GUIDANCE ON THE IDENTIFICATION, MANAGEMENT AND REMEDIATION OF MERCURY-CONTAMINATED SITES

Lee Bell

IPEN Mercury Policy Advisor

November 2016

IPEN

a toxics-free future

IPEN is a leading global network of 700 non-governmental organizations (NGOs) working in more than 100 developing countries and countries with economies in transition. IPEN works to establish and implement safe chemicals policies and practices to protect human health and the environment. It does this by building the capacity of its member organizations to implement on-the-ground activities, learn from each other's work, and work at the international level to set priorities and achieve new policies. Its mission is a toxics-free future for all.

IPEN launched its Mercury-Free Campaign to address the alarming level of environmental and human health threats (such as permanent damage to the nervous system and kidneys) posed by mercury around the world. Following the adoption of the Minamata Convention on Mercury in 2013, IPEN launched its International Mercury Treaty Enabling Activities Program (IMEAP). The program provides funding to local organizations working on Mercury Treaty ratification and enabling activities. The activities, which include awareness-raising campaigns, mercury pollution monitoring, national situation reports, and the identification of hotspots, have helped prepare governments for ratification by elevating the mercury issue in 29 developing and transition countries.

ACKNOWLEDGEMENTS

IPEN would like to thank the hundreds of NGOs, CSOs, labor groups, and health groups around the world for their contributions to the IPEN Mercury-Free Campaign and the IPEN Toxic Metal Program. IPEN gratefully acknowledges the financial support provided by the Government of Sweden and other donors that made the production of this document possible. The expressed views and interpretations herein shall not necessarily be taken to reflect the official opinion of any of the institutions providing financial support. Responsibility for the content lies entirely with IPEN.

Cover Photos: ***(Top) Mercury-contaminated waste water from a set of ball-mills discharged to a septic fish pond (Banten, Indonesia, October 2014. On a hot day, the water bubbles rose to the surface, covered by a thin layer of mercury*** *[Photo: BaliFokus & Medicuss]****; (right) Interior of odor control enclosure during excavation*** *[Source: Australian Federal Government (2013)]****; (left) XRF field training in Thailand*** *[Source: Nicha Rakpanichmanee]****.***

GUIDANCE ON THE IDENTIFICATION, MANAGEMENT AND REMEDIATION OF MERCURY-CONTAMINATED SITES

Lee Bell
IPEN Mercury Policy Advisor

November 2016

CONTENTS

EXECUTIVE SUMMARY

The signing of the Minamata Convention on Mercury (the “Mercury Treaty”) in 2013 represents the first global attempt to address such mercury pollution. However, the Mercury Treaty currently lacks concrete guidance on the identification, management and remediation of mercury-contaminated sites under the relevant provision (Article 12). Recognizing the need to assist countries to advance action on contaminated sites, IPEN developed the “Guidance on the Identification Management and Remediation of Mercury-Contaminated Sites,” which provides specific guidance on these issues.

This IPEN Contaminated Sites Guide provides a detailed analysis of contemporary and emerging methods for identification, management and remediation of mercury-contaminated sites. It looks beyond cost-benefit-driven remediation to sustainable clean-up provisions that incorporate the “polluter pays” principle as well as clean-up thresholds that ensure inter-generational equity and promote ecological restoration. There is discussion of the latest technologies, practices and techniques (for remediation of mercury-contaminated soil, surface water and groundwater), which minimise further mercury pollution and human health impact during the clean-up and post-remediation phase. This Guide also elaborates the cooperative roles that can be adopted between civil society organisations, local or national authorities and industry to facilitate positive outcomes at mercury-contaminated sites.

By some estimates over 250,000 tonnes of elemental mercury has been released into the global environment as a direct result of gold and silver mining over the last 300 years, leaving an enduring legacy of mercury-contaminated sites. Thousands of tonnes of mercury are still traded throughout the world for industrial, manufacturing and mining uses, resulting in a proliferation of sites contaminated by mercury and impacting the environment and human health.

Current and historical Artisanal and Small-Scale Gold Mining (ASGM) represents a significant, ongoing source of global mercury-contaminated sites. This Guide addresses some of the complexities associated with the identification and definitions of ASGM mercury-contaminated sites, which can range through tailings dumps to villages, communities, waterways and rice paddies. Unlike many industrial contaminated sites that can be isolated for clean-up, many ASGM-contaminated sites occur in complex social environments where human heath can be heavily impacted and remediation may exacerbate those impacts. This Guide gives direction on integrating social, health and environmental concerns at ASGM sites through multi-party stakeholder engagement mechanisms.

IPEN developed this guidance document with the aim of providing a basis for countries to take real actions on contaminated sites in their efforts to implement the Minamata Convention on Mercury, reduce mercury pollution, and protect human health and the environment from mercury contamination.

1. INTRODUCTION

This document is intended to provide a source of preliminary guidance in relation to sites contaminated with mercury and mercury compounds. This includes guidance about identification and management of sites polluted by mercury and aspects of stakeholder engagement that are critical to successful management and remediation of these sites. Consideration has also been given to proven and emerging technologies for the remediation of mercury-contaminated sites as well as techniques and practices that can ensure such remediation occurs in an environmentally sound manner.

Contaminated sites result from a range of anthropogenic practises including industrial activity, mining and waste disposal. The primary concern in addressing contaminated sites is the potential threat to human health and the environment. Contaminated sites may be impacted by a single substance or by a highly complex mixture of chemicals and metals, depending on the source of the contamination. The focus of the guidance in this document is on mercury-contaminated site identification and management.

The Minamata Convention on Mercury ("Mercury Treaty"), which was adopted in 2013 but has yet to enter into force, raises the issue of contaminated sites under Article 12. The Treaty calls on parties to "endeavor" to take action to address contaminated sites. The Treaty specifies a number of actions that Parties should take, including development of guidance for:

- Site identification and characterization;
- Engaging the public;
- Human health and environmental risk assessment;
- Options for managing the risks posed by contaminated sites;
- Evaluation of benefits and costs; and
- Validation of outcomes.

This document represents an initial effort toward the development of guidance in the range of areas noted above and gives further consideration to other aspects of contaminated sites remediation that complement these approaches. In some instances, cross cutting issues between the Mercury Treaty and elements of guidance from the Basel Convention are noted – particularly in relation to guidance on mercury wastes and their management.

Mercury-contaminated site remediation can involve a complex set of technical and social parameters that may not easily be resolved using standard site decontamination practises that have historically been adopted for other pollutants or site-specific scenarios. The practise of mercury amalgamation in artisanal and small scall gold mining (ASGM) is of particular concern due to the decentralised distribution of elemental mercury utilised and its widespread handling, thermal conversion and disposal within social settings such as shops, villages, and food production areas. Management of such sites differs significantly from industrial site remediation and requires more thorough and complex stakeholder engagement.

Similarly, there are significant differences in approaches for management of point source and diffuse mercury contamination, including situations where the former may be responsible for the latter. A number of brief case studies are presented in this document to illustrate the challenges of complex risks associated with management of these forms of contamination.

In addition, this document can also serve as a basis for further discussion between Civil Society Organizations (CSOs) and Parties to the Mercury Treaty about additional guidance required in the management of sites contaminated by mercury to ensure a reduction in the number and severity of such sites and limit their impact on human health and the environment.

1.1 BASIC INFORMATION ABOUT MERCURY AND CONTAMINATED SITES

The toxic properties of elemental mercury have long been known and in recent decades the significance of mercury pollution at a global scale has become apparent. Contamination of the atmosphere, oceans, lakes and rivers with mercury has led to food chain impacts and widespread contamination of fisheries – a key protein source for much of the world's population. In aquatic environments inorganic metallic mercury is converted to the highly toxic organic methylmercury by bacterial organisms. Methylmercury bioaccumulates and biomagnifies in aquatic organisms, reaching high concentrations in peak predators such as sharks, tuna and swordfish. In turn, human consumption of contaminated fish can lead to toxic levels of mercury accumulating in body tissues.

Mercury exposure at high levels can harm the brain, heart, kidneys, lungs, and immune system of people of all ages. High levels of methylmercury in the bloodstream of unborn babies and young children may harm the developing nervous system (US EPA 2014), making the child less able to think and learn and potentially reducing their IQ.

Mercury-contaminated sites are a significant source of anthropogenic mercury contamination due to the physical properties of mercury that allow it to enter a vapour phase at room temperature (with a vapour pressure at room temperature of 0.002 mm Hg) and escape to atmosphere where it may deposit to aquatic environments far from the source (Rom 1992). Mercury from contaminated sites may also impact the local environment as rain washes it into waterways and drives infiltration into groundwater systems eventually carrying it to aquatic environments where methylation occurs. Contaminated sites can represent a serious health hazard to local communities from direct inhalation of vapour and contaminated dust, dermal exposure and contamination of food sources.

Global recognition of the severity of mercury pollution led to the recent adoption of the Minamata Convention on Mercury,[1] which was opened for signing in October 2013. This Convention is an international legal instrument or Treaty designed to protect human health and the environment from anthropogenic emissions and releases of mercury and mercury compounds. Currently, the Convention has been signed by 128 countries and ratified by 18. The Minamata Convention will enter into legal force 90 days after it has been ratified by 50 nations. Signatories to the Minamata Convention on Mercury can access international resources to better identify and manage mercury contamination.

The Minamata Convention requires the phase-out of many products containing mercury, implements restrictions on trade and supply of mercury and establishes a framework to reduce or eliminate emissions and releases of mercury from industrial processes and mining. The Treaty addresses various elements of mercury-contaminated sites under Article 11 (Waste) and Article 12 (Contaminated Sites).

A related international treaty, The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal ("the Basel Convention")[2] also provides guidance on the management of mercury-contaminated sites and wastes. The Basel Convention entered into force in 1992 with the overarching objective to protect human health and the environment against the adverse effects of hazardous wastes.

The Basel Convention provides additional technical guidance on the management of mercury waste and mercury contamination in a consolidated document (Basel Convention 2012) that was recently under review at the joint COP of chemical conventions in Geneva (the 12th Meeting of the

---

1 For more details on the adoption of the convention see the UNEP website http://www.mercuryconvention.org/

2 http://www.basel.int/TheConvention/Overview/tabid/1271/Default.aspx

Conference of the Parties (COP) to the Basel Convention, seventh meeting of the COP to the Rotterdam Convention, and seventh meeting of the COP to the Stockholm Convention). Revision 6 of the Basel technical guidelines on mercury waste was adopted by the Basel Convention Conference of Parties in May 2015. The latest revision contains more detailed guidance on mercury waste and contaminated sites that are relevant to the Articles of the Minamata Convention on Mercury. Updates and revisions of the guidance are accessible on the Basel Convention website[3].

While these treaties serve to raise awareness of mercury-contaminated sites and their impacts, they do not contain legally binding requirements to remediate (clean-up) mercury-contaminated sites or suggest how to determine parties responsible for this activity. The key stakeholder for site identification, assessment and remediation is generally the national government in the context of local legislation and regulation. However, there are critical roles for other stakeholders in this process, including non-governmental organizations (NGOs) and local communities affected by contaminated sites. These groups can play an active role in the identification and mapping of sites, sampling and analysis (under supervision from qualified authorities and with appropriate protection) and development of remediation options and post-remediation land use considerations. At a broader level, NGOs can raise awareness in the community about the sources and impacts of mercury pollution and ways to reduce it.

This document also provides guidance on principles to address contaminated sites that can be adopted irrespective of the national context. It includes a range of suggestions as to how contaminated sites policy, legislation and management may be developed, taking into account local contexts including limited resources and cultural diversity. While considering legal, regulatory and financial issues relevant to mercury impacted sites, this guidance prioritises the protection of human health and ecological integrity from the impacts of anthropogenic mercury pollution arising from contaminated sites.

1.2 THE MINAMATA CONVENTION AND CONTAMINATED SITES

The Minamata Convention on Mercury outlines activities Parties can undertake to address contaminated sites and generate information for the public to raise awareness about their implications for human health and the environment. Guidance such as this document can assist to build capacity within the community, NGOs and policy makers to address

3 http://www.basel.int/Implementation/TechnicalMatters/DevelopmentofTechnicalGuidelines/MercuryWaste/tabid/2380/Default.aspx

mercury-contaminated sites within their country, pending the ratification of the Treaty. No provision of the Treaty precludes any signatory from taking early action to remedy mercury pollution issues in their country.

Article 12 of the Minamata Convention on Mercury states that "*each Party will endeavour to identify and assess sites contaminated by mercury and mercury compounds and that actions to reduce the risks posed by these sites will be performed in an environmentally sound manner* "(ESM). While many countries have not yet ratified the Convention, national environmental authorities could benefit from adopting the suggested approaches of the Convention for identifying and assessing mercury-contaminated sites.

At this point the Parties to the Convention have not yet developed specific guidance for contaminated sites, but this does not prohibit national governments from developing their own management frameworks, policies and legislation to assess, identify, characterise and remediate contaminated sites. It is also important to be aware of the specific statements made in the Treaty about mercury-contaminated sites and the need for public engagement, given that successful remediation of sites may be dependent on this factor.

While the Convention is yet to develop specific, detailed guidance on the management of mercury-contaminated sites, it is suggested that the activities that should be undertaken include:

- Site identification and characterization;
- Engaging the public;
- Human health and environmental risk assessments;
- Options for managing the risks posed by contaminated sites;
- Evaluation of benefits and costs; and
- Validation of outcomes.

In addition, Parties are encouraged to develop strategies and implementing activities for "*identifying, assessing, prioritizing, managing and, as appropriate, remediating contaminated sites*."

The Minamata Convention is specifically focused on sites contaminated with mercury and mercury compounds but the processes identified above can be applied to sites with any form of chemical contamination.

Other articles of the Convention that may have relevance to contaminated sites include:

- Article 11 – Mercury wastes;
- Article 13 – Financial resources and mechanism;
- Article 14 – Capacity-building, technical assistance and technology transfer;
- Article 16 – Health aspects;
- Article 17 – Information exchange;
- Article 18 – Public information, awareness and education; and
- Article 19 – Research, development and monitoring.

Under Article 12, “Contaminated sites”, the Conference of Parties is required to prepare guidance on managing contaminated sites that include methods and approaches for “Engaging the Public” (UNEP 2013).

In addition, under Article 18, “Public information, awareness and education”, each Party is required to provide to the public information on mercury pollution as well as the “results of its research, development and monitoring activities under Article 19”. Parties are also required to provide education, training and public awareness related to mercury health effects in collaboration with relevant intergovernmental entities, NGOs and vulnerable populations.

Public engagement through cross-sector collaboration and cooperation requires an integrated, two-way approach between a national and regional-level engagement of civil society by government, and a local, site-specific process of stakeholder engagement. Each process should have the capacity to inform and adapt to the other. However, public engagement needs also to take into consideration the specific cultural, social and political context to be most effective.

Countries that have not yet done so should give consideration to the steps necessary to ratify the Convention to improve potential access to technical assistance and technology transfer (Article 14) and financial resources (Article 13) that would support the development of mercury (and mercury waste) inventories, contaminated sites databases and other critical information needed to address domestic mercury contamination.

2. SITE IDENTIFICATION AND CHARACTERISATION: WHAT IS A MERCURY-CONTAMINATED SITE?

In developing a robust definition of a mercury-contaminated site it is necessary to address key issues including the definition of a "site" as well as what concentration or form of mercury present constitutes "contamination" as opposed to naturally occurring levels.

In general terms a site that has soil, air, water or sediment (or a combination) impacted by elemental mercury, mercury compounds or mercury waste should at least be considered a *suspected* mercury-contaminated site. Concentrations of just 0.13 ppm mercury in soil (Tipping et al 2010) have been identified as the tolerable limit for soil health in terms of plants and micro-organisms.

Levels of mercury in soil that "trigger" further investigation are also called screening levels. These vary between countries but are generally in the same order of magnitude. As an example the Australian national guidelines for contaminated sites (NEPC 1999) listed 10 ppm methyl mercury and 15 ppm elemental mercury as a screening level for residential property. Dutch Intervention Levels (Netherlands Ministry of Housing, Spatial Planning and the Environment 2010) use 10 ppm elemental mercury as intervention levels for further assessment of sites suspected of contamination[4]. In the UK, residential soil guideline values are even lower with a limit of 1 ppm for elemental mercury in soil and 11 ppm for methylmercury (Environment Agency UK 2009). These screening levels are used in the identification of mercury-contaminated sites and may render it necessary to manage the site and subject it to further investigation and possibly remediation.

---

4 This concentration was revised in 2009 to an intervention level of 36 mg/kg (ppm), but also highlights the use of a target level of just 0.3 mg/kg to ensure sustainable soil health. For further discussion see case study 2 of this document.

These can be complex issues. Some sites may have naturally occurring levels of mercury or mercury compounds present that exceed levels at which negative impacts to human and ecological health may occur. This is often the case at sites where primary mining of mercury has taken place or continues to operate due to naturally occurring high concentrations of mercury in the soil.

In many countries risk-based approaches that take into account the nature of the site (e.g. terrestrial, aquatic), its context (e.g. urban, agricultural or wilderness) and the threat it poses to different "receptors" such as people, wildlife and ecological processes are used to define and manage contaminated sites. This approach can act as a useful tool to prioritise the order in which sites may need to be remediated using limited resources. Generally those sites that present most risk to human health and the environment are remediated sooner and those with least risk later. However, the remediation of large, complex, high risk sites may still be delayed for years or decades due to financial, legal, political and social complications (including conflict), despite having a high priority for remediation.

2.1 DEFINING A "SITE"

A site may not necessarily be limited to a terrestrial form such as a field, forest or a hill. It can include aquatic environments such as streams, rivers, lakes, swamps, damp-lands, estuaries and bays. In other cases sites may include modified landforms that have both terrestrial and aquatic features such as rice paddies, irrigated fields and fish raising ponds. In addressing mercury contamination at different sites, the identification, characterisation, management and remediation (clean-up) may vary considerably when taking into account the form of the site, its current use and the intended use following remediation.

It is also important to consider the geophysical and hydrogeological structure of a given site for the purpose of characterising the extent of contamination into the soil profile and the groundwater. This can also assist in estimating or predicting off-site movement and impacts of contamination through groundwater systems now and in the future, as well as estimating the extent and type of remediation that may be necessary.

Terrestrial mercury-contaminated sites can also be subject to periodic natural events that may result in the spread of contamination beyond property boundaries such as regular or occasional flooding, earthquake and landslides, and extreme weather such as storms, cyclones or hurricanes, which can blow contaminated dust from a site. These events should be considered and their impacts managed in an effort to reduce the spread of pollutants from known and/or suspected contaminated sites. These natural activities can create diffuse mercury-contaminated sites such as that found in the River Nura and its floodplain in Central Kazakhstan (see case study in section 7 of this document). At this site wastewater that was heavily contaminated with mercury from an acetaldehyde plant was historically discharged (largely without treatment) and then mixed in the river with fly ash from power stations. This action created mercury-laden silt (technogenic silt) that was spread by floodwaters contaminating large areas downstream of the initial discharge site (Heaven et al 2000).

2.2 SITE IDENTIFICATION

The identification of contaminated sites provides a key opportunity for community engagement and interaction between CSOs and other stakeholders, including environment and health officials. The process of investigating a suspected contaminated site often necessitates the involvement of local residents and officials, workers and former workers, and local environmental NGOs who may have detailed knowledge of the history of a site and waste dumped at the site or transported to other locations that also may have become contaminated.

Suspected contaminated sites may be identified without specialised technical equipment by the following means (Basel Convention 2012):

- Visual observation of the site conditions or attendant contaminant sources;
- Visual observation of manufacturing or other operations known to have used or emitted a particularly hazardous contaminant;
- Observed adverse effects in humans, flora, or fauna presumably caused by the proximity to the site;
- Physical (e.g. pH) or analytical results showing contaminant levels; and
- Reports from the community to the authorities of suspected releases.

The Minamata Convention on Mercury lists a range of mercury pollution sources including mercury-added product manufacture (Annex A), industrial processes (Annex B), point sources (Annex D), and waste disposal and mining activities (Annex C - particularly refining of ores and tailings disposal). Observation of sites that were historically or currently are engaged in these practices should be considered as a starting point for mercury-contaminated site identification and assessment. Not all sites associated with these activities will be contaminated, but there is a significant probability that such activities may have contaminated groundwater, soil, air or infrastructure and should be investigated, particularly if a change of land use to a more sensitive category is envisaged (e.g. industrial to residential).

Artisanal and Small-scale Gold Mining (ASGM) is one of the largest sources of global mercury contamination. ASGM refers to informal mining activities carried out using low technology or with minimal machinery. Mercury is one of few metals that amalgamates with gold and is used to separate the gold from unrefined or concentrated ore. The mercury is then burned off, leaving behind a small amount of gold. This practice causes widespread mercury contamination to air, water and soil, as well as direct mercury exposure to those engaged in ASGM, their families, and some gold traders who supply mercury or partially process the mercury amalgam in their shops (IPEN 2014).

Mercury-contaminated sites are generally caused by industrial activities, primarily mining, coal ash from power stations, chlorine production[5], and the manufacture of mercury-added products. Disposal of mercury-added products to landfill or incineration can also lead to mercury-contaminated sites. Wastes from the incineration of mercury-added products such as fly ash can also create contaminated sites if the hazardous ash is dumped at sites not authorised for disposal.

Identification of mercury contamination can be linked closely to these types of industrial activity and waste disposal. Regulatory authorities in many countries often scrutinise the history of a specific site as part of a preliminary site investigation. In this phase of investigation the insights of community members close to the site - based on observations across long time periods and specific knowledge of the local environment, livestock and biota across seasonal variations - can provide critical information.

For instance, a local farmer near the site boundary or drainage routes may detect an unusual cluster of animal sickness, death or birth deformities that may be caused by contamination, or a local resident may notice tankers regularly leaving an industrial site at night and dumping waste. Residents may have historically been employed at the site of the activity as drivers, workers or managers, and be familiar with work practices and waste disposal techniques and sites that they can relate to investigators. These important observations may go unnoticed by regulatory authorities that only have intermittent or brief attendance at a site where mercury or mercury compounds are used. Local observations can be very important in terms of assessing community health impacts from contamination, as local residents may have specific knowledge of unusually high rates of

5 Chlorine production from chlor-alkali plants involves the use of large quantities of elemental mercury, which has a tendency to contaminate the facility from emissions and releases to soil, water and air. Many of these mercury-based chlor-alkali plants have been replaced by non-mercury-based chlorine production technology such as the membrane method. However, the sites of the older plants may remain contaminated after the facility has been closed or demolished.

illness in their locality and can communicate this to authorities. Local health care workers may also be able to provide similar information on local health trends that may point to a contamination problem.

Once a suspected contaminated site is identified, the following activities should be conducted:

- Preliminary Site Investigation (and emergency response if required);
- Detailed Site Investigation;
- Site management;
- Remediation, validation and ongoing management; and
- Waste transport and treatment (on-site or off-site).

2.3 PRELIMINARY SITE INVESTIGATION

A Preliminary Site Investigation (PSI) generally consists of a review of site history (desktop study), a site inspection and interviews with stakeholders, and the preparation of a report. The results of the PSI help explain how the site became contaminated and the potential exposure pathways between the contamination sources and receptors, such as people, crops, wildlife or livestock.

2.3.1 Desktop Study

When investigating an industrial site a desktop study should always seek to include interviews with current or former workers, management, and waste haulage drivers to broaden the information base about hot spots of contamination on and off-site.

In addition to stakeholder interviews, investigators can draw upon:

- Current and historical aerial photographs;
- Historical certificates of title (land ownership documents); and
- Local government documentation (industrial development approvals or landfill authorisations).

2.3.2 Site Inspection

A site inspection should then take place with a person with historical knowledge of the site. The inspection is to collect visual, oral and anecdotal information relating to:

- Topography;
- Surface water bodies and flow direction;

- Type and condition of hardstand material;
- Site infrastructure (current and historical);
- Current site activities (and historical, where possible);
- Surrounding land uses;
- Any evidence of soil contamination (staining, odor, stressed vegetation, etc.);
- Chemical or fuel storage areas; and
- Waste management.

2.4 PSI AND EMERGENCY RESPONSE

After completion of the PSI, further information about the nature and extent of site contamination is assessed through a Detailed Site Investigation (DSI). However, the PSI may reveal gross contamination by mercury or other highly hazardous materials. If the contamination is severe and nearby populations are at risk of exposure that is an immediate threat to their health, an emergency response may be required prior to performing the DSI.

The first priority is to isolate the contamination from the receptors as far as possible in order to minimise further exposure. In this way, sites contaminated with mercury are similar to a site with another potentially mobile, toxic contaminant (Basel 2012). If the site cannot be controlled and the risk is high, temporary evacuation of residents and workers may be required until the site can be controlled and the contamination isolated. The volatility of mercury in vapour form at room temperature can make isolation a difficult task in highly impacted sites. Barrier technologies as a means of reducing mercury vapour from contaminated sites are discussed further in this document under remediation technologies (section 6).

Further information on emergency response for small-scale mercury contamination from spills can be found in the US EPA Mercury Response Guidebook for Emergency Responders (US EPA 2004). For larger site contamination issues involving mercury, some guidance is provided in Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small –Scale Gold Miners (Veiga and Baker 2004) that may also be applicable to contamination from industrial and waste-related sites in terms of health assessments and sampling methods.

2.5 DETAILED SITE INVESTIGATION AND CHARACTERISATION

The DSI involves the taking of samples in the field from air, soil, groundwater or other water sources to confirm the presence or absence of contamination identified or suspected in the PSI. The DSI sampling should be comprehensive enough to identify the nature of the contamination and describe its lateral and vertical extent to a sufficient level that human health and environmental risk assessment can be undertaken, and to provide the basis for the development of an appropriate remediation or management strategy.

Risk assessment for contaminated sites relies on the development of a Conceptual Site Model (CSM), which provides a representation of site contamination data (often in the form of a graphic or map) and potential pathways of exposure between the suspected or confirmed contamination and potential receptors. This aspect of the investigation can also be described as "characterisation" of the site.

Data obtained from sampling during the DSI can then be included in the CSM to assist in building a more complete representation of the contamination at the site and how it may impact the environment and human health. Any sampling data obtained from the site should be subject to Quality Assurance and Quality Control (QA/QC) procedures to ensure that the data obtained is representative of the contamination at the site (see also Veiga and Baker 2004 p.123 for specific QA/QC for mercury-impacted sites). This includes details on the storage and handling of samples, taking blind duplicate samples[6] and required holding times of samples. The integrity of the sample and reliability of results will depend not only on the length of time the sample has been stored, but also conditions of the sample handling, preservation and storage. All tests should be carried out as soon as practicable after sampling, and it is recommended that at least half the holding time remains when the sample is received by the laboratory.

Quality assurance (QA) refers to the overall management system, which includes the organization, planning, data collection, quality control, documentation, evaluation, and reporting activities of your DSI while QC refers to the routine technical activities whose purpose is, essentially, error control. All US EPA methods for mercury analysis require that samples be refrigerated as soon as possible and analysed within 28 days of collection (Veiga and Baker 2004).

Following the PSI and DSI stages and the construction of a Conceptual Site Model, risk assessment can be conducted for human health and ecological receptors. In many cases the outcome of the risk assessment de-

6 To check reproducibility of laboratory and field procedures and to indicate non-homogeneity, assign two separate (unique) sample numbers (i.e. one number to the primary sample and one to the duplicate) and submit blind to the lab.

termines whether and how the site is remediated (contamination removed to a specific level) or managed (contamination remains on-site with a range of management activities). Despite its utility as a management tool for contaminated sites, risk assessment should not be the sole method by which the future of a contaminated site is determined. Once the contamination on a site has been adequately characterised, public discussions about its future use should be held, and include how and whether the site should be remediated. Obtaining agreement from civil society about the clean-up and future of these sites can avoid protracted anxiety, conflict and expense, while creating opportunities for social renewal around sites that may have been unproductive for many years.

3. SITE IDENTIFICATION AND PRELIMINARY SCREENING: A ROLE FOR GOVERNMENT, CONSULTANTS AND NGOS

In most developed countries the process of site identification, characterisation, risk assessment and remediation is carried out by private consulting companies regulated by or in cooperation with government agencies. The process often occurs within a legal and regulatory framework that requires specific standards and accreditation to perform this work and to report any suspected or identified sites to an agency that inventories the sites and monitors their management or remediation.

As part of this process guidelines are established by which concentrations of a substance (e.g. chemical or metal) in soil, sediment, air and water are defined as a "trigger" level (or threshold concentrations) for further or formal investigations (PSI and DSI). Not all countries develop their own trigger levels and choose to adopt them from other countries. Commonly used guides include the US EPA Regional Screening Levels[7], Dutch Intervention Values[8], Canada-Wide Standards[9], Australian Health Investigation Levels (HILs)[10], and UK Soil Guideline Values (SGVs)[11].

Comprehensive PSI and DSI can be expensive processes if the contaminated sites are large and complex, and involve multiple contaminants or ongoing industrial activities. Full site characterisation often involves grid sampling for multiple samples repeated seasonally. The cost of drilling test bores for groundwater sampling and specialised laboratory analysis for multiple samples can also be very expensive and beyond the capacity of NGOs. However, the key role that can be played by these organisations is

7 See United States Environmental Protection Agency http://www.epa.gov/region9/superfund/prg/

8 http://www.rivm.nl/en/Documents_and_publications/Scientific/Reports/2013/januari/Proposal_for_Intervention_Values_soil_and_groundwater_for_the_2nd_3rd_and_4th_series_of_compounds

9 https://www.ec.gc.ca/mercure-mercury/default.asp?lang=En&n=C6953AC5-1

10 http://www.scew.gov.au/nepms/assessment-site-contamination

11 https://www.gov.uk/government/publications/land-contamination-soil-guideline-values-sgvs

raising awareness of potentially contaminated sites by locating suspected contaminated sites, documenting the activities that may have caused contamination, and even conducting some basic screening sampling. NGOs can also document an inventory of known and suspected contaminated sites to assist regulatory authorities to conduct further investigations that require a significant level of resources.

NGOs raising public awareness of an inventory or "list" of contaminated sites can encourage national decision-makers to address the issue by developing national frameworks for investigation and remediation that can lead to the development of legal frameworks to determine liability for cleaning up the sites and arranging compensation. A notable example of this arrangement is the US Superfund (US EPA Region 9 2015), which provided funds for hazardous site remediation and created a database of known contaminated sites requiring remediation.

Once sites have been confirmed as contaminated with mercury, NGOs can raise awareness in the community and with local authorities about the hazards posed by these sites and precautionary measures that may be taken to minimise exposure to the contamination. This is particularly relevant to sites contaminated with mercury where nearby fisheries (particularly downstream of contamination) are a food source and may contain elevated levels of methylmercury (MeHg). Similarly, other forms of indirect sampling can reveal localised contamination sources such as lichen, fish, crustaceans and some edible plants.

3.1 SITE SCREENING (SAMPLING)

Direct (on-site) screening sampling (soil, water and air) at suspected contaminated sites or indirect sampling nearby of food sources such as vegetation, fish, birds or human biological samples can provide strong indicators of the presence of contaminated sites and the migration path of pollutants leaving the site.

Biological samples can also be taken if people living or working in close proximity to a contaminated site volunteer to provide them. This process has to be approached with sensitivity, as there are privacy and ethical considerations to take into account, including how individuals may need to be supported and counselled if the sampling shows high levels of exposure. The most common samples that people can provide that report mercury exposure include hair, urine and blood. Hair sampling is often used initially because it is less invasive than other methods and relatively inexpensive to analyse. Hair sampling methodology is described further below.

3.2 INDIRECT SAMPLING

For sites that are suspected of mercury contamination, soil and air can be screened effectively at a relatively low cost. For indirect screening, fish sampling is useful as it can be compared to control fish population known to be uncontaminated from other areas, as well as to known reference doses that state the allowable level of methylated mercury in fish that can be consumed per month. A monthly consumption guideline of 0.22 ppm of methylmercury has been established by the US EPA (US EPA 2001).

The European Commission and the World Health Organization recommend that fish with a level exceeding 1ppm of mercury should not be commercially traded. As in the case of dioxin sampling of eggs, milk and fish, accredited laboratories should be contacted to conduct the analysis, and they may also assist with instructions on how to take samples, handle and store them, and allowable holding times. If results show fish samples exceed the reference dose for methylmercury, more investigation is required to identify the source of the contamination.

Extensive information on field sampling of fish for methylmercury is provided in *Global Mercury Project Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners* (GEF/UNDP/UNIDO, 2004 p86).

3.3 HAIR SAMPLING FOR MERCURY EXPOSURE

Taking hair samples for mercury analysis can provide an indicator of localised ongoing mercury contamination. The US EPA reference dose (RfD) level of 1.0 ppm of mercury in hair establishes a threshold against which hair samples from local workers or community members can be compared to test for elevated mercury levels.

People can be exposed to mercury from numerous industrial and mining sources, including coal-fired power plants and pulp and paper mills, and mixed industrial sites that contain mixtures of chlor-alkali production, oil refining, waste incineration, cement manufacturing, and other potential mercury sources. This has to be taken into account when analysing whether elevated mercury levels in hair are from a local contaminated site or more diffuse sources. Hair sampling of children can be used to assess whether mercury is present at levels of concern that may impact on their neurological development and allow for early intervention by authorities to reduce their exposure (Grandjean 1999).

The National Institute for Minamata Disease in Japan recommends the following process for taking hair samples (other methods may also be valid): collection of hair samples; sending the collected hair samples; direct sampling (on-site); and soil and water sampling for laboratory analysis.

3.4 COLLECTION OF HAIR SAMPLES:

- Cut hairs with scissors close to hair root. A minimum requirement is twenty strands of hair, each with about 10 cm in length. The shorter the length is, the more strands are required. If longer hair strands are available, a proximal portion of hair strand (a hair root side) with about 10 cm in a length may be kept by removal of excessive distal hair strand (a hair tip side) after cutting out the hair strands.

  Note: A proximal portion of hair (a hair root side) is suitable rather than a distal part (a hair tip side) for the analysis in the aim of estimation for methylmercury exposure. The reason is that the contents of methylmercury might decrease during growth of hair under certain conditions, including treatment with artificial hair waving (i.e. permanent wave).
- Put the collected hair sample into an envelope on which the identification (ID) number of the participant is indicated. Use one envelope for one participant.

3.5 SENDING THE COLLECTED HAIR SAMPLES

- Collect and store hair samples until the number of participants exceeds 50 individuals, and thereafter send the samples with a list of participants. The number of participants should not more than 100 for each sampling site.
- The list of participants should include identification (ID) number, sex, age, date of sampling, and sampling site.
  Note: Personal information that can be used for identification of individual participants, including name and address, should be protected from free access. It should be kept under strict control by a specific administrator. The personal information might be necessary in certain cases; for example, a feedback of the analysis results to a local community.

3.6 DIRECT SAMPLING (ON-SITE)

Soil, sediment and water samples can be taken directly from a known or suspected contaminated site by NGOs with some preliminary training and under supervision. However, it is also important to be aware of the exposure hazards present at such sites and the need for an appropriate level of Personal Protective Equipment (PPE) to reduce exposure risks. It is also preferable to take rather more representative pooled samples of soil or sediments from a larger area than just samples from one point, as hotspots may be missed and the site characterisation may be inadequate.

A sampling protocol that includes a detailed description of the sampling process is crucial. This should include a description of the sampling equipment and methods, locations of each sample (preferably latitude and longitude coordinates using a GIS tool), notes on appearance and odor of the sample, and the rationale behind the sampling (e.g. on a drainage line from a chlor alkali plant). If grid patterns for sampling are employed, the

Picture 1. Example of a contaminated site investigator using a portable mercury vapour analyser. *Source: www.mercury-instrumentsusa.com*

grid intervals should be determined using appropriate national or international standards and documented.

One technique to detect mercury contamination at a suspected contaminated site with minimal disturbance of potentially contaminated material (thereby minimising exposure) is the use of mercury "sniffers".

The "sniffers" are portable electronic devices that can detect elevated levels of mercury on-site in the field. Some are calibrated for mercury in soil or other solid objects and others for mercury vapour. Some devices can be adapted with additional kits to test soil, water and air for mercury.

Portable "sniffer" devices include but are not limited to:

- Metorex's X-MET 2000 Metal Master Analyser, X-Ray Fluorescence Analyser

Picture 2. The Olympus Delta portable X-Ray Fluorescence Analyser with screen shot example of digital screen readout for metals in polymer. *Source: www.innovx.com*

- Milestone Inc.'s Direct Mercury Analyser (DMA-80), Thermal Decomposition Instrument
- NITON's XL-700 Series Multi-Element Analyser, X-Ray Fluorescence Analyser (XRF device)
- Lumex's RA-915+ Portable Mercury Analyser, Atomic Absorption Spectrometer, Thermal Decomposition Attachment RP 91C
- MTI, Inc.'s PDV 5000 Hand Held Instrument, Anodic Stripping Voltammeter
- Olympus Delta portable X-Ray Fluorescence Analyser

These portable devices are particularly useful for taking rapid readings at multiple points on a given site, which can assist in the location of hot spots.

The X-Ray Fluorescence Analyser depicted above (see Picture 2) is an example of a solid sample analyser (soil, objects) that can be programmed with different software packages to analyse consumer goods and environmental media such as soil. The device is held close to the target and activated. The analysis in ppm then appears on the screen. This type of

Picture 3. Ohio Lumex RA915+ Portable Mercury Vapor Analyser, which can also be adapted to sample soil and water.
Source: ohiolumex.com

device specialises in heavy metals but can also detect other chemicals if calibrated correctly.

For detecting mercury vapour at a contaminated site a device such as the “Lumex” analyser (see Picture 3) can be effective. These devices can be expensive to purchase but in many countries can be hired for varying periods of time.

The role of NGOs in conducting initial screening-level site sampling has proven highly effective in many countries in raising awareness of contaminated sites and stimulating authorities to address pollution from these sites. Whether it is simple hair testing or more complex use of sniffer devices, there are many options that NGOs may consider for identifying contaminated sites impacted by mercury and other metals.

3.7 SOIL AND WATER SAMPLING FOR LABORATORY ANALYSIS

For those intending to take samples of soil or water from a suspected contaminated site to a laboratory for analysis, it is advisable to consult with an accredited laboratory using internationally recognised methods of analysis before taking the samples. They will advise you on the correct protocol for taking samples, including the correct type of sample storage container. These details are important as some sampling and storage materials (plastics and metals) can contaminate the samples, giving false readings. In some cases laboratories will provide sampling containers that have been pre-prepared to ensure there is no inadvertent cross-contamination of samples. They will also advise of sample holding times and any need for refrigeration or freezing (e.g. in the case of fish) of samples.

4. RISK ASSESSMENT

Risk assessment (RA) of contaminated sites is an important component in determining exposure of human and environmental receptors and for making the decision whether to manage or remediate a site. Risk assessment can also provide a useful tool for prioritising the remediation of numerous contaminated sites based on those that provide the greatest risk. This section provides a brief overview of the basic principles of risk assessment and directs the reader towards comprehensive guidance for those applying risk assessment to sites contaminated with mercury.

Risk assessment models can have significant limitations and many values assigned as inputs to the models involve a degree of value judgement on the part of the RA practitioner. Models may also be limited by toxicological data that traditionally has been based on the analysis of single chemical compounds and their dose-response characteristics[12]. A contaminated site may be impacted by a single chemical or metal, but more commonly they are impacted by a suite of metals and contaminants, especially if the site has been used for dumping of mixed wastes.

In some cases when chemicals are present on a site as a mixture they may develop synergistic toxicity effects whereby the total toxicity of the mixture is far greater than the toxicity sum of its parts. The potentiation of the toxicity of some chemicals by others is often poorly represented in traditional risk assessment models, though work is being conducted to address this issue. However, with over 100,000 chemicals currently in production (Winder et al 2004) comprehensive analysis of all potential interactions within a traditional RA framework will remain a challenging long-term project that may be superseded by other assessment techniques.

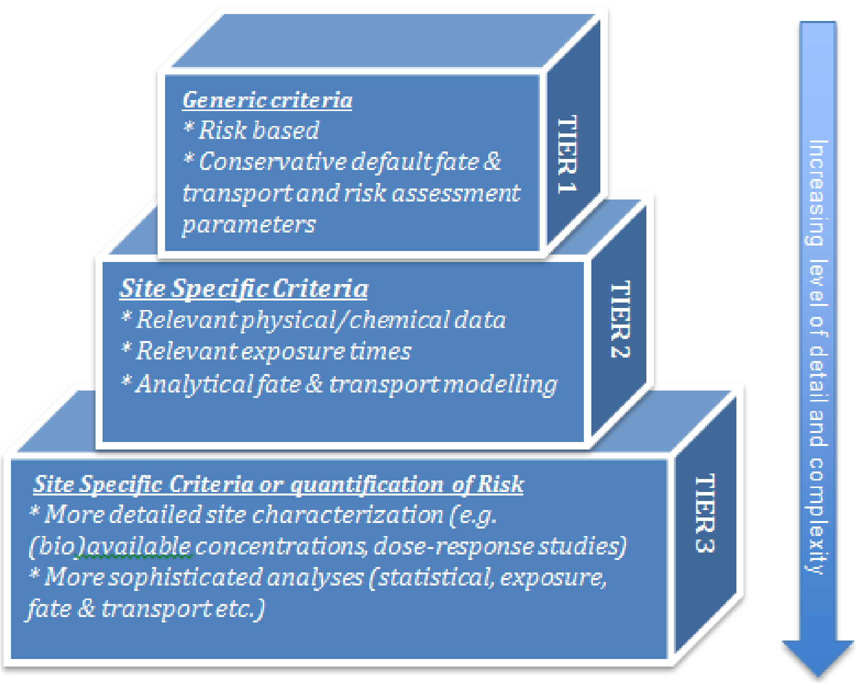
As an alternative to quantitative risk assessment of mixtures, *bioassays* are increasingly being investigated as a determinant of the toxicological impact of contamination sources. Bioassays are a test used to evaluate the relative toxic potency of a chemical by assessing its effect on a living organism. In terms of environmental testing, bioassays provide a comprehensive assessment of total toxicity of an effluent or a sample of water, sediment, or soil from a contaminated site. A range of guidance is available for those considering the use of bioassay procedures to compliment RA or improve assessment and characterisation of contaminated

12 A dose-response relationship describes how the likelihood and severity of adverse health effects (the responses) are related to the amount and condition of exposure to an agent (the dose provided).

water (enHealth 2012), soil (Hooper 2008), and sediment (Barcelo and Petrovic 2006).

Risk assessment of mercury-contaminated sites is possible using existing models, but they are subject to some important limitations that may significantly underestimate the potential exposure of receptors. The main issue is the lack of site-specific speciation and substance-specific bioavailability estimation in current models. Bioavailability can vary between different forms of mercury and related compounds and can be defined as "the fraction of a compound in a matrix that, when released from the matrix, can be absorbed by an organism. This absorbed compound is then available to cause a biological effect "(Stein et al 1996). A typical example is when high levels of mercury in fish are found while there are not high levels in sediments at the site where the fish was caught.

Traditional RA models have a less defined approach as they use total concentration input data and assume fixed coefficients for real impact on the receptor to develop a risk profile of a site at a specific point in time and assume a steady state situation (US EPA 1996).



Picture 4. The three Tiers in contaminated land risk assessment. The steps may be somewhat different in different countries and risk assessment frameworks. *Source: Ohlsson et al 2014*

5. CONTAMINATED SITES: MANAGEMENT AND REMEDIATION APPROACHES

This section addresses different approaches to the management and remediation of sites contaminated with mercury. There is a focus on industrial contaminated sites of the sort that would be expected from former and current industrial activity in Europe and the US, but this information is also applicable to other countries.

Production of chlorine at chlor-alkali plants using the mercury cathode process has been a significant source of mercury contamination due to the large quantities of mercury involved in the production process, loss of fugitive emissions in the vapour phase and spills, leaks and waste disposal.

While chlor-alkali plants are a notable source of industrial contamination, other activities, such as wood preservation (HgCl2), battery manufacturing and recycling, and other manufacturing activities (such as production of thermometers and electrical switches), have potential to cause mercury contamination. An example of point source mercury contamination from a thermometer factory is discussed further in section 7.2.

Industrial processes using mercury-based catalysts can cause on-site contamination and impact other sites through waste disposal. Oil and natural gas production is also a source of mercury, as elemental mercury is stripped from production and refinery plants to protect equipment from corrosion.

Waste disposal (solid wastes, sludges and effluent releases) from industrial operations are the cause of many mercury-contaminated sites. The River Nura and its floodplain in Central Kazakhstan were contaminated with mercury when contaminated effluent from an acetaldehyde plant was discharged into the river. This has led to downstream impacts, including methylmercury contamination of fish from the River Nura. This has in turn led to elevated mercury in residents of Temirtau, who catch and eat fish from the River Nura (Sir 2015a).

In addition to the acetaldehyde effluent, a synthetic rubber factory in Temirtau discharged 2000-3000 tonnes of mercury into the River Nura and surrounding areas, further contributing to the widespread mercury pollution in the Nura valley. This has the potential to affect the health of tens of thousands of people who utilise the river water, wells and other uses of the Nura for agricultural irrigation, watering livestock, swimming and fishing (Sir 2015a). A case study on this site is detailed in section 7.

In some cases a decision may be made following risk assessment and/or other deliberations that a contaminated site should be managed and not remediated. This may entail the containment on-site of the highest concentration contamination, fencing and signage to warn people of the hazard, and regular monitoring of the site using visual observation and technical instruments (such as mercury vapour "sniffers") to ensure exposure levels have not increased. In most cases where groundwater is threatened, monitoring bores (wells) should be established "upstream and downstream" in terms of hydrogeological flows, to sample and characterise the potential spread of contaminants. All of this data should be reviewed at least annually to ensure that the contamination is contained.

Whether the option chosen is to manage or remediate, additional contamination to a known contaminated site should be prevented. In addition, the management or remediation of a known contaminated site should not cause the creation or proliferation of additional contaminated sites (e.g. through waste dumping off-site, disposal of contaminated bore cuttings, wastewater, etc.).

Management of sites is usually chosen for economic reasons when insufficient resources are available for full-scale remediation. However, in some instances disturbing the contamination through a remediation process may cause more environmental damage than leaving it in situ. In some cases there have been reports that dredging of mercury-contaminated sediments has led to re-suspension of mercury-bearing sediments and pollution impacts in aquatic environments causing elevated levels of mercury in downstream biota (Anchor Environmental 2003). Management of contamination on residential sites should not be a preferred option if full remediation is possible.

5.1 MANAGEMENT

Contaminated site management strategies should reflect the need to protect all segments of the environment, both biological and physical. During both assessment and remediation of sites, action must be taken to control emissions to air, land and water.

Mercury can present particular difficulties due to its tendency to be released in vapour phase at ambient temperatures. This includes risk from vapour release during disturbance of mercury-laden sediments, demolition of mercury-contaminated buildings, and excavation of test pits.

Drilling of bore holes for groundwater monitoring can also create pathways for release of mercury vapour from sub-soil contamination. Careful monitoring with mercury vapour detectors at any disturbed sites should be conducted regularly to ensure the safety of workers and any adjacent residents or members of the public.

Clean-up should not proceed if the process is likely to create a greater adverse effect than leaving the site undisturbed. This decision would need to be revised in the light of new technologies or clean-up strategies becoming available over time or if the risk is noted to increase due to mobilisation of the contaminants beyond the site or confinement structures.

5.1.1 Monitoring

If it is determined that a site is contaminated but circumstances or risk-based assessment lead to a decision to manage a site rather than remediate it, a monitoring plan must be developed and implemented.

The detailed site investigation should have already characterised the geology, hydrogeology and hydrology of the site to contribute to risk assessment, management and/or remedial options.

For mercury-contaminated sites (and those impacted by Volatile Organic Compounds or VOCs), monitoring must include vapour monitoring targeted to relevant areas of the site identified by a soil gas survey that should have been conducted during the detailed site investigation. This applies to elemental mercury only as vapour monitoring does not detect mercuric or mercurous salts, which potentially represent a risk to groundwater due to their solubility.

Groundwater monitoring is also critical to monitor contaminant plume movement or growth, including that precipitated by “draw down effects” of off-site bores and wells used for water production that can influence movement of contaminated plumes outside of natural flow directions.

In general terms monitoring wells or bores should be constructed “upstream” (in groundwater terms) and “downstream” of the contamination during the DSI to assist with hydrogeological characterisation and delineation of groundwater contamination. Once the plume of contamination has been characterised by sampling and modelling, further monitoring bores should be placed “downstream” ahead of the advancing plume to detect its spread and calibrate its movement against earlier modelling. Assumptions about the further movement of the plume can then be adjusted and assessed for risk implications. International methods exist for mercury groundwater monitoring such as Water Quality ISO 17852 – 2006.

5.2 REMEDIATION: PRINCIPLES AND APPROACHES

The fundamental goal of remediation should be to render a site acceptable and safe for long-term continuation of its existing use, and maximise to the extent practicable its potential future uses.

A PREFERRED HIERARCHY OF OPTIONS FOR CONTAMINATED SITE REMEDIATION AND MANAGEMENT

- On-site treatment of the soil, so that the contaminant is either destroyed or the associated hazard is reduced to an acceptable level without adverse effects on the environment, workers, the community adjacent to the site or the broader public.
- Off-site treatment of excavated soil, so that the contaminant is either destroyed or the associated hazard is reduced to an acceptable level, after which it is returned to the site without adverse effects on the environment, workers, the community adjacent to the site or the broader public.

If it is not possible for either of the two above options to be implemented, then other options for consideration should include:

- Removal of contaminated soil to an approved site or facility, followed by replacement with clean fill.
- Isolation of the contamination on-site in an appropriately designed and managed containment facility with regular monitoring and review of remedial strategies over time.
- Leaving contaminated material in-situ providing there is no immediate danger to the environment or community and the site has appropriate management controls in place. This requires re-evaluation of remedial measures over time to take account of development of new technologies and remedial practices that could be implemented.

Complex remediation should be supported by the development and implementation of a Remediation Action Plan (RAP). The key components of a RAP are:

- Identification of the key stakeholders and responsibilities;
- Development of remediation goals and clean-up acceptance criteria;

- Assessment of the remediation options and determination of the preferred remediation option;
- Documentation of the remediation methodology, including any regulatory permit/licensing requirements;
- Development of an Environmental Management Plan; and
- Defining the validation program to demonstrate the successful completion of the remediation, including monitoring (EPA Tasmania 2005).

5.2.1 "Fit for Use" Approach

If site contamination is confirmed and represents an ongoing risk to human health and/or the environment, remediation should be conducted. The term "remediation" generally refers to removal and/or treatment of the contamination to reduce human exposure and risk to health or to the environment. In some countries a "fit for use" approach is taken whereby the site is cleaned up to a certain level depending on the proposed future use of the site. Regulatory systems for contaminated sites often categorise site uses in the following categories:

- Residential;
- Parks and recreation;
- Commercial; and
- Industrial.

This system is based on potential for exposure to human receptors – particularly duration of exposure. The exposure scenarios then determine the allowable levels of contamination for a given site use category. In general terms, "residential" land use has the lowest permissible levels of soil contamination of all categories due to the potential for long exposure times of residents (up to 24 hours a day) and the potential for young children to occupy the site and engage in "pica" behaviour (Edward et al 1997). "Pica" literally means eating small quantities of dirt through hand-to-mouth activity.

Exposure calculations sometimes include a scenario for eating home-grown produce, which is particularly important in terms of mercury for people consuming domestically produced fish and vegetables. This becomes imperative when considering ASGM sites, which often cross "site" boundaries from the mining location, combining ore concentration and mercury amalgamation activities in villages close to fish ponds and rice paddies (which often double as fish ponds). While the accumulation of methylmercury in fish has been known for some time, there is now increasing evidence of mercury accumulation in rice (Li et al 2015). This raises complex issues as to how to address mercury contamination in the context of ASGM activities, particularly in southeast Asia where food production of rice and fish takes place alongside mercury amalgamation of gold in residential settings.

The permissible levels of contaminants then rise to higher levels for “Parks and Recreation”, more so for “Commercial”, and then to the highest permissible levels, which are generally for sites that are currently “Industrial” or planned to be used for industrial activity in the future. Commercial and industrial sites are permitted higher soil contamination on the assumption that workers will only be exposed for a limited number of hours per day, may incidentally wear Personal Protective Equipment (PPE) for occupational reasons, and because the site surfaces may be sealed with bitumen or concrete, further limiting exposures.

This approach is not solely determined by a risk assessment, but also by a cost/benefit approach whereby industrial sites may not receive the same standard of remediation (which is a significant cost saving to the site owners or other responsible parties) that a residential site requires. The problem with this approach is that it leaves contamination behind to be dealt with at a later date, even by future generations. It is neither precautionary nor sustainable or best practice, but it is economically beneficial to those responsible for remediating the site.

This approach can also lead to further environmental problems. For example, regulators may decide a residential site must be remediated to the point where there is 2 ppm or less of elemental mercury present in the soil, whereas they may decide that remediation of a badly contaminated industrial site may leave up to 200 ppm of elemental mercury in the soil. The residential site is unlikely to contribute significant mercury vapour or runoff to the ambient air or local environment, whereas the industrial site will continue to contribute fugitive emissions for many years and potentially cause migration of mercury to groundwater. In a worst-case scenario, many decades will pass, records of the contamination on the site are lost or forgotten, and the site is redeveloped into residential housing, repeating the contamination exposure cycle.

There is also the additional issue of future costs to fully clean sites that have only been partially remediated. It is likely that future costs will be higher and that contamination may spread over time, increasing the scope, expense and extent of future site remediation, especially if the land use is changed to a more sensitive scenario such as residential use.

The alternative approach is to fully remediate a site when the opportunity first arises so as to avoid the cost, inconvenience and risk implications of repeated remediation at a site in future years. In terms of ecological sustainability (intergenerational equity, polluter pays and the precautionary principle), this approach is closer to best practice.

Once remediation of a contaminated site has been deemed complete, further steps are required to ensure the efficacy of the operation.

5.3 VALIDATION

Following the remediation, it must be demonstrated that the remediation goals have been met in terms of soil, water and air contaminant concentrations and containment integrity. The site must no longer represent a risk to human health or the environment. Validation sampling of soil, groundwater, sediment, biota and vapour should be conducted to ensure the goals have been met. Groundwater sampling will need to be continued over a period of time to take into account seasonal variations and other influences.

Ongoing monitoring plans should also include a contingency plan to address any shortcomings in the remediation and unexpected reports of contamination in monitoring data that may have arisen from poorly characterised or unknown hotspots or off-site influences.

6. REMEDIATION TECHNOLOGY AND TECHNIQUES

Remediation technology for sites contaminated with mercury are required to deal with some unique challenges associated with the complex behaviour and characteristics of elemental mercury and mercury compounds. In particular, mercury's ability to enter vapour phase at ambient temperatures, as well as the ability of some species to move downward through the soil profile, present particular challenges.

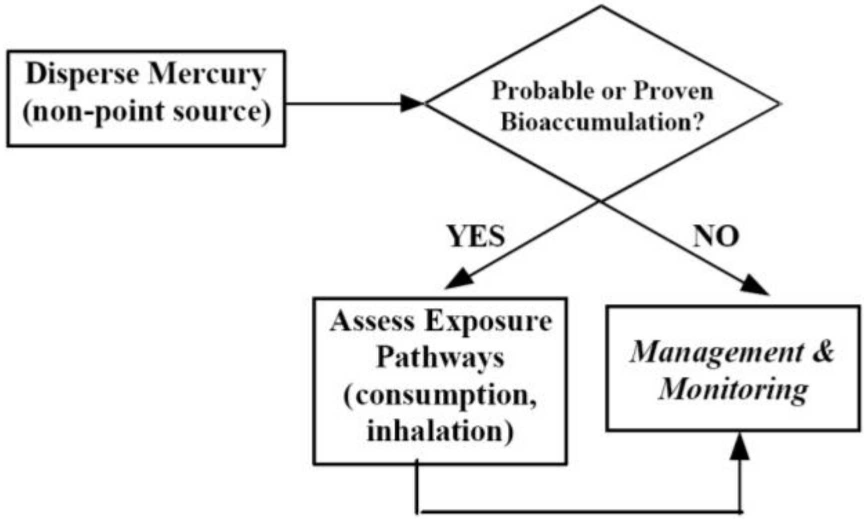
When implementing mercury-contaminated site remediation, it is critical to assess and manage sub-surface mobilisation of mercury and prevent emissions and releases to air, water and soil.

When considering technology selection and the development of a remediation strategy for a site, three key issues must be addressed:

1. The development of a comprehensive conceptual site model (CSM) that includes a detailed site investigation that describes potential releases of mercury from the site as a result of using remediation technology as well as any transformations (such as solid-to-vapour phase) that technology may produce. This relies on accurate identification of the **mercury species** potentially involved in air, soil and water, and their potential risk to human health and the environment.
2. Elemental mercury cannot be destroyed, so any remediation strategy must take into account management of residual mercury waste, including its stabilisation, transport and final disposal.
3. Remediation technologies carry the risk of remobilising mercury during remedial works. Remediation Health and Safety plans for workers and the public must take this into account. For more information see section 8.

As noted previously in this document, risk-based approaches to remediation may produce outcomes that are quite different to sustainable remediation objectives, which infer the integration of sustainability principles in the proposed remediation goals.

A sustainable remediation approach incorporates social, environmental and economic consideration in the clean-up of the site, including the polluter pays principle and intergenerational equity. A strictly risk-based approach such as that proposed by Eurochlor (2009) is determined with



Picture 5. Response to diffuse source mercury contamination proposed by Hinton et al (2001)

a focus on economic considerations. As such there is a necessity for the development of a sustainable remediation approach that promotes social goals. These may be related to and integrated with social goals for health improvement, education outcomes, alternative livelihoods (especially with ASGM sites), and agricultural and fisheries sector development that feed into broader social goals of poverty reduction.

6.1 POINT SOURCE AND DIFFUSE CONTAMINATION

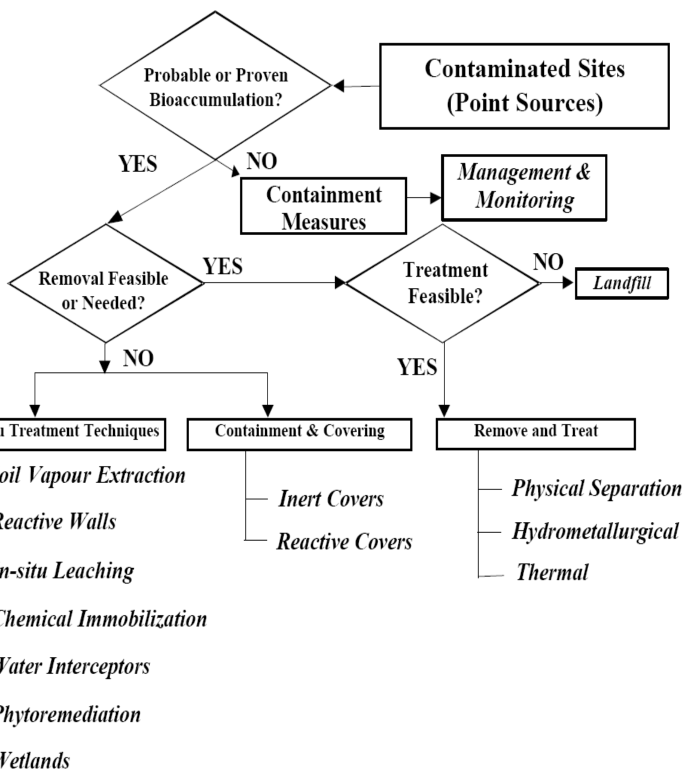
In terms of the mercury contamination, the application of mercury remediation strategies and technology should also be guided by the distributive form of contamination. Contamination may be in the form of a *point source* (such as a former chlor-alkali plant) or take the characteristics of *diffuse* contamination where the mercury has spread far beyond its source due to discharges into aquatic environments such as rivers or streams, and subsequent deposition to riverbanks, reservoirs or estuaries.

Hinton et al (2001) suggested two responses dependent on whether mercury contamination was of a point source or diffuse nature. For diffuse contamination Hinton was of the view that remedial measures were typically not feasible.

For point sources, the response by Hinton was consideration of the possibility of "dig and dump/treat", and, where not possible, assessment of in-situ containment and cover techniques. In both cases Hinton views mercury bioavailability as the driver of remedial strategies. In the absence of a remedial approach to diffuse mercury contamination, risk-based behaviour modification may be implemented. This can involve providing public information to reduce exposure to mercury-bearing soil and sediments, reduction or avoidance of consumption of contaminated biota (especially fish), and changing land use (e.g. agriculture) to avoid areas of elevated contamination. Responses may also involve monitoring of population health, with health intervention for compromised individuals.

More recently, emerging technologies are being developed that may have potential to address diffuse contamination such as phytoremediation. This is a process by which plants are applied to contaminated areas to accumulate mercury in the roots or on the shoots and leaves and then harvested.

Phytoremediation is sometimes referred to as phytostabilisation, phytoextraction or phyto-volatilisation, as plants may also volatilise mercury into the environment (Wang et al 2012). A key issue with this technology is how to address the residual material (harvested plant material contaminated with mercury) to ensure the mercury is not remobilised (e.g. via burning) or consumed as a food product.



Picture 6. Response to point source mercury contamination proposed by Hinton et al (2001)

There are numerous technologies that are applied for point source contamination by mercury. These may be used individually or in treatment trains. A number of technologies are proven and are regularly implemented for soil and water contamination, while others are considered to be emerging technologies with varying degrees of potential for both environmental media.

6.2 PROVEN MERCURY-CONTAMINATED SOIL REMEDIAL TECHNOLOGIES

6.2.1 Excavation and On-site Treatment (Recovery)

This approach removes the highest concentrations of soil contamination by excavation and treatment, followed by isolation procedures such as on-site containment and capping (to prevent vapour release) for the high concentration mass. The high concentration material may also be disposed off-site at an engineered hazardous waste landfill.

This approach is preferred for hot spots on a contaminated site, as widespread excavation raises significant safety, cost and geotechnical issues. The most considerable problem associated with this approach is the remobilisation of mercury-contaminated dust and mercury vapour (rainfall can also wash mercury-contaminated soils from the site during excavation or cause soil infiltration of soluble mercuric wastes). The hazards of this approach need to be considered for workers and the public near the site.

It should not be assumed that contaminated sites are vacant spaces, as structures from industrial and other uses may still be present. The demolition of these buildings can cause large releases of mercury vapour in the same manner as excavation. Building structures and materials may also contain substantial concentrations of mercury, hence the need for accurate, detailed site investigations and conceptual site models before major works begin.

One method to reduce the risk of mercury releases and emissions during excavation is to conduct the activity within a temporary sealed structure under negative air pressure and create a barrier to external receptors. The image below (Picture 7) depicts a negative air pressure enclosure (circled in black) in use in New South Wales, Australia during the remediation of a former gasworks site with volatile contaminants (Australian Federal Government 2013). The 3,800 square metre steel and fabric, odor control enclosure (OCE) has been erected at the northern end of the Platypus Site.

The contaminated material treatment works are taking place within the OCE. All air from within the OCE is being filtered through the emission control system before being released to the environment through a stack (vapour treatment train and stack is circled in yellow).

Picture 7. Remediation with odor control enclosure and treatment train.
Source: Australian Federal Government (2013)

Picture 8. Interior of odor control enclosure during excavation.
Source: Australian Federal Government (2013)

6.2.2 Treatment Following Excavation (Soil Washing and Separation)

Most forms of mercury have a high affinity for fine soils and sediment, with higher adsorption rates for clay and humic (organic) material. Physical separation of fine-grained soils contaminated with mercury from coarse sands and gravels minimises the final amount of material for containment. Physical separation is a 3-to-5 stage process involving physical (including mechanical) separation through sieving and screening and soil washing using either water or washing solutions such as acids, polymers and surfactants (Merly and Hube 2014).

Once soil washing or separation has been completed, a third treatment step can be undertaken using thermal processes.

6.2.3 Thermal Treatment Processes

Thermal treatment processes to remove mercury from soil rely on the application of heat and reduced pressure to liberate the mercury through volatilisation due to its low vapour pressure of 0.002 mm Hg at 25 °C (ATSDR 1999). Incineration of mercury waste is not considered applicable for contaminated site remediation due to the high risk of mercury vapour release.

Most thermal treatment methods require careful consideration before implementation due to their conversion of mercury to the vapour form. Emissions from these technologies can be a significant hazard and costly air pollution controls (APC) are required. Even with comprehensive APC application, mercury emissions can be difficult to control.

Once the contamination is removed from its original position (ex situ) it can be treated on-site or off-site by thermal means. The most commonly used technologies are:

- Ex situ thermal desorption or ESTD (an in-situ method is described later under emerging technologies);
- Incineration; and
- Batch retorting.

Thermal desorption can be conducted in two ways: a) indirect thermal desorption, and b) direct thermal desorption.

Indirect thermal desorption – Indirect thermal desorption should be considered a preferred treatment option for mercury-contaminated sites. Typically, heat is applied to the exterior of the heating chamber and is transferred through the wall of the chamber to the waste material. Neither the burner flame nor the combustion gases come into contact with the waste material or the off-gases (Environment Agency UK 2012), thereby preventing contamination of the heating off-gases.

This is important for treating mercury-contaminated matrices as the burner combustion products can be directly discharged to the atmosphere, as long as a "clean" fuel is used such as natural gas or propane. The objective of thermal desorption should be the maximisation of the recovery of the volatilised contaminants from the off-gases through condensation processes. A key operating principle that sets thermal desorption apart from waste incineration is based upon the optimised recovery of the desorbed contaminants from the gas rather than through their destruction through combustion (Environment Agency UK 2012).

Direct thermal desorption – This process is not recommended for remediation of mercury contamination due to the high risk of fugitive mercury emissions during the process. However, it has been applied in the past at some sites. Heat is applied directly by radiation from a combustion flame and/or by convection from direct contact with the combustion gases. Systems employing this type of heat transfer are referred to as *direct-contact* or *direct-fired* thermal desorption systems (US Government 1998).

The object of the operation is also maximisation of the recovery of the volatilised contaminants from the off-gases through condensation processes. However, additional complexity arises due to the direct contact of the combustion gases with the waste vapour, adding cost to the treatment of the system off-gases. Emissions of mercury vapour can be unacceptably high in systems that do not have very high levels of air pollution control (APC). Even when state of the art APC is incorporated following rigorous environmental impact assessment (EIA) and licensing procedures, mercury emissions can be difficult to control.

A recent example is the emissions failure of a Directly-heated Thermal Desorption (DTD) unit purposely built to destroy mercury waste from a contaminated site of the Orica chemical company in Sydney, Australia. Despite assurances that the operation was safe, the plant breached mercury air emissions limits and was subject to enforcement measures. In a series of samples of environmental air, the New South Wales EPA recorded a mercury level of 0.0049 grams per cubic metre - more than double the Australian regulatory limit of 0.002 grams per cubic metre. The mercury emissions breach may have been ongoing for up to a month before being discovered. The direct thermal desorption plant was shut down after the emissions breach and Orica was later fined $750,000 for this and other pollution breaches.[13]

13 See: http://www.epa.nsw.gov.au/epamedia/EPAMedia14072901.htm

Batch retort – Retort ovens typically operate at temperatures of 425 to 540°C and under vacuum to increase mercury volatilization and reduce off-gases volumes (US EPA 2007). They are typically used for smaller amounts of high concentration mercury-contaminated soils (>260 ppm) and are limited to processing 1-2 tonnes per day (Merly and Hube 2014).

Incineration – Incineration is a destruction process using thermal combustion at elevated temperatures to destroy contaminants, especially organic compounds. As an element, mercury cannot be destroyed, but, when exposed to a combustion environment, will mostly transfer to vapour phase or adhere to particulate emissions. Incineration is not a suitable technology for the treatment of mercury wastes due to its high potential for the release of mercury vapour. The risk of mercury vapour releases, especially when treating contaminated soils and sediments near communities, is unacceptably high. A range of other less expensive and less complex technologies can be utilised which have a much lower risk profile. Therefore, incineration *is not* considered applicable to large volumes of contaminated material due to the potential for mercury emissions and releases (Merly and Hube 2014).

6.2.4 Excavation and Immobilisation Technologies (Excavation and Disposal)

This method has been described in other literature as a "dig and dump" process, with the addition of immobilisation treatment. The waste removed can be contained on-site with capping or disposed off-site at an engineered hazardous waste landfill. Immobilisation of the mercury content refers to treatment that significantly reduces its ability to leach in soluble form or produce vapours. Immobilisation techniques include:

- Amalgamation (with other metallic compounds);
- Stabilisation (usually through chemical reactions with sulphur compounds and polymers); and
- Solidification (physical stabilisation through mixing with solid non-hazardous material.

6.2.5 Amalgamation

The US EPA (2007) defines amalgamation as *"the dissolution and solidification of mercury in other metals such as copper, nickel, zinc and tin, resulting in a solid, non-volatile product. It is a subset of solidification technologies, and it does not involve a chemical reaction. Two generic processes are used for amalgamating mercury in wastes: aqueous and non-aqueous replacement. The aqueous process involves mixing a finely divided base metal such as zinc or copper into a wastewater that contains* *dissolved mercury salts; the base metal reduces mercuric and mercurous salts to elemental mercury, which dissolves in the metal to form a solid mercury-based metal alloy called amalgam. The non-aqueous process involves mixing finely divided metal powders into waste liquid mercury, forming a solidified amalgam."*

The US EPA (2007) has identified amalgamation as the best demonstrated available technology (BDAT) for treatment of liquid elemental mercury-contaminated with radioactive materials. This is an important consideration when developing remediation plans for sites with mixed contaminants that include mercury and radionuclides.

6.2.6 Stabilisation and Solidification (S/S) without Mercury Recovery

The processes of stabilisation involve chemical reactions that can reduce the mobility of waste and, in some cases, its toxicity. Solidification can change the physical properties from a liquid or sludge to a solid, but does not change the chemical form of the waste. In combination these techniques can reduce the toxicity and mobility of the waste. S/S is commonly applied to contaminated soil, sludge, ash, and liquid (Basel Convention 2012). S/S involves physically binding or enclosing contaminants within a stabilised mass (solidification) or inducing chemical reactions between the stabilising agent and the contaminants to reduce their mobility (stabilisation).

The solidification process involves mixing contaminated soil or waste with binders such as Portland cement, sulphur polymer cement (SPC), sulphide and phosphate binders, cement kiln dust, polyester resins, or polysiloxane compounds to create a slurry, paste, or other semi-liquid state, which is allowed time to cure into a solid form (US EPA 2007).

Waste can be encapsulated in two ways: microencapsulation and macroencapsulation. Microencapsulation is the process of mixing the waste with the encasing material before solidification occurs. Macroencapsulation refers to the process of pouring the encasing material over and around the waste mass, thus enclosing it in a solid block (US EPA 2007).

The most common chemical conversion is dosing the waste with sulphur to create mercury sulphide. Conversion of all mercury to mercury sulphide (HgS) should be achieved to reduce leachability and volatility to acceptable levels. In general, HgS is produced by blending mercury and sulphur under ambient conditions for a certain time, until mercury (II) sulphide is produced. Isolation from the environment by encapsulation and disposal in a specially engineered landfill, or permanent underground storage, may be necessary as elevated chloride levels in leachate can increase mercury release (Basel Convention 2012). Elevated chloride conditions are typically encountered in municipal landfills, which are unsuitable for disposal of this form of waste.

Under certain circumstances HgS can be reconverted back to elemental mercury. If elemental mercury waste is intended to be converted to HgS for permanent disposal, it should be recognised that at some future time this process could be reversed.

6.2.7 Sulphur Polymer Stabilization/Solidification (SPSS)

The polymer stabilization process offers the additional advantage that it is difficult to reverse, preventing the recovery of elemental mercury from the matrix. The SPSS process[14] consists of two steps: mercury is stabilised with sulphur as the first step to form beta-mercury sulfide (meta-cinnabar dust: López et al, 2010, López-Delgado et al, 2012) and, in a second step, this mercury sulfide is incorporated and microencapsulated in a polymeric sulphur matrix at 135°C, obtaining a fluid that is cooled to room temperature in moulds, to obtain solid blocks (monoliths).

The second step of the process provides an additional barrier to prevent and avoid mercury releases to the environment, minimising with it the possibility of its conversion to other forms of mercury. Mercury is transformed in the process, which has low energy consumption, low mercury emissions, no water consumption and no effluents, and generates no other wastes (Basel Convention 2012).

6.2.8 S/S with Sulphur Microcements

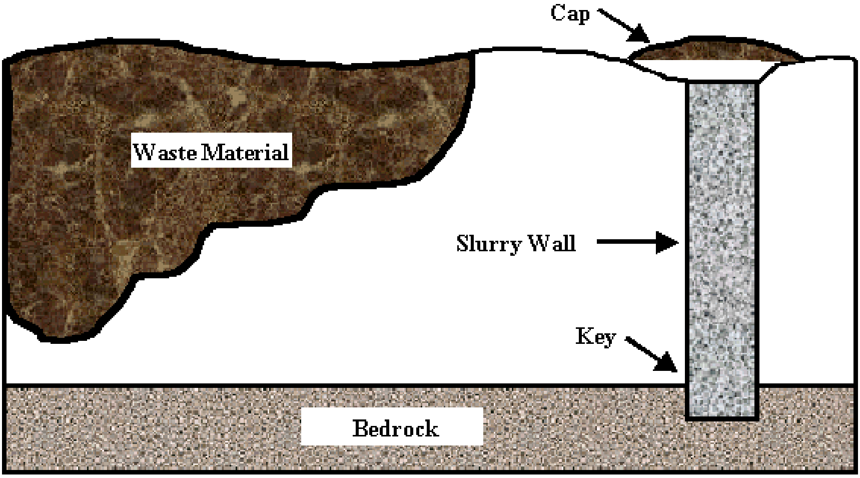
The treatment of mercury wastes with sulphur microcements is another stabilization and solidification technology, which results in a solid matrix that ensures the confinement of mercury because of its precipitation in the form of very insoluble compounds, as oxides, hydroxides and sulfides.[15]

6.2.9 In-situ Containment

This is a process of creating engineered isolation of the mercury-contaminated area from non-contaminated surrounding areas that includes capping to prevent vapour release. Physical barriers are engineered that can prevent re-mobilisation of mercury laterally and vertically (either through the soil profile or to air). There are many different varieties of containment, with differing techniques including the installation of vertical slurry walls or grout curtains (also called cut-off walls), which are made by cut-

14 For further information: www.ctndm.es

15 For further information: info@cementinternationaltechnologies.com; www.cemintech.com.



Picture 9. Section showing capped slurry wall isolation

ting deep trenches into the soil around the contamination and filling with slurries such as bentonite/cement and soil mixtures.

The benefits of this approach include relative simplicity and rapid implementation, with cost reductions compared to excavation (and the hazards associated with excavation). Isolation through capping, vapour barriers

Picture 10. Combined trenching and slurry insertion.
Source: www.dewindonepasstrenching.com

and cut-off walls also permits control and management of mercury migration. There are limitations to this approach in that mercury toxicity and mass are not reduced, groundwater flow may be disturbed, and potentially contaminated wastes may be generated during trench excavation (Merly and Hube 2014). The long-term effectiveness of such containment may also need to monitored, and such mechanisms may be unsuitable for areas with elevated seismic activity.

6.2.10 Off-site Disposal

Mercury wastes and residues from remediation of contaminated sites that are to be disposed off-site must meet licence, regional and/or national acceptance criteria for the waste facility that receives them. In general terms, this does not apply to elemental mercury recovered from processes such as indirect thermal desorption or retorting. Elemental mercury is a commodity that may be traded for an allowed use under the Minamata Convention of Mercury (with the exception of mercury recovered from former chlor-alkali facilities and produced from primary mining for certain uses). However, restrictions may apply in some jurisdictions to the export of elemental mercury such as in the US and EU.

For mercury wastes Europe has relatively strict acceptance criteria for waste facilities under regulatory frameworks - The European Directive 1999/31/EC and Decision 2003/33/E; Decision of 14/11/2008 1102/2008 and The EC Directive 2011/97/CE.

Off site disposal of mercury waste does have disadvantages, such as the high cost for excavation and transport to disposal sites (and potential pre-treatment to meet acceptability criteria at the waste disposal site). In terms of sustainability, this can also create a high carbon footprint for the project, especially when large volumes are transported.

The following table provides regulatory mercury leaching limits from waste for various types of waste disposal facilities (landfills) ranging from inert landfills through to hazardous waste landfills.

6.2.11 On-site Disposal

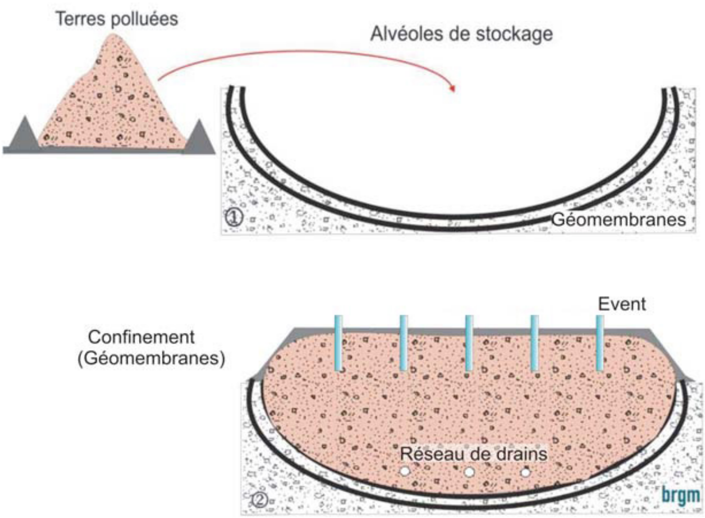
Contaminated residues and soil remaining after mercury site remedial treatment are typical disposed of on-site via entombment. This is an engineered cell designed specifically to isolate the mercury-contaminated waste from the environment. It has the advantage of saving transport costs to an off-site facility.

MERCURY LEACHING LIMIT VALUES FOR DIFFERENT LANDFILL TYPES ACCORDING TO DECISION 2003/33/EC, ANNEX

Landfill Type	L/S =2 l/kg mg/kg dry substance	L/S =10 l/kg mg/kg dry substance	CO (percolating test) mg/l
Criteria for landfills for inert waste	0.003	0.01	0.002
Criteria for granular non-hazardous waste accepted in the same cell as stable non-reactive hazardous waste	0.05	0.2	0.03
Criteria for hazardous waste acceptable at landfills for non-hazardous waste	0.05	0.2	0.03
Criteria for waste acceptable for landfills for hazardous waste	0.5	2	0.3

***Source:** BiPro (2010) Requirements for facilities and acceptance criteria for the disposal of metallic mercury.*

The key features of the "tomb" include compacted, low permeability clay base or cement base incorporating synthetic liners such as HPDE, capping, gas extraction and capture. This is designed to prevent gas escape, rainwater infiltration, groundwater infiltration and mobilisation of contaminants. There are significant costs associated with long-term monitor-



Picture 11. Schematic of on-site waste entombment. *Source: Colombano et al (2010)*

ing of the structure to ensure its integrity and containment of contamination. This structure also relies on seismic stability.

6.3. EMERGING MERCURY-CONTAMINATED SOIL REMEDIAL TECHNOLOGIES

6.3.1 Electrokinetic Techniques

In the literature several different terms are used to describe techniques based on the same principle: electrokinetic remediation (EKR), electrokinetic extraction, electroreclamation, electrorestoration or electrodialysis. Three transportation phenomena are responsible for electrokinetic mercury movement in soils. The transport mechanism for any particulate mercury with charged surfaces, Hg° or colloidal precipitates, for example, is called electrophoresis. By electromigration, all ionic species can be transported to the cathode or the anode. Charged as well as uncharged species present in the pore liquid of soil can be transported towards the cathode by electro-osmosis (Merly and Hube 2014).

Electroremediation of mercury-contaminated soils, facilitated by the use of complexing agents (EDTA), proved to be an attractive alternative treatment for the removal of mercury from mercury-contaminated mining soils (Robles et al 2012) (Garcia-Rubio et al 2011). The addition of complexing agents enabled the formation of coordination complexes that strengthen electromigration. Garci-Rubio et al 2011 demonstrated that for relatively low hydraulic permeability soil, iodide - enhanced EKR allows the same recovery efficiency as an in-situ flushing with the optimum chelating concentration, but the full-scale remediation could be accomplished in time periods several orders of magnitude shorter.

6.3.2 Phytoremediation

Phytoremediation uses plants to remove, transfer, stabilise, or destroy contaminants in soil, sediment, and groundwater. Phytoremediation applies to all biological, chemical, and physical processes that are influenced by plants (including the rhizosphere) and that aid in cleanup of the contaminated substances. Plants can be used in site remediation, both through mineralisation of toxic organic compounds and through accumulation and concentration of heavy metals and other inorganic compounds from soil into aboveground shoots.

Phytoremediation may be applied *in situ* or *ex situ* to soils, sludges, sediments, other solids, or groundwater (US EPA 2012). There are ongoing studies into the effectiveness of phytoremediation techniques using plants to strip mercury from soil and mixed environmental media such as rice paddies. This could have a direct application in ASGM areas where rice and fish (which are often grown in the same rice paddy) are the staple food source and subject to mercury contamination from ASGM activity. It may also prove useful in agriculture areas subject to periodic flushing where contaminated sediments are deposited in low-lying areas.

Bench scale studies have shown that both genetically modified and wild rice were able to remove Hg^{+2} ions when grown in a mercury-spiked hydroponics medium (Meagher and Heaton 2005). Further investigation would be required to assess the impact of fugitive emissions from transpiration of the plants and to ensure that the contaminated rice was not permitted for human consumption. Careful attention to the full lifecycle and fate of mercury hyperaccumulators (plants that can take up and concentrate a particular contaminant up to 100 or 1,000 times greater than the concentration in soil) must be taken in cases where the plants may be harvested unintentionally as a food crop or for fuel to avoid ingestion or releases from combustion.

In addition to rice plants, cottonwood trees have been evaluated for their ability to remediate mercury. Eastern cottonwood trees (*Populus deltoides*) grow rapidly in a variety of conditions, including riverbanks and floodplains (APGEN 2003).

Phytoremediation may have applications in diffuse mercury-contaminated sites such as the River Nura and surrounding agricultural land in the Nura valley where flooding has caused widespread contamination that is difficult to manage by conventional means. Planting crops that are mercury hyperaccumulators can have significant remedial benefits over time at a relatively low cost. Management of the arising biomass containing mercury should be carefully considered.

6.3.3 In Situ Thermal Desorption (ISTD)

In Situ Thermal Desorption (ISTD) is a technology that is applied in the cases of severe contamination of the soil with mixture of organic hazardous materials (dioxins, PAHs, PCBs), geotechnical constraint for large excavation, and the need for a very short operation time (Merly and Hube 2014). It involves heat injection and vapour extraction from the soil and could be utilised for mercury-contaminated sites or sites with a mercury/dioxin combination. Experiments have shown up to 99.8% removal of the mercury from soil matrices using ISTD (Merly and Hube 2014), but the technology is still in the development stage.

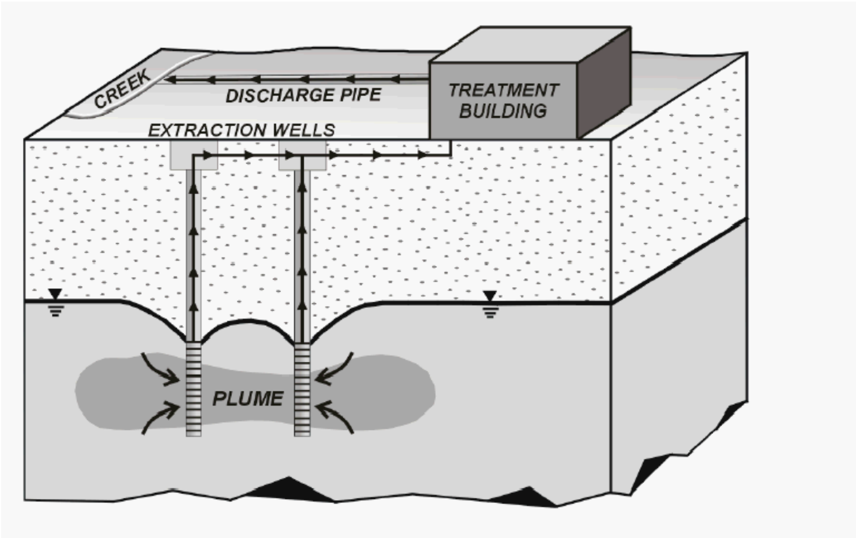
This process has very high energy consumption and requires a dense network of bore holes to be drilled for heating and vapour extraction. Fugitive mercury emissions may also be difficult to control. In addition, the large number of bore holes raises the risk of contaminant leakage to any underlying freshwater aquifer systems and must be closely monitored to ensure the integrity of bore case sealing.

Picture 12. Full-scale ISTD operation on organic compounds contamination in the USA. *Source: Merly and Hube (2014)*

6.4 PROVEN TREATMENT TECHNOLOGIES FOR WATER CONTAMINATED WITH MERCURY

6.4.1 Pump and Treat

This is the most commonly applied treatment for mercury-contaminated groundwater. It has applications for the treatment of mercuric brine, which is common at sites of mercury cell chlor-alkali plants. The method involves drilling bores into the contaminated groundwater zone, pumping contaminated water to the surface, and treating the water with a range of filtration media. The design objective is to capture the whole contaminated plume (or at least the majority of it) over a given period of time (as ongoing maintenance costs are high) and to treat the water to a low level of mercury contamination.



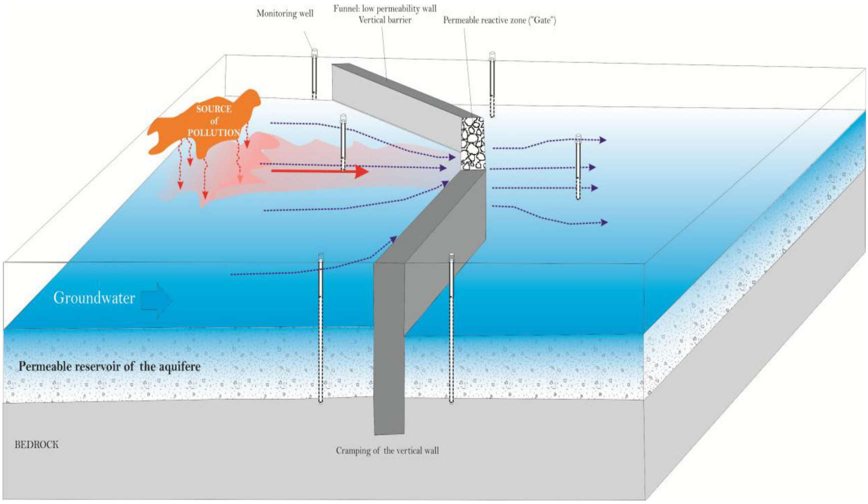
Picture 13. Pump and treat principles.
Dept. of Geosciences Texas A&M University

The effectiveness of the pump and treat system depends on the hydrogeology and the type of contaminants, and the process is very slow.

6.4.2 Permeable Reactive Barriers

The other main technology used for the treatment of mercury-contaminated water is permeable reactive barriers (PRB). PRB technologies consist of passive in-situ groundwater treatment based on the removal of mercury from groundwater flowing through an in-situ permeable reactive media involving sorption and or chemical reduction of mercury. The mercury plume is intercepted by an impermeable wall perpendicular to the groundwater flow and designed to create a funnel, in the direction of the reactive permeable zone ("gate") where mercury removal occurs. These lateral barriers are generally cut-off slurry walls (Merly and Hube 2014).

This technology has been used in Europe, Australia and the US at many sites to treat a range of contaminants including chlorinated solvents, hydrocarbons and inorganic compounds. Reactive materials including copper, pyrite and granular activated carbon (GAC) have been incorporated as filtration and conversion agents in the reactive "gate" section of the barrier.



Picture 14. "Funnel and gate" principle of PRB.
Adapted from Colombano et al, 2010.

The main advantage of this system is the lower cost compared to pump and treat systems. However, the use of GAC to adsorb mercuric compounds requires regular monitoring and replacement upon saturation and must then be treated as a mercury waste with attendant costs.

6.5 EMERGING WATER TREATMENT TECHNOLOGIES

A number of water treatment technologies for mercury technology are being developed but are mostly in the experimental development phase. These include:

- Bioremediation;
- Nanotechnologies;
- Alternative sorption materials; and
- Alternative coagulation & flocculation.

These are in the early development stage and are not detailed in this document; however, a discussion of their relative merits can be found in Dash and Das (2012) and Merly and Hube (2014).

7. CASE STUDIES IN MERCURY-CONTAMINATED SITES: DIFFUSE AND POINT SOURCE

The following case studies document two distinct forms of mercury-contaminated sites discussed in section 6.1 of this guidance – diffuse and point source contamination. The first site is located in the Republic of Kazakhstan, a historically Soviet-controlled country that suffered pollution impacts of industrialisation under the former regime. The second site is located in the Tamil Nadu region of India. The first case study examines the widespread and diffuse mercury contamination along the River Nura and adjacent areas. The second case study relates to a more specific point source of mercury contamination from a former thermometer factory in Kodaikanal. The approaches to characterisation and remediation of each site are different and illustrate the complexities and challenges of mercury-contaminated site management.

7.1 CASE STUDY 1: MERCURY POLLUTION IN THE RIVER NURA AND SURROUNDING AREA

The River Nura flows from the mountainous region in the east of Kazakhstan through the heavily industrialised Karganda region and nearly one thousand kilometres into the terminal lakes of the internationally important Kurgaldzhino wetlands. These wetlands became Kazakhstan's first designated Ramsar site and Lake Tengiz has recorded over 300 species of migratory waterfowl, many of which are endangered. For decades an acetaldehyde plant (known as "Karbid") in Temirtau, a city on the Nura river, discharged large volumes of mercury waste and other pollutants into the river before being closed down in 1997 (Ullrich et al 2007, Sír 2015a).

In the river the mercury became associated with millions of tonnes of power station fly ash, forming a highly contaminated "technogenic silt" which disperses over the floodplain during spring floods (Heaven et al 2000). In 2003 the World Bank loaned the Kazakhstani government $40 million to undertake a long-term remediation of the mercury impacts. Work began in 2007 and was completed in 2013 (Sir 2015a). Prior to the remediation program the topsoils of the floodplain contained an estimated 53 tonnes of mercury, and silt deposits along the banks of the river contained about 65 tonnes, with an additional 62 tonnes in Zhaur Swamp (approximately 1.5 km from Temirtau city).

Seasonal hydrological conditions in the River Nura control mercury concentrations in surface waters, with the majority of mercury mass flow during the annual spring flood when contaminated bed sediments are remobilised (Ullrich et al 2007). The sediments within a 20 km section of the river downstream from the effluent outfall were highly polluted. Concentrations exceeding the legally allowable Kazakhstani limit value of 2.1 mg/kg were found 75 km downstream of Temirtau in Intumak Reservoir, and concentrations above 10 mg/kg total mercury (Dutch intervention value) were found 60 km downstream (Heaven et al 2000).

Zhaur Swamp, just outside the city of Temirtau and less than 1 km from the nearest villages, was found to have extremely high concentrations of mercury and concerns have been raised regarding the long-term viability of the village's drinking water supply. Concentrations of mercury in fish were shown to still be elevated more than 100km downstream from the source and for most species there was no significant decrease in mercury levels over this distance. It has been suggested that this could reflect fluvial transport of methylmercury from upstream sites or increased in-situ production of methylmercury downstream (Ullrich et al 2007).

A 2009 study of mercury concentrations in hair samples involved analysis from Temirtau town and four floodplain villages (Chkalovo, Gagarinskoye, Samarkand and Rostovka) ranging from 1.5 to 35 km from the outfall. From this study it was determined that 17% of the population exceeded the safety standard of 1 ug/g for hair mercury developed by the US EPA, and these people were considered at risk (Hsiao et al 2009).

In the two largest of these population centres (Temirtau and Chkalovo) many residents reported they were concerned about mercury contamination and did not eat river fish that they caught. Discussions with market fish vendors indicated that they recognised the sensitive issue of mercury in fish and often advertised the fish origin of their stock (Hsiao et al 2009). While there may have been a local consciousness of mercury pollution, and possibly lower consumption in the two largest centres, the three riverine villages consumed significantly more locally-caught fish than commercially purchased, up to 80% of all fish meals. In conjunction with this study it was found that about 84% of all fish samples exceeded the Kazakhstani safety level of 0.3 ug/g and 33% exceeded the threshold levels of 0.5 ug/g (Hsiao et al 2009).

A summary of outcomes and impacts from mercury contamination of River Nura includes:

- Unsafe levels of mercury contamination in river sediment, floodplain soils and fish, with the loss of clean water, clean fish and clean agricultural land resulting in associated adverse economic impacts;
- Potential mercury-related health impacts in adults;
- Potential neurotoxic health impacts in children, and associated educational and economic consequences; and
- Potential for further dispersion of mercury-loaded sediments to accumulate in the Ramsar wetlands where the river terminates with risks to endangered wildlife.

7.1.1 Remedial Actions and Outcomes

The remediation activities undertaken between 2007 and 2013 were known as the "Nura River clean-up project". While significant amounts of mercury pollution were remediated, concerns remain as to whether the fundamental goals of the project were achieved.

The main goals of the project were to clean-up the Nura riverbed, ensuring effective management of the landfill site where contaminated soil was contained, as well as to rehabilitate the Intumak dam, which provides flow control downstream and functions as a pollution trap of mercury-contaminated reservoir sediments (Sir 2015a).

The dredging of the riverbed and cleanup of the riverbanks (to remove mercury-contaminated technogenic silt) has improved environmental conditions on the Nura River. At the beginning of the project the mercury pollution levels in soils and sediments ranged from 50 - 1 500 mg/kg. In 2012, mercury-polluted soil has been removed to meet internationally accepted safe levels for upper soils; 2.1 mg/kg for agricultural use; and 10 mg/kg for other land use. Remote areas were cleaned to 50 mg/kg (Sir 2015a). Water quality in the river has improved and mercury levels are now below water quality guidelines for drinking water. The Karbid factory site has been remediated and 2 million tonnes of contaminated soil disposed of to a dedicated hazardous waste landfill that has capacity to receive further wastes in the event of additional remediation activity.

A 30 km long section of the Nura River, from the Samarkand reservoir to Rostovka village and including the impacted area of locality of Zhaur Swamp, was cleaned of mercury contamination. This remedial action made approximately 6,234 hectares of land available for agricultural and cattle grazing purposes, which will be a major benefit to the communities along the Nura river for the foreseeable future. Air quality has also improved considerably, with mercury vapour levels dropping from a range of 6 000 - 140 000 ng/m^3 down to below the regulatory limit of 300 ng/m^3 (Sir 2015a).

In 2013-14, a partial validation sampling survey was conducted by Arnika Association of the Czech Republic to assess post-remediation contamination impacts. The NGO testing revealed elevated amounts of certain heavy metals (mercury, chromium, lead and cadmium) in some of the sediment samples, elevated levels of mercury in fish meat samples, and elevated levels of PCDD/Fs in some egg samples. This indicates that more action needs to be taken to ensure that the river is cleaned up to a satisfactory standard. A comprehensive account of the sampling regime and a detailed site history of the mercury pollution of the Nura River are included in the report by Sir (2015a).

The remediation did lower mercury contamination in many parts of the Nura River and the surrounding area; however, many sites are still polluted and exceed the remediation limits established for the clean-up project. In Rostovka, Temirtau, including Krasniye Gorki, Chkalovo, Samarkand and Gagarynskoe, mercury levels are still too high, as well as the levels of copper, chromium and zinc (Sir 2015a).

Mercury levels in fish from the river still exceed the safe consumption guidelines and warnings should be issued to protect sensitive sub-populations (such as pregnant women and children). Due to the hotspots of contamination detected by the NGO Arnika, and ongoing indirect contamination of fish, it is recommended that ongoing soil, water and biota sampling take place to assess the need for further clean-up activities.

7.2 CASE STUDY 2: MERCURY CONTAMINATION AT KODAIKANAL, TAMIL NADU, INDIA

Kodaikanal is a hill township of around 40,000 people in the southern Indian state of Tamil Nadu. The area is a popular among tourists for its lakes, waterfalls, granite cliffs and forested valleys. At 2000 metres above sea level, it has a climate that is much cooler than most surrounding areas. The cooler climate was a significant factor in the establishment of a mercury thermometer factory by Ponds India in 1983, which was acquired through merger by Hindustan Unilever Limited (HUL) in 1987 (Government of India 2011).

The thermometer factory operated from 1983 to 2001 when it was shut down due to allegations of selling mercury-contaminated glass scrap to local recyclers in the township of Kodaikanal. The scrap yard containing the mercury-contaminated waste was subject to an investigation and the mercury tainted scrap was removed and some soil remediation undertaken. However, the main site of the thermometer factory, located on a forested ridge above the townsite, remains contaminated with mercury and is the subject of further investigations and remediation proposals.

It was found that work practices at the site resulted in "hot spot" mercury contamination of on-site soil and a stream that passes through the factory site. In addition, fugitive emissions of mercury during the life of the facility have caused elevated mercury soil concentrations across the factory site soil and also off-site impacts (URS Dames and Moore 2001).

Subsequent investigations have found that Kodai Lake, a major tourist attraction to the north of the site, has also been contaminated as a result of emissions from the thermometer factory (Karunasagar et al., 2006). Kodai Lake waters reported HgT of 356-465 ng l-1, and methylmercury levels of 50 ng l-1. Kodai Lake sediment showed 276-350 mg/kg HgT with about 6% methylmercury. Samples of fish from the lake reported 120 - 290 micrograms/kg HgT.

Air sampling conducted outside the boundary of the thermometer factory reported significant elevation of ambient mercury concentrations, with levels reaching 1.32 micrograms/m^3 (Balarama Krishna et al 2003). By comparison, airborne mercury levels in areas considered non-contaminated range from 0.5-10 ng m^3 (Horvat et al., 2000). In terms of an occupational setting, the US National Institute for Occupational Safety and Health (NIOSH) has established a maximum permissible air concentration limit of 0.05 mg/m^3 (NIOSH 1992). Other studies have concluded airborne levels of mercury above 0.01 mg/m3 are considered unsafe for sensitive sub-groups such as pregnant women (Moienafshari et al., 1999).

Further off-site contamination was identified in vegetation such as lichen and mosses, which are known to accumulate mercury. Concentrations declined with distance from the factory, with samples ranging from "around 0.2 mg/kg" 20 km from the factory (Balarama Krishna et al., 2003) up to 87 mg/kg dry weight on the site itself (URS Dames & Moore 2002).

Soil contamination on the factory site is significant and has been caused both by atmospheric deposition due to fugitive mercury releases as well as work practices on the site such as waste disposal.

An environmental assessment by URS Dames and Moore (2002) concluded that there are four major hot spots on the site with elevated soil mercury concentrations. These are:

- Hotspot A – Mercury concentrations between 10 and 30 mg/kg in 40% of an area of 1800 m^2. Situated around the old bakery and glass scrap storage areas.
- Hotspot B – An area of 3040 m^2 southeast of hotspot A and south of Ponds Path. Mercury concentrations between 10 and 30 mg/kg in 60% of the site and in excess of 500 mg/kg on 25 m^2 of this area.
- Hotspot C1 and C2 – South of the factory building and Ponds Path. An area of 8590 m^2 of which around 60% contains mercury concentrations between 10 and 30 mg/kg.

A further area of lower contamination (between 0.1 and 10 mg/kg) is designated *Area D* and contains around 75 kg mercury in total. (URS Dames and Moore, 2002).

However, these results were disputed by former employees who suggest that higher soil concentrations are likely to exist (there were allegations by workers of mercury dump sites) but had not been detected due to the sampling methodology of the consultant engaged by HUL.

These views were given some support when a mercury mass balance for factory generated by URS Dames and Moore was found to have underestimated emissions and releases of mercury from the facility during its operational life. The initial mass balance concluded that 559 kg of mercury was deemed as unaccounted losses (to environment). A subsequent site assessment report released by URS Dames and Moore in 2002 took into account a previously undisclosed mercury import of 10,810 kg to the site which was raised by former workers. The consultants (URS Dames and Moore 2002) revised the mass balance for mercury at the site concluding that unaccounted losses totalled 2031 kg with losses to the Pamba Shola of 1350 kg.

An investigation by the Ministry of Labour and Employment (Government of India 2011) found that the actual quantity of mercury that may have been released to the environment was 10,974 kg.

While debate continues over the extent of mercury releases from the site, it is clear that substantial mercury contamination has occurred on-site and has caused significant off-site impacts in aquatic bodies and the high-conservation-status forests adjacent to the factory.

Offsite impacts were also reported in a study by the National Environmental Engineering Research Institute of India (NEERI 2015) who found elevated levels of mercury in 60% of sediment samples taken from streams in the vicinity of the site with the following reported results; LP1: 0.507 mg/kg, PS1: 0.353 mg/kg, LP5: 0.228 mg/kg.

Since the closure of the plant some partial remediation activities have taken place. In May 2003, 290 tonnes of mercury-contaminated materials (which included effluent plant sludge, glass and elemental mercury) were shipped to the US for treatment and recovery of mercury. However, most of the soil contamination remains in-situ.

The site owners have proposed to treat the remainder of the mercury-contaminated soils on-site using soil washing and thermal retorting technology.[16] As with all thermal technologies for the treatment of mercury wastes, mercury-specific and dedicated air pollution control equipment must be incorporated to ensure that mercury vapour is not released to the surrounding environment. Even with these precautions, mercury emissions from direct thermal treatment can remain problematic.

This mercury-contaminated site also raises contextual issues in relation to soil remediation criteria. Many contaminated industrial sites can be cleaned-up to national requirements without controversy, as they are sited in industrial complexes or similar zonings that are not adjacent to residential or sensitive ecological areas. In the case of the Kodaikanal site, highly sensitive ecological receptors are present within close proximity to the site and this may impact on the final remediation criteria for soil and other matrices. The contaminated site abuts the Pambar Shola forest ecosystem, which is an ancient forest and nature sanctuary protected by the Tamil Nadu State Government, and which contains endangered flora and fauna.

The pristine nature of this ecosystem and the off-site impacts of the thermometer factory may require more sensitive remediation end points than are currently proposed. Initially Hindustan Lever Limited (a subsidiary of Unilever) proposed to remediate the site to the Dutch (residential) Intervention Level of 10 mg/kg (i.e. leaving mercury in site soils at a maximum concentration of 10 ppm). However, after negotiations with the Tamil Nadu Pollution Control Board, the clean-up criteria were relaxed to 25 mg/kg. India does not currently have any applicable soil criteria for mercury contamination and therefore any proposed limit should take into account the site-specific sensitivities of Kodaikanal.

---

16 Accessed at https://www.unilever.com/sustainable-living/what-matters-to-you/kodaikanal-india.html

URS Dames and Moore estimated that a clean-up criterion of 10 mg/kg would result in the removal and treatment of 4100 m^3 of contaminated soil and sediment from the site. The proposed 25 mg/kg criteria would result in substantially less material being treated and lower remedial costs. The Dutch Intervention Level of 10 mg/kg does not necessarily reflect "sustainable" remediation outcomes (an approach that prioritises the precautionary principle, intergenerational equity and polluter pays) but rather a risk assessment derived exposure approach. For this reason the Dutch also quote a "target level" of 0.3 mg/kg (MHSPE 1994). This is considered to be a sustainable level with negligible risks to the ecosystem, which allows soil to fully recover functionality for human plant and animal life (including soil microbes and microfauna). At least one study (Tipping et al 2010) has determined that the critical limit for mercury in soil in terms of soil organism health is as low as 0.13 mg/kg.

Reaching such low concentrations of mercury in soil through current remediation technology remains challenging; however, some techniques and technologies claim to be approaching this level.

7.2.1 Potential Remedial Actions

Taking into account the sensitive surroundings of the former thermometer factory, consideration should be given to remediation criteria that incorporate sustainability objectives approaching full soil functionality in and around the site. The pristine nature of the Pambar Shola forest ecosystem should be regarded as the driving receptor in any exposure assessment due to the ongoing release of mercury vapour from the site and its resulting off-site impacts. The current proposed remediation criteria will result in ongoing mercury vapour emissions from the site and potential releases to the local aquatic ecosystems via precipitation, leaching and mobilisation through surface water systems. The link between the contaminant source and important ecological receptors such as Kodai Lake has already been demonstrated (Karunasagar et al., 2006).

In this instance the source of the contamination - the soil at the factory site - should be remediated to the highest standard possible to prevent the ongoing release of mercury into the local environment. A potentially sustainable approach may require some modification of the existing remediation proposal and criteria. A combination of soil washing and a vacuum thermal desorption unit could approach the higher levels of remediation to protect the sensitive receptors and prevent further spread of contamination.

Soil washing can assist to separate the more coarse materials from the soil to which mercury is less likely to bind. The coarse material can then be

Picture 15. Indirectly heated vacuum distillation unit.
Source: econ industries GmbH cited in UNEP/ISWA 2015

tested and either declared clean or, if still contaminated, can be crushed into fine material and sent back into the process. The finer material, which contains the majority of the mercury contamination, can then be fed into the vacuum distillation unit. A French version of this technology was able to treat contaminated soil to a final mercury content of less than 1 ppm (1 mg/kg) and had a leaching value of <0.001 mg/l (UNEP/ISWA 2015). The soil was then able to be backfilled on-site.

It is unlikely the soil washing and thermal retort operation proposed by HUL will be able to achieve this level of soil remediation, and it may also encounter issues with mercury vapour release during operation if a direct thermal technology is employed. It would be preferable to employ the indirectly heated vacuum thermal desorption unit described for final treatment, while retaining the soil washing step of the process. If low ppm soil mercury concentrations could be achieved with this technique, the source of the ongoing pollution to waterways and the Pambar Shola forest could be removed. Ongoing monitoring of the environmental receptors around the site should continue to ensure that all hotspots have been identified and remediated.

Further remedial may be necessary to address the sediment contamination of Kodai Lake to ensure that local fish species may recover from high mercury body burdens over time.

8. OCCUPATIONAL AND COMMUNITY SAFETY AND HEALTH MANAGEMENT FOR CONTAMINATED SITES

Building social capacity through the free flow of information is the basis for ensuring that occupational health and safety management is linked to community health and safety around contaminated sites. All site investigation reports, health and safety plans, risk registers, remediation plans and waste transport and treatment plans should be available to all stakeholders for discussion and amendment at the earliest possible time.

Contaminated sites remediation can involve a number of stages:

- Preliminary site investigation;
- Detailed site investigation;
- Site management;
- Remediation, validation and ongoing management; and
- Waste transport and treatment.

Occupational and community safety and health issues are to be addressed throughout all stages of the process. It should also be recognised that site workers will have specialised protective and monitoring equipment that is not available to those outside the site boundaries, as well as shorter exposure duration periods (<8 hours per day) on-site. Monitoring trigger levels (alert levels) for fugitive emissions should be undertaken so that levels can be established that are protective for members of the public on the other side of the site fenceline to reflect their lack of protective equipment and long exposure periods (up to 24 hours per day).

Any risk-based calculation of acceptable air contamination concentrations and averaging periods should reflect this difference and be calibrated for sensitive receptors among the community (e.g. children, elderly, pregnant women and immune-compromised individuals).

8.1. OVERVIEW

Contaminated sites may present health and safety risks to workers and community members during investigations and remediation, and, while these risks may vary between on-site and off-site impacts, they should be addressed in one framework to ensure transparency and accountability.

Hazards can be encountered at any stage of site works and may include other heavy metals in addition to mercury, as well as volatile organic solvents, hydrocarbons, pesticides, industrial chemicals or even persistent organic pollutants and radioactive materials. These contaminants can be in a solid, liquid, vapour or dust form in the soil, air or groundwater. Other potential hazards include fires, explosions, confined spaces and gas lines, and electricity, machinery, manual handling and transport risks.

In some former and current conflict zones, contaminated sites may also be impacted by buried unexploded ordinance (UXOs). Special precautions must be taken when investigating sites with UXOs and advice should be sought as early as possible from defense personnel with experience in screening for and neutralizing these devices. An extensive preliminary site investigation (including all former uses of the site) will assist in identifying the potential presence of radioactive material and UXOs and the need for more detailed screening for these materials. In a number of cases UXOs have also been found in old municipal waste dumps where nearby defense force bases have historically dumped ammunition and ordnance.

Management of contaminated sites should ensure that all workers and potentially-impacted community members are not exposed to hazards. While employers have a "duty of care" to employees, total site management has a social responsibility to the broader community. Work on contaminated sites may involve risks from hazardous substances in an uncontrolled state with minimal or no information on their identity and concentration. Precautions must be taken and the assumption made that the site contains significant risks to the safety and health of workers and the broader community. Suspected contaminated areas should be viewed as hazardous unless proved otherwise by testing.

8.2 DUTY OF CARE AND SOCIAL RESPONSIBILITY

Management of contaminated sites must ensure that:

- There is full compliance with all relevant health and safety laws and consultation and cooperation is afforded to worker and government safety and health representatives;

- Employees and other workers are provided with a workplace and safe system of work to protect them from hazards;
- The community is informed of and protected from hazards emanating from the site. This includes dust, vapours, contaminated water flows and soils;
- All workers receive relevant site-specific information, instruction, training and supervision to work in a safe manner without exposure to hazards;
- Adequate personal protective clothing and equipment is provided without cost to the workers where hazards cannot be reduced to an acceptable level;
- All plant is installed or erected in such a way that it can be used safely;
- All handling, processing, storage, transportation and disposal of substances at the site are carried out in a manner that does not expose the workers or other community members to hazards; and
- All site investigation reports, health and safety plans, risk registers (see below), remediation plans and waste transport and treatment plans are freely available to all workers and other stakeholders.

8.3 RISK REGISTERS

Management of contaminated sites must ensure that workers and the community have access to a regularly updated Risk Register, which sets out the identified hazards, the assessment of risk of injury or harm, and the measures put in place to eliminate or reduce the risks. Workers and the community must be protected by hazard mitigation.

Application of a hierarchy of control measures ranging from the most effective to the least effective measures would include:

1. **Elimination** – removing the hazard or hazardous work practice;
2. **Substitution** – replacing a hazard or work practice with a less hazardous one;
3. **Isolation** – separating the hazard or work practice from people involved in the work (enclosing systems, remote access or physical barriers);
4. **Engineering controls** – modifications to tools or equipment or machinery guards;
5. **Administrative control** – work practices to reduce the risk, instruction, training and warning signs;

6. **Personal protective clothing and equipment (PPE)** – to be provided when other control measures have been applied and protection needs to be increased; and
7. **Continuous monitoring and review of control measures** – to ensure continuing effectiveness and guard against unintended consequences.

The frequency of monitoring and review should be based on the level of risk, the type of work practice, and the plant or machinery involved, as well as environmental factors.

8.4 INFORMATION AND TRAINING

Management of contaminated sites must ensure that:

- Information and education on all identified hazards—in the form of a Risk Register—be provided to the workers and broader community. This must include information relating to known and suspected contaminants;
- Induction, information, instruction, training and supervision in safe procedures are provided to all workers;
- Specific training is provided to workers involved with hazardous substances, including health effects, control measures, emergency response and correct use of PPE;
- Records kept of all induction and training for work with hazardous substances; and
- All workers are trained in emergency evacuation procedures and these are made available to communities at risk to help develop emergency response procedures should impacts occur off-site.

8.5 SUPERVISION

All workers must be provided with adequate supervision to ensure they are not exposed to hazards and take reasonable care of their own and others' health and safety. This requires that:

- Supervisors have the skills, knowledge and authority to fulfill the roles;
- Training is ongoing and there is regular revision of safe procedures; and
- PPE is used and kept in adequate working condition.

8.6. GENERAL STORAGE AND TRANSPORT CONTROLS FOR CONTAMINANTS

General principles for storage and transport control include:

- Limit access to authorised people only;
- Store contaminants in a cool secure, ventilated area with signage indicating material, concentration, risks and controls;
- Monitor atmospheric contamination and temperature levels in storage areas to ensure they are within appropriate levels;
- Choose an appropriate container for storage, such as corrosion or solvent-resistant;
- Ensure all containers are labeled correctly and labels are kept intact;
- Ensure all unknown substances are labeled as UNKNOWN SUBSTANCES – TREAT WITH EXTREME CAUTION;
- Check the compatibility of substances stored together and separate if required. Avoid risks of mixing and cross contamination;
- Check all containers against leakage or seepage;
- Ensure appropriate fire fighting and emergency equipment is available;
- Ensure a well-developed evacuation procedure with regular drills for emergency situations;
- Ensure all contaminants are secured before and during transport; and
- Ensure all plant and equipment is decontaminated before leaving the site.

All chemicals, contaminated soils and liquids must be stored and transported according to the relevant laws.

8.7 TRANSPORT AND LONG-TERM STORAGE OF ELEMENTAL MERCURY FROM CONTAMINATED SITES

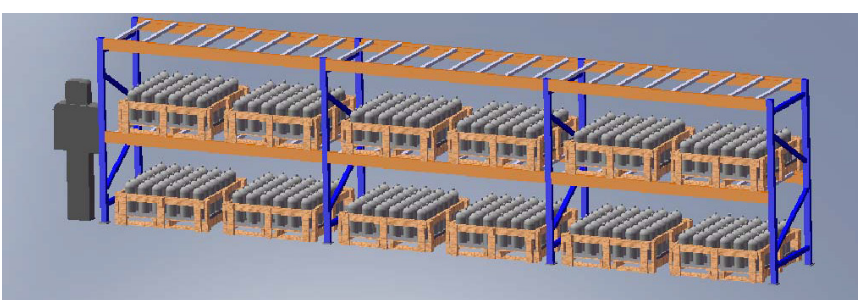
Some contaminated site remediation efforts may result in the recovery of free elemental mercury from pockets within the sites or from on-site treatment and recovery operations. Transport and packaging of elemental mercury requires careful planning and packaging using suitably prepared vehicles. The US mercury export ban resulted in the development of stringent standards for the packaging, documentation, transport, acceptance and storage of elemental mercury in purpose-built facilities for the permanent retirement of the mercury from the market.

The US Department of Energy developed comprehensive guidance (U.S. DoE 2009) on the practical and administrative measures required to con-

Picture 16. Examples of mercury packaging - standard 3 litre elemental mercury flasks individually and packed in a 49 x 3 litre crate with built-in spill tray. *Source: US DoE 2009*

duct these activities when dealing with thousands of tonnes of elemental mercury that was destined for permanent storage. The detailed guidance includes packaging and loading procedures, vehicle unloading and interface at the storage facility, transfer of mercury between vessels and final packaging guidance for storage. Environmental monitoring procedures throughout the process are also detailed. Packaging of smaller quantities of mercury is usually in sealed metal flasks containing 3 litres of mercury in the US.

When gathered in sufficient numbers and checked for structural integrity (including seals), the flasks can be combined into crates with built-in spill trays for racking.



Picture 17. Racking of crates containing 49 x 3 litre mercury flasks for permanent storage. *Source: US DoE 2009*

The seismically rated racks are located on a sealed, sloped floor (3° slope) toward the centre of the room to allow easy visual inspection and containment of leaks. The racks also have fire suppression devices and usually do not exceed 3 metres in height.

Depending on the quantity of elemental mercury recovered at a contaminated site, it may be necessary to use larger volume packaging than standard 2.5 litre or 3 litre flasks. In these cases specially constructed 1 metric tonne containers have been developed to meet the stringent transport and long-term storage requirements.

A range of guidance is currently being developed around interim and long- term storage criteria for elemental mercury that is traded as a commodity or has been retired from the market (allowable uses). Important information on this subject can be sourced from the Basel Convention *Updated technical guidelines for the environmentally sound management of wastes consisting of, containing, or contaminated with mercury or mercury compounds (Rev 6)* as well as the recently released UNEP/ISWA *Practical Sourcebook on Mercury Waste Storage and Disposal*.

Picture 18. An example of 34 kg steel flasks and a 1 metric tonne steel storage unit. *Source Bethlehem Apparatus Co. Hellertown, PA.*

8.8 WORKPLACE AMENITIES AND FIRST AID FACILITIES

Specific requirements for amenities relevant to the contaminated site should be established as part of the site-specific safety and health planning. Where applicable, clean decontamination facilities should be provided that include, but are not limited to:

- Showers;
- Hand washing facilities;
- Eye wash facilities;
- Separate clean area;
- Areas for decontamination of all equipment, including washdown areas for trucks. If there is a high level of contamination, a separate decontamination unit should be provided for workers, in addition to and separate from other sanitary and washing amenities; and
- Mercury intoxication requires specialist medical intervention and treatment including chelation (treatment to accelerate mercury excretion from the body), and requires the worker to be removed from the source of exposure until treatment is completed and the exposure source investigated and removed.

8.9 EXPOSURE MONITORING

Exposure monitoring is a means of measuring the exposure to contaminants experienced by people working on the site. In some cases this may also be considered appropriate for community members. Exposure monitoring should be carried out by a competent person using recognised monitoring standards. All exposure monitoring results are to be made available to anybody likely to be exposed to hazardous contaminants. In the case of mercury-contaminated sites, biological monitoring via hair sampling on a regular basis may form part of the exposure monitoring program. This should be performed by an accredited laboratory with QA/QC procedures and experience in interpretation of analysis results.

8.10 HEALTH SURVEILLANCE PROGRAMS

In addition to the requirements for hazardous substances already outlined, health surveillance programs should be undertaken for workers and community members known to have been exposed to “high concern” hazardous substances. These include, but are not limited to:

- Asbestos;
- Inorganic arsenic;

- Inorganic chromium;
- Inorganic mercury;
- Cadmium;
- Lead;
- Methylmercury;
- Polycyclic aromatic hydrocarbons (PAH);
- Crystalline silica;
- Thallium;
- Organophosphate pesticides; and
- Persistent Organic Pollutants (POPs).

A health register can be established by local health workers under supervision of experienced clinicians and toxicologists. Workers and/or residents at risk of exposure can be added to the register and their medical condition monitored over time. The benefit of this approach is that local health workers can be trained to identify sentinel symptoms of exposure to specific contaminants and identify the early stages of the symptoms in patients that would otherwise go undetected. A register can also help to identify any clusters of contamination-related health problems in a locality that may have legacy sites leading to long-term exposure of residents.

9. CONTAMINATED SITES AND THE REQUIREMENTS OF THE MINAMATA CONVENTION ON MERCURY: ENGAGING STAKEHOLDERS

The Minamata Convention on Mercury outlines activities Parties can undertake to address contaminated sites and generate information for the public to raise awareness about the implications of contamination for human health and the environment. Guidance such as this document can assist to build capacity within the community, and among NGOs and policy makers to address mercury-contaminated sites within their jurisdiction. It can also uncover valuable information for industry about the contaminated site, increasing the effectiveness of site assessment and limiting costs while reducing potential social conflict.

At this point the Parties to the Mercury Treaty have not yet developed specific guidance for contaminated sites, but this does not prohibit national governments from developing their own management frameworks, policies and legislation to assess, identify, characterise and remediate contaminated sites. As countries makes progress toward ratification of the Mercury Treaty, it is important to be aware of the specific statements made in the Treaty about mercury-contaminated sites and the need for public engagement.

Under Article 12, "Contaminated sites", the Conference of Parties are required to prepare guidance on managing contaminated sites that include methods and approaches for "Engaging the Public" (UNEP 2013).

In addition, under Article 18, "Public information, awareness and education", each Party is required to provide to the public information on mercury pollution as well as the "results of its research, development and monitoring activities under Article 19". Parties are also required to provide education, training and public awareness related to mercury health effects in collaboration with relevant intergovernmental organisations, NGOs, and vulnerable populations.

Public engagement and the empowerment of civil society through cross-sector collaboration and cooperation requires an integrated, two-way approach between a national and regional-level engagement of civil society and a local, site-specific process of stakeholder engagement. Each process should have the capacity to inform and adapt to the other. However, public engagement needs also to take into consideration the specific cultural, social and political context to be most effective.

9.1 GUIDANCE FOR SITE-SPECIFIC STAKEHOLDER ENGAGEMENT

Stakeholder engagement in the identification, assessment and remediation of mercury-contaminated sites involves the deliberate participation of individuals, communities, NGOs, industry, government authorities and others who may have an interest in, or be potentially affected by, the contaminated site and the clean-up activities. Stakeholders may include: landowners and residents living near (or on) the site; communities and industries affected by the ongoing impacts of mercury pollution; public health, environmental and other regulatory authorities; NGOs; and site management and workers.

In cases where industry has a contaminated site(s) and wishes to engage with stakeholders over remediation, it can be beneficial to engage third parties (e.g. consultants or academics) to lead the engagement processes as an independent "broker". This can be particularly helpful where they may be issues of trust or historical conflict between some stakeholders. Some companies may experience problems when they acquire a contaminated site as part of a corporate merger or similar transaction, but are not responsible for creating the contamination (but are responsible for implementing remediation). Past conflict between the original polluters and stakeholders such as local residents may have created an impasse for site remediation. In these situations the new site owners can "reset" the relationship with local communities with a genuine stakeholder engagement plan, and benefit from a respectful dialogue about the future of the site that best meets the requirements of all parties while restoring the land to an agreed standard.

Industries in possession of contaminated sites may also benefit from the information held by stakeholders on the historical use of the site and identification of potential hotspots where dumping may have occurred. This may include local residents, truck drivers, community officials and others with a long-term knowledge of the site and wok practices. This type of information can be very valuable during the preliminary and detailed site assessment phases, reducing costs through more accurate and efficient sampling. For this reason stakeholder engagement should begin as early as possible when remediation is being considered.

Stakeholders have a right to information about environmental health factors that affect their lives, the lives of their children and families, and the future of their communities.

The aim of stakeholder engagement is to improve the quality of the decisions made for the particular remediation project as well as also improving the decision-making process itself. Two-way engagement, which effectively conveys information and enables stakeholder participation in the decision-making process, can provide significant cost savings and improve credibility for organisations involved in contaminated sites management. Stakeholders benefit by contributing to improved risk management decisions and more acceptable site management options that deliver improved health, safety and amenity benefits.

Stakeholder engagement should start as early as possible and continue throughout the identification, assessment, remediation and management of the contaminated site. In addition, stakeholders should be engaged whenever a new issue is identified that may pose a risk to health or the environment, or raise public concern.

Preparation and research for stakeholder engagement can be integrated into the process of site identification and characterisation, as there is considerable potential for information from each process to inform the other. The stakeholder engagement plan should be flexible and responsive to changing circumstances and stakeholder input.

9.2 STAKEHOLDER ENGAGEMENT IMPLEMENTATION

A concise summary of an agreed stakeholder engagement plan should be provided to all stakeholders in the form of a "statement of intent". This would include the following:

- Background information about the site, a statement about the project and the purpose and objectives of the engagement process;
- A description of the major issues likely to be addressed and potential future uses for the land;
- A statement on the kind of involvement that is being sought and engagement techniques that will be used;
- A commitment on how the information from the process will be used, and feedback given to stakeholders on how their input was used to reach decisions;

- A timeline for the engagement program that allows sufficient time for stakeholders to discuss and form opinions on the issues; and
- Sources of further information, including contact details for relevant staff and stakeholder representatives.

Stakeholder engagement techniques will need to be designed for the local context and consider cultural, social and seasonal factors that may influence participation. Examples of techniques include:

- Public meetings;
- On-site meetings;
- Printed information in the local language;
- Workshops; and
- Design meeting.

Feedback to stakeholders should be provided at each stage of the engagement process following key meetings, and at the completion of the program. This should include a summary of the input provided by stakeholders and how it was considered and incorporated into the decision-making process, as well as documentation of the key features of the engagement process. Feedback should also include any other factors outside the engagement process that may have influenced the decision made.

9.3 STAKEHOLDER ENGAGEMENT EVALUATION AND REPORTING

Evaluation of the processes and outcomes is an integral part of a stakeholder engagement program and can help to:

- Identify if stakeholders are satisfied that the process is fair and fulfills expectations;
- Improve future stakeholder engagement activities and programs;
- Establish if there is a need for ongoing engagement activities; and
- Improve the cost-effectiveness of future processes.

All stakeholders should be involved in the evaluation and feedback on the effectiveness of the program throughout the implementation of the stakeholder engagement plan, as well as after the conclusion of the process. This will allow for an adaptive management approach and improvements to be made where necessary. Consideration should be given to whether evaluation tasks are better allocated to a separate organization in order to more objectively analyse the success of the program.

10. REFERENCES AND BIBLIOGRAPHY

Agency for Toxic Substances and Disease Registry (ATSDR). *Toxicological Profile for Mercury*. Public Health Service, U.S. Department of Health and Human Services, Atlanta, GA. 1999.

Anchor Environmental (2003) Effects of Resuspended Sediments Due to Dredging Operations. Literature Review of Effects of Resuspended Sediments due to Dredging Operations. Prepared for Los Angeles Contaminated Sediments Task Force Los Angeles, California.

Applied PhytoGenetics (APGEN). 2003 Cited in US EPA (2007) Treatment Technologies for Mercury in Soil, Waste, and Water. Office of Superfund Remediation and Technology Innovation Washington, DC 20460.

Australian Federal Government (2013) Platypus Remediation Project. Sydney Harbour Federation Trust. Community Newsletter edition 8.

Balarama Krishna M.V., Karunasagar, D., Arunachalam, J., (2003) Study of Mercury Pollution near a Thermometer Factory using Lichens and Mosses. *Environmental Pollution 124 (2003) 357-360*.

Barcelo, D. and Petrovic, M. (2006) Sustainable Management of Sediment Resources Vol 1: Sediment Quality and Impact Assessment of Pollutants. Elsevier, 29 Sep 2006.

Basel Convention (2007). Updated general technical guidelines for the environmentally sound management of wastes consisting of, containing or contaminated with persistent organic pollutants (POPs). http://www.basel.int/pub/techguid/tg-POPs.pdf.

Basel Convention (2012). Technical guidelines for the environmentally sound management of wastes consisting of elemental mercury and wastes containing or contaminated with mercury. As adopted by the tenth meeting of the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (decision BC-10/7). Geneva, Secretariat of the Basel Convention: 67.

Bellanger, M, et al, 2013, Economic benefits of methylmercury exposure control in Europe: Monetary value of neurotoxicity prevention. Available from, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3599906/

BiPro (2010) Requirements for facilities and acceptance criteria for the disposal of metallic mercury. 07.0307/2009/530302. Final report 16 April 2010. For the European Commission, Brussels. Beratungsgesellschaft für integrierte Problemlösungen.

Bozek, F., et al. (2010). "Implementation of best available techniques in the sanitation of relict burdens." *Clean Technologies and Environmental Policy* 12(1): 9-18.

Colombano. S,, Saada. A,, Guerin. V., Bataillard. P., Bellenfant. G., Beranger. S,, Hube. D, Blanc. C., Zornig et aI. Girardeau. C., (2010) Which techniques for which treatments – A cost-benefit analysis. BGRM

Dash. H., and Das.S., (2012) Bioremediation of mercury and the importance of bacterial mer genes. *International Biodeterioration & Biodegradation 75* (2012) 207-213.

Dyusembayeva, N. K. (2014). Экология Балхаша и генетическое здоровье населения (Environment Quality and Genetic Health of Inhabitants in Balkhash City). Toxics Free Kazakhstan: International conference, August - 7, 2014. Astana.

Environment Agency UK. (2009) Soil Guideline Values for mercury in soil Science Report SC050021 / Mercury SGV. Technical note. Environment Agency, Rio House, Almondsbury, Bristol BS32 4UD.

Environment Agency UK (2012) Treating waste by thermal desorption – How to comply with your environmental permit Additional guidance for: Treating waste by thermal desorption (An addendum to S5.06) 382_12 – Guidance. Bristol, United Kingdom.

Environmental Health Committee (enHealth) 2012, The role of toxicity testing in identifying toxic substances: A framework for identification of suspected toxic compounds in water, Department of Health and Ageing, Canberra.

Environmental Protection Authority of Tasmania - Contaminated Site Assessment (2005) as outlined in the *National Environment Protection (Assessment of Site Contamination) Measure 1999*. http://epa.tas.gov.au/regulation/contaminated-site-assessment.

Eurochlor (2009). Management of mercury contaminates sites, Env. Prot. 15, 2nd Edition, November 2009, Eurochlor publication .

European Commission (2011). Commission Regulation (EU) No 1259/2011 of 2 December 2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for dioxins, dioxin-like PCBs and non dioxin-like PCBs in foodstuffs (Text with EEA relevance). European Commission. Official Journal of the European Union. EC 1881/2006: 18-23.

Garcia-Rubio A., J.M. Rodriguez-Maroto, C. Gomez-Lahoz (2011) Electrokinetic remediation: The use of mercury speciation for feasibility studies applied to a contaminated soil from Almaden. *ELECTROCHIMICA ACTA*, Volume: 56, Issue: 25 , Pages: 9303-9310

Government of India (2011) Report of the Technical Committee Constituted by the Ministry of Labour and Employment, Government of India in connection with the Writ Petition No.8291 of 2006 in the Hon'ble High Court of Madras. Ponds Hindustan Unilever ex-mercury Employees Vs M/S Hindustan Unilever Ltd & 6 Others.

Grandjean, P., et al (1999) Methylmercury Exposure Biomarkers as Indicators of Neurotoxicity in Children Aged 7 Years. *American Journal of Epidemiology,* 1999;149:301-5.

Heaven, S., Ilyushchenko, M. A., Kamberov, I. M., Politikov, M. I., Tanton, T. W., Ullrich, S. M. and Yanin, E. P. (2000) Mercury in the River Nura and its floodplain, Central Kazakhstan: II. Floodplain soils and riverbank silt deposits. *Science of The Total Environment,* Vol 260, Issue: 1–3 p45-55

Hinton J., M. Veiga M. (2001). "Mercury Contaminated Sites: A Review of Remedial Solutions", NIMD National Institute for Minamata Disease), Forum 2001. March 19 20, 2001, Minamata, Japan.

Hooper, M. (2008) Soil Toxicity and Bioassessment Test Methods for Ecological Risk Assessment: Toxicity Test Methods for Soil Microorganisms, Terrestrial Plants, Terrestrial Invertebrates and Terrestrial Vertebrates. Prepared for the Office of Environmental Health Hazard Assessment California Environmental Protection Agency

Horvat, M., Jeran, Z., Jacimovic, R., Miklavcic, V., (2000) Mercury and other elements in lichen near the INA Naftaplin gas treatment plant, Molve, Croatia. *Journal of Environmental Monitoring,* 2, 139-144.

Hsiao, H, Ullrich, S, Tanton, T, (2009), "Burdens of mercury in residents of Temirtau, Kazakhstan I: Hair mercury concentrations and factors of elevated hair mercury levels", *Science of the Total Environment*, Vol 409, Iss 11, 2011 pp 2272-2280. Available from http://www.sciencedirect.com/science/article/pii/S0048969709012753

IPEN (2014) An NGO Introduction to Mercury Pollution and the Minamata Convention on Mercury. May 2014 http://ipen.org/documents/ngo-introduction-mercury-pollution-and-minamata-convention-mercury

Kajenthira, A, Holmes, J, McDonnell, R, (2012) "The role of qualitative risk assessment in environmental management: A Kazakhstani case study", *Science of the Total Environment*, Vol 420, pp 24-32. Available from http://www.sciencedirect.com/science/article/pii/S0048969711015294

Kania, J & Kramer, M, 2011, Non Profit Management: Collective Impact, *Stanford Social Innovation Review,* Winter 2011. Available from http://www.ssireview.org/articles/entry/collective_impact

Kania, J & Kramer, M, (2013), "Embracing Emergence: How Collective Impact Addresses Complexity", *Stanford Social Innovation Review*, Jan 2013. Available from, http://www.ssireview.org/blog/entry/embracing_emergence_how_collective_impact_addresses_complexity

Karunasagar, D., Balarama Krishna M.V., Anjaneyulu, Y., Arunachalam, J., (2006), Department of Atomic Energy (DAE). Studies of mercury pollution in a lake due to a thermometer factory situated in a tourist resort: Kodaikkanal, India. *Environmental Pollution,* 143 (2006) 153-158.

Li, P., Feng, X., Chan, HM., Zhang, X., Du, B. (2015) Human Body Burden and Dietary Methylmercury Intake: The Relationship in a Rice-Consuming Population. *Environ Sci Technol.* 2015 Aug 18;49(16):9682-9. doi: 10.1021/acs.est.5b00195. Epub 2015 Jul 27.

López, F.A., López-Delgado, A., Padilla, I., Tayigi, H. and Alguacil, F.J. (2010): Formation of metacinnabar by milling of liquid mercury and elemental sulfur for long term mercury storage, *Science of the Total Environment,* 408 (20), 4341-4345.

López-Delgado, A., López, F.A., Alguacil, F.J., Padilla, I. and Guerrero, A. (2012): A microencapsulation process of liquid mercury by sulfur polymer stabilization/solidification technology. Part I: Characterization of materials. *Revista de Metalurgia*, 48(1), 45-57.

Marsh et al., 1995b; Boishio and Henshel, 2000, cited in Hsiao, H, Ullrich, S, Tanton, T, 2009, "Burdens of mercury in residents of Temirtau, Kazakhstan I: Hair mercury concentrations and factors of elevated hair mercury levels", *Science of the Total Environment,* Vol 409, Iss 11, 2011 pp 2272-2280. Available from http://www.sciencedirect.com/science/article/pii/S0048969709012753

Meagher. R., and Heaton. A.C.P., (2005) Strategies for the engineered phytoremediationof toxic element pollution: :mercury and arsenic. *Journal of Independent Microbiology and Biotechnology.* (2005) 32:502-513.

Merly. C., and Hube. D., (2014) Remediation of Mercury Contaminated Sites. Snowman Network: Knowledge for sustainable soils. Project No. SN-03/08. February 2014.

MHSPE, Ministry of Housing, Spatial Planning and Environment (1994) Intervention values and target values soil quality standards. Directorate-General for Environmental Protection, Department of Soil Protection, The Hague, The Netherlands.

Moienafshari, R., Bar-Oz, B., Koran. G., (1999) Occupational exposure to mercury. What is a safe level? *Can Fam Physician.* 1999 Jan; 45: 43–45.

National Environmental Engineering Research Institute (NEERI) (2015) Interim report – Assessment of mercury levels in soil, sediment, and water samples from the offsite area of Hindustan Unilever Limited factory (HUL), Kodaikanal, Tamilnadu- INDIA 26th October 2015.

National Environmental Protection Council (NEPC) of Australia (1999) NEPM Schedule B (1) - Guideline on Investigation Levels for Soil and Groundwater. http://www.esdat.com.au/Environmental%20Standards/Australia/NEPM%20Tables.pdf

NIOSH (1992) NIOSH recommendations for occupational safety and health: compendium of policy documents and statements. National Institute for Occupational Safety and Health. Department of Health and Human Services. Publication No. 92-100. Cincinnati, Ohio.

Ohlsson. Y., Back.P. and Vestin., J. (2014) Risk Assessment of Mercury Contaminated Sites. SNOWMAN NETWORK - Knowledge for sustainable soils Project No. SN-03/08

Petrlik, J. (2014). POPs and heavy metals pollution in Ekibastuz and Balkhash. Presentation for the conference held within the project "Empowering the civil society in Kazakhstan through improvement of chemical safety" on 7th August 2014 in Astana, Kazakhstan.

Randall, P, Ilyushchenko, M, Lapshin, E, Kuzmenko, L, 2007, "Case Study: Mercury Pollution near a Chemical Plant in Northern Kazakhstan." Available from: http://pubs.awma.org/gsearch/em/2006/2/randall.pdf

Robles I, M. G. Garcia; S. Solis (2012). Electroremediation of Mercury Polluted Soil Facilitated by Complexing Agents. *International Journal of Electrochemical Science*, Volume: 7 Issue: 3 Pages: 2276-2287.

Rom, W.N. ed. (1992). *Environmental & Occupational Medicine*. 2nd ed. Boston: Little Brown and Company.

Sir, M. (2015). Results of environmental sampling in Kazakhstan: heavy metals in sediments and soils (Final report). In: Toxic Hot Spots in Kazakhstan. Arnika – Toxics and Waste Programme, Prague – Karaganda, 2015. Available at: http://english.arnika.org

Sir, M. (2015 a). Results of environmental sampling in Kazakhstan: mercury, methylmercury, PCBs and OCPs contamination of the River Nura (Final report). Contaminated sites and their management. Case studies: Kazakhstan and Armenia. J. Petrlík. Prague-Karaganda, Arnika - Toxics and Waste Programme.

Stein ED, Cohen Y, Winer AM. (1996) Environmental distribution and transformation of mercury compounds. *Crit Rev Environ Sci Technol.* 1996; 26:1-43.

Tipping, E, et al, Critical Limits for Hg (II) in soils, derived from chronic toxicity data, *Environmental Pollution (2010)*, doi:10.1016/j.envpol.2010.03.027

Ullrich, S, Ilyushchenko, M, Kamberov, I, Panichkin, V, Tanton, T, (2004), "Mercury pollution around a chlor-alkali plant in Pavlodar, Northern Kazakhstan", *Materials and Geoenvironment*, Vol 51, Iss 1, pp 298 – 301.

Ullrich, SM, Ilyushchenko, MA, Uskov, GA, Tanton, TW, (2007), "Mercury distribution and transport in a contaminated river system in Kazakhstan and associated impacts on aquatic biota", *Applied Geochemistry*, Vol 22, Iss 12 pp. 2706-2734. Available from http://www.sciencedirect.com/science/article/pii/S0883292707002090

UNEP (2013) Minimata Convention on Mercury: Text and Annexures. Available from, http://www.mercuryconvention.org/Portals/11/documents/Booklets/Minamata%20Convention%20on%20Mercury_booklet_English.pdf

UNEP/ISWA (2015) *Practical Sourcebook on Mercury Waste Storage and Disposal.*

UNITAR (2014) http://www.unitar.org/thematic-areas/advance-environmental-sustainability-and-green-development/mercury-0

United Nations (2015).United Nations *Enable* website provides generic information on the process of treaty adoption. http://www.un.org/disabilities/default.asp?id=230

URS Dames and Moore (2001) Summary Report. Environmental Site Assessment and Preliminary Risk Assessment for Mercury. Kodaikanal Thermometer Factory, Tamil Nadu. Prepared for Hindustan Lever Limited (HLL), Mumbai. 24 May 2001.

URS Dames and Moore (2002) Environmental Site Assessment for Mercury. Kodaikanal Thermometer Factory, Tamil Nadu. Prepared for Hindustan Lever Limited (HLL), Mumbai.

US DoE (2009) U.S. Department of Energy. Interim Guidance on Packaging, Transportation, Receipt, Management, and Long-Term Storage of Elemental Mercury. November 13, 2009. Prepared by Oak Ridge National Laboratory.

US EPA (1996) Mercury study report to Congress - Volume III: An assessment of exposure from anthropogenic mercury emissions in the United States - EPA-452/R- 96-001c, April 1996.

US EPA (2001) Water quality for the protection of human health: methylmercury. EPA-823-R-01-001, US EPA, Office of Science and Technology, Office of Water, Washington, D.C. 20460.

US EPA (2004) Mercury Response Guidebook (for Emergency Responders) http://www.epa.gov/mercury/spills/#guidebook

US EPA (2007) Treatment Technologies for Mercury in Soil, Waste and Water. Office of Superfund Remediation and Technology Innovation Washington, DC 20460.

US EPA (2012) Phytotechnologies for site cleanup. http://www.clu-in.org/download/remed/phytotechnologies-factsheet.pdf

US EPA (2014, 29-12-2014). "Mercury - Basic information." Retrieved 05-04-2015, 2015, from http://epa.gov/mercury/about.htm.

US Environmental Protection Agency, 2014, "Environmental Effects: Fate and Transport and Ecological Effects of Mercury", Available from http://www.epa.gov/hg/eco.htm

US EPA Region 9 (2015) http://www.epa.gov/region9/superfund/prg/

US Government (1998) Overview of Thermal Desorption Technology. An Investigation Conducted by Foster Wheeler Environmental Corporation and Battelle Corporation on behalf of the US government. Contract Report CR 98.008-ENV.

Veiga, M.M. and Baker R.F. (2004), Global Mercury Project Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners. Vienna, Austria: GEF/ UNDP/UNIDO, 2004, 294p.

Wang J., X. Feng, C. Anderson, W. N. Christopher (2012) Remediation of mercury contaminated sites - A review. *Journal of Hazardous Materials,* Volume: 221, 1-18.

Watson, A., Petrlík, J. (2015). "Dangerous State of Play – Heavy Metal Contamination of Kazakhstan's Playgrounds." Public Interest Consultants and Arnika – Toxics and Waste Programme. In: Arnika, EcoMuseum, CINEST 2015: Toxic Hot Spots in Kazakhstan. Monitoring Report. Arnika – Toxics and Waste Programme, Karaganda – Prague, April 2015.

Winder. C., and Stacey. N., (2004) Occupational Toxicology, Second Edition Chris Winder, Neill H. Stacey (ed) CRC Press; 2 edition (February 25, 2004).

WHO, 1990; Castoldi, 2001 cited in Hsiao, H, Ullrich, S, Tanton, T, 2009, "Burdens of mercury in residents of Temirtau, Kazakhstan I: Hair mercury concentrations and factors of elevated hair mercury levels", *Science of the Total Environment,* Vol 409, Iss 11, 2011, pp 2272-2280. Available from http://www.sciencedirect.com/science/article/pii/S0048969709012753

IPEN

a toxics-free future

www.ipen.org

ipen@ipen.org

@ToxicsFree