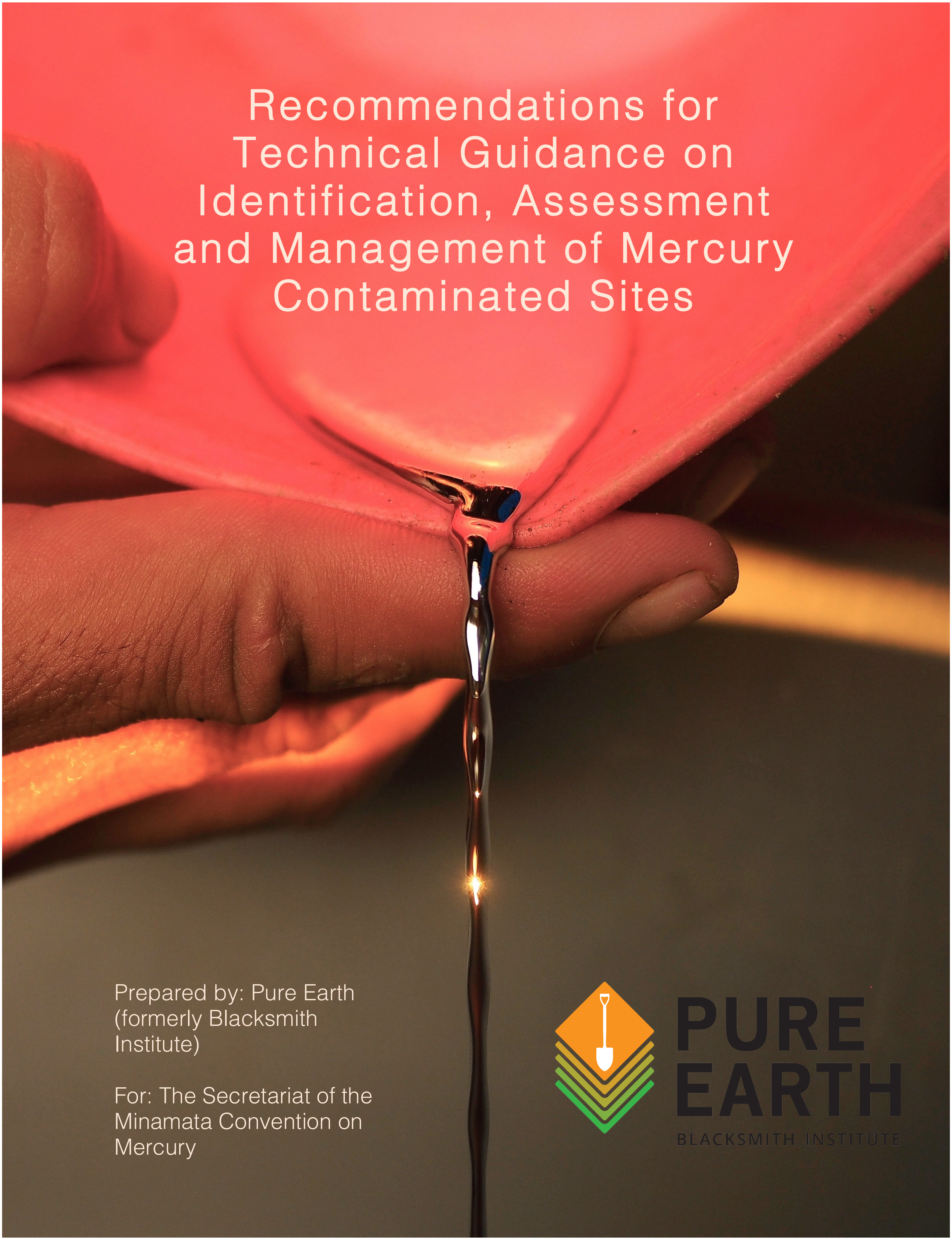
Recommendations for Technical Guidance on Identification, Assessment and Management of Mercury Contaminated Sites



Prepared by: Pure Earth (formerly Blacksmith Institute)

For: The Secretariat of the Minamata Convention on Mercury

PURE EARTH
BLACKSMITH INSTITUTE

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Photo cover: Gold miner pouring mercury in Indonesia. Photo by Larry C. Price.

ABOUT PURE EARTH

This document was prepared by Pure Earth (formerly Blacksmith Institute)—an international non-profit organization dedicated to solving pollution problems in low- and middle-income countries, where human health is at risk. To date, Pure Earth has implemented more than 70 projects around the world to prevent, mitigate or remediate pollution from industry and artisanal activities, including mercury releases from artisanal and small-scale gold mining.

In addition to designing and executing pollution management projects, Pure Earth manages the Toxic Sites Identification Program (TSIP). TSIP aims to identify and screen sites contaminated by toxic pollution in low- and middle-income countries, and to quickly and efficiently characterize the relative public health risks associated with such sites through a rapid on-site screening protocol. Information and data collected are shared with governments and are used to prioritize high-risk sites for remediation and other risk-reduction activities.

Pure Earth serves as the Secretariat to the Global Alliance on Health and Pollution (GAHP). GAHP is a collaborative body that facilitates the provision of technical and financial resources to governments and communities to reduce the impacts of pollution on health in low- and

middle-income countries. GAHP advocates for solutions that address pollution broadly, including indoor and outdoor air, water and contaminated sites. It initiates activities that reduce adverse health impacts caused by legacy pollution, helps actively polluting small-scale industries move to cleaner production practices and measures project performance based on health and economic outcomes. GAHP members include government ministries and agencies, bilateral organizations, multilateral organizations, not-for-profit organizations and academic institutions.

More information about Pure Earth is available at www.pureearth.org.
More information about GAHP is available at www.gahp.net

Acronyms

AMA – Advanced Mercury Analyzer
ASGM – Artisanal and Small-Scale Gold Mining
CVAAS – Cold Vapor Atomic Absorption Spectrometry
DMA – Direct Mercury Analyzer
GPS – Global Positioning System
ICP – Inductively-Coupled Plasma
ISM – Incremental Sampling Methodology
ITRC – Interstate Technology and Regulatory Council
NGO – Non-Governmental Organization
NIST – National Institute of Standards and Technology
PPE – Personal Protective Equipment
PPM – Parts Per Million
TSIP – Toxic Sites Identification Program
UNEP – United Nations Environment Programme
US – United States
USAID – United States Agency for International Development
USEPA – United States Environmental Protection Agency
WHO – World Health Organization
XRF – X-Ray Fluorescence

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EXECUTIVE SUMMARY

The Minamata Convention on Mercury represents a historic advance in the global effort to reduce the harmful effects of mercury pollution on public health and the environment. To ensure that this achievement produces its maximum potential benefit to all parties and stakeholders, it is important to provide governments with technical guidance on the identification, screening, assessment, management and remediation of mercury contaminated sites, as articulated under Article 12.

This document focuses primarily on the design and implementation of national contaminated site identification and screening programs, and on the roles of the public, private and civil society sectors to facilitate public outreach and education, and to ensure effective and efficient risk-reduction activities at mercury-contaminated sites.

Through the process of drafting this document, Pure Earth identified a number of comprehensive technical guidelines focused on the design of detailed assessments of mercury-contaminated sites and on remediation strategies. This document does not reiterate the findings of those reports, but notes the publication titles and provides citations for future review by the Secretariat and its expert working groups.

Pure Earth believes that a comprehensive approach to addressing mercury contamination must include actions to identify and reduce environmental health risks, and that such risks should be a primary factor in setting priorities for future actions. This guidance aims to facilitate concrete actions to reduce the impacts of mercury contamination, with a particular emphasis on environmental health risk identification and reduction strategies for low- and middle-income countries.

INTRODUCTION

This guidance document aims to facilitate decisions and actions to identify, assess and reduce risks from mercury-contaminated sites. It describes considerations, tools and strategies for contaminated site identification, site screening and management of sites contaminated by mercury. It focuses primarily on the design and development of national contaminated site identification and screening programs and on public engagement.

Article 12 of the Minamata Convention on Mercury states[i]:

1. *Each Party shall endeavour to develop appropriate strategies for identifying and assessing sites contaminated by mercury or mercury compounds.*
2. *Any actions to reduce the risks posed by such sites shall be performed in an environmentally sound manner incorporating, where appropriate, an assessment of the risks to human health and the environment from the mercury or mercury compounds they contain.*
3. *The Conference of the Parties shall adopt guidance on managing contaminated sites that may include methods and approaches for:*
    a. *Site identification and characterization;*
    b. *Engaging the public;*
    c. *Human health and environmental risk assessments;*
    d. *Options for managing the risks posed by contaminated sites;*
    e. *Evaluation of benefits and costs; and*
    f. *Validation of outcomes.*
4. *Parties are encouraged to cooperate in developing strategies and implementing activities for identifying, assessing, prioritizing, managing and, as appropriate, remediating contaminated sites.*

Since 2008, Pure Earth has implemented a global contaminated site identification and screening program titled the Toxic Sites Identification Program. The program and the protocols designed under it are based on Pure Earth’s many years of experience in contaminated site identification, screening, assessment and remediation. The program and its protocols also draw on many other established assessment programs described in this report. The TSIP program is designed specifically for suitability in low- and middle-income countries, and therefore may serve as a replicable model for new national contaminated site identification and screening programs developed under the Minamata Convention on Mercury.

Pure Earth recommends that actions to address mercury contamination focus particularly on identifying and reducing environmental health risks, and that such risks should be a primary factor in setting priorities for government actions. This guidance places a particular emphasis on environmental health risk identification and reduction strategies for low- and middle-income countries.

NATIONAL CONTAMINATED SITE IDENTIFICATION AND SCREENING PROGRAMS

The first step in the effective management of mercury-contaminated sites is the development of a robust national contaminated site identification and screening program. Such programs typically aim to catalog contaminated sites, screen them to preliminarily assess potential risks and compare risks across a variety of sites within a country. A national site identification and screening program allows public, private and civil society stakeholders to review relevant site information and prioritize further actions based on an understanding of the hazards and risks associated with each contaminated site.

Step 1: Defining the Scope, Goals and Terms of the Program

A practical first step in identifying, screening and ultimately addressing contaminated sites is to define the goals of a site identification and screening program and the meanings of key terms.

Defining the Scope of the Program

Having a clear understanding of the scope of a site identification and screening program will decrease the likelihood that time and resources are spent on activities that fail to advance the goals. The scope of the program should define any and all limiting factors, including the geographic area in which the program takes place and the chemicals that the program aims to identify and characterize. Other scoping issues and limitations to consider include:

- Anthropogenic contamination versus naturally occurring contamination
- Point versus nonpoint sources
- Organic versus inorganic contamination
- Contaminant concentrations above screening levels versus any concentration
- Direct risks to human health versus broader ecological risks
- Public vs. occupational health risks

Defining the Goals of the Program

A clear and concise statement of the goals of a contaminated site identification and characterization program will help to ensure that all

participants and stakeholders share an understanding of the program's objectives and are working towards the same end. A clear statement of goals can help ensure that all planned program activities are designed to advance the program's goals and do not waste time and resources on unnecessary actions. A statement of a broad goal such as "identify and characterize sites contaminated with mercury" is likely insufficient because it does not identify a specific objective regarding improvements on the status quo. A better goal statement will identify specific impacts of contaminated sites and describe what improvements the program aims to achieve.

The statement of the goal will influence the scope of the program and how activities are designed and implemented. For example, if the program's goals are primarily focused on hazard identification, but not necessarily risk assessment, this may influence the site identification and characterization protocol and the specific types of data that are collected. If the program's goals are explicitly related to understanding public health risks, rather than occupational risks or ecological risks, this could shape how a "site" is defined, and how environmental sampling and remediation activities are designed and implemented in the future.

Contaminated site identification and screening programs should include and emphasize the goal of preliminarily characterizing public health risks. Programs should aim to go beyond simple hazard identification, and aims to generate data that allows relevant stakeholders to compare relative public health risks to prioritize future site remediation or other risk-reduction actions.

The goal statement of an initial site identification and screening program could read, for example: "The goal of the initial site identification and screening program is to identify sites where mercury contamination exists above (list relevant screening level) and where human or ecological health is potentially at risk, and to provide a preliminary assessment of the relative severity of those risks across all identified sites for the purpose of prioritizing further contamination assessment, management and risk-reduction actions."

Defining the Term "Site"

The definition of a site may depend, in part, on the goals of the contaminated site identification and screening program. If the program aims to identify and characterize public health risks from mercury

contamination, the definition of the site and its boundary may be informed by the way in which people use the land, plants and animals around a contaminated site. The types of interactions between people and the site will likely influence the mercury exposure pathway into the human body. Exposure pathways include: dermal contact, inhalation, direct ingestion (such as ingestion of contaminated water, soils or dust) and ingestion of contaminated food. Understanding the exposure pathways at sites will provide information about where people are exposed, and thus may inform the program's architects about how broadly to define a "site."

At a minimum, a site should not be limited to only those soils or other land-based materials presently contaminated with high levels of mercury. The risks from mercury-contaminated sites often extend well beyond the most contaminated terrestrial materials into nearby lakes, rivers and oceans. In many cases, mercury may be migrating away from the original source or area of highest contamination. The actual location where people are exposed to mercury may be quite far from the source of contamination. For example, if mercury contamination exists upstream from a lake or river where people fish, the definition of the site may extend into the fishing area, and environmental or biological sampling may be appropriate at the downstream location.

A reasonable definition of a contaminated site may be "anywhere the contaminant has come to be located and exceeds relevant screening thresholds or maximum recommended concentrations." However, the definition of a "site" should not be so broad as to be unworkable. For example, "the Caspian Sea" or "the Donbas coal mining region of Ukraine" are not useful site definitions because they encompass too large an area. The site definition should be constrained to a limited geographic area or location as much as possible. Note that in some cases, a specific cause of mercury contamination may result in several discrete contaminated sites.

Defining the Term "Contamination"

Low levels of mercury are ubiquitous in the earth's atmosphere, surface water and soil resulting from anthropogenic and natural activities. Mercury can travel around the globe in the atmosphere and be deposited far from its original release point. It is therefore important to establish a threshold of contamination that limits the scope of a national contaminated site identification and screening program. Such a threshold serves to "screen out" sites where contaminant levels are low and do not pose significant risks, and are referred to as "screening levels."

Screening levels are used in remediation programs and projects to provide a reference point for priority setting. They are used to screen out sites (or areas within sites) that are low-risk and therefore low-priority. A separate screening level may exist for each species of chemical in each type of environmental or biological medium. For example, screening levels for elemental, inorganic and organic mercury may differ respectively, and the screening level for each species may depend on whether mercury exists in industrial soil, residential soil, agricultural soil, sediment or other media. It is possible that a single site may have several screening levels at different locations due to different land uses around the site.

There are a number of well-established screening level systems internationally, and most industrialized countries have developed their own systems. They are based on the following general approach: health data for a particular chemical is combined with assumptions about typical exposures and with policy judgments about acceptable levels of risk to provide guidance on acceptable concentration levels of contaminants in various environmental or biological media.

If national screening levels for mercury do not exist in a given country, it is possible to adopt another nation's screening level system. In this case, it is best to adopt screening levels from countries that make the research and justifications behind their values transparent. It is also important to understand of what assumptions are used in the development of screening values. For example, residential risk screening levels in the United States may be based on exposure parameters (such as a daily soil ingestion rate) that do not apply to a residential scenario in a low- or middle-income country.

Because of the ubiquitous nature of mercury, it is also important to establish a background concentration of mercury. This is most relevant in soil, yet may be relevant in sediment and surface water depending on the type of mercury contamination and the media affected. This not only helps define the site, it also may become necessary if more detailed risk assessment is conducted. A statistically robust background concentration may not be available, but regional backgrounds or even literature values for earth's crust (for soil), or atmospherically-derived sediment values will generally be sufficient for initial screening.

Step 2: Identifying Potentially Contaminated Sites

Once a country program's goals, scope and terms have been defined, a practical next step is to produce a national database of sites that currently host or have hosted industries or activities that potentially used or released mercury in the process. Such industries may include, but are not limited to:

- Mining, including mercury, gold and other precious and non-precious metals
- Chlor-alkali plants
- Coal-fired power-plants
- Cement production
- Steel and other non-ferrous metals industries
- Production of pig iron
- Chemical production, including fertilizers, pharmaceutical products and catalyzers
- Batteries and fluorescent light production, recycling or disposal
- Other waste industries, including medical waste.

In countries where artisanal and small-scale gold mining (ASGM) is prevalent, special attention should be paid to identify current or former ASGM sites. ASGM processes frequently involve the use of mercury to separate gold from other materials and may cause, or have caused significant releases.

After a database of potentially contaminated sites is created, it can serve as a platform to collect additional information about each site to be added as screening, characterization or other types of site assessment activities that are conducted. A contaminated sites database could be developed by governments, NGOs or private consultants. Pure Earth has a model database that could be replicated for government agencies. Additional details regarding the content and format of such databases are discussed further below.

Potentially contaminated sites can be identified through a variety of resources, including:

- Government reports on industrial activities, sites and corporations
- Newspaper and other media reporting on industries, chemicals or health impacts
- Medical or environmental reports on pollution-related illnesses or impacts to flora or fauna

- Observations and reporting from the public, private or civil society sectors
- Academic research on chemical contamination, health impacts or other indicative factors
- Reports from bilateral or multilateral organizations
- Interviews with community members
- Current or historical photographs
- Records of hazardous material usage such as receipts from chemical purchases or waste manifests

Step 3: Designing an Initial Site Screening Protocol to Confirm Mercury Contamination and Preliminarily Assess Potential Public Health and Environmental Risks

Once potentially contaminated sites have been identified, governments should characterize relative risks at sites and prioritize further actions by conducting initial site screenings of each site. Such screenings should have the following objectives: confirm the presence of mercury, define the borders of the contaminated site, estimate the scope and severity of the contamination, assess the migration route from the source to other environmental media, characterize the types of interactions between people and contaminated media, analyze potential pathways of human exposure (e.g. inhalation, incidental ingestion, fish consumption or dermal contact) and estimate the number of people exposed or potentially at risk of exposure.

Before initial site screenings begin, a uniform protocol for initial site screenings should be developed and adopted nationally. The development of the protocol can be led by government, NGOs or private consultants, but should be managed by persons familiar with the chemical properties of mercury, the public health and environmental implications of mercury contamination and contaminated site risk assessment methods. It is important that a single uniform protocol be adopted and implemented across the country. If screening methodologies, equipment or reporting requirements differ from site to site, or from region to region within a country, the relative risks presented by various sites cannot be accurately compared and the data collected cannot be effectively used to prioritize remediation or other risk-reduction activities at high-risk sites.

Initial site screenings, as described below, aim to help government and other actors prioritize future actions and allocate time and resources to

high-risk sites. Site screenings are typically conducted during a one or two day site visit, and are not designed to provide the level of detail about hazards and risks that would be necessary to design a remediation plan without further assessment.

General Sampling Notes

Sampling and sample analysis are critical elements in the initial site screening process. Sampling and analysis should be conducted by trained professionals in accordance with a carefully designed screening protocol and using internationally or nationally accepted methods. As with other elements of the screening protocol, sampling and analysis should be conducted uniformly at all sites, and should be subject to rigorous quality assurance and quality control measures. Deviations from standard protocols or mistakes made during sampling can result in data that mischaracterizes hazards and risks. Proper training of field investigators is necessary to ensure uniform sampling.

A uniform sampling protocol should, at a minimum, include instructions on the following:

1. Identifying the person taking the sample
2. Labeling samples with consistent terminology
3. Location of sample-taking, using GPS if possible
4. Number of samples to be collected
5. Sampling frequency
6. Sample sizes (volume or weight of material to be collected)
7. Sample depth
8. Time, date and duration of the sampling
9. Sampling method
10. Appropriate sampling tools and decontamination of tools, if needed
11. Collection of Quality Assurance samples (i.e. field “blanks” or duplicates)
12. Sample containers
13. Preservation of samples during transportation and storage
14. Chain-of-custody of samples
15. Selection of laboratory for analysis
16. Generic health and safety plan for protection of workers collecting samples

Types of media sampled at mercury-contaminated sites may include the following liquids, solids and gases:

1. Liquids

    a. Leachate from dumpsites and landfills
    b. Liquid collected from spills
    c. Water (surface water, drinking water and industrial effluents)
    d. Biological materials (urine, blood, breast milk)
2. Solids
    a. Soil, sediment, rubble, sewage sludge and compost
    b. Products and waste containing mercury (mine tailings, fly ash, sludge, industrial residues)
    c. Human hair and nails
    d. Plants
    e. Animal tissues (particularly fish)
3. Gasses
    a. Indoor air
    b. Outdoor (ambient) air

Soil Sampling Methods

Two types of soil samples are commonly collected during an initial site screening: “discrete” (sometimes called “targeted”) samples and “composite” samples. Discrete samples contain only soil from a single geographic point at the site and are used to reveal the contamination level at that point only. Discrete samples are useful at specific points where there is believed to be a high-risk of exposure, such as areas where children play, or at other locations where a specific concentration value is needed. Composite samples comprise a mixture of multiple samples of equal volume, collected at equal intervals across a sampling area and homogenized in a single sampling bag. Composite samples are used to identify whether contamination exists anywhere in a larger area.

At mercury-contaminated sites, it is common for mercury levels to vary significantly from one location to another. This can make it difficult to accurately identify and characterize risks, and can lead investigators who only conduct discrete sampling to inadvertently miss contamination hotspots. The composite sample is advantageous in this context because it captures a large area without the cost of analyzing many samples. It is important to remember that the mercury level found in a composite sample does not represent a uniform level of contamination across the composite sampling area. Each sample mixed into the homogenized composite sample will pull the concentration of the entire sample up or down. It is possible that a composite sample that shows elevated levels of mercury, and is comprised on 10 sub-samples, actually has 9 sub-samples with low levels of mercury and a single sub-samples with high levels of mercury.

Nevertheless, the composite sample is a cost-effective tool for identifying contamination and assessing possible human exposure pathways during the initial site screening.

For the purpose of an initial site screening, Pure Earth's sampling protocol under the Toxic Sites Identification Program instructs site investigators to begin the soil sampling process by dividing a potentially contaminated site into several "sectors" based on land use in different areas (typically 2 or 3 for small sites, and up to 6 for larger sites). For example, if a potentially contaminated site includes an industrial area, an agricultural area and a several residential areas all in close proximity, each of these land use areas would be defined as a discrete sector for the purpose of sampling. Site investigators are instructed to collect a composite soil sample (comprising at least 6 sub-samples) from each sector to provide a preliminary estimate of the scope and severity of contamination. Composite samples from larger sectors may require up to 15 or 20 homogenized sub-samples.

Pure Earth's TSIP sampling protocol is designed to assess public health risks and specifically instructs site investigators to select sampling sectors where public exposures are likely. The protocol assumes that public exposures are unlikely on industrial properties where public access is restricted. The protocol therefore instructs site investigators to identify likely migration routes from the contamination source to public or residential areas and conduct sampling of the media with which the public will have the most direct contact (for example, residential dust, residential tap water, playground soil, road dust, agricultural products, etc.). Notice in Image 1 below that the investigator did not create a sampling sector for the industrial site at the center of the map but chose instead to sample public areas immediately surrounding the industrial site.

Image 1. An industrial contamination source (center) and six sampling sectors in surrounding public areas with differing land uses

Image 2. An abandoned source (center) now accessible to the public surrounded by various land uses

A variety of similar rapid risk assessment protocols have been developed by other agencies and may provide useful guidance, including:

- Persistent Organic Pollutants: Contaminated Site Investigation And Management Toolkit, published by the United Nations Industrial Development Organization[ii]
- Guidance For Identifying Populations At Risk From Mercury Exposure, published by the World Health Organization and United Nations Environment Programme[iii]

Sampling of Fish and Other Indirect Media

Consumption of fish contaminated by methylmercury is one of the most prevalent human exposure pathways for mercury. While initial site screening will likely rely on relatively inexpensive soil and air sampling, fish sampling is a useful tool for assessing community risks. Fish samples can be compared against fish populations from uncontaminated waters as a control. Concentrations of mercury in fish can also be compared against national and international reference levels. The United States Environmental Protection Agency (USEPA) has set a monthly consumption guideline of 0.22 parts per million (ppm) of methylmercury, and the World Health Organization and European Commission suggest that fish containing more than 1 ppm of mercury not be traded or sold. Additional screening and reference levels are described on page 32 of the Guidance For Identifying Populations At Risk From Mercury Exposure, published by the World Health Organization and United Nations Environment Programme.[iv]

Although the contaminant of primary concern in fish tissue is methylmercury, total mercury is a close approximation to methylmercury in tissue. It is generally cheaper to analyze fish tissue for total mercury than for methylmercury, and thus analyzing for total mercury in fish tissue is a practical cost-saving measure.

To determine exposure levels among community members based on fish consumption, the following information must be gathered:[v]

- The daily average quantity of fish consumed (grams), for different meals. Note that quantities may differ depending on the meal (i.e. breakfast, lunch, dinner).
- The frequency (number of meals per day, per week) that fish is consumed.
- The relative proportion of different fish species consumed (i.e. the target species). Note that target species may differ depending on season (i.e. wet versus dry) in many countries.

- How the fish is prepared before consumption (i.e. fillets versus whole body, and whether skin is left on or taken off)
- Size (length and weight) of the fish consumed.
- The tissue mercury concentration (ppm whole muscle in wet weight) of the target species consumed. Note that if more than one species comprises a major part of dietary fish consumption, mercury concentration must be determined for each target species. [vi]

As with all other forms of sampling, fish sampling should be conducted in conformance with accepted guidelines and coordinated with the lab that will conduct the analysis.

The following reports provide additional guidance on appropriate fish sampling methods:

- The US State of Utah Department of Environmental Quality Division of Water Quality report: Standard Operating Procedure for Collection and Preparation of Fish Tissue Samples for Mercury Analysis [vii]
- Page 272 of the Global Mercury Project report: Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners[viii]

Human Biological Sampling

Human biological sampling is typically not necessary or recommended during the initial site screening, but may be appropriate during a follow-up detailed site assessment. Special considerations must be taken when collecting, analyzing and publishing human biological samples. No human sampling should be conducted without a well thought out plan to communicate the results to the participants. Human biological samples should only by taken from people with their full consent and understanding of the program and the manner in which the sampling data will be handled, published or otherwise used. Human biological sampling should be approached with particular sensitivity to, and consideration of privacy and ethical considerations. Individuals may require support or counseling if biological samples reveal high levels of mercury exposure. Human biological sampling should only be conducted by properly trained medical professionals and may require the approval of an institutional review board. It is recommended that any human biological sampling be conducted in collaboration with, or approval from the national, regional or municipal health agency.

Additional information about appropriate human biological sampling methods is available from the following reports:

- Page 40-49 of the World Health Organization and United Nations Environment Programme report: Guidance for Identifying Populations at Risk from Mercury Exposure[ix]
- Page 121 of the Global Mercury Project report: Protocols for Environmental and Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners[x]

Laboratory Analysis of Samples

A variety of accepted analytical methods are available for the analysis of mercury species and concentrations in samples. International methods for analyzing mercury have been developed by the International Organization for Standardization and the European Committee for Standardization, among others. Many national methodologies have also been created, including by USEPA, which has a detailed description of analytic technologies appropriate for analysis of mercury species and concentrations at the following website: https://clu-in.org/characterization/technologies/.[xi]

Field Analysis

A variety of field tools are available that can identify mercury in soil, sediment and air and provide instant analysis of mercury concentrations. However, even with such tools, sampler should understand generally what forms of mercury are being assessed at the site before they begin. For example, mercury from a recent spill would predominantly be in the elemental form and could be assessed by mercury vapor analyzer or by field portable X-ray fluorescence (XRF) analyzer. However, mine tailings, fly ash, or other waste products may have very little elemental mercury, thus the mercury vapor analyzer will likely not be useful and the XRF may be the only field tool that provides representative results. An understanding of the forms of mercury likely present at the site should dictate the sampling process and analytical tools.

Before conducting a site screening or detailed assessment using field analysis tools, it is wise to prepare a work plan specific to the site. The work plan not only guides the samplers in the field, but helps samplers adapt to changes or unexpected events. A work plan can be fairly simple, or highly complex if the site is already well understood and the screening or assessment involves many actors. A work plan can also serve as an

agreement with site stakeholders, identifying an agreed upon program which adheres to a budget and the agreed expectations of the stakeholders.

A basic work plan should have the following elements:

- Introduction and site background
- Objectives (general program objectives)
- Data quality objectives (i.e. what detection limits are needed, will the proposed analysis tools work?)
- General plan of the proposed work (this should be a simple walk through of the sampling actions)
- Sampling protocol (specific to the type of media and contaminant)
- Conclusions (this might include how the results will be interpreted, it might identify a basic conceptual site model)
- Health and Safety Plan (This can be included in the work plan in the text or as an attachment. Safety of the sampling team as well as the local community should be the priority, and the sampling plan should not put either at risk of exposure to contaminants or physical hazards.)

Safety and Personal Protective Equipment

Site investigators should be aware of, and plan for potential hazards and health risks at contaminated sites and have access to essential personal protective equipment (PPE). If investigators may be exposed to mercury levels above occupational health and safety standards, they should bring and wear personal protective equipment.

Basic equipment includes:

- Boots (closed shoes – open toes shoes must not be worn)
- Protective clothing such as long sleeve pants and shirt
- N-95 respirator: dusk mask must be worn whenever there is potential exposure to hazardous dust. These respirators should only be used once (they should NOT be cleaned or washed and/or reused)
- Respirator to avoid exposure to mercury vapor (a full description of recommended respirators is available from the U.S. Centers for Disease Control and Prevention at https://www.cdc.gov/niosh/npg/npgd0383.html)
- Goggles or safety glasses: must be worn whenever there is the presence of particles in the air that may damage the eyes (for

example, flying debris or significant amounts of dust) or when there is the risk of splash or splatter of contaminated substances
- Gloves: if touching or picking up any material that may be contaminated

Other PPE may be identified as relevant to a specific site. PPE should be inspected before every site visit and it should be cleaned, repaired or replaced if needed.

Site investigators that identify visible elemental mercury can occasionally “follow” visible traces back to the mercury source. However, when elemental mercury is visible, the sampler may be exposed to mercury vapor depending on the mercury volume, proximity, wind patterns and whether it is inside or outside. Any disturbance of soil or other media with visible elemental mercury may exacerbate the contamination and associated risks.

XRF Analyzers

Field portable XRF analyzers provide instant sample analysis and are incredibly powerful and valuable mercury screening and assessment tools. XRF analyzers use an x-ray tube to generate x-rays that are delivered to the sample. Each heavy metal in the sample, after being excited by the x-rays, returns an element-specific signal back to the XRF unit. The XRF then uses internal software to prepare a spectrum for that sample, which is in turn calculated to provide a concentration of each metal in the sample. Although the presence of certain metals in a sample can cause interferences with the XRF analysis resulting in inaccurate readings, mercury does not have any significant interferences with other metals.

In addition to the benefits of portability and instant sample analysis, XRFs also analyze samples for other metals. Mining sites and waste sites (fly ash, landfills, electronics recycling) may be contaminated by other heavy metals of concern beyond mercury, including arsenic, lead, cadmium and chromium. Understanding cumulative risk from other contaminants even at an initial screening level is an important for site-prioritization.

The XRF should have three or more “standards” (samples provided by the manufacturer or lab with known metal concentrations) to analyze for calibration. Standards should have two or three different levels of concentrations for the target metals (e.g. NIST 2709, 2710 and 2711). For an initial site screening, the operator may only need to analyze the

standards once at the beginning of the day and once at the end of the day to provide qualitative assurance that the device is reading accurately. For more quality assurance, the standards could be analyzed several times a day with the results being incorporated into a regression analysis that provides a correlation and an understanding of the level of error in the sample set.

XRF analyzers are often used for soil sampling, but can also be used for sediment sampling. Special attention should be paid to drying sediment samples when assessing mercury. Wet soil samples or sediment samples can have up to 20% error due to moisture interference (USEPA Method 6200). However, elemental mercury in samples will volatilize at standard temperature and pressure. Volatilization increases as the temperature increases. Sediment or wet soil samples should therefore be dried slowly and with as little temperature increase as possible. USEPA 6200 method provides additional guidance on drying samples. For initial site screenings, XRF analysis of wet samples may be sufficient to confirm the presence of mercury. The 20% error potential in wet sampling may be preferable to the potential loss of mercury mass from heating and drying the sample. For example, background mercury in the earth's crust is generally below 1 ppm, thus any XRF reading above the detection limit (generally 15 to 20 ppm) suggests that the soil is contaminated with mercury unrelated to background levels. Even with a 20% error, this is enough to identify where contamination exists.

Samples for XRF analysis can be collected in specially designed XRF sampling cups, or in any clean, new, sealable plastic bag. XRF cups are useful for long-term storage, cataloging samples and analyzing samples on an XRF stand in a mobile lab. Plastic bags may be preferable if cups are not available or cost prohibitive. Samples in plastic bags can be analyzed directly through the plastic. In addition to analyzing collected samples, an XRF unit can be used to analyze in situ materials by placing the analysis end of the unit directly against the ground or other sampling medium (with a piece of plastic to between the XRF unit and the sample to protect the XRF unit and keep it clean). This method allows for rapid sampling of many locations.

The USEPA method 6200 and the Interstate Technology and Regulatory Council (ITRC) guidance document on Incremental Sampling Methodology (ISM) provide detailed XRF and sampling protocols. Popular XRF models include those manufactured by Niton and InnovX, among others.

XRF Safety
XRF analyzers can be dangerous if handled improperly. All site investigators that handle an XRF should receive training in proper XRF use and safety. Most manufacturers have a device-specific manual or standard operating procedure that includes safety guidelines. Field portable XRF analyzers made before 2006 (approximately), may have contained an internal continual radiation source. More recent models use x-ray tubes and create less potential for radiation exposure to the operator. Models with x-ray tubes may require fewer registrations or certifications by governments, and are generally easier to bring through customs while traveling.

Mercury Vapor Analyzers
Mercury vapor analyzers, sometimes called mercury "sniffers," are powerful field analysis tools. They use ultra-violet light (254 nanometer wavelength) to excite mercury atoms in air, which in turn provide a signal relative to the mercury concentration. This is often referred to as cold vapor atomic absorption spectrometry (CVAAS).

The WHO screening level for chronic residential mercury exposure is 200 ng/m^3. Mercury vapor analyzers with detection limits below 200 nanograms per meter cubed (ng/m^3) are therefore best for assessing human exposure risks. Mercury vapor analyzers with higher detection limits can be useful for source identification but are less well suited for risk assessment. Mercury vapor analyzers are particularly helpful when used in conjunction with XRF analyzers. The vapor analyzer can quickly identify potentially contaminated areas, and the XRF can then confirm actual mercury concentrations in those areas.

Newer mercury vapor analyzers with low detections limits include the Lumex RA 915, Jerome J505 by Arizona Instruments, and the Tracker 3000 by Mercury Instruments. These types of devices are robust, frequently have data storage capacity and are easy to setup.

Government agencies with limited resources may consider looking for the Jerome 431X mercury vapor analyzer. This is an older model that was commonly used throughout the United States. It is relatively inexpensive, robust and was used in many elemental mercury cleanup projects. Although it generally does not have the detection limits to meet the data quality objectives for chronic residential exposures, it is likely cheaper to

buy or rent than other models and may prove useful for source identification where concentrations exceed 1000 ng/m^3.

Laboratory Analysis Using Thermal Decomposition/Atomic Absorption

The XRF and mercury vapor analyzers are the mainstay of mercury analysis in the field. However, the use of semi-portable laboratory-grade equipment is becoming more common. The USEPA method for analysis of mercury in solids, liquids, and even in vapor (Method number 7473) uses heat to desorb mercury from the sample medium, carry the mercury vapor in a gas medium, collect mercury on a gold surface. The mercury is then subjected ultra-violet light to excite mercury atoms and retrieve a signal relative to the total mercury concentration. This is also referred to as atomic absorption and can provide near-laboratory-grade results with proper calibration and operation. This type of mobile lab system can be developed if a fixed lab is unavailable.

The Milestone DMA-80 is an example of a semi-portable atomic absorption device. It can run approximately 40 samples in a carousel with about 5 minutes per analysis with very little sample preparation. The DMA-80 can be used without a carrier gas, which makes the device even more portable. The device can be setup on a counter or desk in a small office or tent, and requires an hour or so to calibrate. Samples do need to be weighed which includes some processing that decreases the efficiency of the sampling team. Samples of all media can be analyzed in these types of devices, even vapor samples can be collected in manufacturer-specific sorbent tubes that fit in the carrousel.

There are other similar atomic absorption devices available, such as the LECO AMA 254 and the Nippon MA-3000. Each of these have similar set-up, calibration, and operation requirements.

The Lumex RA 915+ with oven attachment can be used for the USEPA Method 7473, but the setup is more complicated and the operation is less efficient than the Milestone, LECO, or Nippon devices. In this case, the Lumex can be used for both direct read vapor or can be setup in a mobile lab to analyze various types of sample media. This could a cost effective, yet project efficiency is significantly reduced.

Additional field tools mostly for liquids may include pH, conductivity, oxidation-reduction potential, sulfate/sulfite reagent kits, dissolved oxygen,

and thermometer. These can be important tools for assessing methylation potential in a surface water body. Or they can also identify the potential for dissolved phase metals in a surface water or groundwater.

Fixed lab analysis may be an option for the project. If so, there are a variety of analytes or methods that can be employed to provide a more detailed and accurate risk assessment. For example, methylmercury could be analyzed in sediment or water to determine if methylation is occurring. However, analysis of total mercury in fish tissue is a reasonable surrogate for methylmercury in tissue, because most of the mercury in tissue is in the methylated form. Other specific analyses could include mercury speciation, mercury bioavailability, synthetic leaching procedure, or even bioavailability-specific analyses.

Estimating the Populations at Risk for Sites and Samples

Pure Earth's global Toxic Sites Identification Program instructs site investigators to estimate the potential population at risk at each sampling location. For discrete samples, the population at risk is the number of people that likely interact or come into contact with the sample location on a daily basis. For a composite sample, the population at risk is the number of people that likely interact or come into contact with the composite sample sector on a daily basis. Estimates of the population at risk from each sample allow reviews to assess the relative numbers of people that are interacting with different levels of contamination. Additionally, site investigators are instructed to provide an estimate of the total population at risk from the entire area suspected of contamination. These estimates are a useful tool in evaluating the potential scope and severity of public or occupational health risks at the site.

Step 4: Designing a Database for Initial Site Screening Information and Data

Developing a national database of mercury-contaminated sites allows a government to not only store, share and display information regarding contaminated sites, but also to analyze and compare the relative risks among various sites and prioritize sites for further action.

A contaminated sites database should be designed to capture any and all information gathered during the initial site screening process. Such a database should ideally capture the following information about each site:

1. A site name
2. The state, province, county, or other administrative district in which the site is located
3. The date of the initial site screening and the date of any additional assessment, characterization or remediation work conducted at the site
4. Location data (GPS coordinates) for any significant locations around the site, possibly including the location of an industrial source, each sampling point, any other high-risk areas (e.g., nearby schools, markets, playgrounds, high-traffic areas, fishing areas, and others.
5. A narrative description of the site location, boundaries, geographical features, geological features, hydrological features, and other physical properties
6. A narrative description of permanent or seasonal water bodies (streams, rivers, lakes, oceans) that exist on the site, run through the site, or may collect water from the site, including any water bodies within the same catchment basin or drainage of the site.
    a. This section should also include a description of how the contamination or source of contamination relates to the topography and slope of the site
7. A narrative description of the source of contamination, the process by which the site became contaminated, the history of the contamination and any other relevant information regarding mercury uses and releases at the site
8. A narrative description (or pull down menu) of human uses of the site and adjacent areas (e.g. agricultural production, industrial uses, commercial uses, schools, play areas, transportation uses, etc.)
9. A narrative description of any known human health impacts from the mercury contamination or suspected links between illnesses and the site
10. A narrative description of any other contaminants known or suspected to exist on or near the site
11. Sampling data
    a. For each sample, a description of the sample context and the results sample analysis should be included. This includes:
        i. Description of sampling equipment
        ii. Description of sampling methodology
        iii. Location of each sample using GPS latitude and longitude coordinates
        iv. Narrative description of the sample location (e.g. public dirt road in front of X gold shop) and any relevant factors regarding the (e.g., sample location is a

playground with daily use by many children under five years of age)

v. An estimate of the number of people who regularly come into close proximity to that sample location (i.e. how many people work, walk, play or otherwise interact with that specific location on a daily basis.)
vi. Description of the sample material (river sediment, workshop dust, agricultural soil, etc.)
vii. Description of the sample depth
viii. Mercury species of each sample
ix. Total mercury concentration of each sample
    1. NOTE: it is important that sample concentrations for each sampling media in the database use the same units. Soil and sediment concentrations are typically measured in parts per million (ppm) or milligram per kilogram (mg/kg). Concentrations in water are measured in micrograms per liter (µg/L). If different sites report concentrations using different units, the concentrations and associated risks are difficult to compare.

12. A narrative description of all interviews conducted or other information gathered from local residents, health officials, municipal authorities, business, non-government organizations and other relevant stakeholders
13. Attachments and links to additional resources describing the site context, history, contamination, uses, future plans, or other pertinent information
    a. Ideally, the database would allow users to upload or link to PDFs, photos, field notes, documents, spreadsheets, lab reports and other media.

In addition to simply storing information and data gathered during initial site screenings, national databases can be designed to analyze site information and contamination data to estimate relative human health risks. Algorithms can be embedded in such databases to generate a relative risk score for each site. Such analytical tools can help governments prioritize sites for further assessment and risk-reduction activities.

Our not-for-profit organization Pure Earth (formerly Blacksmith Institute) developed a global toxic sites database and risk analysis algorithm under its Toxic Sites Identification Program (TSIP). The TSIP has operated since

2008 with support from the European Commission, the World Bank, USAID, Green Cross Switzerland and the Asian Development Bank. As of October 2016, assessments had been completed through TSIP at more than 2,600 sites in 65 countries, including 359 assessments of mercury-contaminated sites.[xii]

The TSIP database includes an algorithm embedded in the software that generates at relative risk score from 0 to 10 for each site. While this score does not definitively characterize the risks posed by a site, and is based only on preliminary screening data, it is a helpful tool for risk-based prioritization of contaminated sites. The risk analysis algorithm developed by Pure Earth may serve as a model for national databases and is described in more detail in the paper: Approaches to systematic assessment of environmental exposures posed at hazardous waste sites in the developing world: The Toxic Sites Identification Program.[xiii]

Step 5: Prioritization of Sites for Detailed Assessments, Site Remediation and Other Risk-Reduction Activities

Once potentially contaminated sites have been identified and screened to confirm the presence of mercury contamination and assess possible health and environmental risks, high-risk sites should be prioritized for more detailed assessments and risk-reduction projects.

Detailed site assessments require a more intensive environmental sampling regime than the initial site screening and aim to provide a complete understanding of the source of contamination, levels of contamination along all migration routes, exposure pathways and exposures among receptor communities. This level of detail allows the assessment team to develop a conceptual site model, which demonstrates through a visual map or graphic how the contamination moves through the environment to the receptors. In the design of a detailed site assessment, the assessment team should be aware of the most prevalent exposure pathways related to mercury-contaminated sites: occupational elemental mercury vapor inhalation; incidental ingestion of mercury-contaminated soil; and methylmercury ingestion from contaminated food, especially fish.

It is recommended that teams designing and conducting detailed site assessments at ASGM sites review the suggested protocols and findings of the Global Mercury Project report: Protocols for Environmental and

Health Assessment of Mercury Released by Artisanal and Small-Scale Gold Miners.

PUBLIC PARTICIPATION AND COMMUNITY ENGAGEMENT

Public participation should be emphasized throughout the site identification, screening, assessment and remediation process. Public participation in planning and decision-making processes is critical for avoiding potential unforeseen delays, costs, conflicts and misconceptions. The fundamental tenet of public participation in the environmental context is that all persons who are potentially interested, concerned, or affected by an action should have opportunity to participate in decision-making processes.

Public participation is essential to ensure that actions affecting public health and the environment adhere to standards of environmental justice. Communities affected by environmental contamination are often marginalized and under-represented in government and other decision-making structures and require concerted outreach efforts. In addition, there is often:

- Misunderstanding of the nature and risks of mercury contamination
- Mistrust of governments and other actors in site investigations, often due to poor communications and failure to deliver action in the past
- Fear about both the contamination and the potential impact on livelihoods related to actions to address the contamination

These concerns must be overcome in order to obtain cooperation of communities regarding information collection and risk management plan development.

The USEPA Model Guidelines for Public Participation lists the following core values for public participation and critical elements of effective community engagement.[xiv]

Core values for public participation:

- Public participation is based on the belief that those who are affected by a decision have a right to be involved in the decision-making process
- Public participation includes the promise that the public's contribution will influence the decision
- Public participation promotes sustainable decisions by recognizing and communicating the needs and interests of all participants, including decision makers

- Public participation seeks out and facilitates the involvement of those potentially affected by or interested in a decision
- Public participation seeks input from participants in designing how they participate
- Public participation provides participants with the information they need to participate in a meaningful way
- Public participation communicates to participants how their input affected the decision
- *Pure Earth adds to this list that public participation in the context of mercury contamination includes a commitment to effectively communicating risks*

Critical elements of effective community engagement:

- A two-way process of distributing and receiving information in plain language to increase understanding among all stakeholders, and encourage active listening and the exchange of information.
- A process that aims to increase the number of community members who recognize themselves and their communities as stakeholders in the issues at hand.
- A system of processes and mechanisms for community outreach, input, and engagement at different levels.
- A greater emphasis on the quality of community input rather than the quantity of input. The quality of community engagement should be based more on what is “uploaded from” the community than what is “downloaded to” the community; and how well agencies are able to practically apply the input received from community members.
- Recognition of local community members as an “encyclopedia of experientially-tested and validated insight,” and consultation of that resource as part of the foundation of community engagement efforts. The success of community engagement depends on the maximum utilization of local community members as the foundation (not just an added value) to a comprehensive, holistic approach.
- Efforts to “meet people where they are.” Methods, processes, and information should be targeted and applicable to the specific communities.
- An approach that is tailored to the specific, unique needs of the particular community where activities are being implemented. Common elements of engagement should not overshadow the uniqueness of every community.

Public participation is also a core principle of the Basel Declaration on Environmentally Sound Management and many other international agreements.[xv] The 1998 Aarhus Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters requires specific public participation measures when governments undertake the development of plans, policies and programs, and the development of environmental legislation. Governments that undertake mercury assessment and risk-reduction activities should implement education, awareness-raising and sensitization campaigns to increase public interest in reducing the risks of mercury to human health and the environment. Local civil society groups should be involved in campaigns to foster closer relationship with residents and other stakeholders in the communities.

Public education campaigns should aim to provide basic knowledge of mercury properties, toxicology, known human health effects and behavioral risk-reduction strategies. Printed materials should be translated into local languages based on target populations.

Components of an environmental education program on mercury contamination may include efforts to:[xvi]

1. Increase awareness and sensitivity to the environment and environmental challenges;
2. Increase knowledge and understanding of the environment and environmental challenges;
3. Foster concern for the environment and a motivation to improve or maintain environmental quality;
4. Improve skills to identify and help resolve environmental challenges;
5. Increase local technical capacities
6. Increase participation in activities that lead to the resolution of environmental challenges.
7. Institutionalize public participation

Partners for public participation and community engagement programs may include:[xvii]

1. Officials and staff in governments who work for environmental issues;
2. Official and staff in governments and or NGOs who work on public health issues. In particular, Pure Earth has found that public health nurses and educators are often among the most effective and trusted people for community outreach and education.

3. People who are interested in environmental and public health problems and have a high potential to understand and disseminate information to others:
    a. Children and students;
    b. Teachers and professors;
4. Leaders and representatives who work in the environmental and public health fields at the local or community level:
    a. Non-governmental organizations;
    b. Small and medium-sized enterprises; and
    c. Local producers, collectors and recyclers; disposal facility owners, operators, and workers who handle mercury waste.
5. People who are, or reside, in proximity to mercury-contaminated sites or waste sites;
6. Local organizations:
    a. Community and neighborhood groups;
    b. Community service organizations (health, welfare, and others);
    c. Educational institutions and academia;
    d. Environmental organizations, including Local Emergency Planning Committees;
    e. Industry and business;
    f. Medical community;
    g. Non-governmental organizations;
    h. Religious communities;
    i. Spiritual communities;
    j. Indigenous peoples;
    k. Civic/public interest groups;
    l. Unions and other employment related organizations;
7. City residents; and
8. Enterprises.

In addition to the above guidelines, it is also important to communicate risks to communities potentially affected by contamination or by risk-reduction activities. The USEPA's Seven Cardinal Rules of Risk Communication suggests the following guiding principles:[xviii]

1. **Accept and involve the public as a partner.**
   Your goal is to produce an informed public, not to defuse public concerns or replace actions.
2. **Plan carefully and evaluate your efforts.**
   Different goals, audiences, and media require different actions.
3. **Listen to the public's specific concerns.**

People often care more about trust, credibility, competence, fairness, and empathy than about statistics and details.

4. **Be honest, frank, and open.**
   Trust and credibility are difficult to obtain; once lost, they are almost impossible to regain.
5. **Work with other credible sources.**
   Conflicts and disagreements among organizations make communication with the public much more difficult.
6. **Meet the needs of the media.**
   The media are usually more interested in politics than risk, simplicity than complexity, danger than safety.
7. **Speak clearly and with compassion.**
   Never let your efforts prevent your acknowledging the tragedy of an illness, injury, or death. People can understand risk information, but they may still not agree with you; some people will not be satisfied.

An effective public participation and engagement strategy is critical to the success of any contaminated site identification, assessment and risk-reduction strategy. Failure to adequately involve and educate the public can be a costly mistake and can ultimately derail an otherwise well-executed plan.

OPTIONS FOR MANAGING THE RISKS POSED BY CONTAMINATED SITES

Key Considerations When Selecting Remediation or Risk-Reduction Strategies

Identification of Project Goals
The appropriateness of remediation or intervention strategies at a mercury-contaminated site will depend on the goals of the government, local community and other stakeholders. For example, if the goal is to reduce human health risks, a strategy based on blocking or eliminating the human exposure pathway could potentially succeed without removing the contamination or otherwise remediating the source. For example, in the contest of methylmercury risks, many communities have implemented fish consumption advisories as a way to reduce exposures without necessarily remediating mercury contaminated sediments. Risks of fish consumption are explained to the public with signage at the water body and fact sheets delivered to the community. The information typically details the size or species of fish to avoid and the amount of fish that can be eaten without creating unacceptable risks.

Other communities have taken steps to erect physically barriers to prevent people from interacting with contaminated materials, or have relocated buildings, homes or events to reduce exposures. Such steps are typically less expensive than an environmental engineering solution, and can be effective at reducing risks.

Another outreach strategy for incidental ingestion of contaminated material such as soil, could include simple hygiene related education. This might recommend additional handwashing before or after working with contaminated materials or after working in a contaminated area, or restrictions on eating or smoking in those areas.

Basil Convention Technical Guidelines
In 2011, the Basel Convention issued technical guidelines concerning the environmentally sound management of mercury-contaminated waste. These guidelines require that signatories to the convention use environmentally sound management in dealing with such hazardous wastes.

Basil Convention Article 2, paragraph 8 defines environmentally sound management as "taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner that will protect human health and the environment against the adverse effects, which may result from such wastes." Article 4 requires parties to ensure the availability of adequate disposal facilities in which environmentally sound management shall be located [Para. 2(b)]. It also requires parties to ensure that all those involved in environmentally sound management take whatever steps shall be necessary in order to prevent pollution arising from such hazardous wastes, and – in the event of the occurrence of such pollution – that negative consequences on human health and the environment be minimized as much as possible [Para. 2(c)].[xix]

Commonly Employed & Emerging Techniques for Mercury Remediation

Commonly employed & emerging techniques for mercury remediation include:

- Stabilization/solidification
- Immobilization
- Vitrification
- Thermal desorption
- Nanotechnology
- Soil washing
- Electro-remediation
- Phytostabilization
- Phytoextraction
- Phytovolatilization

A complete description of each of these technologies, including a discussion of their costs, applicability, benefits and drawbacks and previous applications is available in the U.S. EPA report: Treatment Technologies For Mercury in Soil, Waste, and Water, available for download at: https://clu-in.org/s.focus/c/pub/i/1464/.

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