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Tool 3

Toolkit to End Childhood Lead Poisoning

Assessing Environmental Lead Exposure in Resource-Constrained Settings

March 2025

END CHILDHOOD LEAD POISONING
PARTNERSHIP FOR A LEAD-FREE FUTURE

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Acknowledgements

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Disclaimer

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The tool will be revised as new information and contributions become available and posted on the Partnership for a Lead-Free Future website.

Suggestions and comments are welcome and may be sent to ceh@unicef.org.

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Photo caption: On 24 October 2016 in Yenagoa, Nigeria, 15-year-old Badamasi Ibrahim works all day smoking meat, called Kanda, at an abattoir. To fuel the fire, workers burn cow bones, tires, wires, cans, and other waste. "I work here because there's no other job. It's hard and hot. I have a bad cough," he says. Badamasi sometimes visits the clinic for breathing problems, gets pills, then returns to work. According to UNICEF's Clear the Air for Children report, nearly 300 million children worldwide live in areas with air pollution six times higher than global guidelines.

Contents

Acronyms and abbreviations

BLL	blood lead level
CDC	United States Centers for Disease Control and Prevention
CSM	conceptual site model
EU	European Union
IEUBK	Integrated Exposure Uptake Biokinetic Model for Lead in Children
LOD	limit of detection
NGO	non-governmental organization
Pb	lead
ppb	parts per billion
ppm	parts per million (mg/kg)
PPP	purchasing power parity
pXRF	portable X-ray fluorescence
SLI	starting, lighting and ignition
TEL	tetraethyl lead
US EPA	United States Environmental Protection Agency
WHO	World Health Organization

I. Introduction

1.1 Scope and purpose of this tool

The purpose of this tool is to familiarize readers with key concepts of lead (Pb) risk assessment as the basis for developing and carrying out investigations in resource-constrained settings where children have been found to have elevated BLLs. 'Risk assessment' in this context refers to the process of identifying and characterizing lead exposure risks in children's environments.

This document is intended to be used as part of a larger toolkit under development by a working group led by UNICEF, the purpose of which is to end childhood lead poisoning. This tool does not itself constitute adequate guidance for the development and implementation of environmental risk assessments. Rather, key considerations are outlined and a preliminary list of possible actions is presented.

Target audiences include staff of ministries of health and environment, international organizations, and non-governmental organizations (NGOs) with moderate to no experience in assessing and characterizing environmental lead exposure. Designers and executors of risk assessments are referred to collectively as investigators throughout. Further guidance should be sought from experienced organizations or experts before designing or executing the kind of assessments described herein.

This tool is organized sequentially, proceeding from background research to design and execution and finally to interpretation and communication of results. Some additional detail on sampling methods and estimating BLLs is presented in the annexure (Annexes A and B, respectively) as is a glossary of useful terms (Annex C). Case studies have also been inserted into the document throughout to highlight certain concepts. The process flow chart (see Figure 1) presents the overall organization of this tool.

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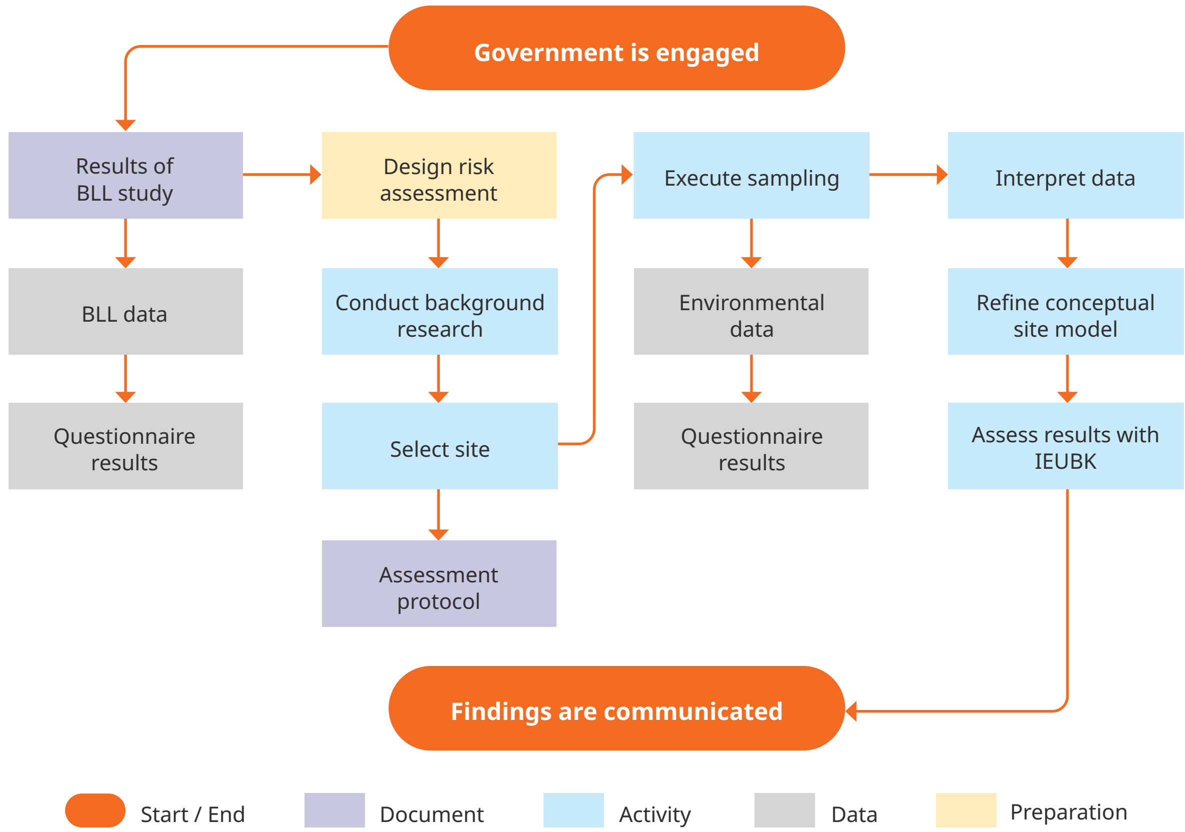
Figure 1: Lead risk assessment process



Source: UNICEF, 2024.

1.2 Lead toxicity globally

Lead is a naturally occurring bluish-grey metal with multiple commercial and industrial applications. It is dense, malleable and an excellent conductor of electricity. The largest application of lead (roughly 86 per cent of the total) is in the fabrication of starter, lighting and ignition (SLI) batteries for use in automobiles, backup power supplies and battery banks for solar arrays and cell phone towers. Other major uses include radiation shielding, ammunition and soldering (UNEP, n.d.).

Exposure to lead can result in an array of adverse health outcomes, including lifelong neurological impacts in children and cardiovascular disease in adults (ATSDR, 2020). Symptoms are typically subclinical with poisoning best confirmed through blood testing. A recent UNICEF/Pure Earth joint report notes that an estimated one in three children globally have BLLs exceeding the World Health Organization (WHO) reference value of 5 mcg/dL (UNICEF and Pure Earth, 2020). The economic burden of decreased productivity owing to these exposures has recently been quantified by the World Bank as equivalent in size to 1.6 per cent of global gross domestic product, or US$1.38 trillion (2019 PPP) (Larsen & Sánchez-Triana, 2023).

The most significant historical source of lead exposure has been automobile emissions, owing to the addition of tetraethyl lead (TEL) to petrol throughout the 20th century. Nearly all countries had phased out TEL for use in automobiles by the early 21st century; thus, remaining sources of exposure are diverse and tend to be regionally specific. There is a dearth of research in this area and new significant sources of exposure continue to be identified. Table 1 provides a summary of the recent reviews of exposure sources, organized by subregion. The table is not exhaustive, and investigators should not rule out any potential source of exposure.

Table 1: Regional sources of lead exposure identified in the literature compiled from multiple sources

Subregion	Identified sources of lead (Pb) exposure
Eastern Africa	automobile repair; battery manufacture or recycling; dietary sources, including spices; mixed industrial sources
Middle East and North Africa	automobile repair; battery manufacture or recycling; ceramics; cosmetics; dietary sources, including spices; mining and smelting; mixed industrial sources
Southern Africa	mining and smelting; mixed industrial sources
Western Africa	automobile repair; battery manufacture or recycling; cosmetics; e-waste recycling; lead-based paint; mining and smelting; mixed industrial sources
Caribbean	battery manufacture or recycling
Central America	battery manufacture or recycling; ceramics; mining and smelting
South America	battery manufacture or recycling; ceramics; dietary sources, including spices; lead-based paint; mining and smelting; mixed industrial sources
Central Asia	mining and smelting
Eastern Asia	battery manufacture or recycling; dietary sources, including spices; e-waste recycling; mining and smelting; lead-based paint; mixed industrial sources; traditional medicines
South-Eastern Asia	battery manufacture or recycling; ceramics; dietary sources, including spices; mining and smelting; mixed industrial sources
Southern Asia	automobile repair; battery manufacture or recycling; cosmetics; dietary sources, including spices; lead-based paint; mining and smelting; mixed industrial sources; traditional medicines
Western Asia	aluminum cookware; automobile repair; battery manufacture or recycling; ceramics; dietary sources, including spices; mining and smelting; mixed industrial sources
Eastern Europe	mixed industrial sources
Southern Europe	mining and smelting; mixed industrial sources

Source: Ericson et al., 2021; Obeng-Gyasi, 2019; Hore et al., 2019.

There has been a renewed interest in characterizing the global lead-attributable disease burden and identifying major sources of exposure. In this context, several countries have recently completed national or small-area BLL surveys with the assistance of UNICEF. A 2019 study of 1,578 randomly selected children (2–7 years old) in Georgia found that 41 per cent had BLLs exceeding 5 mcg/dL (National Statistics Office of Georgia, 2019). A similar study in Ulaanbaatar, Mongolia of 507 children under 5 years of age found that 46 per cent had BLLs exceeding 3.5 mcg/dL (UNICEF, 2023). UNICEF also supported case-control studies in Bangladesh (children 1–18 years old) and Ghana (children under 5 years old) around lead recycling sites. The pooled values of children in these studies showed that 40 per cent in Bangladesh and 53 per cent in Ghana had BLLs exceeding 5 mcg/dL (UNICEF Ghana, 2023; UNICEF Bangladesh, 2023). Large BLL surveys have also recently been conducted in China, Mexico, the Philippines and elsewhere by national governments or NGOs (M.-M. Li et al., 2020; María Téllez-Rojo et al., 2019; Bernhardt, 2021).

A critical next step to these assessments is the identification of the principal sources of exposure. This facilitates the design and implementation of control measures that can reduce exposure, decrease children's BLLs, and improve health outcomes.

1.3 Fate, transport and human exposure

Investigators should have a basic understanding of how lead moves through the environment and how human beings become exposed. Lead can be divided usefully between inorganic and organic forms, with the latter being highly hazardous, skin permeable and rare. Organic lead is unlikely to be uncovered during risk assessment, however, due to the phase-out of leaded petrol, which was the primary source of this form.

The inorganic form comprises the vast majority of lead in the environment and includes white lead (a lead carbonate compound), yellow lead (lead chromate, lead monoxide) and red lead (lead tetroxide). Inorganic lead is found in batteries, consumer goods, paint and spices, among other applications. This section will focus entirely on inorganic forms.

Lead can be released into air, water, soil and other media. Large particles (> 2 µm) comprise the majority of lead released from emission sources and settle out very quickly. When TEL was used in automobiles, most large particles settled out near roadways (Smith, 1976). Deposition from informal lead processing sites attenuates steeply after 25 m and rarely extends beyond 100 m (Ferraro et al., 2023). Lead emitted from formal smelters can result in elevated BLLs as far as 2.7 km away (Hodge et al., 2016). Submicron particles can circulate globally in the upper atmosphere.

Lead is sparingly soluble in water, with most lead occurring in an undissolved form. Lead particles can enter water through contaminated supply or distribution systems (Champion et al., 2022; Fisher et al., 2021; Buerck et al., 2023). Soil is not a passive repository for lead. Particles that deposit on surface soil can be resuspended as aerosols that can be inhaled and ultimately ingested. Vertical migration through the soil profile is minimal; most lead will not move down from the top several centimeters of soil (Semlali et al., 2004)

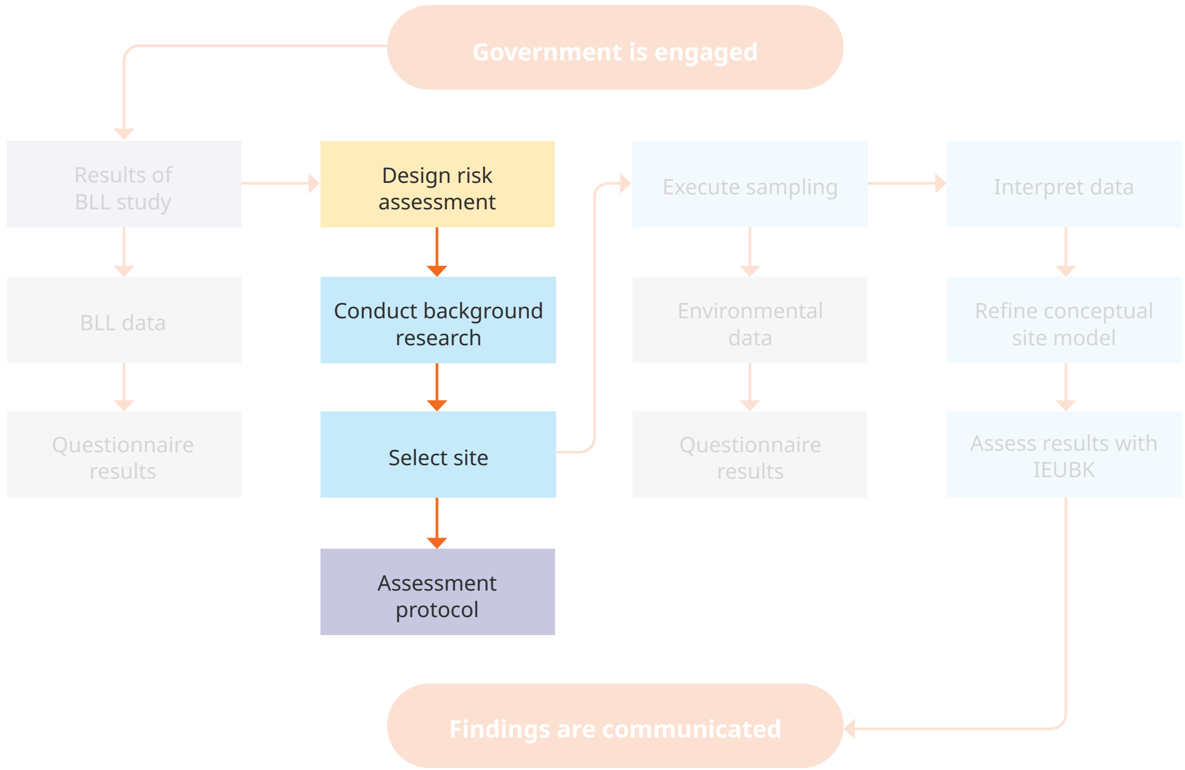
Incidental ingestion of lead-contaminated soil and dust is a common human exposure pathway, especially among children given their hand-to-mouth behaviour. Deliberate ingestion of lead-contaminated material as a result of either pica behaviour or contaminated food is also a significant exposure pathway. Inhalation of respirable lead particles is uncommon outside of industrial settings. Children both take in and absorb proportionally much more lead than adults, owing to their growing bodies (ATSDR, 2020).

Lead exposure risks in water

Lead is sparingly soluble in water. As a result, lead contamination of water at the tap is likely due to contamination in the distribution system rather than at the source. This means that, where lead exists in water, it is usually coming from plumbing components that contain lead. Such components have been identified in various countries (Champion et al., 2022; Fisher et al., 2021; Buerck et al., 2023).

Humans are exposed to lead from multiple media, and water may not be the most significant source of exposure in many communities. Water is, however, often at the forefront of caregivers' minds when considering risk. It is therefore essential that care is taken to collect and analyse tap water in a method that is seen as valid and authoritative by the community, regulators and regional experts. Investigators should consider other sources that may have a similar importance to stakeholders.

II. Risk assessment design



The purpose of this section is to outline major considerations when designing an environmental sampling plan in response to elevated BLLs.

2.1 Background research

Background research in this context is the process of understanding what is known and unknown about lead exposure in the country or region before the investigation begins. Lessons learned and suspected sources should be documented.

2.1.1 Literature review and expert consultation

Sources of lead exposure are diverse and tend to be regionally specific (see Table 1). Even leaded petrol – the largest single historical contributor to elevated BLLs – affected certain populations more than others. Indeed, perhaps 80 per cent of all leaded petrol produced before 1970 was used in the United States of America, owing to larger vehicles and longer distances travelled (Nriagu, 1990). Lead-adulterated spices, with exceptions, seem to be concentrated in South Asia (Hore et al., 2019; Forsyth et al., 2019). Lead-glazed ceramics, while fabricated in various countries, are uniquely prevalent in Mexico (María Téllez-Rojo et al., 2019).

To the extent possible, investigators should try to identify possible sources of lead exposure through a regionally specific literature review. Databases like PubMed (maintained by the United States National

Institutes of Health), Google Scholar and nationally or regionally specific databases should be queried using appropriate keywords.

Interviews, too, are a necessary step in gathering background information. Possible interviewees could include staff in ministries of health and environment, WHO collaborating centers and local NGOs, as well as public health researchers, paediatricians and other medical practitioners. During interviews, investigators can assess regional knowledge on the extent and severity of lead exposure, and identify the existence of any relevant grey literature. Databases or existing site assessment data can also be identified during interviews.

2.1.2 Analysis of questionnaire data

It is likely that the blood lead survey that triggered the assessment was accompanied by a questionnaire. Investigators should assess the data contained in the questionnaire to identify associations between elevated BLLs and questionnaire responses. At a minimum, a series of regressions should be run using statistical software to identify possible relationships, while bearing in mind that correlation is not equivalent with causation. Note, however, that this approach may not produce useful results. A 2013 systematic review of the efficacy of personal questionnaires in the United States found that they performed little better than chance in predicting elevated BLLs in individual children, despite the dominant sources of lead exposure being well known (Ossiander, 2013).

2.1.3 Determination of available human and financial resources, and time

Before designing a sampling plan, investigators should inventory the available human and financial resources for the assessment. A preliminary budget and work plan should be developed to guide the selection of analytical methods and scope of the assessment.

2.1.4 Selection of sample collection and analysis methods

2.1.4.1 Field portable versus stationary

A useful separation can be made between field portable and stationary analytical methods. In general, field portable methods tend to be less costly and more qualitative in nature. By contrast, stationary methods (i.e., laboratory techniques) tend to be of higher cost and more quantitative. In the context of constrained resources, sampling plans often contain a balance of each, with the majority of analysis being carried out in the field and a subset of 10 per cent being analysed in the lab. The 10 per cent subset is a standard rule of thumb, though more or less may be required. Table 2 presents a list of common analytical methods and approximate associated costs.

Hazard versus risk

A fundamental concept underlying risk assessment is the differentiation between hazard and risk. In short, a hazard is a potential source of harm, while a risk is the probability and severity of harm. A hazard becomes a risk when a human has the potential to become exposed to it. Thus risk assessment in this context refers to the identification and measurement of hazards in a human exposure pathway. A plastic toy may contain elevated concentrations of lead and is thus a hazard. Without a human exposure pathway, however, that toy may not pose a risk. Well maintained lead-based paint presents a hazard; it becomes a risk when that paint is damaged and converted to dust, where it can be inhaled and ultimately ingested.

Table 2: Comparison of various analytical techniques used in lead risk assessment

Method of analysis	Qualitative or quantitative	Cost	Field portable?	Medium	US EPA recognized?	Limitations
Sodium rhodizonate swabs	Qualitative	Low (approx. US$0.30 per test)	Y	Leachable surfaces	N	Not US EPA recognized; colorimetric nature may diminish utility with yellow or red materials
Colorimetric water tests	Qualitative	Low (approx. US$15–US$30 per kit)	Y	Water	N	Not US EPA recognized
LeadCheck™	Qualitative	Low (approx. US$5–US$10 per test)	Y	Leachable surfaces	Y	Difficult to integrate into exposure assessment; colorimetric nature may diminish utility with yellow or red materials; currently discontinued by manufacturer
D-Lead® paint test	Semi-quantitative	Low (approx. US$10 per test)	Y	Paint	Y	Difficult to integrate into exposure assessment; colorimetric nature may diminish utility with yellow or red materials
pXRF	Quantitative	Moderate to high (approx. US$30,000 instrument; nil cost per sample)	Y	Multiple solid media	Y	May require laboratory confirmation to ensure the validity of findings
Field sampling with lab analysis (ICP-MS, ICP-OES, GFAAS, GFAES)	Quantitative	High (approx. US$100,000 instrument; approx. US$25–US$50 per test)	N	Multiple media (liquid or solid)	Y	Not logistically feasible for a large number of samples; level of precision not always necessary for exposure assessment.

Source: Adapted from multiple sources.

2.1.4.2 X-ray fluorescence (XRF)

XRF is a non-destructive analytical method with a wide range of applications. In short, it relies on the interpretation of the spectra of secondary gamma radiation emitted by a particle after that particle has been excited by an outside source of high energy gamma radiation. Each element fluoresces differently in this process, allowing multiple elements to be identified simultaneously. Laboratory-based XRF technology has been commercially available since the mid-20th century, however over the past twenty years manufacturers have developed increasingly more portable and accurate XRF instrumentation. Modern portable XRFs (pXRFs) weigh less than 2 kg, last upwards of 4 hours on a single charge, and can produce results comparable with laboratory wet techniques (Rouillon & Taylor, 2016). These instruments are available from multiple manufacturers and typically cost in the range of US$10,000–US$40,000, depending on the different options and calibrations chosen. Thus, pXRFs have come to form an essential component of many environmental lead assessments carried out today.

2.1.4.3 Laboratory analysis

An assessment of regional laboratory capacity should be conducted. Some approaches used for the assessment of lead in various media are presented in Table 2 above. A list of accredited laboratories is provided by the International Laboratory Accreditation Cooperation (ILAC) directory, available here: https://ilac.org/signatory-search/.[1] Laboratories should be contacted and investigators should become familiar with laboratory practices including cost, quality assurance and control procedures, chain of custody, sampling materials, required sample amounts and detection limits. Relevant government counterparts should be consulted during laboratory selection to ensure confidence in results.

2.2 Site selection

2.2.1 Defining the study area

The study area is the geographic focus of the assessment. It is likely an administrative area and could be as small as a section of a neighbourhood or as large as a national survey. The study area is defined based on the results of BLL screening.

The study area is comprised of a 'population,' which represents every possible sampling unit. In the case of a national BLL survey, the population refers to every household in that country where a child resides. It is not feasible or desirable to assess each of these households. As an alternative, a 'sample' (i.e., multiple households) comprised of 'sampling units' or 'sites' (i.e., single households) is assessed to draw conclusions about the population.[2]

The data may show elevated BLLs in one or more regions and lower BLLs elsewhere. Certain point sources may be apparent, such as hazardous waste sites or mining-smelting complexes. Possible control areas with apparent lower levels of exposure may also become clear. These observations will help define the sampling design, as described below.

2.2.2 Statistical considerations

It is necessary to consider the size of the sample required to gain useful information about sources of exposure. Investigators should endeavor to achieve statistical significance by calculating the size of the required sample as part of the project design. Multiple sample size calculators are freely available online and, where possible, a statistician should be consulted. Sample size calculations should consider the response rate of potential participants (e.g., homeowners or tenants). Response rate refers to the percentage of individuals that accept or refuse to participate in the study (Egan et al., 2022). Other relevant considerations may include the stratification desired for the results, geographic specificity of exposure estimates, feasibility and any population weighting.

Several factors, including the size of the study area, the results of BLL analysis, and the available budget will inform the selection of sampling design. Outside of emergency situations, probabilistic (i.e., statistical) sampling is almost always preferred to judgemental (i.e., expert judgement) sampling. Table 3 below lists some common study design types and typical applications.

1 Per their website, "ILAC is the international organization for accreditation bodies operating in accordance with ISO/IEC 17011 and involved in the accreditation of conformity assessment bodies including calibration laboratories (using ISO/IEC 17025), testing laboratories (using ISO/IEC 17025), medical testing laboratories (using ISO 15189), inspection bodies (using ISO/IEC 17020), proficiency testing providers (using ISO/IEC 17043) and reference material producers (using ISO 17034)."

2 Note that while sites are most likely to be households, they could also include schools or other outdoor play areas like parks. The selection of sites outside of homes should be informed by the results of BLL data, other background data and field work.

Case study

Follow the data: Eastern Europe

This country had recently completed its first national study of children's BLLs. A questionnaire based on a CDC example was completed by the parents of participants. Analyses of questionnaire data failed to identify any discernible trends. Some limited environmental assessment did identify one possible source of exposure: lead-based paint.

Investigators developed a stratified random sample consisting of two strata: one with acceptably low BLLs and another with elevated BLLs. Participants were then randomly selected within this group. A protocol was developed which focused on the presence of lead-based paint in the home but also included other media. Early household assessments in the study found little to no lead in homes. Eventually, elevated lead concentrations began to appear in an unexpected location: spices – in particular, in a regionally specific spice blend not used anywhere else in the world. Sceptical investigators followed the data. Regional recipes were acquired and approximate dietary lead intake from spices was entered into the IEUBK software. Indeed, the data mirrored actual BLLs almost exactly. Subsequent campaigns to control spice lead concentrations have resulted in precipitous declines in BLLs.

Table 3: Common sampling design types used in environmental risk assessment

Sampling design	Description	Possible applications
Simple random sampling	A random number generator (or equivalent process) is used to select all sampling locations. Each household has an equal probability of being selected.	The least likely design following a national BLL survey. Most appropriate in small, well-defined areas or larger areas when significant resources (time, human, financial) are available. Appropriate where existing data do not present discernable trends. Most often used in conjunction with another sampling design.
Stratified random sampling	Useful when a sample population can be broken down into groups, or strata, that are internally more homogeneous than the entire sample population. Groups can be based on spatial or temporal proximity, or on pre-existing information or professional judgement. Random samples are taken from each stratum, although the probability of being selected might vary from stratum to stratum depending on cost and variability.	The most likely scenario following a national BLL survey. Households may be usefully divided into low, moderate or high exposure from which a random sample could be drawn. Also appropriate if certain regions present higher BLLs than others.
Cluster sampling	Clusters are randomly selected and every household in the cluster is measured.	May be appropriate when existing data do not present discernable trends. More cost-effective approach than simple random sampling.
Multistage sampling	Clusters are randomly selected, and households are randomly selected from each cluster.	May be appropriate when existing data do not present discernable trends. More cost-effective approach than cluster sampling.
Systematic sampling	This sampling has a random starting point with each subsequent observation located at a fixed interval (space or time) from the previous observation.	Appropriate at sites with clear point sources. Can be used to inform mitigation measures. Control areas and non-prioritized media should be included.
Adaptive cluster sampling	Random households are selected. Sampling is expanded to adjacent or similar households based on unique findings.	May be appropriate when existing data present limited discernable trends that are suspected of being spatially clustered and sparsely distributed. May be applicable if multiple small point sources are suspected but their location is unknown. More cost-effective approach than systematic sampling.

Source: Adapted from U.S. EPA 1997, 2023b.

Sample size should also be considered with regard to the various media being analysed. A single soil sample from a residential yard does not yield much information about exposure. The pooled results of multiple samples from the same yard, however, or of single samples from multiple yards may be enough to provide a more nuanced assessment of potential exposure.

2.3 Protocol development

2.3.1 Materials required

The sampling protocol should have in place a list of required materials such as bags, swabs, gloves, spoons, wipes, indelible markers and so on. Materials should be confirmed lead-free and be consistent across the entire assessment. Materials certified lead-free by a known provider should be used when possible and should be confirmed lead-free with pXRF before use.

2.3.2 Sample handling, labelling and records keeping

The sampling design should have in place a well-defined system for labeling and recording samples, including medium assessed, site (with latitude and longitude), location within the site (with latitude and longitude as appropriate) and date. For water and air samples – or other media where concentrations vary by time of day – the time should also be recorded. All samples should have a unique sample ID that is associated with the site where they were taken. In general, it is good practice to keep records in duplicate using both hard copy and electronic formats. Photographs and drawn diagrams can form a useful tool in reconstructing an exposure scenario later in the process.

The protocol should have in place a system for handling samples in a consistent method that inhibits contamination. Where samples are being conveyed to a laboratory, the chain of custody procedure of that facility should be followed. More information on sample handling is provided in Annex A.

2.3.3 Sampling and analysis

Samples should be collected in a uniform manner for each site and each medium. A similar number of samples should be collected across similarly sized and organized sites. Dust wipes should be taken over a specifically sized area, pXRF measurements should be of a certain duration, water samples should follow a specific protocol. Decisions should be made about whether composite or discrete sampling will be used. Consistency is essential to achieve comparability and reliability between samples and locations. Equipment should be calibrated to the manufacturer's instructions and, where appropriate, certified reference materials should be used to confirm the accuracy of the assessment instrument. Methods for sample collection for various media are provided in Annex A. A third-party expert might be engaged to observe a limited number of assessments for the purpose of quality assurance and control.

2.3.4 Team members and roles

Each household is inspected by a team of investigators. At a minimum this should include a spokesperson, a sample collector/assessor and a data recorder. Additional team members can assist in any one of these roles to expedite the assessment.

2.3.5 Interviews

A regionally appropriate questionnaire should be developed in the locally used language. The purpose of the questionnaire is to record specific demographic characteristics and identify known risk factors, such as occupation (e.g., lead smelting) or behaviour (e.g., smoking). It is important to record behavioural information for both the caretaker and children. The questionnaire should also include questions that can help inform potential exposures to the various media (e.g., time spent indoors, specific product usage information). Whenever product usage is reported by family members, investigators should document relevant product-related information. The questionnaire should include names and contact information for participants. The questionnaire should be administered by a trained investigator. As above, a third-party expert might be engaged to observe a limited number of interviews for the purpose of quality assurance and control.

2.3.6 Conceptual site model

A preliminary CSM should be developed while assembling the protocol. CSMs are visual representations of the physical, chemical and biological processes that impact the fate and transport of contaminants in the environment. It is an iterative tool that should be refined throughout the investigation and mitigation process. The preliminary CSM will help guide the development of the sampling protocol, including which spaces (e.g., homes, schools, parks) and media (e.g., soil, food, water) to assess. An example CSM is included below for illustrative purposes (see Figure 2).

2.3.7 Health and safety

Investigators should consider the various hazards present in their CSM and on different sites and develop a health and safety plan that responds to those hazards. Chemical hazards such as lead exposure should be considered, as should safety hazards (e.g., falling), physical hazards (e.g., electrocution, sun exposure) and ergonomic hazards. The health and safety plan should note the unique danger posed by confined spaces.

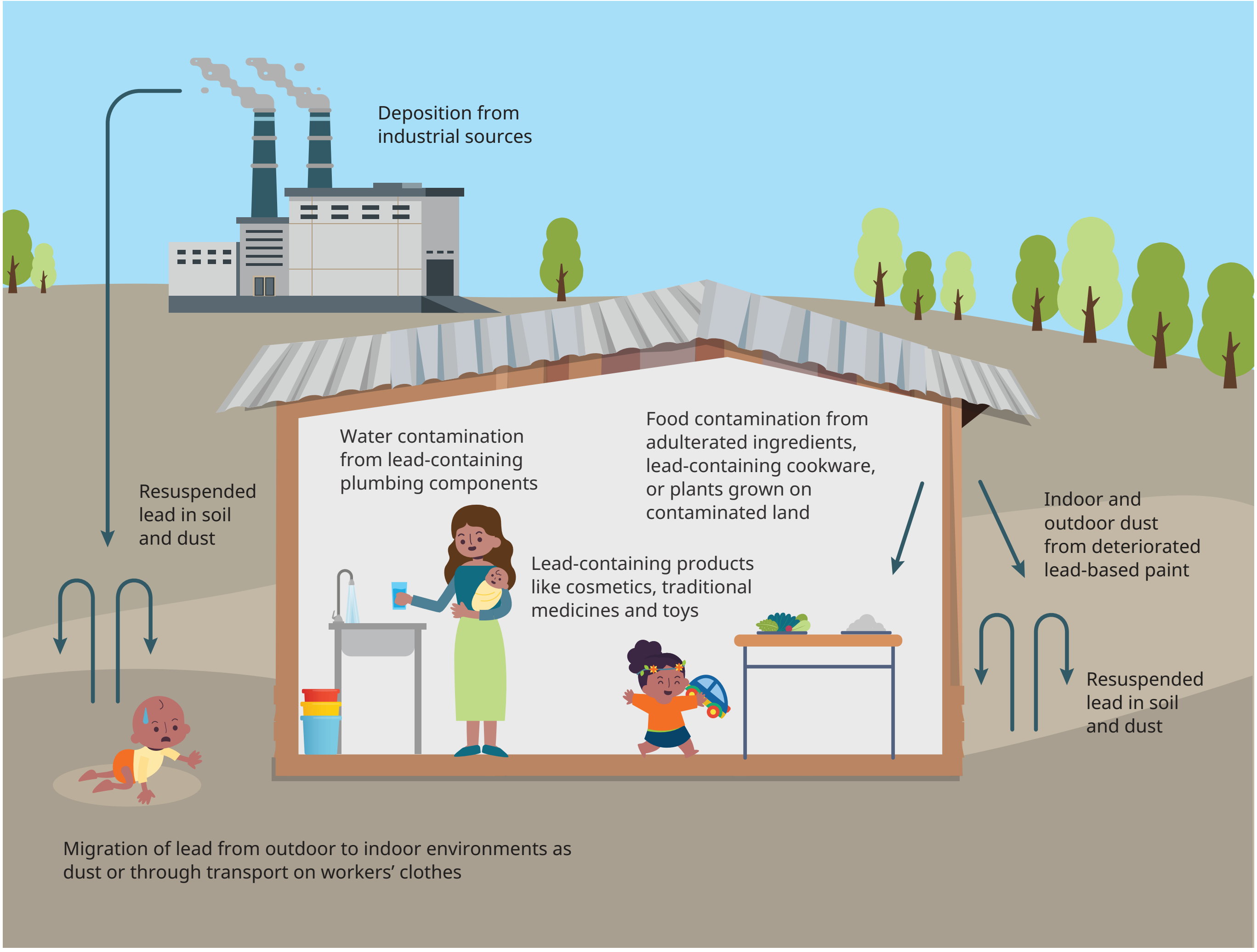
Case study

Missing the forest for the trees

Several seemingly unrelated children had recently presented with elevated BLLs. All of the children lived adjacent to a formal lead smelter. An in-depth environmental investigation found that lead emissions, ambient air levels and residual soil and dust lead concentrations were generally within acceptable levels. This absence of environmental concentrations or obvious emissions drew into doubt whether the lead smelter was actually the source of exposure.

Later, follow-up studies of children's homes revealed one significant and overlooked factor: each had a parent employed at the lead smelter. They were carrying the contamination home on their clothes. This situation is known as 'take-home exposure.'

Figure 2: Example conceptual site model



Source: UNICEF, 2024.

2.3.8 Hazard versus risk

A fundamental concept underlying risk assessment is the differentiation between hazard and risk. In short, a hazard is a potential source of harm, while a risk is the probability and severity of harm. A hazard becomes a risk when a human has the potential to become exposed to it. Thus risk assessment in this context refers to the identification and measurement of hazards in a human exposure pathway. A plastic toy may contain elevated concentrations of lead and is thus a hazard. Without a human exposure pathway, however, that toy may not pose a risk. Well maintained lead-based paint presents a hazard; it becomes a risk when that paint is damaged and converted to dust, where it can be inhaled and ultimately ingested.

2.3.9 Ethical considerations

To the extent that investigators will attempt to identify relationships between BLLs and environmental media, a decision should be made about whether to seek institutional review board (IRB) approval. Investigators should be familiar with research ethics, including those relating to sexual exploitation and abuse.

2.3.10 Sampling plan

2.3.10.1 Work plan

A well-developed work plan organized in a Gantt chart is an essential project management tool. The work plan should consider all major aspects of the project, including planning, execution and sharing of results. A larger number of sites visited and samples taken will improve the statistical significance of the sample and the overall utility of the exercise. It is therefore essential that work plans be developed to optimize time in the field with efficient use of site visits. All samples from each site should be collected in a single visit.

2.3.10.2 Consent forms

Study participants (e.g., home owners or tenants) should provide informed consent before any work begins at each site. Informed consent means that the participant understands the risks, benefits and alternatives to participating in the study before she or he consents to be included. Consent forms in an appropriate language should be signed and collected. Participants should be provided with a reasonable timeline of when the results of the study will be available.

2.3.10.3 Checklist for each site, organized around media

Investigators should enter each site with a checklist and confirm its completion before leaving. The checklist should be developed in advance and be organized around each medium being sampled. It should also include regular equipment calibration and administrative matters, such as the signing of consent forms. Methods for sample collection from various media are provided in Annex A.

2.3.10.4 Records keeping

A central repository for all data should be developed. The system should contain the full results of all environmental analyses organized by site and medium. All data must be backed up on an external off-site server. Data should be entered into the repository as soon as feasible. Data management should be conscious of identifying medical information and follow requirements laid out in IRB, where applicable.

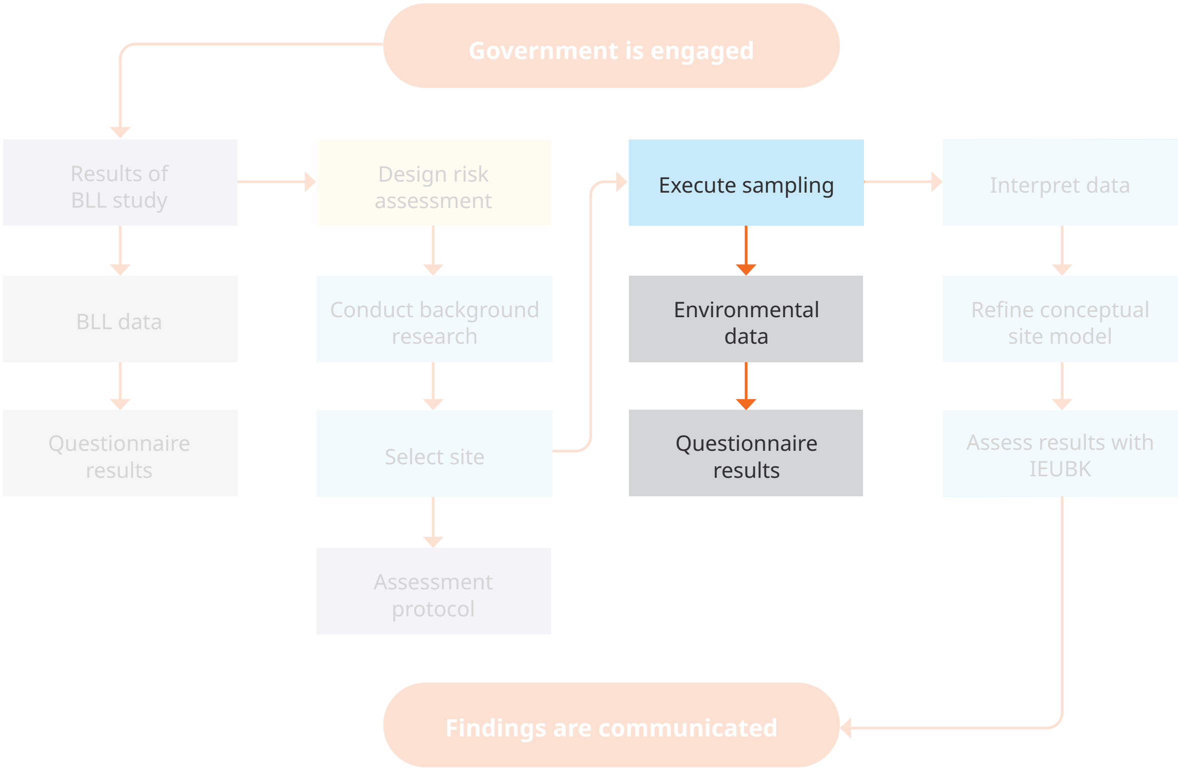
2.3.10.5 Plan for adaptive management

In some cases the major sources of lead exposure will not be known or suspected in advance. It is possible that during the investigation, new sources will be identified. It is therefore essential that the sampling plan has the capacity to adapt to new information or circumstances. CSMs should be revised accordingly and, where necessary, sampling of new media should be included. Any modifications should be made in the context of a deliberate adaptive management plan that contemplates time and financial and human resources.

2.3.10.6 Collection of biological samples

The environmental assessment described in this technical note is intended to be triggered in response to elevated BLLs found in a national or subnational survey of children. Blood lead screening should always be repeated in targeted homes, involving both the original participants as well as their siblings or other children living in the home. The reason for this is because BLLs are likely to fluctuate over time in response to increased or decreased exposure, as lead in blood has a half-life of approximately 28 days. Therefore, environmental and biological samples taken concurrently offer the best opportunity to link exposure with source. The collection and analysis of biological samples is outside the scope of this document. Interested parties should refer to the United States Centers for Disease Control and Prevention's (CDC's) *Small Area Surveillance to Estimate Prevalence of Childhood Blood and Environmental Lead Levels: A technical guide* (Hodge et al., 2016). The CDC's Lead and Multi-element Proficiency (LAMP) programme provides blood lead laboratories with testing resources to improve precision and accuracy (CDC, n.d.a).

III. Sampling execution



Timing

Sample collection should be carried out as near to BLL assessment as is reasonably possible. Duplicate biological sampling during the environmental assessment is highly encouraged as BLLs fluctuate relatively quickly in response to increased or decreased exposure.

Arranging site visits in advance

Once the sampling locations have been determined, a schedule of site visits should be developed. In most cases arrangements to gain access to the site should be made in advance and confirmed with participants both before and on the day of assessment. Investigators should anticipate that access may be cancelled without notice and adapt the work plan accordingly. In other cases, investigators should be prepared for more ad hoc recruitment of households – such as 'door-knocking' – by taking steps such as having talking points in place to convey the purpose and significance of the study.

Risk communication

Investigators should have a project-specific risk communication plan in place before beginning the exercise. Risk communication is the exchange of information, advice and opinions between experts and people at risk to enable them to make informed decisions on risk mitigation. It is essential that information be shared with participants in a deliberate and structured manner. The ad hoc sharing of results without a risk communication plan in place should be avoided. Risk communication guidance from the US EPA and WHO is referenced in the 'Further reading' section below.

Case study

Involve the community as a legitimate partner: Southeast Asian informal industry

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Multiple households in this village had informally recycled car batteries for decades. Families would melt lead inside their homes into ingots that would be reformed elsewhere in the village into new battery plates. An international research team visited the village and conducted a study of community BLLs, finding extremely elevated levels in children and adults. Unfortunately, those results were not made fully accessible to community residents. This in turn fostered a suspicion of outside researchers in a community already protective against any potential threats to their tenuous livelihoods.

A separate group of investigators later visited the village in an effort to mitigate lead exposure sources. This research team listened to community residents and involved them in the assessment work. They took care to explain how the analysis was being conducted and immediately shared results with residents in a clear and culturally appropriate manner. Community residents were treated as a legitimate partner in the assessment and helped guide its direction. Results were shared with the village leadership on a regular basis and subsequent interventions were designed jointly with residents and experts. The result was an effective, affordable and sustainable intervention.

Following the checklist

While in the field, investigators should follow the protocol developed during planning. Equipment should be calibrated according to the schedule laid out and samples should be collected in a consistent manner. Before leaving each site, the checklist should be consulted to ensure all necessary steps were taken. After leaving the site all data should be entered into the repository as soon as possible.

Avoiding tunnel vision

Investigators should stay curious. Some major sources of lead exposure have only recently been identified in several countries. It is possible that new sources of exposure will be found in future studies. While being careful to meet the study requirements set out in the protocol and mindful of time, investigators should endeavor to identify new sources of exposure.

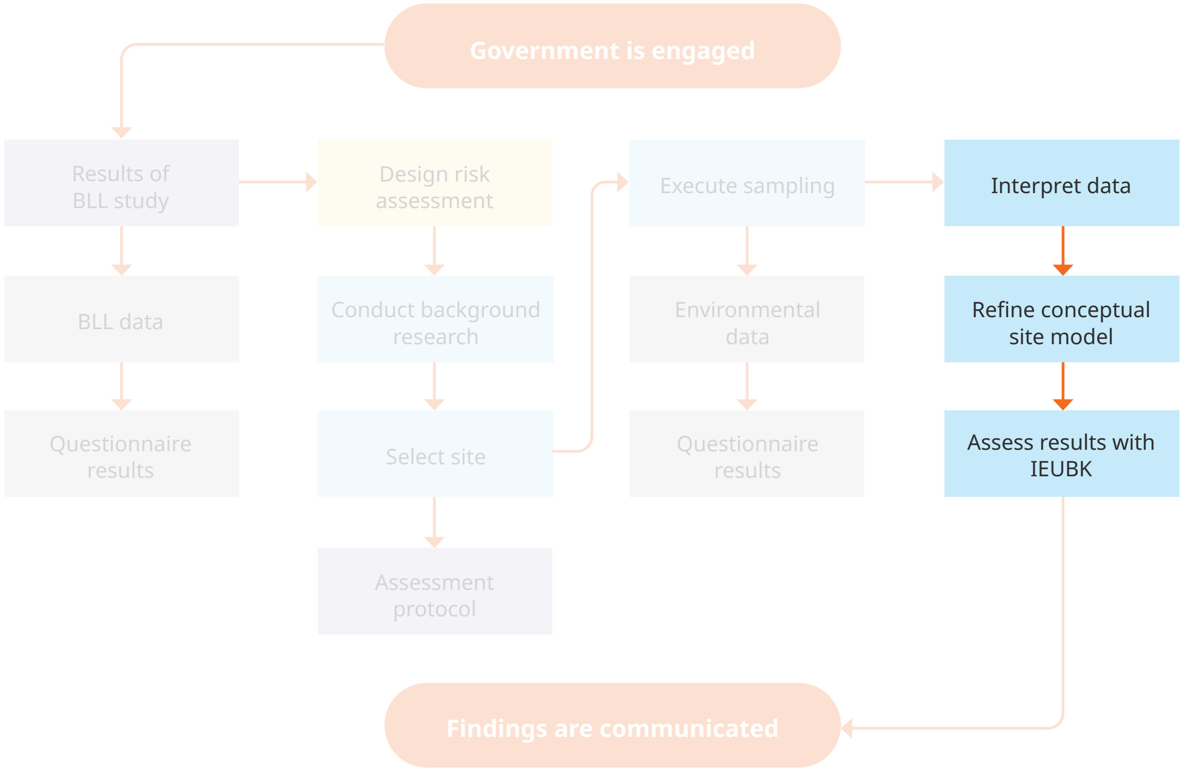
Case study

Avoiding tunnel vision: South Asia

The research team had recently completed a regional survey of point source pollution from small informal battery recycling sites. The sites all exhibited similar characteristics: high soil-lead contamination at a point source attenuating steeply after 10–20 m. The contamination was severe and BLLs taken presented results consistent with environmental soil-lead concentrations. Accordingly, the research team then designed and executed a mitigation intervention targeting the known pollution source (battery processing) and documented route of exposure (incidental ingestion of contaminated soil).

When exposure is discontinued, human BLLs typically decline at a predictable rate of halving every 28 days. At the completion of this mitigation project, BLLs quickly began to decline but eventually stopped at a point. Ongoing monitoring showed persistently elevated BLLs, despite the known source of exposure having been mitigated. This triggered another round of detailed investigations, during which researchers would find an unrelated but substantial lead exposure source: turmeric adulterated with lead chromate. This novel source of exposure had not yet been rigorously documented in the literature and was not initially considered by investigators. Eventually, after controlling this source, BLLs began to decline as expected.

IV. Data interpretation



4.1 Refining the CSM

The CSM should be refined based on the results of field testing and questionnaire responses. Possible human exposure pathways to media with elevated lead concentrations should be identified and quantified. It is likely that different CSMs will be needed to characterize the exposure scenarios at different sites.

4.2 Reference values and risk

Regulators in most countries have either developed or adopted reference values for lead in various media. These typically include soil, water and air at a minimum, and may also include food sources, cookware, toys and other media (see Table 4). Reference values are essential to help limit exposure to hazardous chemicals by setting necessary thresholds for regulators. They do not necessarily provide the most robust characterization of risk (see Table 5). Investigators should reconstruct exposure scenarios using site-specific information, such as environmental concentrations and the behaviour of receptors.

Table 4: Example regulatory reference values for lead in various media adapted from multiple sources

	Soil	Water	Air	Paint	Spices	Toys	Dust	Cosmetics
US EPA (US EPA, 2023a, 2024)	200 ppm for bare soil where children play	5 ppb	0.15 mcg/cm^3	1 mg/cm^2			10 mcg/ft^2 for floors; 100 mcg/ft^2 for windowsills	
WHO (WHO, 2022)		10 ppb						
European Union (Commission Regulation 2021/1317, 2021; European Chemicals Agency, 2023)		5 ppb			1.5 ppm	0.5–23 ppm, depending on toy type		0%
United States Consumer Product Safety Commission (CPSC, n.d., 2018)						90 ppm		
UNEP (Global Alliance to Eliminate Lead Paint, 2017)				90 ppm				

Source: UNICEF, 2024.

4.3 Interpreting qualitative data

Field portable instrumentation is often qualitative in nature. In sodium rhodizonate swabs, for instance, the relevant compound turns a distinctive reddish colour when exposed to lead. In the most precise use of this technology – LeadCheck™ swabs, previously manufactured by the 3M Company but not currently being produced – this reaction consistently occurs when surface lead concentrations are above 1 mg/cm^2, the US regulatory threshold for lead-based paint (Buehler & Rhoda, 2012). There is, however, a wide range of sodium rhodizonate swabs available on the market, often at substantially lower cost. Few of these will undergo the level of testing and calibration done by 3M, but in the context of risk assessment that level of precision may not be necessary.

As an example, terracotta clay used in earthenware sometimes contains naturally elevated lead concentrations. If earthenware is used for serving food, it is typically coated in a ceramic glaze. If that glaze is lead free, it can effectively eliminate exposure to the lead-containing clay underneath. A reading of that piece of earthenware with highly quantitative pXRF technology would find high levels of lead but tell us little about exposure. Likewise, lead-based paints that have been covered with a lead-free paint may also return an elevated pXRF reading. In both cases it is necessary to assess the surface with a sodium rhodizonate swab. If the ceramic glaze contains lead – as is common in Mexico and parts of Brazil – the swab will turn red and a source of exposure can be confirmed. Likewise, if a painted surface turns red then the layer of lead-based paint is on top and may present a risk.[3]

3 LeadCheck™ swabs are calibrated to the US regulatory standard of 1 mg/cm2 or 0.5 per cent by volume (500 ppm). This is well above the 90 ppm lead-based paint regulatory threshold used by many countries.

4.4 Interpreting quantitative data

A human's exposure to a chemical is mediated through multiple behavioural, environmental and physiological factors. These factors will differ by age and sex, among other characteristics. The highest level of contamination found at an individual site is not representative of a human's daily exposure to that chemical, nor is the lowest value. In reality, humans spend their time at multiple sites and multiple places within each site on any given day. Some days they will eat or drink more of a given food than on other days. Investigators should reconstruct an individual's average exposure over a given period of time based on interviews and reasonable assumptions. Individual results should be pooled with others to accurately reconstruct that scenario. In many cases, this pooling can be a simple average or weighted average of results.

4.5 Maps

Results should be projected on a map that covers the sampling area. Colour-graduated points presenting low to high concentrations can help investigators identify apparent clusters that can later be confirmed with statistical testing. Maps can also be important tools for risk communication depending on the exposure scenario.

4.6 Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children

The US EPA makes freely available a Windows® platform software product that approximates BLLs in a given population of children (age 0–84 months) based on exposure data. The IEUBK accepts user inputs for lead concentrations in various media and outputs an estimated geometric mean BLL based on a number of assumptions about intake and uptake. The model was initially developed by the US EPA for use in the Superfund programme in the mid-1990s and has since been employed and validated at multiple sites around the world, sometimes with adjustments to input parameters (Y. Li et al., 2016). The current version of the IEUBK (version 2, released May 2021) includes a number of updates and improvements on previous incarnations that greatly enhance its accuracy. The model is largely customizable, with the option to adjust default parameters and assumptions to local contexts. It is capable of simultaneously running assessments of 500 different exposure scenarios through its batchrun functionality. The IEUBK is an invaluable tool for lead risk assessment.

Table 5 below provides an illustration of theoretical exposure scenarios. In these cases, model inputs have been adjusted to force the IEUBK to output certain BLLs (i.e., 2.5, 5, 7.5 and 10 mcg/dL). Incremental increases in different inputs result in incrementally higher BLLs. The table is intended to provide a visualization of the required exposures to various contaminated media to result in certain BLLs. In addition, Annex B provides a series of tables presenting estimated BLLs for children exposed to lead at different concentrations in various media. The values in these tables were calculated using different inputs into the IEUBK.

Table 5: **Concentration of lead in various media required to meet certain BLL thresholds (average of ages 24–36 months)**

Medium (regulatory standard)	Anticipated BLL			
	2.5 mcg/dL	5 mcg/dL	7.5 mcg/dL	10 mcg/dL
Air (US EPA: 0.15 mcg/m^3)	3.5 mcg/m^3	7.2 mcg/m^3	11 mcg/m^3	15.2 mcg/m^3
Water (WHO: 10 ppb)	28 ppb	60 ppb	96 ppb	136 ppb
Soil (US EPA: 200 ppm)[4]	380 ppm	800 ppm	1275 ppm	1830 ppm
Diet (EU: 1.5 ppm in spice)[5]	56 ppm	120 ppm	188 ppm	268 ppm

Source: UNICEF, 2024.

4.7 Understanding multiple sources of exposure

In some scenarios, children will become exposed to lead through multiple pathways. In South Asia, for instance, informal battery recycling is common, as are lead-adulterated spices, lead oxide and lead sulfide cosmetics, and traditional remedies that contain lead. In Mexico, families living adjacent to a smelter may also be eating from earthenware with a lead-oxide glaze.

In other scenarios, one or two dominant sources of lead exposure will become apparent in the data. While not ruling out potential sources, assessed media can be ranked by relative risk considering levels found and likelihood of exposure. The ranking should include a characterization of the level of certainty in the finding as well as the assumptions that underlie it.

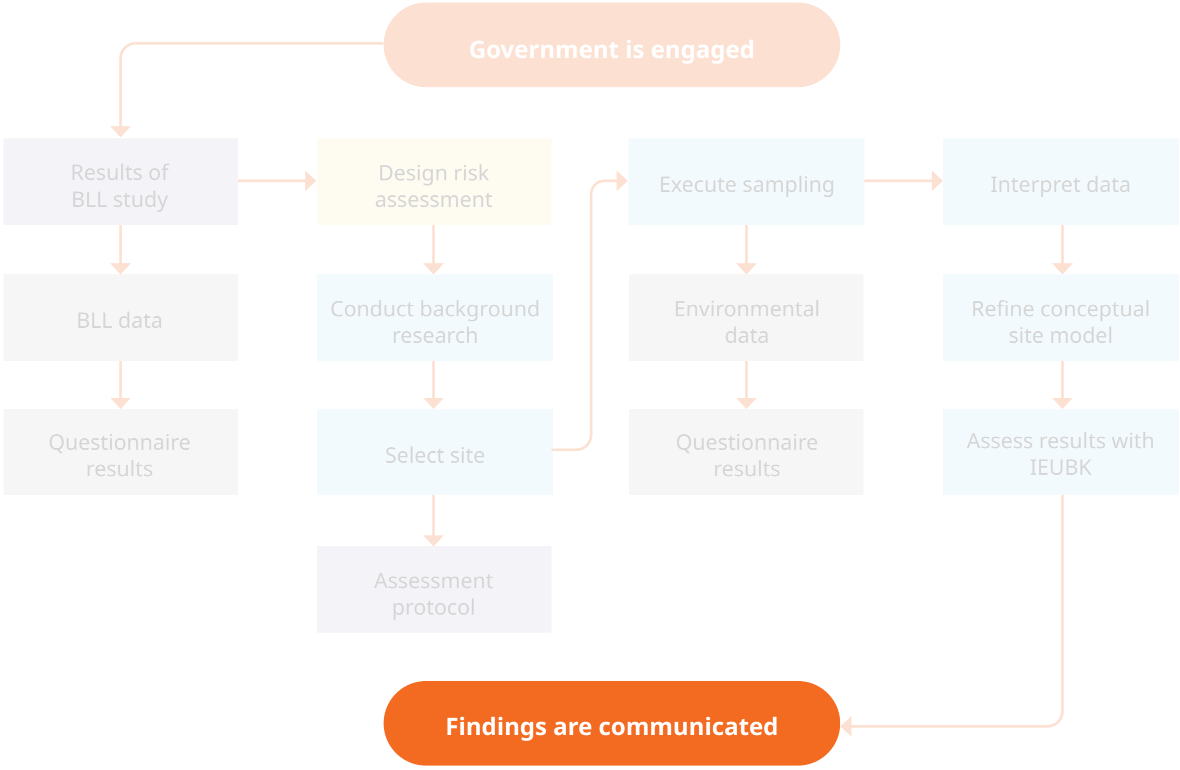
4.8 Considering other contaminants

In most modes, pXRF will analyse for a range of elements in addition to lead. Certain lead sources are also sources of other toxicants. Coal-fired power plants, for example, sometimes release mercury in addition to lead that can be deposited on area soils. If these levels are within the detection limit of the pXRF they will be included in the results exported from the instrument. The same is true for multiple other toxicants. Investigators should exploit the opportunity to review data for the elevated presence of other chemicals.

4 Dust concentration is calculated automatically based on other inputs. It can also be set manually.

5 Assumes a daily intake of 0.25 grams of adulterated spice. Value should be doubled for an intake of 0.125 grams, quadrupled for an intake of 0.0625 grams and so on. Assumes lifelong ingestion at the same rate.

V. Communicating findings



After the results have been analysed, the findings should be communicated to study participants and key stakeholders, including relevant government agencies. A deliberate and project-specific risk communication plan should be developed. Related reports and summary documents should be generated in line with that plan. Risk communication is the exchange of information, advice and opinions between experts and people at risk to enable them to make informed decisions on risk mitigation. The importance of engaging the public as a legitimate partner as part of a deliberate risk communication plan is highlighted in some of the case studies throughout this document.

A large amount of guidance is freely available to support the development of risk communication plans. These plans do not need to be overly complicated, but they must be in place before any investigation begins and be refined as the study results are assessed. It is absolutely essential that households included in the study are provided results and interpretation.

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VI. Further reading

6.1 Guidance on the assessment of lead contamination in homes

- Hodge, J., Nielson, J., Dignam, T., & Brown, M. J. (2016). Small area surveillance to estimate prevalence of childhood blood and environmental lead levels: A technical guide. United States Centers for Disease Control and Prevention. https://www.cdc.gov/nceh/lead/BLL_PrevalenceStudy_TrainingManual_Final_508.pdf
- Pure Earth. (2023, October). Home-based source assessment protocol. https://www.pureearth.org/wp-content/uploads/2023/11/Pure-Earth-Home-Based-Assessment-Protocol.pdf
- New York City Department of Health and Mental Hygiene. (2023). Investigating and addressing exposures to lead-containing consumer products: Technical guide. https://www.nyc.gov/assets/doh/downloads/pdf/lead/lead-technical-guide.pdf

6.2 Guidance on risk communication

- United States Environmental Protection Agency. (n.d.). Risk communication. https://semspub.epa.gov/work/11/174720.pdf
- World Health Organization. (n.d.). Guidance. https://www.who.int/emergencies/risk-communications/guidance

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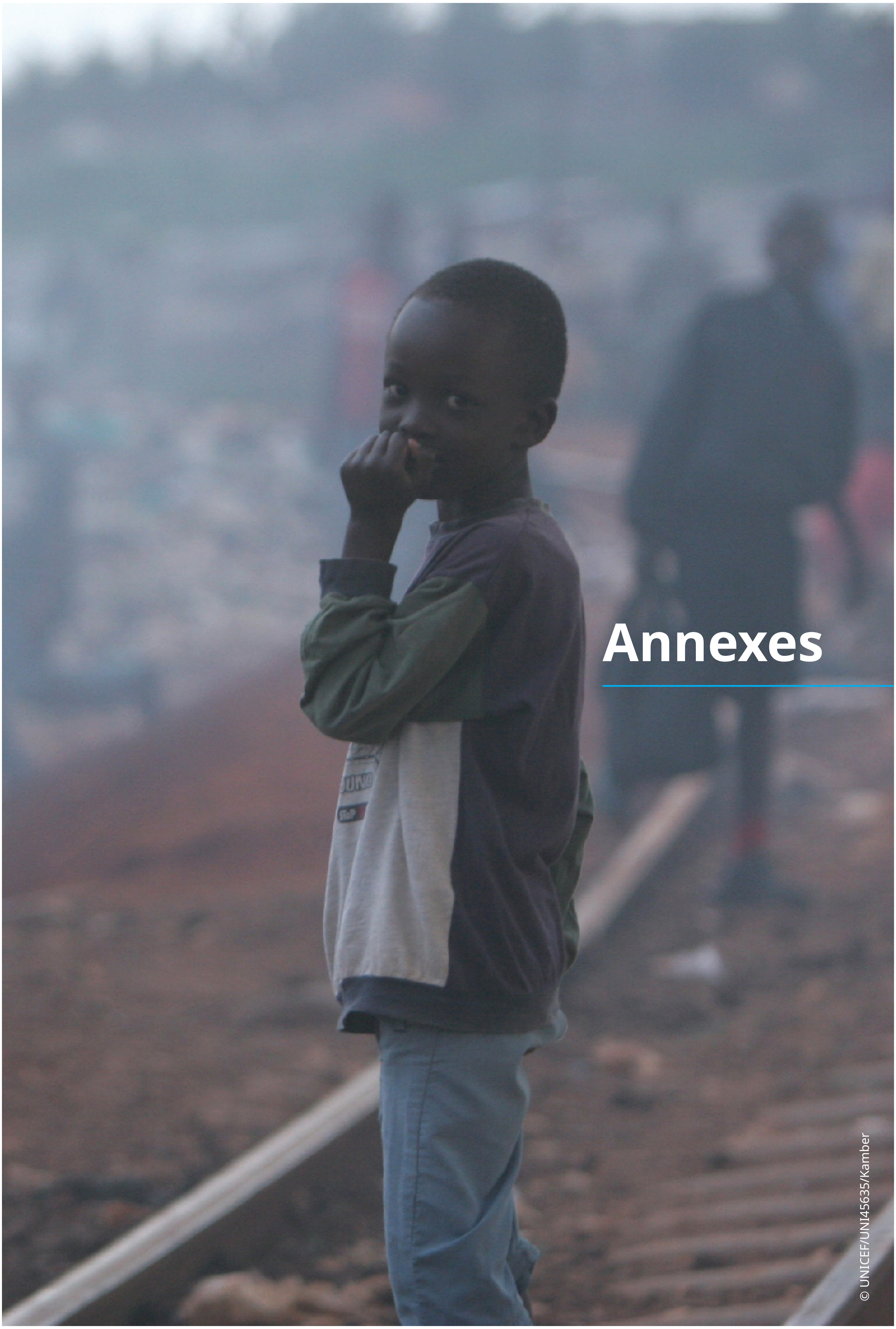


Annexes

Annex A

Collecting and analysing samples in various media

Purpose

The purpose of this annex is to outline some of the steps required in collecting and analysing samples in the field. The information presented here is compiled from multiple sources which are referenced below. Where possible, original sources should also be consulted. An expert with experience in environmental sampling should be engaged for any project before samples are collected or analysed. This document is intended as a primer on the topic to supplement but not replace formal training.

Materials

Certified lead-free materials and supplies should be procured from a known provider. For samples that will undergo laboratory analysis, materials and supplies should be procured following the laboratory's protocols and instructions. If available, a pXRF should be used in the appropriate mode to spot-check the lead content of the materials and supplies (above the limit of detection (LOD) of the equipment, typically 5 mg/kg) and should be calibrated and assessed against certified reference materials.

In cases where certified lead-free materials and supplies cannot be procured, alternatives may be acceptable. These materials must be spot-checked with a pXRF to assess possible lead content (up to the pXRF LOD). Any material containing detectable lead cannot be used and should be discarded.

Cross contamination

Unused materials and supplies should be kept separate from collected samples or possibly contaminated areas. In general, investigators should move from 'clean' to 'dirty' when assessing sites. In this context, 'clean' refers to areas where lead is expected to be present in a lower total mass than 'dirty' areas where more lead is expected. Because water contains less lead than other media (ppb versus ppm), it should be collected first. Likewise for other media. Following this logic, a typical sampling plan might proceed as follows: water > cookware > paint > spices > dust > soil.

Laboratory protocols and chain of custody

It is essential that the chain of custody is maintained. In short, chain of custody is the process for documenting each person that handles a sample. If the laboratory has a method for tracking chain of custody, their method should be used. Investigators should consult the laboratory on other relevant protocols that they maintain and endeavor to meet the requirements of those protocols whenever possible and document when they have not been met.

Step by step guidance for various media

Drinking water[6]

Materials required: gloves, sampling bottles, indelible marker

Example regulatory threshold: WHO, 10 ppb

Step 1. Label sampling container.

Step 2. Take a 250 mL first draw sample from all taps used for human consumption. 'First draw' means that the tap has sat unused for 8 to 18 hours. This sample assesses contamination in the fixture.

Step 3. Run the water for 30 seconds and take a second 250 mL flush sample in order to identify lead beyond the fixture.

Step 4. Seal containers and transport to the lab. Follow laboratory requirements for sample storage which may include acidification and/or refrigeration.

6 Adapted from CDC, 'Conducting Environmental Sampling', <www.cdc.gov/nceh/lead/docs/publications/Environmental_Sampling.pdf>

Painted surfaces with pXRF

Materials required: gloves

Example regulatory threshold: US EPA, 1 mg/cm^2

Step 1. Set the instrument to 'paint' mode. Readings should be returned in concentration per area (e.g., mcg or mg/cm^2). Other modes are not appropriate for painted surfaces, as the composition of the substrate material may be recorded as part of the sample. Plastic, metal and plaster surfaces sometimes contain lead. When assessed with a mode other than 'paint' these surfaces may return an elevated lead concentration even if the paint in question does not contain lead.

Step 2. Take measurements as per the manufacturer's instructions. Take at least one measurement from each painted wall, door and window in the home. If different paints are used on a single surface, test each paint type. Pay particular attention to enamel and brightly coloured paints. Do not ignore painted furniture or cabinets.

Step 3. Record the results on paper as the assessment proceeds.

Step 4. Consider the use of sodium rhodizonate swabs to confirm positive findings.

Dust[7]

Materials required: gloves, 100 cm^2 sampling template, Environmental Express GhostWipe® SC4250 (or similar), lead-free bags, indelible marker

Example regulatory threshold: US EPA, 10 mcg/ft^2 for floors, 100 mcg/ft^2 for windowsills[8]

Step 1. Prepare and label collection containers and wipes and apply gloves.

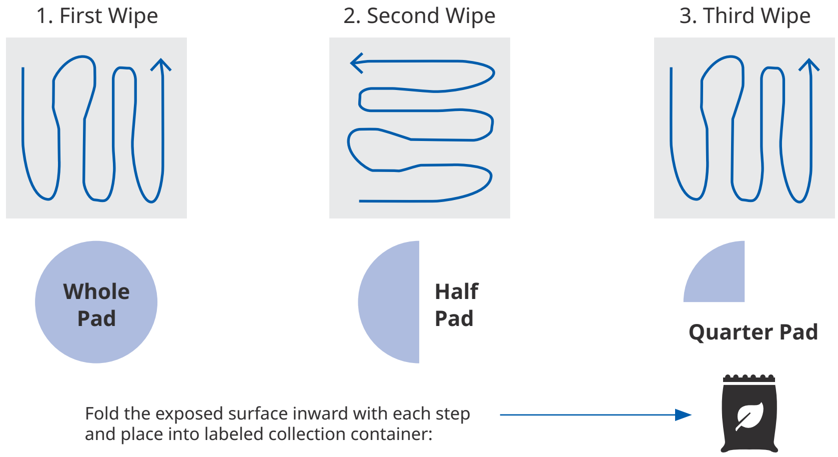
Step 2. Identify the following locations: the entrance, where children play on the floor, surfaces near where children sleep, and windowsills. Do not clean the area prior to sampling but do remove any large debris.

Step 3. Sample the previously identified areas and revise the locations if the surfaces are not hard surfaces. Sample under the doormat if applicable.

Step 4. Measure a 30 cm x 30 cm space with a rule for each floor location, remove wipe from packet, and obtain the sample using the schematic shown in Figure A1.

Step 5. Place wipes into respective labeled containers and transport to the lab if using laboratory analysis. If using pXRF for analysis, follow the manufacturer's instructions.

Figure A1: Dust wipe schematic



Source: Brown, M.J., & Falk, H. (n.d.).

7 Adapted from CDC, 'Conducting Environmental Sampling', <www.cdc.gov/nceh/lead/docs/publications/Environmental_Sampling.pdf>, and Fry et al., 'Anthropogenic Contamination of Residential Environments from Smelter As, Cu and Pb Emissions: Implications for human health', in vol. 262 of Environmental Pollution, July 2020.; American Society for Testing and Materials, 'ASTM E1728-16 Standard Practice for Collection of Settled Dust Samples Using Wipe Sampling Methods for Subsequent Lead Determination', last updated 10 January 2020, <www.astm.org/Standards/E1728.htm>.

8 Confirm with the laboratory beforehand that it can report results in the units desired (e.g., mass per area).

Soil[9]

Materials required: gloves, hand trowel, lead-free bags, indelible marker

Example regulatory threshold: US EPA, 200 ppm for bare soil where children play

If using laboratory for analysis:

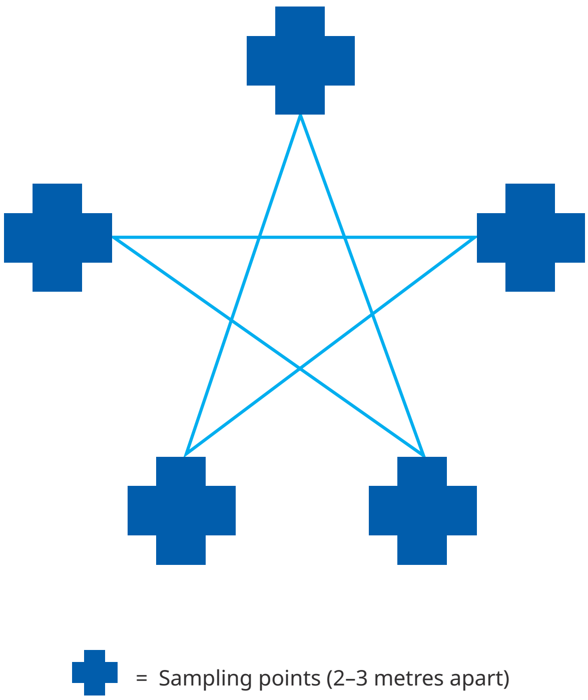
Step 1. Identify the area where children play and where there is bare soil. Create a sampling schematic for the area using Figure A2.

Step 2. Label the sampling bag with its unique ID and latitude/longitude.

Step 3. Wearing gloves, take five discrete and equally sized (25–50 g) samples from the top 1–1.5 cm of the soil using a scoop and combine in one bag to form a composite, manipulating to mix the soils.

Step 4. Seal and transport the bag to the lab.

Figure A2: Area where the child plays



9 Adapted from CDC, 'Conducting Environmental Sampling', <www.cdc.gov/nceh/lead/docs/publications/Environmental_Sampling.pdf>, and Hodge et al., *Small Area Surveillance to Estimate Prevalence of Childhood Blood and Environmental Lead Levels: A technical guide*, <www.cdc.gov/nceh/lead/BLL_PrevalenceStudy_TrainingManual_Final_508.pdf>.

If using pXRF for analysis

Step 1. Identify bare soil areas where children play.

Step 2. Remove any organic material or debris from the soil surface.

Step 3. Shielding the pXRF with PET bag that has been confirmed lead free, make full contact with the soil and take measurement in line with the manufacturer's instructions.

Step 4. Record the sample location, unique ID and latitude/longitude in hard copy.

Step 5. If elevated levels are identified, dispose of the PET bag and continue sampling other locations with additional bags as needed.

Spices[10]

Materials required: gloves, lead-free plastic or wooden spoons, lead-free bags

Example regulatory thresholds: EU, 1.5 ppm

Step 1. Identify different spices within the home.

Step 2. Using a spoon or by pouring directly into the bag, collect a 25–50 g aliquot of the spice.

Step 3. In 'soil' mode, assess the surface on which the test is being conducted to ensure it is lead free.

Step 4. Analyse the spice in 'soil' mode.

Step 5. If the spice contains elevated concentrations of lead, advise the participant in the context of the project's risk communication strategy. If spices consistently contain elevated concentrations, collect 10 per cent of elevated spice aliquots across the project for laboratory analysis.

Cookware

Materials required: gloves, sodium rhodizonate swabs

Cookware that contains lead presents a hazard. That hazard becomes a risk when the lead can be leached into food. Terracotta clay used in ceramics sometimes contains naturally occurring amounts of the metal. Receptors are usually protected by a glaze that separates the food from the terracotta underneath. However, in some countries (e.g., Mexico and Brazil) it is common to use a low-temperature lead-based glaze on terracotta earthenware. This glaze readily leaches into food and presents a serious risk to children.

Step 1. Identify any earthenware used for food preparation, storage or serving.

Step 2. Without cleaning the cookware, assess with a sodium rhodizonate swab.

Step 3. Record the result.

Step 4. Assess the cookware with a pXRF in 'test all' mode. If unavailable, use 'soil' mode.

Step 5. Clean sodium rhodizonate residue from the cookware and return to the participant.

* Note that moist sodium rhodizonate swabs that have not yet come into contact with lead can be used a second or third time.

Aluminum cookware, too, often contains lead. In these cases, the metal has been deliberately added to improve casting. During cooking, lead can leach into food. The efficacy of sodium rhodizonate swabs has not been confirmed in these cases.

Step 1. Assess the cookware with a pXRF in 'test all' or 'cookware' mode. If unavailable use 'soil' mode.

Cosmetics, toys, traditional remedies

There are no standard methods for the field portable analysis of various media. In these cases, the investigator can use her or his judgment to select the appropriate instrument calibration. Newer pXRF models are more likely to come equipped with advanced calibrations for certain consumer goods. If no analysis method is defined and no calibration available, results of pXRF measurements should be considered semi-quantitative. Investigators should record these results and relevant metadata (e.g., mode used, object assessed).

It is important to ensure that whichever surface (e.g., table, box, kitchen counter) is being used to support the object during assessment is confirmed lead free. Glazes, tile mastic, plastic and wood surfaces all may contain lead.

LeadCheck™ swabs can also be used to qualitatively assess various objects for lead.

10 See Lopez et al., 'Assessing Analytical Methods for the Rapid Detection of Lead Adulteration in the Global Spice Market', in vol. 56 no. 23 of *Environmental Science and Technology*, 6 December 2022.

Air sampling

It is highly unlikely that air sampling will be carried out as part of the investigations described in this technical note. Air sampling requires specialized expertise. Most lead settles out of air in a very short time. Thus, other simpler and more cost-effective measures can be used to assess exposure. The following is included as background only.

Indoor air sampling

Testing for heavy metals in air is often more complex than other media as a result of the variability caused by meteorological effects, ventilation systems and household chemicals. Therefore, it is important that both the amount and location of samples are representative of the local air quality and contaminant statuses. When sampling indoors, an additional sample should also be collected outside of the sample area in order to provide a meaningful comparison between the data. The protocol for indoor air sampling is as follows:

Step 1. Prepare and calibrate the appropriate air sampling instrument (the manufacturer provides detailed instructions on use of the equipment).

Step 2. Identify sampling locations as well as locations of doorways, HVAC equipment, chemical storage areas and any other variables that may affect the sample.

Step 3. Collect air samples in canisters in the previously identified locations and at breathing height (3–5 ft above ground). Note any conditions in the space.

Step 4. Take several indoor samples and record specified dates, times and durations. Take an outdoor sample to provide a meaningful comparison.

Step 5. Ensure proper labeling and transport samples to the lab.

Ambient air sampling

Air sampling equipment is diverse and almost always requires laboratory analysis following sampling. The following procedure is for filter-based sampling of particulate matter in air:

Step 1. Field personnel take filters, data sheets and other equipment to the monitoring site and set up portable samplers.

Step 2. Verify air flow rate, barometric pressure and temperature using two alternative devices.

Step 3. Ensure calibration of all devices.

Step 4. Conduct an external leak check.

Step 5. Programme sampler to operate and lock.

Step 6. Collect exposed filters 8–16 hours after the sampling event and transport (refrigerated) to the laboratory.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Annex B

Blood lead level estimates associated with environmental concentrations

Summary

The tables below present values generated using the US EPA's Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children. The default IEUBK parameters have not been changed. The purpose of these tables is to illustrate possible blood lead levels (BLLs) for multiple age groups that may result from exposure to various concentrations of lead in different media. BLL values represent the estimated geometric mean BLL for a given population of children exposed to a given concentration of lead in the defined medium. Default parameters that have not been changed include exposure time, ingestion rate and absorption. Note that multiple physiological, behavioural and environmental factors can influence any one individual's BLL. These values therefore should be interpreted as indicative. For more information on the IEUBK, refer to the associated US EPA website, here: https://www.epa.gov/superfund/lead-superfund-sites-software-and-users-manuals

How to use this annex

For tables 1–3

Using the first column, identify the row for the exposed age group. Next, using the top row, identify the column that best approximates the mean environmental concentration to which these children are exposed. The value at the intersect represents the estimated geometric mean BLL for that age group based on default IEUBK parameters. The column highlighted in red represents an example regulatory standard.[11]

For tables 4–5

For a given population of 24-month-old children only. Using the first column, identify the row that best approximates the mean environmental concentration for the relevant environmental medium. Next, using the top row, identify the column that best approximates the mean environmental concentration for a second medium to which the child is exposed. The value at the intersect represents the estimated geometric mean BLL for a given population of 24-month-old children based on default IEUBK parameters. The column highlighted in red represents an example regulatory standard.

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11 World Health Organization, Lead in Drinking-Water: Health risks, monitoring and corrective actions – Technical brief, 2022, <https://iris.who.int/bitstream/handle/10665/361821/9789240020863-eng.pdf?sequence=1>; United States Environmental Protection Agency, Hazard Standard Risk Analysis: TSCA Section 403 – Risk analysis to support standards for lead in paint, dust, and soil, June 1998, <www.epa.gov/lead/hazard-standard-risk-analysis-tsca-section-403>; Commission Regulation (EU) 2021/1317 of 9 August 2021 amending Regulation (EC) No. 1881/2006 as regards maximum levels of lead in certain foodstuffs, <https://eur-lex.europa.eu/eli/reg/2021/1317/oj#d1e32-3-1.>

Table A1: Estimated geometric mean BLLs of a given population of children exposed to different soil lead concentrations

Age (months)	Soil concentration (mg/kg)													
	200	400	1000	1500	2000	2500	3000	3500	4000	4500	5000	5500	6000	6500
6	3.02	5.00	9.82	13.00	15.7	18.06	20.19	22.13	23.94	25.63	27.24	28.77	30.25	31.67
18	2.92	4.66	9.15	12.28	14.99	17.41	19.59	21.58	23.41	25.13	26.74	28.26	29.71	31.10
30	2.23	3.42	6.65	9.00	11.12	13.04	14.80	16.44	17.96	19.38	20.72	21.99	23.20	24.36
42	1.99	3.01	5.83	7.94	9.87	11.64	13.29	14.83	16.27	17.63	18.91	20.13	21.29	22.40
54	1.95	2.95	5.73	7.83	9.77	11.56	13.23	14.80	16.27	17.66	18.97	20.22	21.41	22.55
66	1.76	2.58	4.91	6.70	8.37	9.94	11.42	12.81	14.14	15.39	16.59	17.74	18.84	19.89
78	1.61	2.35	4.45	6.09	7.62	9.08	10.46	11.76	13.01	14.20	15.34	16.43	17.48	18.49

Table A2: Estimated geometric mean BLLs of a given population of children exposed to different water lead concentrations

Age (months)	Water concentration (ppb)													
	5	10	25	50	75	100	125	150	200	250	300	350	400	450
6	1.33	1.86	3.36	5.59	7.55	9.31	10.90	12.36	14.96	17.25	19.30	21.18	22.92	24.55
18	1.47	1.91	3.18	5.13	6.92	8.57	10.10	11.52	14.11	16.41	18.50	20.41	22.18	23.83
30	1.41	1.84	3.10	5.05	6.84	8.49	10.02	11.45	14.04	16.36	18.45	20.37	22.15	23.81
42	1.37	1.81	3.08	5.06	6.88	8.56	10.13	11.60	14.28	16.68	18.86	20.85	22.70	24.42
54	1.36	1.80	3.07	5.06	6.90	8.62	10.22	11.72	14.48	16.96	19.21	21.28	23.20	24.98
66	1.35	1.78	3.04	5.02	6.85	8.57	10.18	11.69	14.48	16.99	19.28	21.39	23.34	25.17
78	1.28	1.70	2.94	4.87	6.68	8.37	9.96	11.45	14.22	16.72	19.00	21.11	23.06	24.89

Table A3: Estimated geometric mean BLLs of a given population of children exposed to different spice lead concentrations[12]

Age (months)	Spice (mg/kg)										
	1	1.5	5	10	20	50	100	250	500	750	1000
6	1.33	1.86	3.36	5.59	7.55	9.31	10.90	12.36	14.96	17.25	19.30
18	1.47	1.91	3.18	5.13	6.92	8.57	10.10	11.52	14.11	16.41	18.50
30	1.41	1.84	3.10	5.05	6.84	8.49	10.02	11.45	14.04	16.36	18.45
42	1.37	1.81	3.08	5.06	6.88	8.56	10.13	11.60	14.28	16.68	18.86
54	1.36	1.80	3.07	5.06	6.90	8.62	10.22	11.72	14.48	16.96	19.21
66	1.35	1.78	3.04	5.02	6.85	8.57	10.18	11.69	14.48	16.99	19.28
78	1.28	1.70	2.94	4.87	6.68	8.37	9.96	11.45	14.22	16.72	19.00

12 Assumes a daily intake of 0.25 g of adulterated spice. Value should be doubled for an intake of 0.125 g, quadrupled for an intake of 0.0625 g and so on. Assumes lifelong ingestion at the same rate.

Table A4: Estimated geometric mean BLLs of a given population of 24-month-old children exposed to different combined soil lead and water lead concentrations

Soil concentration (mg/kg)	Water concentration (ppb)													
	5	10	15	20	25	50	75	100	125	150	175	200	225	250
100	1.87	2.26	2.65	3.03	3.40	5.18	6.81	8.33	9.75	11.07	12.32	13.49	14.61	15.66
200	2.33	2.72	3.10	3.47	3.84	5.58	7.18	8.67	10.07	11.37	12.60	13.76	14.86	15.91
300	2.79	3.17	3.54	3.90	4.26	5.97	7.54	9.01	10.38	11.67	12.88	14.02	15.11	16.15
400	3.23	3.60	3.97	4.32	4.68	6.35	7.90	9.34	10.69	11.96	13.15	14.29	15.36	16.38
500	3.67	4.03	4.39	4.74	5.08	6.73	8.25	9.67	11.00	12.25	13.43	14.54	15.61	16.62
600	4.10	4.45	4.80	5.14	5.48	7.10	8.59	9.99	11.30	12.53	13.70	14.80	15.85	16.85
700	4.51	4.86	5.21	5.54	5.87	7.46	8.93	10.31	11.6	12.81	13.96	15.05	16.09	17.08
800	4.93	5.27	5.6	5.93	6.26	7.82	9.26	10.62	11.89	13.09	14.22	15.30	16.33	17.31
900	5.33	5.66	5.99	6.32	6.64	8.17	9.59	10.93	12.18	13.36	14.48	15.55	16.56	17.53
1000	5.72	6.05	6.38	6.69	7.01	8.51	9.91	11.23	12.47	13.63	14.74	15.79	16.80	17.76
1100	6.11	6.43	6.75	7.06	7.37	8.85	10.23	11.53	12.75	13.90	14.99	16.03	17.03	17.98
1200	6.49	6.81	7.12	7.43	7.73	9.19	10.55	11.82	13.02	14.16	15.24	16.27	17.25	18.20
1300	6.87	7.18	7.48	7.79	8.08	9.52	10.85	12.11	13.30	14.42	15.49	16.51	17.48	18.41
1400	7.23	7.54	7.84	8.14	8.43	9.84	11.16	12.40	13.57	14.68	15.73	16.74	17.70	18.63

Table A5: Estimated geometric mean BLLs of a given population of 24-month-old children exposed to different combined soil lead and spice lead concentrations[13]

Soil concentration (mg/kg)	Spice (mg/kg)										
	1	1.5	5	10	20	50	100	250	500	750	1000
100	1.51	1.54	1.70	1.93	2.39	3.71	5.73	10.84	17.30	22.29	26.44
200	1.99	2.01	2.17	2.40	2.84	4.13	6.12	11.14	17.52	22.48	26.6
300	2.45	2.47	2.63	2.85	3.29	4.55	6.50	11.44	17.75	22.66	26.75
400	2.90	2.92	3.08	3.29	3.72	4.96	6.87	11.74	17.97	22.84	26.91
500	3.34	3.36	3.52	3.73	4.15	5.36	7.24	12.03	18.19	23.01	27.06
600	3.78	3.80	3.95	4.15	4.57	5.76	7.60	12.32	18.40	23.19	27.21
700	4.20	4.22	4.37	4.57	4.98	6.14	7.95	12.60	18.62	23.37	27.36
800	4.62	4.64	4.78	4.98	5.38	6.52	8.30	12.88	18.83	23.54	27.51
900	5.03	5.05	5.19	5.38	5.77	6.90	8.65	13.16	19.04	23.71	27.66
1000	5.43	5.45	5.58	5.78	6.16	7.26	8.98	13.43	19.25	23.89	27.81
1100	5.82	5.84	5.97	6.16	6.54	7.62	9.32	13.70	19.46	24.06	27.96
1200	6.21	6.23	6.36	6.54	6.91	7.98	9.64	13.96	19.66	24.23	28.11
1300	6.59	6.60	6.73	6.92	7.28	8.33	9.96	14.23	19.86	24.40	28.26
1400	6.96	6.98	7.10	7.28	7.64	8.67	10.28	14.49	20.06	24.56	28.40

13 Assumes a daily intake of 0.25 grams of adulterated spice. Value should be doubled for an intake of 0.125 grams, quadrupled for an intake of 0.0625 grams and so on. Assumes lifelong ingestion at the same rate.

Table A6: **Estimated geometric mean BLLs of a given population of 24-month-old children exposed to different combined water lead and spice lead concentrations**[14]

Water concentration (ppb)	Spice (mg/kg)										
	1	1.5	5	10	20	50	100	250	500	750	1000
5	1.44	1.47	1.63	1.86	2.32	3.64	5.67	10.79	17.26	22.27	26.42
10	1.84	1.87	2.03	2.26	2.71	4.00	6.00	11.05	17.46	22.42	26.55
15	2.24	2.26	2.42	2.64	3.09	4.36	6.33	11.31	17.65	22.57	26.68
20	2.63	2.65	2.80	3.02	3.46	4.71	6.64	11.56	17.83	22.73	26.81
25	3.01	3.03	3.18	3.40	3.82	5.06	6.96	11.81	18.02	22.88	26.94
50	4.81	4.83	4.97	5.17	5.57	6.70	8.47	13.01	18.93	23.62	27.59
75	6.48	6.50	6.63	6.81	7.17	8.23	9.87	14.15	19.80	24.35	28.21
100	8.02	8.04	8.16	8.33	8.67	9.65	11.19	15.23	20.65	25.05	28.83
125	9.45	9.47	9.58	9.74	10.06	10.98	12.43	16.26	21.46	25.74	29.43
150	10.80	10.81	10.92	11.07	11.36	12.23	13.60	17.24	22.25	26.41	30.02
175	12.06	12.07	12.17	12.31	12.59	13.41	14.71	18.19	23.01	27.06	30.60
200	13.25	13.26	13.35	13.49	13.75	14.53	15.76	19.09	23.75	27.70	31.18
225	14.37	14.39	14.48	14.60	14.85	15.59	16.77	19.96	24.47	28.32	31.74
250	15.44	15.46	15.54	15.66	15.90	16.60	17.73	20.80	25.17	28.94	32.29

14 Assumes a daily intake of 0.25 grams of adulterated spice. Value should be doubled for an intake of 0.125 grams, quadrupled for an intake of 0.0625 grams and so on. Assumes lifelong ingestion at the same rate.

Annex C

Glossary of useful terms

This annex presents a non-exhaustive list of terms that may be useful in discussing lead risk assessment. It was adapted from multiple sources and expert interviews.[15] Some – though not all – of these terms appear in the main text of this document.

Abatement – Work done to remove or cover a lead hazard. Abatement includes replacing windows and encapsulation. It is permanent or meant to last a long time.

Accuracy – The degree of agreement between an observed value and an accepted reference value (a 'true' value); a data quality indicator. Accuracy includes a combination of random errors (precision) and systematic errors (bias) due to sampling and analysis.

Ambient – Relating to the immediate surroundings. Ambient air refers to air in the community.

Biological monitoring – The analysis of blood, urine, or both to determine the level of lead contamination in the body. Blood lead levels are expressed in micrograms of lead per deciliter (one-tenth of a liter) of blood, or mcg/dL.

Blank – An unexposed sample of the medium being used for testing (i.e., wipe or filter) that is analyzed to determine if the medium has been contaminated with lead (e.g., at the factory or during transport).

Blood lead level – A measurement of the concentration of lead in whole blood. Typically reported in mcg/dL.

Certified reference material – Reference material that has at least one of its property values established by a technically valid procedure and is accompanied by or traceable to a certificate or other documentation issued by a certifying body.

Children – The focus of most lead poisoning prevention activities has been children 0–72 months old because children in that age range absorb more lead and are more likely to have adverse health effects than older children or adults.

Chelation therapy – A medical treatment that removes lead from blood. It can be administered by intravenous infusion or orally by pills. It is not recommended for children with blood lead levels less than 45 mcg/dL.

Control of lead sources – Methods of preventing lead exposure by lowering lead contamination through measures that keep lead from being accessible but do not permanently remove the lead. For example, making painted surfaces intact rather than replacing walls or floors.

Elimination of lead sources – Methods of preventing lead exposure by permanently removing the lead from the environment. For example, removing and replacing lead-contaminated soil.

Half-life – The time it takes for the concentration of lead in blood or other tissues to be reduced by 50 per cent.

15 Jacobs, *Fifty Years of Peeling Away the Lead Paint Problem: Saving our children's future with healthy housing*, 2022; CDC, Lead Poisoning: Words to know from A to Z, n.d., <www.cdc.gov/nceh/lead/docs/leadglossary_508.pdf>

Hazard – A potential harm (e.g., lead solder). Distinct from a risk (e.g., lead solder that is likely to be ingested in tap water).

Elevated blood lead level – Typically defined as a blood lead level of 5 mcg/dL or higher. Elevated means high or raised. Elevated blood lead level is sometimes written as EBLL.

Ingest – To swallow or take in through your mouth.

Inhale – To breathe in.

Investigator – A person who conducts an investigation of a dwelling to identify possible sources of lead exposure. The investigator must be proficient in interviewing techniques, environmental sampling, and the interpretation of risk assessment and environmental sampling data.

Lead poisoning – A health condition caused by ingesting or inhaling lead. Lead poisons children when it gets into their bodies. Lead poisoning can hurt the brain and nervous system and slow down growth and development. The health consequences of lead poisoning can be lifelong.

Low- and medium-income countries (LMICs) – World Bank country income classifications. Defined as annual per capita income of less than US$12,695.

Medium – The material being assessed (e.g., air, water, soil, paint, spice, ceramic, cosmetic or other products). Plural is 'media.'

mcg – Microgram. The prefix micro means 1/1,000,000 (or one-millionth); a microgram is 1/1,000,000 of a gram and 1/1000 of a milligram. Also abbreviated at µg.

Pb – The symbol for the lead element.

Risk – A function of the probability and severity of a hazard to cause harm (e.g., flaking lead paint, contaminated soil in a playground). Distinct from a hazard (e.g., encapsulated lead paint, contaminated soil in a restricted and secured industrial area).

Risk assessment – The process of identifying hazards and characterizing their risk, including their severity and probability to cause harm.

Substrate – A surface on which paint, varnish or other coating has been applied or may be applied. Examples of substrates include wood, plaster, metal and drywall.

Take-home exposure – The exposure risk caused by parents or guardians carrying lead contamination into the homes on their clothes or person. Possible when the individuals are engaged in an occupation that uses lead.

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