This stage is to comparatively evaluate the candidate binding agents. The operator should test the effectiveness of different waste/binder ratios. Water/cement ratio (W/C) is a major factor controlling porosity and strength of the final product. For any set of material and conditions of curing, the quality of the hardened product is strongly influenced by the amount of water in relation to the amount of binder or cementitious materials. It is important to note that the strength decreases as the water content increases.

The US EPA recommends cement ratio of is 0.48 and the cement will fully hydrate at this ratio (U.S. EPA, 1993). However some specialty binders may operate optimally at other ratios. Higher or lower ratios may be needed depending on factors such as waste complexity and toxicity.

The water cement ratio (W/C) is calculated by dividing the weight (mass) of water by the weight (mass) of cement or combined cementitious materials (including fly ash, ground slag, etc) in a given volume.

Calculating Water/Cement Ratio (W/C)	
Water in litres (converted to tonnes) divided by cement in tonnes	
<u>Example calculation</u>	
<i>Type 1 cement</i>	<i>X tonnes</i>
<i>Ground Slag</i>	<i>Y tonnes</i>
<i>Water</i>	<i>Z tonnes</i>
W/C =	$X / (Y + Z \text{ tonnes})$
	0.48

3.7 Bench-scale performance testing - Process Optimisation

This stage in the treatability study is to demonstrate that the binder will achieve all relevant project performance standards and to optimise the S/S process in terms of design field implementability and cost performance.

Depending on the performance standards, the operator should consider one or two performance tests such as the Leachability. The Landfill Directive specifies **BS EN 12457-3:2002 L/S10 (for granular waste) and EA NEN 7375:2004 (for monolithic waste)** and Unconfined Compressive Tests for screening purpose (**BS EN 12390-4 series**). The leachability test is recommended because of regulatory requirements, e.g. the Landfill & Groundwater Directive whereas the UCS test is recommended because Landfills and most re-use options will have some level of UCS performance standards.

The choice of leaching test to employ depends on a number of factors, e.g. the anticipated disposal setting and environment or human health risk, type of contaminants and their level of hazard and concentration, the planned disposal or re-use scenario, all influence the choice of leaching tests. For example, the final remedial design may specify that the S/S treated waste be placed above the seasonal high water table and an impervious cap and run on/run off controls be constructed. In such a case, leaching and physical integrity tests will usually suffice to demonstrate whether the S/S process can be considered reliable for the site.

Advisory Notes
<ul style="list-style-type: none"> • There are no specific regulatory standards for the reuse of S/S treated waste (except for landfills), therefore the performance standard for the S/S treated waste must be determined on a case by case basis. • Treatment performance should be determined by the performance test and whether the S/S treated waste meets all the pre-determined standards. • Every bench scale treatability study should consider test of leaching such as, BS EN 12457-3:2002 L/S10 (for granular waste) and EA NEN 7375:2004 (for monolithic waste), and unconfined compressive strength (BS EN 12390-4 series). • The level or robustness of the performance testing should be set by the potential level of risk posed to human health and the environment. That is, the testing program should be based upon the guiding principles derived from the ultimate risk posed by the waste in its planned disposal or re-use environment.

The level of risk determines the general extent of recommended performance testing. The greater the risk, the more extensive testing requirements for the operator to increase the level of confidence that the treated waste will remain stable for the long term.

Following the bench-scale performance testing and process optimisation, the operator should be able to demonstrate whether or not the S/S treated waste is:

- Chemically and physically stable, i.e. no free liquids
- Compatible with its disposal or reuse/recovery environment, e.g. possesses adequate compressive strength, is non biodegradable and has sufficiently low permeability
- In line with article 13 of the Waste Framework Directive (WFD)
- Demonstrated effective and readily implementable in the field

Following leachability test and based on concentration values of released pollutant compounds, a comparison of the concentrations or of the mass releases with the performance levels or relevant regulatory values should be carried out.

3.7.1 How Much Performance Testing

3.7.1.1 Levels of Risk

One approach for determining risk as it relates to S/S projects is based on the principle risk factors identified in table 3. This simplified approach is provided as a rule of thumb guidance only as numerous exceptions are likely to exist.

The risk categories in table 3.1 are:

- Waste quantity
- Type and quantity of metal contaminants
- Type and quantity of organic contaminants
- Site (disposal or recovery) characteristics, and
- Demonstrated effectiveness of the S/S process

Each of the risk categories is subdivided into low, medium or high risk levels. Larger quantity of waste, higher hazard contaminants, site conditions promoting possible exposure to human, environment and ecological receptors and undemonstrated S/S process are all associated with higher risk.

Table 3.1 RISK FACTORS FOR EVALUATING LEVELS OF PERFORMANCE TESTING			
Risk Levels			
Risk factors	I. Low risk	II. Medium risk	III. High risk
A. Waste Quantity	<1000 tonnes	>1000 to <5000 tonnes	>5000 tonnes
B. Metal Contaminants	<ul style="list-style-type: none"> • Non carcinogenic • Soluble, Low toxicity (e.g., Cr[III], Ba, Zn, Mo, Cu) • Low concentrations 	<ul style="list-style-type: none"> • Non carcinogenic • Soluble, Low toxicity (e.g., Pb, Se, Sb) • Low to medium concentrations 	<ul style="list-style-type: none"> • Known or suspected carcinogen • Soluble, High toxicity concentration (e.g., Bi, Ba, Cr[VI], Cd, Hg, As Be) • Very high concentrations
C. Organic contaminants	<ul style="list-style-type: none"> • Low total organic carbon content • Low hazardous organics • Low-interference organics 	<ul style="list-style-type: none"> • Non carcinogenic • Medium toxicity (e.g., MBTE, cresols, Toluene, Xylene, and aldehydes) • Low to medium concentrations 	<ul style="list-style-type: none"> • Known or suspected carcinogen (e.g., Benzene Chloromethane Benzo(a)pyrene) • High toxicity concentration (e.g., PAHs, PCBs, dioxins, furans, certain pesticides, chlorophenols) • High-interference organics
D. Site characteristics	<ul style="list-style-type: none"> • Dry condition • Unsaturated zone disposal • Low population density • >50m from SPZ1 or any spring or well or any borehole used to supply water for domestic or food production purposes • >200m from a designated sites (SPA/SAC, SSSI) 	<ul style="list-style-type: none"> • Conditions intermediate between I and III • Unsaturated zone disposal • Average population density • >50m from SPZ1 or any spring or well or any borehole used to supply water for domestic or food production purposes • >200m from a designated sites (SPA/SAC, SSSI) 	<ul style="list-style-type: none"> • Saturated zone disposal • Wet condition • High population density • <50m from any spring or well or any borehole used to supply water for domestic or food production purposes • <200m from a designated sites (SPA/SAC, SSSI)

			<ul style="list-style-type: none"> Windy conditions coupled with above ground disposal
E. History of process effectiveness	<ul style="list-style-type: none"> Well-established, frequently used process with generic binders and contaminants that stabilise readily 	<ul style="list-style-type: none"> Field-demonstrated, but not as frequently used 	<ul style="list-style-type: none"> Innovative or complex process for contaminants that are more difficult to stabilise (e.g., Cr[VI], phenol)

3.7.1.2 Need of individual S/S project

The level of test carried out by the operator will depend on the level of risk. High risk projects require more rigorous levels of testing to establish degree of confidence. The amount and type of test run will also depend on the need of the individual S/S project, i.e. site specific. For e.g. a freeze/ thaw test may not make sense for an S/S treated waste placed entirely below the frost line. For most high risk S/S project, this also means that the potential for long term leaching should be assessed. For final placement close to natural waterways, the need for acute bioassay testing may also be considered. A larger number and wide variety of performance tests may be conducted. Table 4.1 provides levels of performance testing and example testing requirements. More examples are available in chapter 4.

Testing level	Example testing requirements		
	Leaching	Physical	Other chemical
I. Low	<ul style="list-style-type: none"> One short-term test (e.g., 5-day ANSI/ANS16.1) 	<ul style="list-style-type: none"> Minimum number of parameters needed to demonstrate compatability with disposal or reuse/recovery environment 	<ul style="list-style-type: none"> As needed; pH (CEN / TS 14429 or CEN / TS 14997 usually required to determine the influence of the pH on the leaching behaviour)
II. Medium	<ul style="list-style-type: none"> One short-term test (e.g., 5-days ANSI/ANS16.1) and one medium or long-term test (e.g., MEP) 	<ul style="list-style-type: none"> Several physical parameters (e.g., UCS, permeability) Freeze/thaw and wet/dry tests if above ground use is planned 	<ul style="list-style-type: none"> As needed (eg., pH, acid neutralization capacity)
III. High	<ul style="list-style-type: none"> Several tests, including one long-term test (e.g., MEP or 90-days ANSI/ANS16.1); geo-chemical and/or transport modeling may be advisable A solvent extraction test (Total waste analysis) Non routine analytical procedures as required to indicate chemical bonding 	<ul style="list-style-type: none"> Applicable properties from Level II plus, freeze/thaw and wet/dry tests, and others as appropriate Biodegration tests of pertinence to the binder 	<ul style="list-style-type: none"> pH, acid neutralization capacity, Eh, volatile emissions as appropriate to show chemical stability and compatibility Bioassays as appropriate Specification of contaminant metals to show potential for long-term stability

Source – Adapted from the Technical Resource Document, EPA/530/R-93/012, U.S. EPA, 1993

3.7.1.3 Performance Acceptance (based on Performance Objectives)

The success of the treatability study will be measured in terms of whether the tests satisfy predetermined performance objectives and standards. Some of these standards are based on regulatory limits such as those required by the Landfill Directive (WAC) while others are determined on site specific basis or factors such as the anticipated disposal setting and environment or human health risk, type of contaminants and their level of hazard and concentration and etc. The more stringent the performance standards, the more robust the testing needs to be.

4. PILOT SCALE AND FIELD DEMONSTRATION

4.1 The need for process scale-up

A pilot test generally refers to an intermediate scale simulation (often in the laboratory) of a full scale operation. Usually in S/S technology, the field test is a dry-run of the full scale treatment equipment under carefully monitored conditions prior to proceeding with the full scale treatment.

If treatability or bench-scale testing has shown that the waste contains common forms of contaminants that respond well to the stabilisation in a matrix that contains no significant amount of interferants and if the binder system is well demonstrated and commonly used on these contaminants, then a pilot or field demonstration may not be necessary.

If the contaminant species is complex in the waste matrix, if the waste contains interferants or if a “not-so-well-understood” binder system is being used, the operator should be advised to carry out a pilot or field scale demonstration to ensure the effectiveness of the process.

Conditions, both physical and chemical during the full-scale cleanup may vary from those in the laboratory so as to alter the desired reactions of the stabilisation process. Studies have shown that environmental conditions sometimes prevent the reaction between chemical compounds or components from reaching completion.

Advisory note:
<ul style="list-style-type: none">The same pre-acceptance procedure as for Treatability study should be implemented: Indicative BAT for Pre-acceptance for on-site treatability study
<ul style="list-style-type: none">After allowing the treated waste to cure, the samples can be analysed for critical verification parameters that can be compared with established performance standards. Details of this should be included in the report submitted to the Environment Agency as part of the application process. If the samples meet the performance standards, the operator may be advised to proceed with the full-scale cleanup, subject to satisfactory environmental/amenity risk assessment.If the samples fail the performance objectives, the operation cannot proceed and the operator should be advised to determine whether the field scale equipments, the binder formulation and/or other engineering parameters, e.g. flow rates, storage environment, etc are at fault. Further testing may be necessary to identify the cause of the deviation between bench-scale and field-scale results.

4.2 Full Scale Treatment/Clean-UP Issues

Waste stabilisation can be carried out via ex-situ mixing which involves removing the waste from its location and transferring it to a treatment plant for processing. Ex-situ treatment can also be used to describe a process whereby waste is excavated from the ground and treated on the surface. The waste is mixed with the stabilisation agents in the fixed or mobile treatment plant. In the case of In-situ mixing, the waste remains in place and the stabilised agents are injected or mixed with specialised augers or other equipment.

The treatment operation should address each of the following wherever applicable:

- Waste Acceptance for imported waste (ex-situ)
- Waste excavation for ex-situ process (land remediation)
- Waste handling
- Equipment selection and sizing
- Chemical reagents (binder) storage
- Pretreatment of waste (see section 2.4)
- Presence of debris
- Materials balance (see key issues in section 3.3.1.4)
- Mixing and curing
- Stabilized waste disposal and/or reuse/recovery

4.2.1 Waste Acceptance

Information obtained from the treatability studies, waste sampling, pre-acceptance and characterisation should provide sufficient details on the type, composition, character and complexity of the waste. This means that acceptance procedures when the waste arrives at the site should serve to confirm the characteristics of the waste. This should also minimise the time the vehicle delivering the waste is kept waiting.

To prevent unnecessary accumulation of untreatable waste onsite, a clear acceptance criteria and destination or intended use for the S/S treated waste should have been identified. While there is a clearly defined Waste Acceptance Criteria for waste going to landfill for disposal, this is not the case for waste re-use/recovery on land as there are site specific issues to be considered.

Therefore, the Environment Agency will expect that a treatability study would have been carried out and treatment/remediation standards and site specific reuse criteria agreed with them before the waste is accepted at the site. All these should be included in the Waste Recovery Plan which is required for any Waste Deposit for Recovery

Scheme. The Environment Agency's Geotechnical (GTT) as well as the Groundwater & Contaminated Land Teams have a major role to play in this. The GTT will advise on the acceptability of the S/S treated waste, basing their decision on the intended use of the treated waste. The GWCL will advise on the suitability and/or site specific reuse/recovery criteria of the S/S treated waste with respect to impact on land and groundwater.

Indicative BAT for waste treatment
<p>Waste Acceptance Procedures when waste arrives at the site</p> <p>Load arrival</p> <ol style="list-style-type: none"> 1. On arrival loads should: <ul style="list-style-type: none"> • be weighed, unless alternative reliable volumetric systems linked to specific gravity data are available • not be accepted into site unless sufficient storage capacity exists and site is adequately manned to receive waste • have all documents checked and approved, and any discrepancies resolved before the waste is accepted • have any labelling that does not relate to the contents of the drum removed before acceptance on site. 2. Hazardous wastes should only be received under the supervision of a suitably qualified person (HNC qualified chemist or higher) <p>Load inspection</p> <ol style="list-style-type: none"> 3. Visual inspection. Where possible, confirmatory checks should be undertaken before offloading where safety is not compromised. Inspection must in any event be carried out immediately upon offloading at the site. 4. Check every container to confirm quantities against accompanying paperwork. All containers should be clearly labelled and should be equipped with well-fitting lids, caps and valves secure and in place. Any damaged, corroded or unlabelled drums should be put into a quarantine area and dealt with appropriately. Following inspection, the waste should then be unloaded into a dedicated sampling/reception area. 5. At this stage the waste tracking system unique reference number should be applied to each container. Each container should also be labelled with the date of arrival on-site and primary hazard code. 6. Where containers are bulked, the earliest date of arrival of the bulked wastes should be transposed from the original container onto the bulk container. 7. The inspection, unloading and sampling areas should be marked on a plan and have suitably sealed drainage systems. <p>Sampling - checking - testing of wastes - storage</p> <ol style="list-style-type: none"> 8. Other than pure product chemicals and laboratory smalls, no wastes should be accepted at the site without sampling, checking and testing being carried out. Reliance solely on the written information supplied is not acceptable, and physical verification and analytical confirmation are required. All wastes must be sampled and undergo verification and compliance testing. 9. The Operator should ensure that waste delivered to the site is accompanied by a written description of the waste describing: <ul style="list-style-type: none"> • the physical and chemical composition • hazard characteristics and handling precautions • compatibility issues • information specifying the original waste producer and process 10. On-site verification and compliance testing should take place to confirm: <ul style="list-style-type: none"> • the identity of the waste • the description of the waste • consistency with pre-acceptance information and proposed treatment method • compliance with permit 11. The Operator should have clear and unambiguous criteria for the rejection of wastes, together with a written procedure for tracking and reporting such non-conformance. This should include notification to the customer/waste producer and the Regulator. Written/computerised records should form part of the waste tracking system information. 12. Documentation provided by the driver, written results of acceptance analysis, details of offloading point or off-site transfer location should be added to the tracking system documentation. 13. A record of the sampling regime for each load and justification for the selection of this option should be maintained at the site. 14. Wastes must not be deposited within a reception area without adequate space. 15. Wastes in containers should be unloaded into a dedicated reception area pending acceptance sampling. Such storage should be for a maximum period of 5 days. During this period there should be no bulking up or mixing of drums or decanting the contents into bulk storage. Wastes should be stored within this reception area according to compatibility in line with HSE Guidance Note HSG71. Appropriate storage must be achieved immediately upon offloading.

16. Should the inspection or analysis indicate that the wastes fail to meet the acceptance criteria (including damaged or unlabelled drums), then such loads should be stored in a dedicated quarantine area and dealt with appropriately. Such storage should be for a maximum of five working days. Written procedures should be in place for dealing with wastes held in quarantine, together with a maximum storage volume.
17. If the cause of failure to meet acceptance criteria is due to incompatibility, then the wastes should be segregated immediately to remove the hazard.
18. Tankered wastes should be sampled prior to acceptance. There should be no storage pending sampling.
19. The driver of the vehicle carrying the waste may arrive at the site with a sample that has been taken at some stage beforehand. This should be the exception and only be relied on if:
 - there are health and safety and environmental control considerations, for example, water reactive substances which would make sampling difficult, and
 - the following written information has been supplied - the physical and chemical composition, hazard characteristics, incompatible substances and handling precautions, information specifying the original waste producer and process, and
 - the waste has been taken directly from the production site to the waste treatment site
20. The site should have a designated sampling point or reception area. These should be in close but safe proximity to the laboratory/checking facility and the sampling point should be visible (or covered by CCTV), if sampling is not directly supervised by, for example, laboratory staff.
21. The offloading, sampling point/reception and quarantine areas should have an impervious surface with self-contained drainage, to prevent any spillage entering the storage systems or escaping off-site. Most spills and leaks during sampling are on a small scale, resulting from releases from the back valve of a tanker if the sample is being obtained in this way. Attention should be given to ensuring that incompatible substances do not come into contact resulting from spills from sampling, for example, within a sump serving the sampling point. Absorbents should be made available.

Sampling of bulk liquid wastes

22. Deliveries in bulk road tanker should be accompanied by a "wash-out" certificate or a declaration of the previous load so that contamination by this route can be checked.
23. Samples are usually taken by the tanker driver from one of three points on the tanker:
 - top hatch
 - back valve
 - sight glass
24. The key requirement is to obtain a sample that is representative of the load, that is, the sample takes account of the full variation and any partitioning within a bulk load such that "worst-case" scenarios are accounted for. Taking a sample through a top hatch of the surface of the liquid may not be representative, but may be useful in establishing whether there may be a layer of, for example, solvent or some other immiscible substance, which may be unsuitable for treatment. Top samples should be obtained from the cross-section of the load, that is, a core sample.
25. A gantry should be used to avoid the need to take samples from the back valve of tankers, which is likely to result in a small spillage.

Sampling drummed waste

26. The contents can only be identified with certainty if every container is sampled. Acceptance should involve sampling every container. However, analysis of composite samples is acceptable with such a sampling regime. A representative sample must be obtained by taking a core sample to the base of the container. Operators should ensure that lids, bungs and valves are replaced immediately after sampling.

Drum Labelling

27. For drummed waste, controls should ensure each drum is given a unique label to facilitate a record of:
 - the location of each drum
 - the duration of storage
 - the chemical identity of the drums contents
 - the hazard classification for each drum
28. Drums should be handled and stored so that the label is readily visible

Acceptance of laboratory smalls

29. The procedure for accepting laboratory smalls on-site should be essentially identical to that for drummed waste. They differ from the "normal" waste inputs to site in that they are in a pure concentrated form.
30. In situations where the Operator has undertaken the identification and packaging on behalf of the customer, then the on-site verification can be restricted to opening the drums to check that the containers remain undamaged. In such cases the load must be accompanied by documentation confirming the checking and packing. In situations where the drum has been packed by the customer, then full checking and verification

should be undertaken. Checking packaging and segregation adequately should include emptying of the drum as soon as possible and in any event at facilities that are operated 24 hours a day, within 24 hours. At sites not operated around the clock, checking must be undertaken before the end of the working day. Repackaging the waste must be undertaken as soon as the necessary checks have been undertaken.

Waste Rejection procedures

31. Lab smalls must not be accepted at a facility where there is insufficient suitably qualified personnel to process these wastes within the above timescales
32. If on opening a drum it is found that it contains incompatible substances, or that the substances have not been packaged adequately, then the drum should be sorted and repacked immediately and the non-conformance procedure followed.
33. Sorting and repackaging of laboratory smalls should take place in a dedicated area/store. Once the wastes have been sorted according to hazard classification, with due consideration for any potential incompatibility problems, and repacked, then these drums should not be stored within the dedicated laboratory smalls area but should be removed to the appropriate storage area.
34. The operator should have clear and unambiguous criteria for the rejection of wastes, together with a written procedure for tracking and reporting such non-conformance. This should include notification to the customer/waste producer and the Environment Agency. Written/computerised records should form part of the waste tracking system information. The operator should also have a clear and unambiguous policy for the subsequent storage and disposal of such rejected wastes. This policy should achieve the following:
 - identifies the hazards posed by the rejected wastes
 - labels rejected wastes with all information necessary to allow proper storage and segregation arrangements to be put in place
 - segregates and stores rejected wastes safely pending removal

Records

35. The waste tracking system should hold all the information generated during pre-acceptance, acceptance. Records should be made and kept up to date on an ongoing basis to reflect deliveries, on-site treatment and despatches. The tracking system should operate as a waste inventory/stock control system and include as a minimum:
 - date of arrival on-site
 - producers details
 - all previous holders
 - a unique reference number
 - pre acceptance and acceptance analysis results
 - package type and size
 - intended treatment/disposal route
 - record accurately the nature and quantity of wastes held on site, including all hazards and identification of primary hazards
 - where the waste is physically located in relation to a site plan
 - where the waste is in the designated disposal route
 - identification of operators staff who have taken any decisions re acceptance or rejection of waste streams and completion of treatment by S/S.
36. All records relating to pre-acceptance should be maintained and kept readily available at the site for cross-reference and verification at the waste acceptance stage. Records should be held for a minimum of two years after the waste has been treated or removed off-site. Records should be held in an area well removed from hazardous activities to ensure their accessibility during any emergency.
37. The system adopted should be capable of reporting on all of the following:
 - total quantity of waste present on-site at any one time, in appropriate units, for example, 205 litre drum equivalents
 - breakdown of waste quantities being stored pending on-site treatment (by S/S)
 - breakdown of waste quantities by hazard classification
 - indication of where the waste is located on site relative to a site plan
 - comparison of the quantity on site against total permitted
 - comparison of time the waste has been on-site against permitted limit

These records should be held in an designated area, as agreed with the Agency, well removed from hazardous activities to ensure their accessibility during any emergency

38. Back-up copies of computer records should be maintained off-site.

General

39. Wastes should not be accepted at the site without a clear and defined performance objectives/remediation target and a clear destination or intended use of the S/S treated waste. These checks should be performed before the waste acceptance stage is reached.
40. The Operator should ensure that the site personnel who may be involved in the sampling, checking and analysis

procedures are suitably qualified (HNC qualified chemist or higher) and adequately trained, and that the training is updated on a regular basis.

41. Analysis should be carried out by a laboratory with suitably accredited test methods.
42. Samples should be retained on-site for a minimum of two days after the waste has been treated or removed off-site including all residues from its treatment.
43. Once analysis has confirmed that the waste is acceptable, the Operator should only then create a batch for treatment based on information obtained from treatability study.
44. There must be a clear distinction between sales and technical staff roles and responsibilities. If non-technical sales staff are involved in waste enquiries then a final technical assessment prior to approval should be made. It is this final technical checking that should be used to avoid build-up of accumulations of wastes and to ensure that sufficient capacity exists.

Indicative BAT for waste treatment

- **Waste Excavation and Handling (land remediation)**

This involves the use of traditional earth moving equipment e.g. backhoes, drag lines, bulldozers, front end loaders. If free liquid is present on top of the waste, it may have to be pumped out and treated as a separate waste stream.

Depending on the nature of the waste and potential receptors, the excavated waste can be transported to the treatment plant by a fixed system, e.g. conveyor or screw auger, dump truck (for soil) or pump and hose (for liquid and sludges) or if the waste is particularly hazardous, in drums. Spillage should be avoided during transport.

- **Stabilising Agent Storage**

The amount of chemical reagents should have been determined from treatability testing results, specifically the binder/waste ratio. Bins, hopper and silos are used for storage of dry chemicals. If liquid chemicals are being used, fully bunded liquid storage tanks or drums may be necessary. Unless the waste volume is small, chemicals generally need to be replenished on a continuous basis during the project. Pre-weighed amount of the binder may be delivered directly to the processing site. The binder can then be added directly to the mixing area rather than being stockpiled in bulk containers.

- **Pretreatment of waste**

Wastes requiring pretreatment include materials that are considered to be hazardous by virtue of ignitability, reactivity, infectiousness, presence of radionuclides. Any waste displaying any of these hazardous properties would normally not be treatable by S/S nor disposed of in landfills without adequate pretreatment.

This is required for;

- a. Improving the material handling characteristics of the waste
- b. Improving waste/binder compatibility
- c. Removing constituents that either interfere with or are not affected by S/S processing (inert material)

Pretreatment may include screening, size reduction, crushing, drying or dewatering, blending and homogenisation, pH adjustment or heating to drive off volatiles. Landfills and Reuse of waste only allows the desposit of waste. Therefore, a separate environmental permit or variation to the existing permit (for S/S) may be required to authorise other forms of treatment/pretreatment.

- **Mixing and Curing**

Thorough mixing is critical and adequate measures must be taken to ensure that the waste and binder chemicals are mixed thoroughly and allowed to cure propely. It is also critical that known volumes or weights of waste and chemicals are added with reasonable accuracy. Before mixing, a compatibility study must be carried out to prevent runaway reactions and accidents. This is especially important when dealing with potentially hazardous waste.

- Mixer performance needs to be evaluated in order to confirm the amount of stabilisation agent needed. During bench-scale testing, the amounts of chemicals required for full-scale operations can be underestimated because less than ideal mixing efficiency was not accounted for.

Curing of the waste can occur in either containers, pits or free-standing piles. Controls should be implemented both to protect the surrounding environemnt from possible run-offs or leaching from the curing waste and to protect the curing waste from wind and precipitation.

4.3 Key Issues and Environmental Risk

4.3.1 Accident Risk

There is always the risk of accidents when dealing with hazardous waste. Wastes are heterogeneous in nature and are potentially aggressive to plant and equipment. Any failure in the management of the waste, from the process of characterisation and checking of wastes, to operational control for reactions and mixing of wastes, will significantly increase the risk from unwanted or runaway reactions. Combinations of inappropriate equipment and poor inspection and maintenance procedures also increase the accident risk through, for example, tank overflow situations where level indicators may not be working or have not been correctly calibrated.

4.3.2 Relationship to BAT

Article 13 of the Waste Directive (WFD) (2008/98/EC) requires Member States to take the necessary measures to ensure that waste management is carried out without endangering human health, without harming the environment and, in particular:

- without risk to water, air, soil, plants or animals;
- without causing a nuisance through noise or odours; and
- without adversely affecting the countryside or places of special interest.

Article 18 of the same directive also prohibits the mixing of hazardous waste either with other categories of hazardous waste or with other waste, substances or materials. Where this is to be carried out, the mixing operation must conform to best available techniques. Therefore for any waste S/S activity, an assessment of the appropriate measures including BAT will be needed to support any application.

4.3.3 Waste hierarchy

Where waste is produced, the WFD requires that waste be recovered, re-used or used as a source of energy in preference to disposal.

With regard to the S/S treatment activities **involving disposal**, this raises the question of whether these activities constitute the appropriate means of dealing with the waste. Clearly, where an opportunity to recover a waste exists, then disposal or treatment may not be the appropriate measure.

4.3.4 Cross-Media Transfer Potential

- Under dry and/or windy environmental conditions, both ex situ and in situ S/S processes are likely to generate fugitive dusts.
- S/S processes can produce gases, including vapors that are potentially toxic, irritating, or noxious.
- Leaching of contaminants or excess reagents to ground water from treated waste that is disposed on site.
- Long-term degradation of the stabilised mass, creating the potential for solidified wastes, reagents, VOCs, and other contaminants to be released from the treated waste.

BAT for Avoiding Potential Cross-Media Transfers During Solidification/Stabilisation

Operational Controls or practices that can be implemented to reduce dangerous emissions include:

- Plan site remediation for times of year with relatively cooler temperatures and lower wind speeds to minimize volatilisation and particulate matter emissions.
- Fugitive dust emissions should be controlled during excavation by spraying water to keep the ground moist. During excavation, material handling and preprocessing activities, meteorological conditions should be strongly evaluated. Soil stockpiles should be covered with reinforced plastic sheets to prevent fugitive dust emission and rainwater infiltration.
- Vapor treatment systems should be used to the extent possible to control the movement of these vapors. VOC emissions associated with these activities that exceed acceptable regulatory limits should be controlled by capturing these emissions and then treating the captured vapor/air to the extent practicable. Hand-held organic vapor analyzers provide quick readings on VOCs. Effective VOC, methane, and odor emissions should be controlled by using covers, foam suppressants, enclosures, vapor collection systems, gas flares, or other methods as appropriate.
- Mixing, crushing, or conveying activities should generally be conducted under an environment where the off gases, volatiles, dusts, etc. are all captured inside a hood. The VOC emissions associated with these activities should be controlled by capturing and then treating the captured vapor/air. The vaporized organic contaminants can be captured by condensation of the off-gas, passing through a carbon absorption bed or other treatment system.
- Maintain lower speeds with all vehicles on unpaved roads.
- Materials that are removed during prescreening activities should be disposed of properly.
- Control placement and shape of storage piles. Place piles in areas shielded from prevailing winds. Shape pile in a way that minimises surface area exposed to wind.

- During excavation, use larger equipment to minimize surface area/volume ratio of material being excavated.
- During dumping, minimise soil drop height onto pile, and load/unload material on leeward side of pile.
- Cover all loads being moved by truck, open piping, or other conveyance with roofs or other structures that will eliminate or reduce the likelihood of particulate release into the atmosphere. Increase freeboard requirements and repair trucks exhibiting spillage due to leaks.
- "Blanket" the emitting source with foam, thus forming a physical barrier to emissions. Also isolate emitting surface source from wind and sun, further reducing particulate and volatile emissions.
- Air emission monitoring must be conducted to detect and quickly act on potential crossmedia transfer. Monitoring (visual or olfactory) upwind/downwind concentrations of ambient dust/particulates or odorous target compounds. Hand-held organic vapor analysers provide quick readings on presence of organic vapors.
- Periodic visual inspection of pipes and joints for corrosion and leaks could provide early detection and prevent major leaks and spills. Reagent delivery piping should be regularly checked to ensure tight fittings. This will reduce the likelihood of releases of VOCs.
- Wastes should be homogenised as much as practicable before processing. This can improve the efficiency of the stabilisation activities, and may help to reduce spillage and other problems related to encountering irregular masses during the mixing process.

4.3.5 Site restoration (prevention of emissions to land)

IPPC in common with Waste Management Licensing (now EPR) requires that, on completion of activities, there should be no pollution risk from the site. As required by the Environmental Permitting Regulations 2010, prevention of both short and long-term contamination of the site requires the provision and maintenance of surfacing of operational areas, measures to prevent or quickly clear away leaks and spillages, maintenance of drainage systems and other subsurface structures.

4.4 S/S Post-treatment performance test and QA/QC

Only adequate testing can ensure the attainment of the quality objectives and ensure that the treated waste meets the required standards. Many different tests can be applied to measure the performance of S/S process, following treatment. For the purpose of this guidance, these are referred to as Compliance Test. The compliance tests are used to determine if the treated waste is in compliance with specific reference thresholds as determined during treatability study.

To ensure formulation of the treated waste within the acceptable range, quality control charts can be developed for daily operations. A QA/QC plan containing the following should be developed:

- Required treatment standard(s)
- control and documentation of cementing materials and waste;
- monitoring materials quality;
- equipments calibration;
- personnel requirements;
- real-time testing;
- pilot scale demonstration;
- early failure indication with indicator parameters; and
- testing on freshly treated and hardened waste forms.

Testing of freshly treated waste has two purposes; to assure the uniformity of the mixture and determine the suitability of the treated waste for handling and disposal. Test of hardened treated wastes evaluates product performance and establishes the process parameters for generating an acceptable product.

Post-treatment or compliance testing generally should consist of both chemical and physical tests. There are other available chemical, biological, extraction and micro-characterisation test but this section only presents an overview of example physical tests. The operator should select appropriate tests based on the waste and site conditions and treatment program objectives. Analysis should be carried out by a laboratory with robust quality assurance and quality control methods and record keeping.

4.4.1 Physical Tests

- Visual observation: for surface spalling, grain exfoliation, crack development, colour, surface pore size and conduction, salt efflorescence.
- Permeability (Hydraulic Conductivity) Test: measure of flow of fluid through the pore structure of the S/S treated waste.
- Strength Tests: An indication of how well a material will hold up under mechanical stresses caused by overburden or earth moving equipment. Better strength provides better physical barriers from the containment of contaminants but S/S treated waste strength should not be mistaking for the degree of containment stabilisation.

- Unconfined Compressive Strength (UCS): This is a measure of the shear strength of an S/S treated material/waste without lateral confinement. The minimum required strength should be determined from the design loads to which the material may be subjected. This European Standard, a part of the BS EN 12390-4 series, specifies the requirements for the performance of compression testing machines for the measurement of the compressive strength of hardened concrete.
- Immersion compressive Test: To test the strength of simulate the performance of the S/S treated waste in a saturated disposal environment
- Durability Test: This evaluates the ability of a material to withstand environmental stresses such as freezing and thawing or wetting and drying. The ability of the material to withstand such conditions or cycles is an indication of its physical stability. Other performance tests such as UCS and permeability can be conducted on the material after each cycle to determine the change in performance due to climate stresses.
- Leaching/Extraction Tests: Leaching tests measure the potentials of a stabilised waste to release contaminants to the environment. The waste is exposed to a leachant and the amount of contaminant in the leachate (or extract) is measured and compared to a previously established standard, which may be regulatory standard of baseline leaching data. Treated waste may give reduced contaminant concentration in the leachate due to waste dilution with binders (independent of any immobilisation mechanism). This should be taken into consideration when using leaching tests.

4.4.2 Other European Test Methods

- EN 13137- Determination of TOC in waste, sludge and sediments
- prEN 14346- Calculation of drymatter by determination of dry residue or water content Leaching tests
- prEN 14405- Leaching behaviour test - Up-flow percolation test (Up-flow percolation test for inorganic constituents)
- EN 12457/1-4 Leaching- Compliance test for leaching of granular waste materials and sludges: Digestion of raw waste
- Analysis of eluates- Determination of pH, As, Ba, Cd, Cl, Co, Cr, CrVI, Cu, Mo, Ni, NO₂, Pb, total S, SO₄, V and Zn (analysis of inorganic constituents of solid waste and/or its eluate; major, minor and trace elements)
- ENV 13370 Analysis of eluates — Determination of ammonium, AOX, conductivity, Hg, phenol index, TOC, easily liberatable CN, F (analysis of inorganic constituents of solid waste and/or its eluate (anions))
- prEN 14039 Determination of hydrocarbon content in the range of C10 to C40 by gas chromatography