

CRC for Contamination Assessment and Remediation of the Environment

National Remediation Framework

Technology guide: Thermal desorption

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National Remediation Framework

The following guideline is one component of the National Remediation Framework (NRF). The NRF was developed by the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) to enable a nationally consistent approach to the remediation and management of contaminated sites. The NRF is compatible with the *National Environment Protection (Assessment of Site Contamination) Measure* (ASC NEPM).

The NRF has been designed to assist the contaminated land practitioner undertaking a remediation project, and assumes the reader has a basic understanding of site contamination assessment and remediation principles. The NRF provides the underlying context, philosophy and principles for the remediation and management of contaminated sites in Australia. Importantly it provides general guidance based on best practice, as well as links to further information to assist with remediation planning, implementation, review, and long-term management.

This guidance is intended to be utilised by stakeholders within the contaminated sites industry, including site owners, proponents of works, contaminated land professionals, local councils, regulators, and the community.

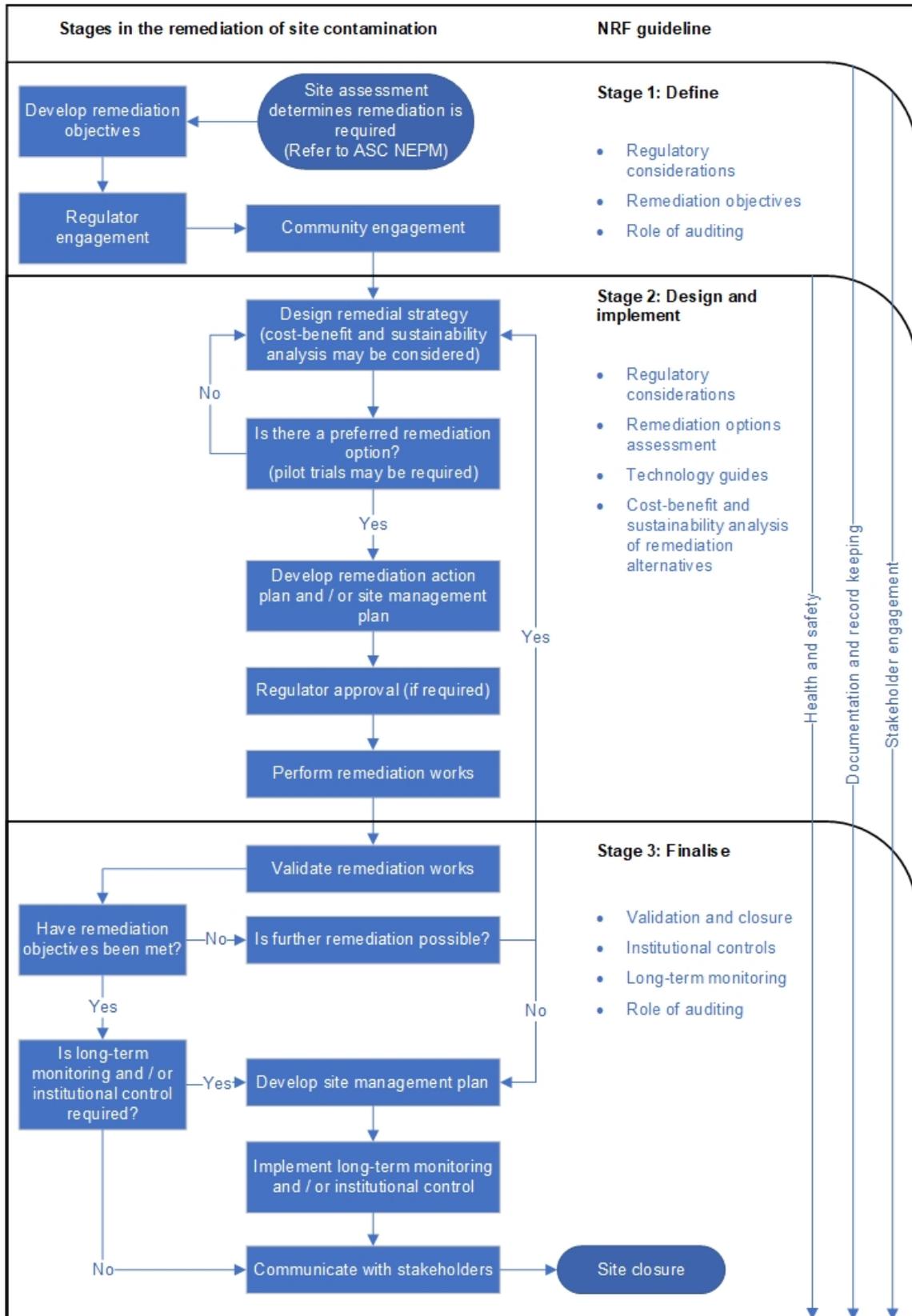
The NRF is intended to be consistent with local jurisdictional requirements, including State, Territory and Commonwealth legislation and existing guidance. To this end, the NRF is not prescriptive. It is important that practitioners are familiar with local legislation and regulations and note that **the NRF does not supersede regulatory requirements**.

The NRF has three main components that represent the general stages of a remediation project, noting that the remediation steps may often require an iterative approach. The stages are:

- Define;
- Design and implement; and
- Finalise.

The flowchart overleaf provides an indication of how the various NRF guidelines fit within the stages outlined above, and also indicates that some guidelines are relevant throughout the remediation and management process.

It is assumed that the reader is familiar with the ASC NEPM and will consult other CRC CARE guidelines included within the NRF. This guideline is not intended to provide the sole or primary source of information.



Executive summary

Thermal desorption is a process that directly or indirectly heats contaminants to a temperature high enough to volatilise and separate them from a contaminated solid medium. The technology can be applied either in situ or ex situ, and can be considered for processing soil, sludge, sediments and filter cakes. Thermal desorption is potentially applicable for the treatment of a wide range of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and even higher-boiling-point, chlorinated compounds such as polychlorinated biphenyls (PCBs), dioxins, and furans.

Successful design and implementation of a thermal desorption system is dependent on the following key technical considerations:

- Physical properties of the soil to be treated
- Chemical composition of the soil to be treated
- Groundwater conditions (for in situ applications)
- Chemistry and concentrations of contaminants

Moisture content, contaminant mass and distribution, grain size and heterogeneity are key factors to consider in assessing whether thermal desorption will be effective.

Operation of a thermal desorption unit generates several waste streams, including treated material, dust, thermal oxidiser residues and spent carbon. The treatment of waste streams and compliance with regulatory controls should be considered during the detailed remediation options assessment.

If there is uncertainty as to whether thermal desorption will achieve the required outcome, treatability studies may need to be conducted to resolve the issues. Treatability studies can be undertaken in three stages – the first stage is feasibility testing to assess the ability of thermal desorption to meet the remediation objectives. The second, more detailed stage of treatability testing involves bench tests to evaluate the application of the technology under the specific site conditions. The information obtained in stages 1 and 2 is generally sufficient to enable formulation of a Remediation Action Plan (RAP). However, where additional data are required to enable the remediation system to be designed a third stage of treatability testing involving pilot trials should be undertaken to determine specific operating requirements and performance criteria to enable completion of a RAP.

Abbreviations

CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
DTD	Directly- Heated Thermal Desorption
ECS	Emission Co Control System
ISTD	In-Situ Thermal Desorption
ITD	Indirectly-Heated Thermal Desorption
NRF	National Remediation Framework
PAHs	Polycyclic Aromatic Hydrocarbons
PCBs	Polychlorinated Biphenyl
PPE	Personal Protective Equipment
RAP	Remediation Action Plan
TCH	Thermal Conductive Heating
TRH	Thermal Resistive Heating

Glossary

Aquifer	An underground layer comprising bedrock, unconsolidated natural material, or fill, that is capable of being permeated permanently or intermittently with groundwater, and that allows the free passage of groundwater through its pore spaces.
Concentration	The amount of material or agent dissolved or contained in unit quantity in a given medium or system.
Conceptual site model	A representation of site-related information including the environmental setting, geological, hydrogeological and soil characteristics together with the nature and distribution of contaminants. Contamination sources, exposure pathways and potentially affected receptors are identified. Presentation is usually graphical or tabular with accompanying explanatory text.
Conductive heating	The process by which a solid is heated by coming into contact with a hot solid.
Contaminant	Any chemical existing in the environment above background levels and representing, or potentially representing, an adverse health or environment risk.
Contaminated site	A site that is affected by substances that occur at concentrations above background or local levels and which are likely to pose an immediate or long-term risk to human health and/or the environment. It is not necessary for the boundaries of the contaminated site to correspond to the legal ownership boundaries.
Contamination	The presence of a substance at a concentration above background or local levels that represents, or potentially represents, a risk to human health and/or the environment.
Convective heating	The process by which a fluid is heated via mixing and movement with a hot fluid. The fluid can include both groundwater or soil gases.
Environment(al) protection authority / agency	The government agency in each state or territory that has responsibility for the enforcement of various jurisdictional environmental legislation, including some regulation of contaminated land.
Practitioner	Those in the private sector professionally engaged in the assessment, remediation or management of site contamination.
Proponent	A person who is legally authorised to make decisions about a site. The proponent may be a site owner or occupier or their representative.

Remediation	An action designed to deliberately break the source-pathway-receptor linkage in order to reduce the risk to human health and/or the environment to an acceptable level.
Risk	The probability that in a certain timeframe an adverse outcome will occur in a person, a group of people, plants, animals and/or the ecology of a specified area that is exposed to a particular dose or concentration of a specified substance, i.e. it depends on both the level of toxicity of the substance and the level of exposure. 'Risk' differs from 'hazard' primarily because risk considers probability.
Site	A parcel of land (including ground and surface water) being assessed for contamination, as identified on a map by parameters including Lot and Plan number(s) and street address. It is not necessary for the site boundary to correspond to the Lot and Plan boundary, however it commonly does.
Spadeable	A geotechnical term that describes material able to be moved with a spade or excavator at room temperature. Often used to describe an acceptable end state of dewatering, or as the definition of a solid for waste disposal.
Thermal desorption	A process that directly or indirectly heats contaminants to a temperature high enough to volatilise and separate them from a contaminated solid medium.
Treatability studies	A series of tests designed to ascertain the suitability of the treatment for the contaminants under the site conditions

Measurements

Unit or symbol	Expansion
m	Metre
mm	Millimetre
°C	Degrees Celsius

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1. Introduction

The purpose of this guideline is to provide information on thermal desorption as a treatment technology for the remediation of contaminated sites to assist with selection of remediation options. The document contains information to inform remediation planning and aid compilation of a remediation action plan (RAP).

This guidance is primarily intended to be utilised by remediation practitioners and those reviewing practitioner's work, however it can be utilised by other stakeholders within the contaminated sites industry, including site owners, proponents of works, and the community.

Thermal desorption is one of many technologies available for contamination remediation, and other technologies may be more appropriate. It is assumed that the information presented within will be used in a remediation options assessment to identify and select the preferred technologies for more detailed evaluation. This guideline provides information for both initial options screening and more detailed technology evaluation. This guideline does not provide detailed information on the design of barrier systems as this is a complex undertaking and should be carried out by appropriately qualified and experienced practitioners. Readers are directed to the NRF *Guideline on performing remediation options assessment* for detailed advice on assessing remediation options. In addition, the remediation objectives, particularly the required quality of the soil after treatment, are a critical matter and it is assumed that these have been determined and considered in the remediation options assessment and selection process. Readers are directed to the NRF *Guideline on establishing remediation objectives* for more detailed advice.

References to case studies are provided in **Appendix A**.

A number of sources of information were reviewed during the formulation of this document to compile information on potential technologies. These are listed in references, and provide an important resource to readers.

2. Technology description and application

Thermal desorption is a process that uses either direct or indirect heating to heat organic contaminants to a temperature high enough to volatilise and separate them from a contaminated solid medium. Typically, a mix of air and combustion gas or an inert gas is used as the transfer medium for the volatilised components. Thermal desorption systems are physical separation processes that transfer contaminants from one phase to another. They are not designed to provide high levels of organic destruction in the transfer stage, although the higher temperatures of some systems will result in localised oxidation or pyrolysis depending on the contaminants involved. Thermal desorption is not incineration, because the destruction of organic contaminants is not the desired result of the thermal desorption step. The bed temperatures achieved, and residence times used by thermal desorption systems will volatilise selected contaminants, but usually will not fully oxidise or destroy them. System performance is usually measured by the comparison of untreated solid contaminant levels with those of the processed solids.

Thermal desorption technology can be applied in situ or ex situ and has been shown to be able to reduce soil contaminant concentrations by over 99%. The technology can treat many different types of contaminants over a wide range of boiling points (e.g. petroleum hydrocarbons, PCBs, dioxins and tars). There is a distinction between in-situ and ex-situ treatment, and high and low temperature treatment; these distinctions essentially relate to the physical treatment setting and boiling point range of the target contaminants.

The desorbed contaminants need to be treated or destroyed. The most common emission control system (ECS) for the desorbed gases is destructive, with gases combusted at high temperature in a thermal oxidiser. The combusted gases are then cleaned in air pollution control systems prior to release to the air. In some cases, the desorbed gases are treated in a recovery type ECS and condensed for subsequent treatment. This is a more complex undertaking, is generally not practised in Australia and thus will not be considered in this document.

All thermal desorption technologies consist of the following steps:

- Heating the contaminated material to volatilise the organic contaminants;
- Treating the exhaust gas stream and preventing emissions of the volatilised contaminants to the atmosphere;

The systems available are differentiated from each other by the methods used to transfer heat to the contaminated materials, and by the vapour treatment system used to treat the off-gases.

2.1 Ex-situ and in-situ methods

In ex-situ applications, heat can be applied directly to the contaminated soil by a combustion flame and/or by direct contact with the combustion gases. Systems employing this type of heat transfer are referred to as *direct-contact* or *directly-heated* thermal desorption) systems. The predominant heat transfer mechanism in direct-heating is convection. Heat can also be applied indirectly by transferring the heat from the source (e.g. combustion or hot oil) through a physical barrier, such as a steel wall, that separates the heat source from the contaminated materials. Systems employing

this type of heat transfer are referred to as *indirect-contact* or *indirectly-heated* thermal desorption (ITD) systems. The predominant heat transfer mechanism in indirect-heating is conduction.

In-situ systems comprise treatment of the contaminated material in place without excavation and rely on either conductive or convective heating. Conductive heating is achieved using electric elements or combustion gas to heat steel pipes in contact with contaminated soil usually above the water table. Convective heating is typically achieved by applying electric current to the subsurface where fluids are heated due to electrical resistance.

2.2 Continuous-feed and batch-feed systems

Thermal desorption systems can be further divided into two broad categories, each with subcategories:

- Continuous-feed;
 - Directly-heated thermal desorption (DTD)
 - Indirectly-heated thermal desorption (ITD)
- batch-feed.

Continuous-feed systems are ex-situ processes, meaning that the contaminated material must be excavated, followed by some degree of material handling and physical pre-treatment, and then fed to the treatment unit. Continuous systems use either direct-heating equipment or indirect-heating equipment.

Batch-feed systems can be either ex-situ or in-situ, the latter meaning that the contaminated material is treated in place without excavation. Batch systems all rely on indirect heating with both conductive and convective heat transfer. As with all thermal desorption systems, the off-gases from in-situ systems must be treated prior to discharge to the atmosphere. The following are representative types of batch thermal desorption technologies:

- Ex situ - Electric or gas heated stockpiles with metal, cement or other covers to control emission and preserve heat such as the Enhanced Thermal Conduction (ETC) process.
- In situ - thermal wells, in conjunction with soil vapour extraction or dual phase vapour extraction to capture emissions, which may also be designed to lower contaminant boiling points.

2.2.1 *Ex situ thermal desorption*

In terms of volumes treated, the most common application of thermal desorption is the ex-situ treatment of contaminated soil. The ex-situ thermal desorption process generally involves direct heating and typically comprises the stages described in Table 1 below.

Table 1: Typical stages of thermal desorption

Stage	Description
Stage 1	<p>Pre-treatment</p> <p>This may include screening the excavated contaminated soil, with crushing or shredding to remove oversize particles and magnets to remove metal as may be necessary. Material is stockpiled prior to treatment and blending of materials may be necessary to provide a uniform feed material suitable for treatment. If the material has a high moisture content, an initial drying step may be required, otherwise drying will need to be accounted for in the thermal treatment stage.</p>
Stage 2	<p>Heating of the contaminated material to volatilise and desorb the contaminants, followed by off-gas collection and treatment.</p> <p>Soils are heated in suitable reactors or vessels¹ where treatment temperatures can be set between approximately 200 and 600°C, dependent on the contaminant boiling point and residence time. The hot treated soil is then cooled by water in a pug mill.</p>
Stage 3	<p>Removal of dust particles (by dry cyclone, wet scrubbing or fabric filters in a bag house), high temperature oxidation to destroy vapour phase contaminants, fast quenching to minimise dioxin reformation if chlorine is present and removal of any remaining contaminants such as acid compounds (by wet scrubbing) or mercury (via activated carbon adsorption).</p>

Figure 1 is a schematic illustration of the basic elements of the ex situ thermal desorption process.

¹ Soils can be heated either directly where a flame is applied to the surface of the solid media or indirectly where a rotary dryer heats an air stream which passes through the material and desorbs water and organic constituents. Thermal desorption can also be undertaken via indirect heating where an externally heated rotary dryer volatilises water and organics from the contaminated media which are captured and treated.

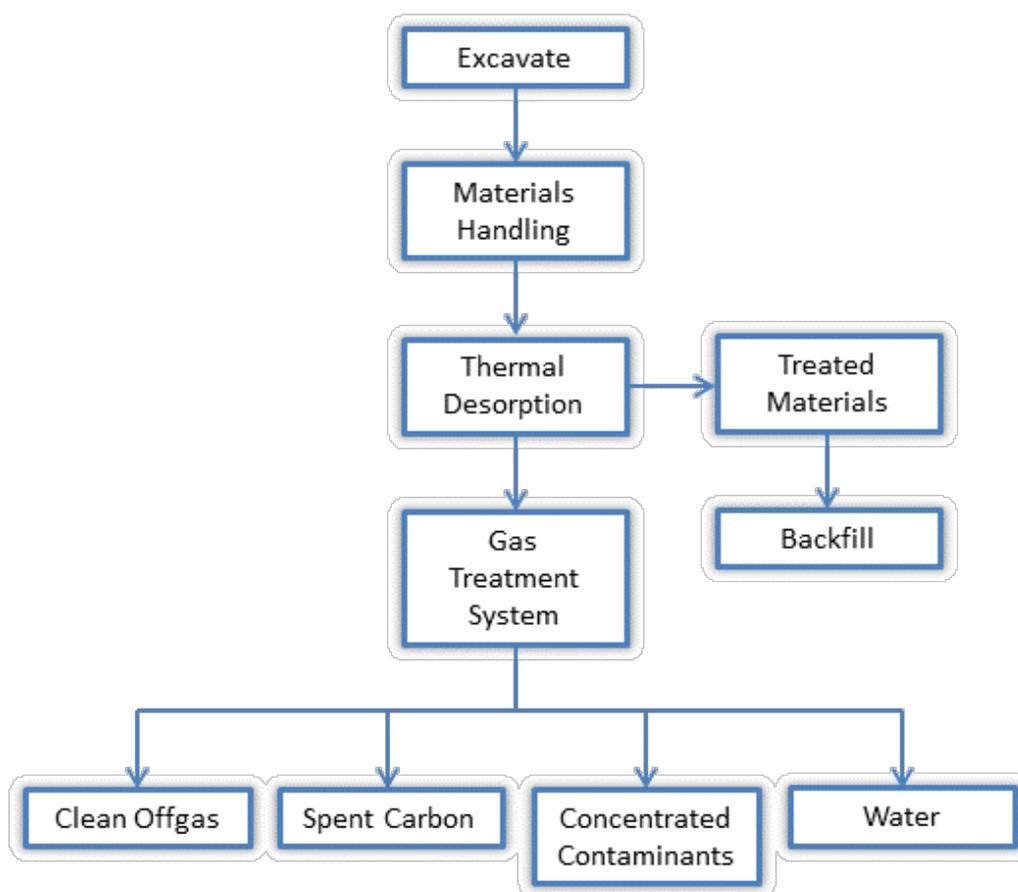


Figure 1: Generalised schematic of ex-situ thermal desorption processes

2.2.2 *In-situ thermal desorption*

In situ thermal desorption (ISTD) is a soil remediation process in which heat and low to high vacuum are applied simultaneously to subsurface soils. ISTD generally comprises subsurface heating with an array of vertical heater wells in conjunction with a soil vapour extraction system or dual phase extraction system.

In situ application of thermal desorption may be subdivided into:

- Thermal conductive heating (TCH) using electric or gas heating; and
- Thermal resistive heating (TRH) using electric resistance heating.

The TCH process involves the application of heat to a soil from a high-temperature surface in contact with the soil, with heat transfer occurring by radiation from the heater and heat transfer by thermal conduction and convection occurring in the soil that is not in the immediate vicinity of the heater. It is usual that thermal conduction will account for over 80% of the heat transfer. The heaters typically operate at 800 to 900 °C, creating a high temperature (>500°C) zone near the heater, which causes destruction of many contaminants before they are released from the soil. TCH can also be operated at lower temperatures (down to 100°C) depending on the boiling point of the contaminants and remediation criteria.

The basic TRH process involves introducing three phase electric current into the subsurface, which heats soil moisture and groundwater to 100°C. Heat transfer is principally convective with contaminant removal occurring by steam stripping and volatilisation. The vaporised water and contaminants are removed by the soil vapour system or dual phase extraction system and treated in an emission control system.

When used in conjunction with a high vacuum extraction system boiling points are depressed, so that it may volatilise contaminants with boiling points of up to 180°C. Water is usually reintroduced and reheated to achieve low residual contaminant concentrations. A large proportion of higher boiling point compounds may also be removed with low temperature heating if sufficient time is allowed.

One of the characteristic advantages of ISTD is that it can effectively treat clay. When heated to around 80°C, clays microfracture making them permeable to gas, so that volatilised contaminants can be mobilised.

The processes by which contaminants are vaporised or destroyed include:

- Evaporation into the air stream;
- Steam distillation into the water vapour stream;
- Boiling;
- Oxidation; and
- Pyrolysis.

The vaporised water, contaminants and natural organic compounds are drawn by vacuum into the blankets or wells in a direction opposite to the heat flow.

Figure 2 is a schematic showing the typical elements of an ISTD system.

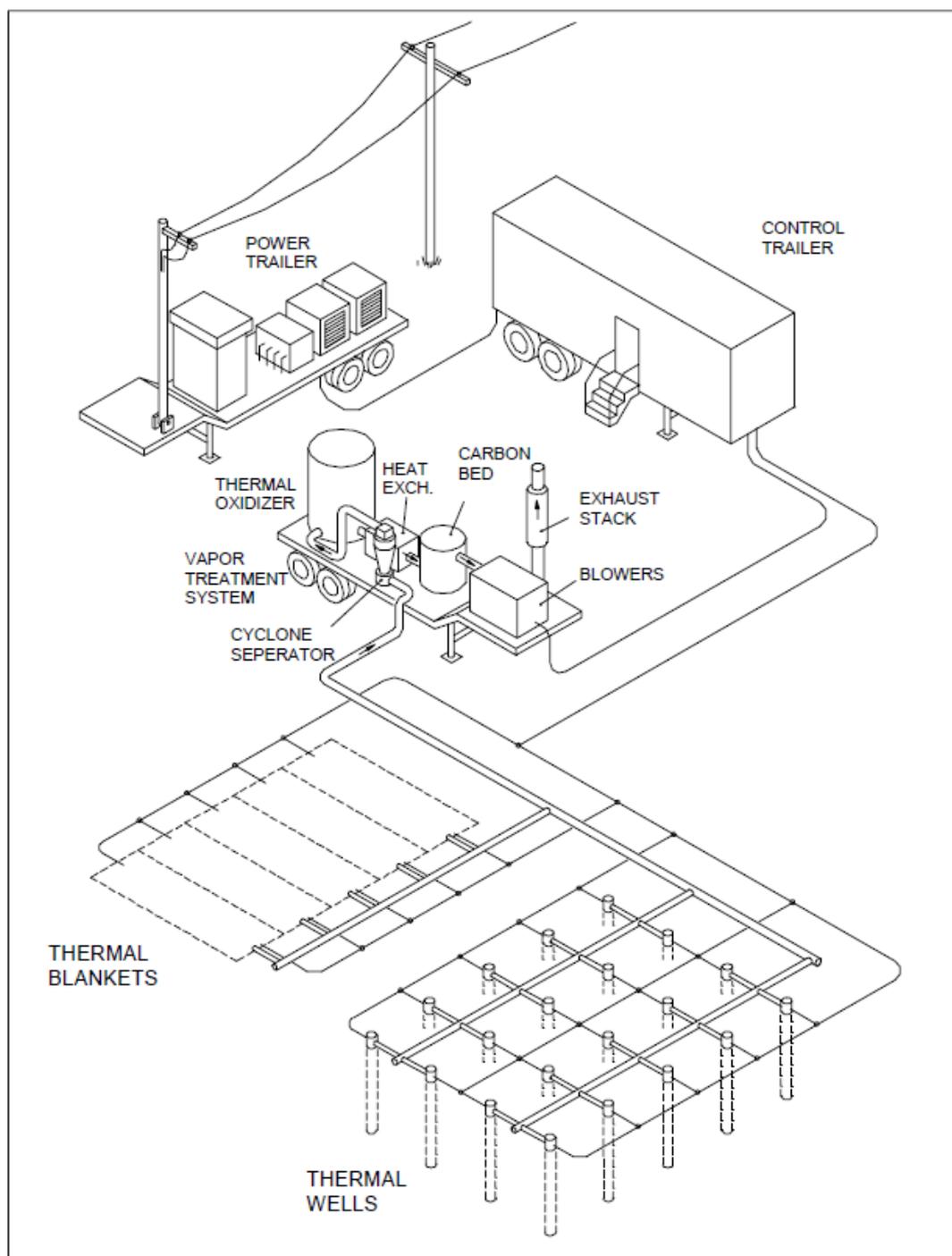


Figure 2: Typical elements of an in-situ thermal desorption system, from Stegemeier & Vinegar (2001)

2.2.3 *Ex situ batch applications*

Ex situ batch applications generally take place where contaminated soil has already been excavated or stockpiled. Alternatively, small amounts of widely scattered contaminants can be gathered to a single location for treatment rather than dealt with separately in the ground. In these cases, it can be more effective to modify the ISTD system and use thermal conduction heating at the surface of the stockpile. Unlike other ex situ processes that are carried out in reactors where residence times are only a few seconds or minutes, the ex situ application of in situ TCH allows treatment times ranging from hours to many days.

The longer residence times are permitted because large volumes can be treated at one time. Thus, large inclusions in soils such as metallic objects, lumps of soil, concrete, etc., which is troublesome for continuous systems, can be more readily accomplished by ex situ applications. The high temperature drying achieved can increase the permeability of the soil, increasing the effectiveness of removal of contaminants from low permeability material such as clay.

Batch reactors are rare with most ex situ processes undertaken in large stockpiles.

3. Feasibility assessment

Key considerations that will often determine the feasibility of applying thermal desorption as a potential remediation option include:

- Whether stakeholders are strongly against thermal treatment (for example, stakeholders may consider that thermal desorption has unacceptable risks, particularly whether there are concerns regarding emissions);
- Whether the material to be treated contains substances such as halogens or volatile metals at concentrations that exceed regulatory limits, or may require treatment conditions, additional pollution control systems or operational controls that make the process uneconomic;
- Whether the water content of the material to be treated requires additional treatment (eg drying) that makes the process uneconomic;
- Whether the composition of the material can be made sufficiently uniform (eg through blending if necessary) to provide for safe and reliable treatment (eg avoid forming an explosive atmosphere, or to reliably meet the target concentrations); and
- Whether the required temperature and residence time for treatment of the contaminant can be achieved by the available thermal treatment system.

If there is reasonable confidence that thermal desorption will achieve the required treatment outcome, then other issues will need to be considered to determine if thermal desorption is likely to be an appropriate technology for the site. These include:

- Will the relevant regulatory agencies accept thermal desorption as a viable means of remediation?
- Can the treated material be used, or disposed of economically? Will the concentrations of inorganics and residual organics allow the treated material to be reused as backfill on the site or as clean fill elsewhere, or will subsequent treatment (e.g. stabilisation) or landfill disposal be required?
- Is it likely that other stakeholders (such as local government or members of the public) will accept the use of the technology, particularly those stakeholders that can have a significant bearing on whether the technology is applied at the site? Are there sensitive sites nearby that would not be compatible with the proposed operation?
- Is there a time constraint, and can the application of thermal desorption meet this constraint?
- Are power, water and other services available at the site in adequate supply?
- Is sufficient space available at the site for the thermal desorption system, waste feed preparation area, treated residue staging area, and water treatment system, if required?
- Is the expected order of cost of treatment acceptable?

Consideration needs to be given to whether residence time is critical to meeting the remedial objectives. If treatment time is not critical, a batch system can run at a lower

soil temperature by operating for a longer time and achieve the same outcome as a continuous system and could offer a cost and energy saving over a continuous system.

3.1 Data requirements

Successful implementation and design of a thermal desorption system, whichever approach is used, is dependent upon the following key technical considerations:

- The physical properties of the soil to be treated;
- The chemical composition of the soil to be treated;
- Groundwater conditions (in the case of in situ thermal desorption); and
- The chemistry and concentrations of contaminants.

3.1.1 *Physical properties*

The physical composition of the material to be treated needs to be well characterised. Important factors include:

- Moisture content: this is a primary cost factor for ex-situ plants because most of the applied heat is used to vaporise water;
- Density: this is also a critical factor because mass and energy balances and cost estimates are based on the mass and not volume of material to be treated;
- Soil heterogeneity: differing grain sizes and the presence of larger lumps of material (such as masonry in fill) can affect the uniformity of heat distribution through the material and the level of treatment achieved. Larger size material (e.g. greater than 50 mm) may need to be crushed or shredded to allow effective treatment or passage through ex situ handling systems;
- Soil particle size and its variability needs to be characterised: fine grained material could lead to clogging of an ex-situ rotary dryer ECS; coarse material (gravel or sand) is likely to be most amenable to treatment and may be added to aid in moving fine grained material through the rotary dryer;
- The permeability and plasticity of the material, which can lead to feed problems, accelerate or impede the distribution of heat and migration of vapour through the soil medium; and
- Resistivity of the subsurface material is important in the case where electrical resistive in-situ heating is involved; resistivity will be affected by moisture content and there may need to be sophisticated localised water injection to control resistivity and heat generation.

3.1.2 *Chemical composition*

The composition of the material to be treated needs to be well characterised. Important factors include:

- The distribution concentrations and mass of contaminants in soils at the site, and the requirement to locate and treat contamination that exceeds certain concentrations, noting that contamination may be irregular in extent and location. This can be particularly important for in-situ methods, where physical inspection and testing is restricted;

- Range of contaminants, their concentrations and their ability to degrade or volatilise (perhaps aided by steam stripping) as the material is heated. Generally higher boiling point contaminants will require higher temperatures;
- The suitability of the air pollution control systems for removing chemicals such as dioxins and furans. This will depend on the extent to which conditions favour *de novo* synthesis of dioxins and furans, and the ability of the air pollution control systems to remove these substances. Regulatory agencies can impose 'best practice' requirements and stringent limits on the emission of such chemicals for combustion and air pollution control systems and it may be necessary to demonstrate that the proposed systems will conform to these requirements; and
- Limitation on humic acids and natural organic material, particularly for indirectly-heated plants which will capture their distillation products, including dissolved phase in water.

Maximum allowable concentrations

- The maximum allowable concentration and variation in concentration of the contaminants in the treated soil. If very stringent remediation criteria are applicable, then higher temperatures, longer treatment times and smaller maximum soil particle sizes may be required, impacting on costs;
- Allowable concentrations of volatile metals such as mercury. The maximum concentrations will depend on the ability of the air pollution control systems to capture such metals. Note that some metals such as mercury may accumulate within the treatment unit and be released at higher concentrations, placing a more stringent limit on the allowable soil concentration and control of emissions;
- Maximum allowable concentrations of metals that will remain in the treated soil; this depends on the intended use or disposal of the treated soil and whether subsequent treatment (such as stabilisation) may be required, making the treatment by thermal desorption uneconomic or perhaps unnecessary;
- Concentrations and forms of compounds containing chlorine, sulphur, nitrogen or fluorine that are present in the soil and resulting combusted gases, and the suitability and effectiveness of the air pollution control systems for removing such substances. Such substances can also give rise to corrosive conditions requiring more expensive construction materials or additional maintenance and downtime and can also give rise to greater concentrations and volumes of wastewater from air pollution control systems that may be difficult or expensive to dispose of; and
- Maximum allowable concentrations and forms of miscellaneous material such as plastic lining systems, steel, rock or asbestos, and the requirement for exclusion of unacceptable material. The presence of highly abrasive material may damage the processor unit. For *ex situ* application, soils are generally screened to remove oversize or deleterious material prior to treatment.

Calorific value and water content

- Variations in calorific value of the materials being treated and the maximum concentrations of volatile combustible contaminants that could give rise to

rapid temperature rise and gas release that would result in explosion or uncontrolled releases of gas. Blending of material may be necessary to achieve a uniform composition and reliable and safe operation. For example, there could be a limit of 4% of total available organic carbon at the proposed treatment temperature for directly-heated plants (including non-contaminants and contaminants), which could be exceeded if NAPL or saturated soil is encountered in some locations. The presence of combustible material may also provide a saving in fuel; and

- Water content (high water content can greatly increase the energy cost), rate of desorption and size of the accompanying combustion system. Typically, the rate of fuel consumption rises by approximately 3 to 5% for each per cent of moisture, and fuel costs could make the technology not viable.

3.1.3 **Groundwater conditions**

In the case of in-situ treatment, hydrogeological conditions such as depth to groundwater, flow paths, flow rate and seasonal variations can be very important. For example:

- The distribution of contamination with respect to the saturated zone and whether it is necessary to treat contamination under water;
- What contaminant concentrations will remain in the groundwater after treatment and whether these will meet the remediation criteria;
- Whether dewatering is necessary to effect treatment;
- Understanding water table variations and migration pathways to assess the potential for vertical or horizontal migration into the unsaturated treatment zone; and
- Groundwater flow velocity, because high velocities can remove heat faster than it is supplied, such that a cut off wall is necessary to effectively remediate.

3.1.4 **Waste streams**

The operation of a thermal desorption unit can create different waste streams, including for example:

- Treated material;
- Oversized material rejected during pre-treatment;
- Condensed contaminants and water;
- Dust from particulate control system;
- Thermal oxidiser residues;
- Clean off-gas;
- Spent bag house bags;
- Spent carbon; and
- Used PPE and associated consumables.

Several of these streams may be recycled or reused in the treatment process. For example, thermal desorption systems often recycle contaminant free condensed water

and use it to suppress dust emitted from the treated feedstock exiting the system. Scrubber purge water that has been treated in a site wastewater treatment facility (if available) may also be used to suppress dust or can be discarded into the sewer.

The concentrated condensed organic contaminants may be collected for further treatment and recovery, dependent on the thermal desorption unit. The dust collected from a baghouse or cyclone may be able to be mixed with the contaminated feedstock for conditioning, although this is generally avoided because the proportion of dust or contaminants may increase until the point where treatment is no longer practicable or cost effective. Alternatively, this dust can be mixed with the treated feedstock and backfilled on-site if the mixed material meets relevant guideline criteria. Spent carbon can be recycled by the supplier or other processor (though this may not be acceptable to the regulator).

In some cases, the waste may be able to be recycled and mixed with the feed stream to the thermal desorber. However, this is only possible where the recycled contaminant will be destroyed or removed in the treatment system (such as would be the case with dioxins and furans). If the contaminant is not destroyed or removed (for example mercury), it may build up in the system and eventually discharge at higher concentrations.

Clean off-gas is released to the atmosphere as part of the thermal desorption process. The air emissions from the thermal desorption system must comply with regulatory standards. Because of the potential for production of toxic products of incomplete combustion such as dioxins and furans, the ability to show compliance with stringent Australian or other international criteria is essential. This can include demonstration that the air pollution control system complies with best practice, including a rapid quench system to reduce the production of dioxins and furans, scrubbing to remove acid gases, high efficiency particulate removal (such as a bag house), and possibly additional polishing such as modified activated carbon, particularly if a volatile metal such as mercury is present.

3.1.5 **Regulatory requirements**

The regulatory agencies (particularly the agencies responsible for protection of the environment, town planning, and licensing treatment facilities) should be consulted to determine the specific requirements relating to obtaining the necessary approvals and licences, and controls that can be expected. The application of thermal desorption is often a matter of concern for the community and it can be expected that the regulatory agencies will be careful in applying their processes for permitting and approval.

For more detailed information on regulatory requirements readers are directed to the NRF *Guideline on remediation considerations*.

3.2 **Treatable Contaminants**

Thermal desorption is potentially applicable for the treatment of a wide range of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), and even higher-boiling-point, chlorinated compounds such as polychlorinated biphenyls (PCBs), dioxins, and furans. It can be considered for processing soil, sludge, sediments and filter cakes. The technology is not effective at treating soils or other materials contaminated solely with inorganics such as metals or asbestos. It may also not be effective for the treatment of organic corrosives and reactive oxidizers and reducers, depending on the chemical composition of these contaminants.

Table 3 summarises the contaminant types for which thermal desorption may be suitable.

Table 2: Effectiveness of thermal desorption on general contaminant groups for a variety of media

Affect	Contaminant Groups		Potential for effective application			
			Soil	Sludge	Sediment	Filter Cake
Contaminant groups likely to be affected:	Organic	Halogenated Volatiles (e.g. TCE)	1	2	2	1
		Halogenated semi volatiles	1	1	2	1
		Non-halogenated volatiles (e.g. hydrocarbons, low molecular weight PAHs)	1	2	2	1
		Non-halogenated semi volatiles (e.g. oils, high molecular weight PAHs)	1	2	2	1
		PCBs	1	2	1	2
		Pesticides and herbicides (non-metallic)	1	2	2	2
		Dioxins/Furans	1	2	2	2
		Organic Cyanides	2	2	2	2
Inorganic	Volatile Metals	2	2	2	2	
Contaminant groups unlikely to be affected:	Organic	Organic Corrosives	3	3	3	3
	Inorganic	Non-volatile metals	3	3	3	3
		Asbestos	3	3	3	3
		Radioactive materials	3	3	3	3
		Inorganic corrosives	3	3	3	3
		Inorganic cyanides	3	3	3	3
	Reactive	Oxidisers	3	3	3	3
Reducers		3	3	3	3	
Notes to Table:		2 – There is potential for the technology to be effective in commercial application.				
1 – Has been demonstrated to be effective in commercial application.		3 – Unlikely that the technology will be able to be applied effectively at a commercial level				

3.3 Treatable Matrices

Ex situ thermal desorption is potentially applicable for the treatment of a wide range of matrices including sludges and fine to coarse grained soil. In most cases sludge is converted to a spadeable solid for treatment by blending with dryer contaminated materials or the addition of calcium oxide. Sludge can however be treated using ex situ thermal screw type plants (related to sewage drying plants) or indirectly heated rotary dryers with modified feed systems. High moisture and fine-grained soils may be expensive to pre-treat, difficult to feed, and slow to process, to the point of being uneconomic.

ISTD can treat a wide range of material types and is particularly suited to treating interbedded fine-grained soils. Clay microfractures at around 80°C, becoming permeable to gas, thus allowing volatilised contaminants to mobilise under an applied vacuum. Both TCH and TRH have limitations in terms of the thermal and electrical conductivity of the matrix. Basaltic rock is a problem for both methods and TRH has limitations for application to soil containing fresh water, which may not conduct electricity well.

TRH is applicable to both the unsaturated and saturated zones providing groundwater flow is not less than 1 ML per day. In this case heat would be removed faster than it was applied, and a cut-off wall would be required. TCH methods may also be applicable to the saturated zone but are usually applied to the unsaturated zone.

Some soil types may shrink and swell in the ISTD process, which may be an issue depending on the location.

4. Treatability studies

If there is uncertainty as to whether thermal desorption will achieve the desired outcome in terms of treated soil, or there are other issues that makes it uncertain as to whether thermal desorption will prove to be applicable, it may be necessary to conduct treatability tests to resolve the issues. Treatability studies also allow remedial costs and technology efficiency to be better determined.

Designing the treatability study may require input from several technical specialists including environmental specialists, chemical engineers, mechanical engineers and air quality specialists to ensure that the study is targeted to obtain the data required to enable the most appropriate implementation strategy to be developed.

The type of additional information required can be decided upon by undertaking additional research into the available information on the application of the type of thermal desorption process being evaluated. If the technology has been widely applied and the results are readily available, it may possible to extrapolate the information from these previous case studies and avoid carrying out a treatability study to assess the technology performance.

4.1 Ex-situ thermal desorption

There are three stages of treatability studies that can be undertaken:

- The first stage of testing should determine whether thermal desorption is a viable treatment solution for the specific site.
- The second stage of testing should enable an assessment of the effectiveness of thermal desorption for the specific site conditions and contaminant concentrations. It should also be suitable for estimating emission parameters and predicting compliance with local air emission regulations. In general, the RAP the RAP can be designed at written upon completion of this stage.
- If additional data is required to enable the remediation system to be designed, a third stage of testing should be undertaken to determine specific operating requirements and performance criteria and provide sufficient information to enable completion of a RAP.

The data from each stage of treatability testing should be reviewed and interpreted jointly by the consultant and remediation contractor, with a projection being made of the results that will be achieved under full scale operation and requirements established for implementation.

In the case of ex-situ treatment (typically involving a rotary kiln), the purpose of the testing will be to determine the results that could be achieved with treatment that corresponds to the conditions that will occur within the full scale treatment system.

If it has been established that treatability testing is required to adequately assess the application of thermal desorption or to assist in cost appraisals, then there are generally three stages of testing that can be undertaken. Data requirements will be site specific and may include information such as moisture content and heat content if the soil has a high organic content.

4.1.1 **Laboratory screening**

Bench tests comprise the first stage of treatability testing, to assess the ability of thermal desorption to meet the previously established remediation objectives and its applicability to the specific waste type. In many cases, this stage may be preceded by some testing of discrete soil samples at the site assessment stage as a preliminary options screening, and as part of determining suitable materials for the treatability tests.

Screening tests are usually conducted in a laboratory and can test a wide range of performance and soil chemical composition and physical factors. Remediation screening is relatively fast to undertake (usually a few weeks or months to obtain results) and the cost is small in relation to the overall remedial program. The tests are usually staged with conditions varied depending on the results of each stage of testing.

Setting the data quality objectives for the screening treatability testing at the outset is vital to obtain the desired results. Usually the main goal of this preliminary treatability testing is to establish the minimum temperature and residence time required to meet the remediation criteria.

Initial screening testing can be undertaken relatively simply by placing a tray of contaminated soil into a laboratory oven capable of reaching the anticipated maximum treatment temperature in a short time frame, to obtain data to assist with establishing the required treatment time and temperature for the thermal desorption unit. Differential bed reactors can also be used where the contaminated medium is placed into an oven in a thin layer and pre heated gas is passed through the medium. Both these tests should generate data that indicate the treatment time required at temperatures to achieve the remediation criteria.

The results of this initial testing can be used to indicate the parameters for the next stage of treatability testing. However, they are indicative rather than definitive of the required treatment conditions, involve little quality control and should not be used to derive cost or design data as the chemical composition and physical properties of the soil may vary from that used in the test and therefore, the degree of volatilisation and level of treatment achieved in practice may vary significantly.

4.1.2 **Bench tests**

The next stage of treatability testing is to evaluate the application of the thermal desorption process for the specific site conditions.

This test work is significantly more expensive than the initial screening testing and generally takes several months to plan and implement. These tests have the objective of more closely replicating the physical and chemical parameters of the site under investigation and the specific thermal desorption process being considered. This test work will usually involve much larger waste volumes and a pilot treatment unit.

This stage of testing will usually involve multiple test runs, and samples tested should be representative of site conditions and contamination concentrations, as well as being as homogenous as possible. Moisture content is an important factor that affects volatilisation and the moisture content of the test samples should be chosen to be representative of the moisture content of the contaminated medium at the site.

It will also need to be determined whether to use samples from “hot spot” areas, representing a worst-case scenario (in terms of contaminant concentrations) or to use composite samples to represent ‘average’ conditions (perhaps indicative of blended

soil) and use this information to extrapolate the expected outcome for the range of material to be treated.

The key objectives for the second stage of treatability testing are to:

- Assess contaminant concentrations achieved following treatment (to determine whether the nominated remediation criteria can be met);
- Determine the required heat input parameters and average temperatures required for efficient treatment; and
- Obtain preliminary performance data for the off-gas treatment systems relevant to the contaminated medium. Note that while the separation efficiency will be highly site-specific and process-specific, typically thermal desorption processes achieve separation efficiencies of over 95%.

While the important objective of this work is to confirm that the level of treatment will meet the objectives, characterisation of the chemical and physical composition of the material to be treated should also be carried out – factors such as the variability in water content and calorific value, presence of volatile metals, presence of corrosive halides (F, Cl, Br), composition of material after treatment (e.g. residual metals and salts), size fraction and whether the material is of a form that will be handle-able (e.g. clayey), and the potential for large items to be present that may require removal by screening, or shredding or other size reduction measures.

The information obtained in the second stage of testing is usually sufficient to enable development of the remediation action plan (RAP).

4.1.3 *Pilot trials*

If insufficient data was obtained during the detailed screening tests to design the RAP, a third stage of treatability testing can be undertaken to obtain information necessary for the design of the thermal desorption system, specific to the conditions of the site.

These studies usually take months to complete and the cost is high so the benefit of obtaining more specific operating design parameters and cost estimates should be weighed against the cost of the overall remedial program.

This testing can be undertaken on-site using a pilot scale treatment unit or using an off-site unit if this is available.

On completion of this testing, it should be possible to establish the requirements for the full-scale unit, the time scale for the completion of remedial works, and an improved estimate of the level of cost.

4.2 In-situ Thermal Desorption

Treatability testing for ISTD is rarely undertaken. Instead, electrical resistivity and heat conductivity testing is usually completed via comparison with typical soil and rock types to assess the feasibility of ISTD application in the given environment of the specific contaminated medium to be treated.

5. Validation

The following information describes the specific validation appropriate for thermal desorption, to assist validation planning within the RAP. Readers are directed to the NRF *Guideline on validation and closure*, which among other things, provides further information on each of the lines of evidence.

The primary lines of evidence for the validation of thermal desorption are;

- A reduction in contaminant concentration over time or with distance through the reactive zone;
- The analysis of geochemical and biochemical parameters; and
- Assessment of the mass discharge from treated materials.

For detailed information readers are directed to:

- US ACE (2014);
- UK EA (2012); and
- Altenbockum & Kraft (2001).

6. Health and safety

Thermal desorption is a common treatment process used at hazardous waste sites to separate organic contaminants from feedstock like soil or sludge. Operating these units can expose site workers to safety and health hazards such as chemical exposure from site contaminants and process chemicals, fire or explosion, noise, heat stress, confined space entry, and physical injury from pinching or crushing.

Work Health and Safety Legislation mandate specific requirements for occupational health and safety which must be complied with. Due to the characteristically temporary nature of the thermal desorption process, in addition to large variations in contaminant concentrations in the feedstock, the assessment and control of occupational exposure risks to workers requires particular and regular attention.

It is recommended to seek specialist advice as part of the risk assessment process from a competent occupational hygienist as part of the project planning process. Such specialists should be engaged to provide a qualitative occupational risk assessment and provide advice on the selection of appropriate control measures to reduce occupational exposure in accordance with relevant legislative requirements. Occupational hygienists should be selected with reference to their certification or membership status with the Australian Institute of Occupational Hygienists, with their experience relevant to the nature of the risk requiring control.

Thermal desorption units, like many types of industrial equipment, pose hazards to workers. If these hazards are properly evaluated and controlled, the technology can be used safely. Workers can be exposed to unanticipated safety hazards and receive unexpected exposure to site contaminants while working in and around treatment technology.

Common health and safety hazards associated with thermal desorption are highlighted in Table 3. The hazards listed are associated with the technology itself, with site-specific contaminants, and with related work operations. Table 3 also lists possible control measures. Many of these matters will be subject to regulatory control measures, and relevant national and state regulations should be referred to. The list is intended to provide an indication of the hazards potentially associated with thermal desorption application. They will vary significantly from site to site and the list is not intended as a substitute for a detailed hazard assessment of the particular operation, which should be provided in the RAP.

Table 3: Common thermal desorption hazards and controls

Hazard	Sources of hazard	Suggested controls
Process chemicals Chemical exposure	<ul style="list-style-type: none"> • Splashing or leaking caustic while transferring it to the air pollution scrubber, from pipelines and storage containers, or while unloading it. • Leaking fuel (propane, fuel oil) from pipelines, storage containers (outside and inside unit), or while unloading it into a storage container. • Responding to an emergency release of process treatment chemicals or fuel. 	<ul style="list-style-type: none"> • Use and store smaller quantities of process chemicals. • Use proper storage containers and inspect both the containers and pipelines for leaks and damage. • Install eye wash and emergency shower. • Prepare and train for spill containment • Use gloves and chemical protective clothing that are suitable for the task eg: ensure they provide chemical resistance to the hazardous chemicals. Refer AS/NZS 2161, AS/NZS 1336, and AS/NZS 4501. • Use respiratory protection that is suitable for the task and selected used and maintained in accordance with AS/NZS 1715. • Perform personal exposure monitoring for hazardous substances as identified in an occupational exposure risk assessment as per the WHS Regulations and associated Guidance Note.

Hazard	Sources of hazard	Suggested controls
Site contaminants Chemical exposure	<ul style="list-style-type: none"> • Off-gassing or releasing contaminants as feedstock is loaded, sized, blended, and moved Releasing emissions from treatment process. • Releasing or encountering contaminants in feedstock while working on equipment. • Releasing or encountering contaminants (metals, excluding mercury) that are not desorbed while sampling, handling or backfilling treated feedstock. • Releasing or encountering contaminants that are not desorbed while removing and containerising waste from air pollution controls. 	<ul style="list-style-type: none"> • Use negative pressure in the unit to decrease fugitive emissions. • Work "up-wind" of disturbed soil, when possible. • Segregate treated feedstock until tested. • Regular monitoring of feed soil concentrations to prevent uncontrolled shutdowns due to a high calorific value load. • Use enclosed excavators to minimise potential exposure to dust or vapour, which are fitted with inlet filters that are adequate to filter or adsorb the identified contaminants. • Routinely monitor work areas. • When possible, spray-off or remove feedstock and slag before working on equipment; do not use compressed air. • Contain treated feedstock. • Ensure medical monitoring requirements as stipulated in the WHS Regulations are completed. • Use gloves and chemical protective clothing that are suitable for the task eg: ensure they provide chemical resistance to the hazardous chemicals. Refer AS/NZS 2161, AS/NZS 1336, and AS/NZS 4501. • Use respiratory protection that is suitable for the task and selected used and maintained in accordance with AS/NZS 1715. • Perform personal exposure monitoring for hazardous substances as identified in an occupational exposure risk assessment as per the WHS Regulations and associated Guidance Note.

Hazard	Sources of hazard	Suggested controls
Process Waste Materials	<ul style="list-style-type: none"> Removing and containerising waste materials from an air pollution control device. 	<ul style="list-style-type: none"> Use the applicable controls listed for Process Chemicals, Site Contaminants and Dusts.
Low oxygen environments	<ul style="list-style-type: none"> Pyrolysis reactions in the dryer, causing a low oxygen and high carbon monoxide environment. 	<ul style="list-style-type: none"> Ventilation Flame arrestors Pressure relief valves Continuous gas monitoring Training and instruction
Dust	<ul style="list-style-type: none"> Moving feedstock to load and unload unit. Releasing dust while working on air pollution equipment. Releasing untreated and treated feedstock, or blending material (sand), from stockpiles or bins. Sizing, blending, and moving untreated feedstock using vibrating screens, crushers, shredders or other pre-treatment equipment. Removing and containerising dust from air pollution equipment. Releasing dust while working on/replacing refractory material in the firebox or desorber. 	<ul style="list-style-type: none"> Spray water or use dust suppressants on storage piles and exposed feedstock. Do not operate earth moving equipment during high winds Cover untreated and treated feedstock or keep the quantity to a minimum. Where possible, enclose sizing, blending, and moving equipment like screens, crushers, shredders, and conveyors. Clean surfaces before doing maintenance. Use gloves and chemical protective clothing that are suitable for the task eg: ensure they provide chemical resistance to the hazardous chemicals. Refer AS/NZS 2161, AS/NZS 1336, and AS/NZS 4501. Use respiratory protection that is suitable for the task and selected used and maintained in accordance with AS/NZS 1715. Perform personal exposure monitoring for hazardous substances as identified in an occupational exposure risk assessment as per the WHS Regulations and associated Guidance Note.

Hazard	Sources of hazard	Suggested controls
Ergonomic Risks	<ul style="list-style-type: none"> • Lifting or performing any other movement with too much force and/or in an awkward position or repeating the lift/movement too often. 	<ul style="list-style-type: none"> • Provide conveniently located equipment for the job, like carts, adjustable work stations (operators), and correctly sized tools. • Train workers on ergonomic risks and prevention.
Thermal Burns and Thermal Heat Stress	<ul style="list-style-type: none"> • Encountering slag that appears to be cool. • Encountering hot surfaces on high-temperature equipment. • Coming in contact with high temperature steam from an In-situ Steam Extractor. • Encountering hot ash/residue that is removed from the desorber. • Encountering the containers used to store treated feedstock or residue. • Wearing chemical protective clothing. 	<ul style="list-style-type: none"> • Perform a Job Hazard Analysis. • Ensure use of engineering controls (e.g. guards), lockout/tagout procedures, work practices (e.g., wait until cooled to certain temperature) and/or personal protective equipment (e.g. heat resistant clothing, face shields, gloves, boots, hard hat) to prevent burns. • Insulate accessible surfaces of high-temperature equipment. • Label hot surfaces and identify them during training. • Perform a thermal stress risk assessment to identify necessary control measures in accordance with the, 'Heat Stress Guide Developed for use in the Australian Environment' (AIOH).

Hazard	Sources of hazard	Suggested controls
Electrical Hazards	<ul style="list-style-type: none"> • Working with standard 440V, three-phase electrical service. • Using ungrounded or unguarded electrical equipment. • Working on or testing an electrical system or any electrically powered equipment without properly locking/tagging out energy sources. • Touching (worker or equipment operated by worker) underground and aboveground utilities. 	<ul style="list-style-type: none"> • Implement lockout/tagout procedures. • Allow live testing only by employees that are properly trained and qualified. • Ensure workers use proper electrical work practices. • Ensure workers use proper electrical protective equipment and insulated tools while working live. • Locate and mark any underground utilities. • Ensure proper clearance between power lines and elevated equipment (e.g., crane or drill rig booms, scaffolding, etc.) and designate an observer. • De-energize utilities, when necessary. • Install ground-fault circuit interrupters (GFCI) when feasible. • Routinely inspect electrical cords and equipment.

Hazard	Sources of hazard	Suggested controls
Electrical Hazards	<ul style="list-style-type: none"> • Working with standard 440V, three-phase electrical service. • Using ungrounded or unguarded electrical equipment. • Working on or testing an electrical system or any electrically powered equipment without properly locking/tagging out energy sources. • Touching (worker or equipment operated by worker) underground and aboveground utilities. 	<ul style="list-style-type: none"> • Implement lockout/tagout procedures. • Allow live testing only by employees that are properly trained and qualified. • Ensure workers use proper electrical work practices. • Ensure workers use proper electrical protective equipment and insulated tools while working live. • Locate and mark any underground utilities. • Ensure proper clearance between power lines and elevated equipment (e.g., crane or drill rig booms, scaffolding, etc.) and designate an observer. • De-energize utilities, when necessary. • Install ground-fault circuit interrupters (GFCI) when feasible. • Routinely inspect electrical cords and equipment.

Hazard	Sources of hazard	Suggested controls
Confined Space Entry	<ul style="list-style-type: none"> • Entering heating chamber, fuel burner, bag house, or other equipment on the unit that is a permit-required confined space. Note: Spaces that may contain a hazardous atmosphere (e.g., oxygen deficient, explosive), have physical hazards (e.g., falling material, heat, entrapment), and/or have mechanical hazards (e.g., moving parts) are considered Permit Required Confined Spaces. 	<ul style="list-style-type: none"> • Planning and implementing tasks in accordance with AS2865. • Require a permit for entry. • Use suitable ventilation systems. • Test atmosphere (oxygen first) • Lockout/tagout any electrical and mechanical equipment and isolate any chemical/steam lines. • Ensure use of PPE, such as heat resistant and flame retardant materials Train employees to recognize and control the hazards of a permit-required confined space. • Make sure employees understand the permit system. • Plan and prepare for rescue.

Hazard	Sources of hazard	Suggested controls
Fire, Explosion, uncontrolled release of hot gases from the thermal system	<ul style="list-style-type: none"> • Leaking or emitting stored fuel from damaged storage containers or pipelines, or while transferring it to a storage container. • Overheating fuel tanks. • Leaking or emitting stored flammable liquids recovered from the desorber or pollution controls. • Operating without using a proper vapour inerting system or inert purge gas, or when these systems fail. • Operating the heating chamber at temperatures above its rated temperature. • Operating the heating chamber with excessive flammable and combustible material (such as hydrocarbons) in the feed stream arising for example, through variations in feed composition. • Mixing feedstock containing flammable contaminants with enough air to reach the lower explosive limit. 	<ul style="list-style-type: none"> • Forbid smoking and open flames in the area. • Prevent combustibles (e.g., paper, trash) from accumulating. • Blend feed streams to avoid high concentrations of flammable and combustible material. • Routinely monitor the area if highly flammable materials are present in the feedstock. • Use controls to prevent unit from operating above a set temperature or without the inerting gas. • Provide appropriate fire suppression systems and/or equipment. • Train workers in fire prevention.

Hazard	Sources of hazard	Suggested controls
Mechanical	<ul style="list-style-type: none"> • Contacting or becoming entangled in moving/ unguarded equipment like conveyor, hollow screw mixer, belts, chains, gears, moving parts with protrusions, etc. • Working on any of this moving equipment without isolating the energy source. 	<ul style="list-style-type: none"> • Place guards during operation. • Train workers on hazards, use of guards, who may remove guards, and how to remove guards. • Ensure use of lockout/tagout procedures for maintenance.
Flying Particles and Falling Material	<ul style="list-style-type: none"> • Getting dust into the air from moving equipment or from high winds. • Falling slag or loosened refractory material in unit. • Falling feedstock, from conveyors and other moving equipment. 	<ul style="list-style-type: none"> • Perform a Job Hazard Analysis. • Ensure workers use proper PPE. • Spray water or use dust suppressants on feedstock piles and exposed soil. • If possible, remove slag and loose material before working on or in unit. • Where possible, enclose sizing, blending, and moving equipment like screens, crushers, shredders, and conveyors.
Noise	<ul style="list-style-type: none"> • Working near feedstock sizing/blending equipment, material handling equipment and air pollution control devices. • Working near air blowers, pumps and fuel burners. • Using powered hand tools, compressed air, welding equipment or any other equipment that creates noise while maintaining process equipment. 	<ul style="list-style-type: none"> • Follow requirements in the Safe Work Australia Code of Practice, “Managing Noise and Preventing Hearing Loss at Work” and AS/NZS 1269. • Locate noisy operations away from other workers. • Isolate or insulate noisy equipment components. • Identify and mark areas requiring hearing protection. • Implement a Hearing Conservation Program. • Perform an occupational noise assessment to identify the need for additional control measures including identification of an appropriate class of hearing protection.

Hazard	Sources of hazard	Suggested controls
Slips, Trips and Falls	<ul style="list-style-type: none"> • Storing construction materials or other unnecessary items on walkways and in work areas. • Creating and/or using wet, muddy, sloping, or otherwise irregular walkways and work surfaces. • Constructing and/or using improper walkways, stairs, or landings or damaging these surfaces. • Creating and/or using uneven terrain in and around work areas. • Working from elevated work surfaces and ladders. • Working in confined spaces • Using damaged steps into vehicles. 	<ul style="list-style-type: none"> • Keep walking and working areas free of debris, tools, electrical cords, etc. • Keep walking and working areas as clean and dry as possible. • Install handrails, and guardrails on work platforms. • Clean and inspect ladders and stairs routinely. • Perform a Job Hazard Analysis. • Ensure workers use proper PPE, including fall arrest systems. • Train workers on fall hazards and use of ladders. • Use an observer (spotter or signal person) when visibility is limited.
Moving Vehicles	<ul style="list-style-type: none"> • Moving and stockpiling untreated and treated feedstock using earth moving equipment. • Loading and unloading unit using heavy equipment. • Receiving and transferring process chemicals and other materials from commercial vehicles. • Establish vehicle inspection schedules and procedures. 	<ul style="list-style-type: none"> • Train affected employees on limitations of equipment and drivers. • Train equipment and vehicle operators in safe operation. • Set acceptable speed limits and traffic patterns Ensure that equipment has, and workers use, back-up alarms, mirrors, and seat-belts. • Set parking brake and if on incline, chock wheels. • Ensure equipment has required roll-over equipment. • Do routine maintenance.

Appendix A – Case studies

- Orica Villawood ITD PCBs (small)- <http://www.orica.com/Sustainability/Environmental-Monitoring-Data/Villawood-Remediation/Villawood-Remediation> (accessed 11/3/14).
- Allied Feeds DTD (dioxins) - <http://www.thiess.com.au/capabilities/projects/rhodes-remediation-homebush-bay-sediment-dioxin-project> (accessed 11/3/14).
- Lednez DTD (dioxins)
- http://www.rhodesremediation.com.au/files/downloads/DTDFactSheetLednez2008_08FinalWeb.pdf (accessed 11/3/14).
- Orica Car Park Waste Encapsulation DTD
- <http://www.thiess.com.au/capabilities/projects/orica-car-park-waste-encapsulation-cpwe-remediation-project> (accessed 11/3/14).
- Highett ETC gasworks (PAHs) - <http://www.thiess.com.au/capabilities/projects/highett-gasworks-remediation-project> (accessed 11/3/14).
- Avenue Coking Works, Chesterfield, Derbyshire, UK
- <http://www.theavenueproject.co.uk/upload/documents/dc0d028b-e7b3-44e7-9ab1-77bbd3f10605.pdf> (accessed 11/3/14).
- Information on all these (and more) US based case studies can be found in the Federal Remediation Technologies Roundtable case studies database²
- Ex Situ Thermal Desorption using the SepraDyne™-Raduce System at Brookhaven National Laboratory (2003)
- Low Temperature Thermal Desorption at Longhorn Army Ammunition Plant, Karnack, Texas (2000)
- Thermal Desorption at Industrial Latex Superfund Site, Wallington, New Jersey (2003)
- Thermal Desorption at Letterkenny Army Depot Superfund Site, K Areas, OU 1 Chambersburg, Franklin County, Pennsylvania (2000)
- Thermal Desorption at Naval Air Station Cecil Field, Site 17, OU 2, Jacksonville, Florida (1998)
- Thermal Desorption at Site B, Western United States (2003)
- Thermal Desorption at the Anderson Development Company Superfund Site, Adrian, Michigan (1995)
- Thermal Desorption at the Arlington Blending and Packaging Superfund Site, Arlington, Tennessee (2000)
- Thermal Desorption at the Cape Fear Superfund Site, Fayetteville, North Carolina (2002)
- Thermal Desorption at the Lipari Landfill, Operable Unit 3, Pitman, New Jersey (2002)
- Thermal Desorption at the McKin Company Superfund Site, Gray, Maine (1995)

² <http://costperformance.org/search.cfm> (accessed 11/3/14)

- Thermal Desorption at the/ Metaltec Superfund Site, Franklin Borough, New Jersey (2001)
- Thermal Desorption at the Outboard Marine Corporation Superfund Site, Waukegan, Illinois (1995)
- Thermal Desorption at the Port Moller Radio Relay Station, Port Moller, Alaska (1998)
- Thermal Desorption at the Pristine, Inc. Superfund Site, Reading, Ohio (1995)
- Thermal Desorption at the Reich Farm Superfund Site, Pleasant Plains, New Jersey (2001)
- Thermal Desorption at the Reilly Industries Superfund Site, OU 3 Indianapolis, Indiana (2002)
- Thermal Desorption at the Re-Solve, Inc. Superfund Site, North Dartmouth, Massachusetts (1998)
- Thermal Desorption at the Rocky Flats Environmental Technology Site, Golden, Colorado (2001)
- Thermal Desorption at the Rocky Flats Environmental Technology Site, Trenches T-3 and T-4, Golden, Colorado (2000)
- Thermal Desorption at the Sand Creek Industrial Superfund Site, OU 5 Commerce City, Colorado (2000)
- Thermal Desorption at the Sarney Farm Superfund Site, Amenia, New York (2001)
- Thermal Desorption at the Solvent Refined Coal Pilot Plant, Fort Lewis, Washington (1998)
- Thermal Desorption at the T.H. Agriculture & Nutrition Company Superfund Site, Albany, Georgia (1995)
- Thermal Desorption at the T.H. Agriculture and Nutrition Site, OU2, Albany, GA (2005)
- Thermal Desorption at the Waldick Aerospace Devices Superfund Site, Wall Township, New Jersey (1998)
- Thermal Desorption/Dehalogenation at the Wide Beach Development Superfund Site, Brant, New York (1995)
- Thermal Desorption/Gas Phase Chemical Reduction at the New Bedford Harbor Superfund Site, New Bedford, Massachusetts (2001)
- Thermochemical Conversion of Demolition Debris from Fort Ord, California (2002)
- Transportable Hot-Gas Decontamination System at the Alabama Army Ammunition Plant Site, Alpine, Alabama (1998)
- Vacuum-Enhanced, Low Temperature Thermal Desorption at the FCX Washington Superfund Site Washington, North Carolina (1998)

Appendix B – References

- ALTENBOCKUM & KRAFT, 2001, *Site specific validation of soil vapour extraction: Experiences and new strategies in Germany*, Presented at NATO/CCMS pilot study meeting: Evaluation of demonstrated and emerging technologies for the treatment of contaminated land and groundwater, Liege, Belgium.
- CL:AIRE, 2007-2017, *Thermal desorption remediation technology training module* [Online], London, UK: Contaminated Land: Applications in Real Environments. Available: <https://www.claire.co.uk/component/joomla/topics/4-Remediation%20Technologies/12-Thermal%20Desorption%20> [Accessed 31 July 2017].
- HIESTER, MÜLLER, KOSCHITZKY, TRÖTSCHLER, ROLAND & HOLZER, 2013, *In situ thermal treatment (ISTT) for source zone remediation of soil and groundwater.*, Centre of Competence for Soil, Groundwater and Site Revitalisation, Leipzig, Germany.
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- US DEPT OF LABOR, 2003, *Remediation technology health and safety hazards: Thermal desorption. Health and safety information bulletin*, SHIB 02-03-03, United States Department of Labour, Occupational Safety and Health Administration,
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