INTERNATIONAL STANDARD

ISO 15800

Second edition
2019-08

Soil quality — Characterization of soil with respect to human exposure

Qualité du sol — Caractérisation des sols en lien avec l'évaluation de l'exposition des personnes

Reference number
ISO 15800:2019(E)

ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Fax: +41 22 749 09 47
Email: copyright@iso.org
Website: www.iso.org

Published in Switzerland

Contents

Page

Foreword iv
Introduction v
1 Scope 1
2 Normative references 1
3 Terms and definitions 1
4 Use of this document 5
5 Background 6
5.1 Characterization of soil and sites with respect to human exposure 6
5.2 Potential human receptors 8
5.3 Exposure pathways 8
5.3.1 General 8
5.3.2 Soil ingestion 11
5.3.3 Cutaneous contact 12
5.3.4 Inhalation of dust 12
5.3.5 Inhalation of vapours (outdoors) 12
5.3.6 Inhalation of vapours (indoors) 13
5.3.7 Intake via plants 13
5.3.8 Intake via animals 14
5.4 Exposure to asbestos in soil 14
6 Sampling for site characterization 14
6.1 Site characterization 14
6.2 Soil ingestion 15
6.3 Vapour and dust inhalation 16
6.3.1 Inhalation of vapour 16
6.3.2 Inhalation of dust 16
6.4 Cutaneous contact 17
6.5 Intake of substances via plants 17
6.6 Intake of substances via the consumption of animal products 17
6.7 Synthesis for site sampling in relation with human exposure 18
7 Characterization of soil as a matrix hosting physical, chemical and biological processes 19
7.1 Relevant soil processes and parameters 19
7.2 Measurement/analysis of soil characteristics 21
7.2.1 Physical characteristics of soils 21
7.2.2 Chemical characteristics of soil 22
8 Analytical strategy 23
8.1 Characterization of contamination 23
8.2 Characterization of contamination in relation to exposures 23
8.2.1 General 23
8.2.2 Metals and metalloids 24
8.2.3 Bioaccessibility and bioavailability 24
8.2.4 Organic contaminants 25
8.2.5 Soil/substance related parameters 26
9 Management of results 26
10 Data handling, evaluation and quality 27
Annex A (informative) **Exposure pathways depending on the site use** 29
Annex B (informative) **Methods and ISO standards** 30
Bibliography 34

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 7, *Impact assessment*.

This second edition cancels and replaces the first edition (ISO 15800:2003), which has been technically revised. The main changes compared to the previous edition are as follows:

— the feedback on contaminated soil management for 15 years has been taken into account;

— the analysis results have been updated.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Characterizations of soils and sites relating to human exposure are performed all over the world. They are often planned and conducted by consultancies and expert organizations. Information from these characterizations is used to assess human exposure. Furthermore, these characterizations are used for decision-making by companies, individuals and local and national authorities as well as a basis for recommendations and regulations issued by national and international authorities.

The assessment of potential human health effects from exposure can be used for:

— the classification of contaminated sites;

— recommendations regarding the remediation of sites, soils and soil materials, e.g. priority of remediation;

— decisions regarding the future/planned use of contaminated sites;

— decisions regarding the disposal/treatment/re-use of contaminated or remediated soil and/or soil material.

The information needed for evaluations of human exposure is, to some extent, dependent on the way in which the exposure is assessed, e.g. calculations can be based on different scenarios, each requiring different information.

The extent of investigations necessary for the assessment of human exposure varies depending on the level of contamination and the investigated area. In some cases, the assessment of potential human health exposure can be based solely on information on the substances present in the soil and their concentrations and the relevant soil parameters. In other cases, it is necessary to know the "availability" of the substance (i.e. the proportion biologically active). This information will depend on the type and concentration of the substance, the relevant soil parameters and the type of exposure relevant for the area investigated, represented in the conceptual site model (CSM). Furthermore, the sampling method and strategies can depend on the use of the project area and the possible exposure patterns.

Soil quality — Characterization of soil with respect to human exposure

1 Scope

This document provides guidance on the type and extent of soil characterization necessary for the evaluation of human exposure to substances present in possibly leading to adverse effects.

It does not provide guidance on:

— the design or selection of numerical models that can be used to estimate exposure;

— potential exposure to radioactivity, pathogens or asbestos in soil.

Background information is provided on human health related to exposure to soil and the influence on exposure via different pathways.

NOTE 1 For convenience "soil" in this document also includes "soil material" unless stated otherwise.

NOTE 2 Overall exposure can be due to potentially harmful substances (PHSs) in soil, groundwater and air. Exposure to those in soil can be direct (e.g. through inhalation, ingestion, cutaneous contact), or indirect (through the consumption of plants or animals that have taken up substances of concern).

NOTE 3 The evaluation of the possible impact on human health of potentially harmful substances is most commonly required when these are present as a result of human activity (e.g. on old industrial sites) but can sometimes be required when they are present naturally.

NOTE 4 Soil characterization precedes the assessment of the compatibility between soil and its use (i.e. soil quality assessment). Tools such as a conceptual site model (CSM) and health risk assessment can be used to aid this assessment.

NOTE 5 Soil characterization can be used to develop an overview of population exposure to soil. Other International Standards are available that can aid the characterization of other media (e.g. surface and groundwater), in terms of their possible adverse effects on humans.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11074, *Soil quality — Vocabulary*

ISO 25177, *Soil quality — Field soil description*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11074, ISO 25177 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
analytical data quality objectives
statement of the required detection limits, accuracy, reproducibility and repeatability of the required analytical and other data

Note 1 to entry: Generic data quality objectives might sometimes be set at national level. Data quality objectives can also embrace the amount of data required for an area of land [or part of a *site* (3.21)] to enable a sound comparison with generic guidelines or standards or for a site-specific or material-specific estimation of *risk* (3.17).

3.2
bioaccessibility
fraction of a substance in *soil* (3.23) or *soil material* (3.25) that is liberated in (human) gastrointestinal juices and thus available for absorption

[SOURCE: ISO 17924:2018, 3.2]

3.3
bioavailability
fraction of a substance present in ingested *soil* (3.23) that reaches the systemic circulation (blood stream)

[SOURCE: ISO 17924:2018, 3.3]

3.4
contaminant
substance or agent present in the *soil* (3.23) as a result of human activity

Note 1 to entry: There is no assumption in this definition that harms results from the presence of the contaminant. See also *pollutant* (3.14).

[SOURCE: ISO 11074:2015, 3.4.6, modified — Term number in Note 1 to entry has been adapted to the numbering of this document.]

3.5
deep soil
soil (3.23) that is generally deeper than 90 cm and that is not accessible in normal situations but can become accessible in case of construction site for example

Note 1 to entry: Examples include construction of foundations and basements, installation of services, planting pits for trees and shrubs.

3.6
exposure assessment
process of establishing whether, and how much, exposure occurs between a *receptor* (3.16) and a contaminated *source* (3.26)

[SOURCE: ISO 11074:2015, 5.2.11]

3.7
exposure pathway
path a chemical takes from a *source* (3.26) to a *receptor* (3.16)

EXAMPLE Ingestion, *inhalation* (3.11) or cutaneous contact.

[SOURCE: ISO 11074:2015, 5.2.12, modified — Note 1 to entry has been replaced by the example, accepted term "exposure routes" not included.]

3.8
groundwater
water which is being held in and can be recovered from an underground formation, except capillary water

Note 1 to entry: Groundwater is usually taken to include any water, beneath the surface of the land or beneath the bed of any stream, lake, reservoir, or other body of *surface water* (3.29), whatever the geological formation or structure in which such water occurs; but water within the beds of streams, etc. is often excluded.

[SOURCE: ISO 11074:2015, 3.2.3]

3.9
hazard
property of a substance or material or situation that in particular circumstances could lead to harm or pollution

[SOURCE: ISO 11074:2015, 5.2.15]

3.10
ingestion
exposure pathway (3.7) of substances reaching the body by oral intake, such as from contaminated food or direct *soil* (3.23) intake, in particular by children

3.11
inhalation
exposure pathway (3.7) of airborne particles and gases reaching the body during breathing

Note 1 to entry: The inhalation exposure covers alveolar exposure as well as bronchial exposure; and this bronchial mucus can subsequently be ingested.

3.12
non–threshold effect substance
substance for which there is considered to be some *risk* (3.17) at any level

3.13
pathway
mechanism or route by which substance or agent could come into contact with, or otherwise affect, a *receptor* (3.16)

Note 1 to entry: Examples can be migration pathway, transfer pathway and *exposure pathway* (3.7).

[SOURCE: ISO 11074:2015, 5.2.21, modified — Note 1 to entry added.]

3.14
pollutant
substance or agent present in the *soil* (3.23) [or *groundwater* (3.8)] which, due to its properties amount or concentration, causes adverse impacts on soil functions or on human health or other *receptors* (3.16)

[SOURCE: ISO 11074:2015, 3.4.18, modified — The phrase "or on human health or other receptors" was added.]

3.15
potentially harmful substance
PHS
substance or agent present in the *soil* (3.23) [or *groundwater* (3.8)] which, due to its properties, amount or concentration can cause adverse impacts on soil functions or human health or *receptors* (3.16)

3.16
receptor
defined entity that is vulnerable to the adverse effect(s) of a hazardous substance or agent

EXAMPLE Human, animal, water, vegetation, building services, etc.

[SOURCE: ISO 11074:2015, 3.3.29]

3.17
risk
combination of the probability or frequency of occurrence of a defined *hazard* (3.9) and the magnitude of the consequences of the occurrence

[SOURCE: ISO 11074:2015, 5.2.24]

3.18
risk assessment
assessment performed with the data and other information from the *site* (3.21) investigations using databases and numerical models for assessment of the release of *contaminants* (3.4) and naturally occurring *potentially harmful substances* (3.15), environmental fate analysis, *exposure assessment* (3.6), environmental impact analysis, environmental impact analysis and an uncertainty analysis

3.19
risk characterization
evaluation and conclusion based on the hazard identification and the exposure and effect assessment

3.20
scenario
quantitative risk assessment
set of conditions or assumptions about *sources* (3.26), *exposure pathways* (3.7), amounts or concentrations of agent(s)involved, and exposed organism, system, or (sub)population (i.e. numbers, characteristics, habits) used to aid in the evaluation and quantification of exposure(s) in a given situation

3.21
site
scope covered by the study

Note 1 to entry: It could be a site in the property sense (plot with defined boundaries) or a more extended area affected by the same contamination.

3.22
site characterization
collection of appropriate information including analytical data, etc. for the assessment in question

Note 1 to entry: In connection with *risk assessment* (3.18), specifically the *source* (3.26) identification and characterization element of the *exposure assessment* (3.6).

[SOURCE: ISO 11074:2015, 2.3.12, modified — The phrase "of data connected to a site providing" was deleted and "including analytical data, etc." was added.]

3.23
soil
upper layer of the Earth's crust transformed by weathering and physical/chemical and biological processes and composed of mineral particles, organic matter, water, air, and living organisms organized in generic soil horizons

Note 1 to entry: In a broader sense, soil includes *topsoil* (3.31) and *subsoil* (3.27), deposits such as clays, silts, sands, gravels, cobbles, boulders, and organic matter and deposits such as peat; materials of human origin such as wastes; ground gas and moisture; and living organisms.

[SOURCE: ISO 11074:2015, 2.1.11, modified — Note 1 to entry "civil engineering" was deleted.]

3.24
soil characterization
determination of relevant physical, chemical and biological properties of the *soil* (3.23) in case of human *exposure assessment* (3.6)

[SOURCE: ISO 11074:2015, 2.1.12, modified — The phrase "in case of human exposure assessment" was added.]

3.25
soil material
material composed of excavated *soil* (3.23), dredged materials, manufactured soils, treated soils and fill materials

[SOURCE: ISO 11074:2015, 7.4.16]

3.26
source
place from which a substance or agent is released giving rise to potential exposure of one or more *receptor* (3.16)

[SOURCE: ISO 11074:2015, 3.3.35]

3.27
subsoil
natural *soil material* (3.25) below the *topsoil* (3.31) and overlying the parent material

[SOURCE: ISO 11074:2015, 2.1.20, modified — Note 1 to entry was deleted.]

3.28
surface soil
soil (3.23) exposed at the surface

Note 1 to entry: Sometimes referred to as accessible soil or superficial soil.

3.29
surface water
water on the surface of the planet such as in a river, lake, wetland, or ocean

Note 1 to entry: It can be contrasted with *groundwater* (3.8) and atmospheric water.

3.30
threshold effect substance
substance where the critical effect is considered to have dose or exposure below which a significant adverse effect is not expected

Note 1 to entry: An adverse effect is a change in morphology, physiology, growth, development or life span of an organism which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility to the harmful effects of other environmental influences. Decisions on whether or not any effect is adverse require expert judgement.

3.31
topsoil
upper part of a natural *soil* (3.23) that is generally dark coloured and has a higher content of organic matter and nutrients when compared to the (mineral) horizons below, excluding the humus layer

[SOURCE: ISO 11074:2015, 2.1.21, modified — Note 1 to entry has been removed.]

4 Use of this document

The purpose of characterizing soil (or other media) as suggested in this document is primarily to perform risk assessments with respect to human exposure. These assessments can be performed by referring to published international or national standards that set out physical, chemical or other criteria that shall be complied with, or according to criteria set on a site-specific basis. In many jurisdictions, formal guidance on such assessments has been published and should be considered. Guidance has also been provided by professional organizations and some standardization bodies.

This document provides guidance on the types of information that might be required for a human health risk assessment and indicates for which parameters or procedures International Standards are available. The assessor should choose those parameters that are appropriate to the task at hand. The assessor will need to bear in mind the disproportionate costs and time delays that might result if it is necessary to carry out an additional sampling campaign, or if, for example, a particular parameter is not determined when the opportunity is available.

To provide context to this guidance, a general, non-normative account of human risk assessment, with particular emphasis on when humans are exposed to soil is provided in Clause 5. Clause 6 considers the relationship between soil and particular exposure pathways. Guidance on characterization of the soil, for example in terms of physical properties is provided in Clause 7, and in terms of what substances to look for and how to measure them in Clause 8. Clause 9 provides information on how the results of characterization can be used and Clause 10 provides guidance on how to ensure that information collected including analytical data are sufficient for the investigation in hand in terms of quality, quantity and type. How to achieve the last is the principal purpose of Clauses 7 and 8.

This document refers in places to substance, potentially harmful substances (PHSs) and to contaminants. The latter applies strictly only when a substance or agent is present due to human activity but unless indicated otherwise or by the context can be assumed to also include substances that are present naturally as well as those present due to human activity. The term pollutant is not used in this document (see Note).

As indicated by the note below, those preparing human health risk assessments should always be careful to define the terms and concepts they are employing in reports. Terms are not used consistently by people with different backgrounds and experience, and there can be subtle differences in how terms are used and understood. It is also important to remember that reports will often be read by those without specific training or education in risk assessment.

NOTE It is important when carrying out human health risk assessment to carefully define the terms that are being used, especially for example “contaminant/contamination” and “pollutant/pollution” because they might not be understood to have the same meaning by people with different backgrounds and experience. This document follows the established convention for documents published by ISO Technical Committee 190 (TC190) in distinguishing between “contaminant” (“substance or agent present in an environmental medium as a result of human activity – see 3.4) and "pollutant" (“substance or agent present in the soil (or groundwater) which, due to its properties, amount or concentration, causes adverse impacts on soil functions” – see 3.14 and ISO 11074:2015, 3.4.18). Hence, “contamination” and “pollution” are not considered to be the same thing. However, it is recognised that this distinction is not always made at “official” level in all jurisdictions. Even in those jurisdictions where it is recognised, it might be for some purposes but not others and the definitions of “contamination” and “pollution” used in legislation and regulations for different purposes can differ. In addition, the use of the terms is not necessarily consistent between and even within guidance documents produced by government and professional bodies.

5 Background

5.1 Characterization of soil and sites with respect to human exposure

Characterizations of soils and sites with respect to human exposure are usually performed as a part of a risk assessment.

In most countries, industrial activities have had adverse effects on soil and groundwater quality. Similarly, soil and groundwater quality is often adversely affected by agricultural and similar activities. Elevated concentrations of potentially harmful substances (PHSs) can also be present naturally.

The accumulation of substances in soil, groundwater and other media (food, air) should be taken into account when quantifying human exposure to PHSs to assess potential effects on humans.

PHSs often have acute and/or chronic effects on human health. The risks usually addressed in formal human health risk assessments (for example, of old industrial sites) are chronic.

In the event of an incidental discovery of contamination during excavation, potential effects on, for example, human health and safety, should be identified, measured and monitored, and assessed

The toxic action of a substance can be divided into acute effects and chronic effects:

— acute health effects are quickly seen, usually after exposures to fairly high levels or concentrations of potentially harmful substances (such exposures often cause severe symptoms in animals or humans which develop rapidly);

— chronic (long-lasting) health effects usually develop more slowly and can be the result of either a short-term exposure or due to a long and continuous exposure to low concentrations of a potentially harmful substance which in some cases (e.g. cadmium) accumulates in the body over time until a harmful concentration is reached.

NOTE 1 Care is required when using the terms "short-term" and "long-term" and "acute" and "chronic" and to be clear whether an "exposure" or "effect" is being described. For example, in terms of occupational exposure, some conventions ascribe "short-term" to only a few minutes exposure, whereas "long-term" might assume exposure lasting up to about 8 h (i.e. a working day). The adverse effect being guarded against, might be "acute", i.e. manifest immediately or shortly after exposure, or might only become manifest in the longer term. For example, a single exposure to asbestos might be the cause of cancer 30 or 40 years later. In contrast, short-term exposure might result in a chronic (long-lasting) effect that first becomes manifest shortly after exposure.

Acute risks and chronic risks should always be considered and appropriate risk assessments carried out (these are often required by regulations relating to occupational health and safety, etc.).

Chronic risks are generally considered using health risk assessment based on long-term exposure (between one year and life-time). Models can be used to predict exposure and can incorporate case-specific and realistic assumptions. The expected effects are either localised or systemic. These effects can be carcinogenic, teratogenic or thresholded, depending on the toxicological properties of the substance.

NOTE 2 Duration of exposure is not taken into account in risk calculations for substances with threshold effects, see Reference [61]. For a substance of concern due to its toxicity (i.e. with threshold effects) but which does not accumulate in the body, the length of exposure is irrelevant in classical model equations.

A risk assessment comprises the following elements:

— hazard identification,

— dose-response assessment,

— exposure assessment, and

— based on the above, risk characterization.

Risk and exposure assessments are usually performed on the basis of one or more defined scenarios, see Reference [60], e.g. to establish general criteria related to the scenario, or on the basis of the data associated with a specific site.

An exposure assessment is the process wherein the intensity, frequency, and duration of human exposure to a substance are estimated. It comprises:

— source identification and characterization,

— identification of exposure pathways,

— identification of relevant receptors groups with relevant exposure scenarios, and

— based on the above, the exposure assessment itself.

The development of a conceptual site model (CSM) can be used to identify exposure pathways relevant to the assessment of a site and hence the type of soil characterization to be carried out. In this context, a (potentially) contaminated site is an area defined, for example, by property boundaries and contaminated by past or present human activities. It might be an area of natural, near natural or agricultural land or an artisanal or industrial site. In many countries, contaminated sites are registered publicly as a consequence of specific legislation.

The CSM first relies on an inventory of sources, transfer pathways and receptors (current or future). In the context of potentially contaminated sites, this CSM in turn leads to the formulation of contamination-related hypotheses that the investigation at the site examines through the collection of relevant information. The term "contaminant linkage" is used to describe a particular combination of contaminant source, exposure pathway, and receptor. It is site-specific and it facilitates the decision-making process relating to a potentially contaminated site. It is used to develop appropriate sampling strategies that enable the sound characterization of soils and others exposure media and hence the risk assessment. The guidance in ISO 21365[1)] should be followed when developing a CSM.

NOTE 3 A building might be contaminated due to the industrial activities performed in it. This contamination is independent of any exposure due to contaminated soil beneath or around the building.

5.2 Potential human receptors

Potential human receptors include:

— current occupants and users: residential population (adults and children),

— current business population: persons exposed due to the localization of their jobs and not due to their activity (adults),

— workers: persons exposed because of their activity (adults),

— planned occupants and users: future residential population (adults and children),

— planned business population (adults),

— planned workers (adults),

— visitors to a site (casual, with or without permission, trespassers, etc.), and

— occupants and users of neighbouring land (nearby community).

Workers potentially exposed because of their activity could be engaged in:

— site clearance,

— remediation works,

— installation of services,

— construction,

— maintenance of services,

— maintenance of landscaped areas, or

— farming and horticultural practices, etc.

5.3 Exposure pathways

5.3.1 General

Human exposure from soil contamination can occur through different media. Table 1 highlights the possible relationships between the different media and the associated uses which cause exposure.

1) Under preparation. Stage at the time of publication: ISO/FDIS 21365:2019.

Table 1 — Examples of uses within a specific medium that are susceptible to expose human populations.

Media		Exposure pathway	Examples of activities/uses
Soil	surface soil	— soil ingestion — indoor and outdoor dust inhalation — indoor and outdoor dust/soil ingestion — cutaneous contact — vegetable ingestion — animal products ingestion	— vegetable gardens — livestock farming — residential garden — hunting
	Subsurface soil	— dust/soil ingestion — dust/aerosol inhalation — cutaneous contact — vegetable ingestion — vapour inhalation	— vegetable gardens — livestock farming — residential garden
	Deep soil	— dust/soil ingestion — dust/aerosol inhalation — vapour inhalation — cutaneous contact	— extraction/quarrying (resources) — construction elements and structures being used or to be kept following the redevelopment of the site.
Water	Surface water	— ingestion — aerosol inhalation — vapour inhalation — cutaneous contact	— tap water uses — industrial water uses — farming uses — fish farming — shell-fish farming — angling and recreational fishing — fish consumption — seafood consumption — crop watering
	Groundwater	— ingestion — aerosol inhalation — vapour inhalation — cutaneous contact	— tap water uses — industrial water uses — wells — farming uses — crop watering

Table 1 *(continued)*

Media		Exposure pathway	Examples of activities/uses
Air	Indoor	— vapour inhalation — dust ingestion — dust/aerosol inhalation	— residential building — industrial building — commercial building — tertiary services (office, school)
	Outdoor	— vapour inhalation — dust/aerosol inhalation — dust/ soil ingestion — cutaneous contact	— residential garden — outdoor area of industrial, commercial building
Sediments	Suspended particles	— ingestion — dust/aerosol inhalation — cutaneous contact	— sediment extraction — fishing
	Bottomed particles	— ingestion — dust/aerosol inhalation — cutaneous contact	— sediment extraction — fishing

Direct routes of exposure to potentially harmful substances in soil are:

— soil ingestion (see 5.3.2);

— cutaneous (skin) contact, including entry through cuts and abrasions (see 5.3.3);

— inhalation and ingestion of fugitive dust;

— inhalation of harmful gases and vapours outdoors (see 5.3.5) and indoors (see 5.3.6).

Indirect exposure through the food chain comprises:

— consumption of plants including crops, wild plants and fungi (see 5.3.7);

— consumption of animals and animal products (eggs, milk, meat), including wild animals (see 5.3.8).

Exposure to substances in soil can also occur when they are translocated into other media including surface and groundwater.

NOTE 1 Exposure pathways associated with surface and groundwater are not included in this document. These routes also include exposure due to showering, dish washing and other domestic uses of water, the ingestion of fish and of piped water contaminated by soil (permeation phenomena) or groundwater surrounding pipes. These routes can be very relevant to pathways in the overall exposure pattern. Groundwater and surface water contamination is often related to soil contamination (see ISO 15175). The transfer of contaminants from the soil to surface waters is highly site-specific and depends on run-off volume, peak flow rate, soil erodibility, slope length and steepness, the sorption capacity of the soil, the type of vegetation cover, and the distance to the receptor. In practice, surface water contamination is usually monitored by direct measurement. Exposure by water ingestion or direct contact with water is possible if wells or catchments (groundwater), water sports or fishing (superficial water) are identified. In this case, this exposure by water can be taken into account in the wide-ranged human exposure assessment.

NOTE 2 Drinking water can be contaminated by permeation of chemicals into plastic pipes. This transfer pathway is rarely considered. Indeed, this contamination is difficult to measure or to model. Consequently, use of material which allows permeation of chemicals is commonly avoided.

The actual exposure pathways will depend on the use of the site:

- Playgrounds and private (kitchen and ornamental) and public gardens can be considered to cause the highest level of human exposure during use. This use could imply close (skin) contact with the soil, the ingestion of soil, the ingestion of plants or fruit grown in the soil (and of soil with these plants) as well as the inhalation of dust and vapours.
- Agricultural areas can cause exposure through the food chain, in particular ingestion of agricultural produce can result in significant exposure for regular consumers. Produce (crops and livestock), except for any consumed by the farmer and his family, is usually widely distributed to a large population (sometimes after processing) thus resulting in little exposure of individuals. However, there might sometimes be a "short" distribution circuit, e.g. when farmers sell locally direct to the public, sometimes to regular customers, in which case exposure of individuals can be more significant.
- Meadows where livestock can be exposed to contaminated topsoil (indirect contamination).
- Parks can facilitate exposure to inhalation of dust and vapours, the contact of skin with soil/dust, but to a lesser degree than gardens, and soil ingestion.
- Sports facilities mainly can facilitate exposure via the inhalation of soil/dust, ingestion of soil and dust and the contact of skin with soil/dust.
- Consolidated surfaces, such as parking lots, roads, etc., give rise to exposure via the inhalation of vapours and from the accumulation of fine dust.
- Buildings (homes, schools, kindergartens, offices, industry and shops) can facilitate exposure via vapours and soil/dust carried into them possibly causing inhalation and/or ingestion and/or cutaneous contact.
- Industrial and commercial sites can comprise consolidated and unconsolidated areas, park-like areas, and buildings. The information needed to evaluate human exposure in these types of area are listed above.

The actual exposure time can differ between similar site uses due to differences in climate and real site use patterns (e.g. number of days per week the site is in use).

An overview of relevant exposure pathways for each site use is given in Annex A. The CSM illustrates all the pertinent exposures pathways.

In the following clauses, the characterization of soils with respect to the different exposure pathways is described. The uptake patterns and thus the importance of the different exposure pathways vary depending on the properties of the substances and soils in question.

5.3.2 Soil ingestion

Soil ingestion by children occurs through the ingestion of dust, sucking dirty fingers and eating soil. A distinction should be made between inadvertent and accidental intake and deliberate long-term persistent behaviour (pica behaviour). In general, pica behaviour should be regarded as a special case, not necessarily relevant for the actual assessment in question.

NOTE Some young children go through a short period of exploratory soil ingestion.

Adults mainly ingest soil as dust, for example, in connection with gardening, and as soil on non-cleaned vegetables and fruits. When characterizing a specific site, actual behaviour should be taken into account.

Indoor settled dust ingestion can be a significant exposure pathway in some contaminated site configurations (e.g. house built on former mining residue deposit).

The hypothesis of total absorption of the substance in the digestive tract is often made but total absorption does not always take place. The actual bioaccessibility and bioavailability can be assessed.

These parameters are used to evaluate the amount of a substance that can reach the bloodstream (see 8.2.1). The potential for absorption of a given substance can vary with soil particle size, thereby illustrating the relevance of information on particle size distribution.

5.3.3 Cutaneous contact

Contact between the skin and contaminated soil can be caused by dust reaching the skin through atmospheric deposition, and by playing or by working with the soil. It should be noted that there is a distinction between skin contact in the home and contact during work, since the latter is usually subject to “health and safety at work” regulations.

Skin contact can cause both systemic effects (damage to organs) and local effect (rashes, hypersensitivity, irritation, corrosion) depending on the substance. This route is therefore potentially important for the more lipophilic compounds (substances which easily cross the skin barrier). However, international consensus recognizes the difficulties of quantifying the effects of cutaneous exposure and the level of exposure by the cutaneous route.

The concentration of a substance usually varies with particle size, the smallest particles often containing the highest concentrations. Only the finest fractions are likely to adhere to the skin and thus the use of average concentrations in calculations of cutaneous exposure can result in an underestimation of exposure.

Water soluble substances such as phenol will tend to be concentrated in the soil moisture. This is important when considering possible localised effects.

5.3.4 Inhalation of dust

The real importance of dust inhalation (and digestion) as an exposure pathway is associated with the activity on the site (e.g. gardening and farming). Climatic conditions and vegetation cover also influence exposure. This exposure pathway is often coupled with the dust ingestion route. It is indeed very difficult to differentiate between substances that are swallowed and those which are inhaled.

Calculations pertaining to the uptake of dust may be based on general models for dust in air. The concentration of a substance usually varies with particle size, the smallest particles often containing the highest concentrations. This should be taken into account if only measurements of the average concentrations are available or otherwise the actual exposure could be underestimated.

NOTE The respirable fraction of dust in air is usually considered to be that below 30 µm and thus it is the concentration of a substance of concern in this fraction that is important to the exposure assessment.

5.3.5 Inhalation of vapours (outdoors)

Assessment of the inhalation of vapours should primarily be based on measurements of soil and soil gas concentrations. Soil gas measurement can be performed by passive or active sampling methods (see ISO 18400-204). If this is not possible or otherwise not relevant (e.g. in the case of planned activities that would alter the distance between the contaminated zone and the receptors, for example by installing venting systems) calculations of air fluxes from the contaminated soil volume to the surface can be performed. The relevant soil parameters for these calculations are (together with information on the depth of the vadose zone and variations therein):

— concentration;

— porosity;

— water content;

— bulk density;

— organic carbon fraction.

5.3.6 Inhalation of vapours (indoors)

The inhalation of vapours indoors can be assessed on the same basis as outdoor vapours taking into account information relevant to the estimation of diffusion and advective (crack) transport through the floor construction. For current buildings located on a soil contaminated by volatile compounds, indoor concentration measurements should be performed together with simultaneous soil gas measurements.

If possible, modelling values should be corroborated by measurements in integrated media such as soil gas (comparisons with measurements are required to evaluate the limitations of the models).

If measurements cannot be performed, and in the case of planned buildings, models can be used to predict indoor concentrations from soil gas concentrations. These models integrate the transport processes of volatile compounds from the soil to the surface (diffusion and convection).

A large number of parameters are required to build the model and to assess exposure to volatile compounds:

— site specific parameters (temperature differences, water filled porosity of soil, dry bulk density of soil, pressure differences between the contaminated area in the soil and the receptor indoor area due to wind, changes in atmospheric pressure, organic carbon partition coefficient/water);

— physico-chemical parameters of relevant substances (partition coefficients: octanol/water and organic carbon/water, Henry's constant, vapour pressure);

— building parameters (for example size, characteristics of the slab, dimensions of under croft or crawl space, ventilation, heating system);

— receptor parameters: human physical characteristics and human behaviour (time spent indoors, human exposure values).

5.3.7 Intake via plants

Substances can be captured and accumulated by plants via uptake by roots and plants can also be contaminated by deposition on leaves and fruits, etc. Human exposure will depend on the type and amount of plant matter consumed and also on how the plant matter is treated before consumption (washing, peeling, cooking, packaging, etc.).

The quantity of substances captured by plants depends on the physico-chemical characteristics of the substance, the characteristics of the soil, the type of plant (including the variety/cultivar of a particular plant type), and climate. Concentrations will tend to vary between plant parts, e.g. roots, stems, leaves, fruits, etc.).

Care should be taken when using general models for the assessment of plant uptake (see below) in a specific case. The results of experimental studies on accumulation by plants from actual soil on the site should be used when available, preferably obtained in conditions similar to those of the assessed site. There are International Standards (see Table B.2) for methods for assessing soil/plant interactions using weak extractants.

Assimilation of substances by plants can be modelled. In this case, the results of specific experimental studies allow estimation of the bioconcentration factor (BCF), i.e. the ratio of the concentration in the plant to the concentration in the soil. The BCF depends on the type of soil and its physico-chemical properties and varies between plant types and between varieties/cultivars within a plant type (species).

Default BCF values from databases can be used, especially for metals or for persistent organic substances. However, as the BCF depends on site parameters, such default values should be used with caution.

"Good practices" for sampling, packaging and analysis can help to reduce error and to have representative values.

The relationship between the contamination of soil and the plants (grown in it) should be made, although the concentrations of substances in soil and in plants cannot be connected (bioaccumulation parameters). This could be due to various factors affecting soil-plant relationships including, by example, physical and chemical properties of soils and plant type, age and parts. It is important to take into account total exposure via plant uptake along with local conditions and the influence of possible.

Uptake of metals or organic compounds [polycyclic aromatic hydrocarbons (PAH), polychlorinated biphenyls (PCB) and dioxins] can be evaluated using parameters such as (pseudo) total concentration, clay content, organic carbon content, cation exchange capacity (CEC), distribution coefficients and pH. Plant uptake can also (at least for some metals) be estimated via extraction tests utilising diluted, non-complexing or organic complexing salts or diluted acids (refer to Clauses 6 and 7).

The importance of the different parameters mentioned varies not only with the soil, but also with the vegetation and individual species and varieties of plants.

NOTE 1 Some plants naturally produce aromatic hydrocarbon substances. These substances can interfere with the analytical results.

5.3.8 Intake via animals

Intake by animals is mainly due to direct ingestion of soil from the surface layer or from soil adhering to forage. To a lesser degree it comes from consumption of fodder after plant uptake and accumulation. The degree of accumulation of the substances by animals will depend not only on the properties of the soil and the components of the animal's diet, but also on the properties of the substance and the level of contamination. Default values from databases can be used with caution to estimate the contamination of animal products due to soil contamination. Care should be taken in using these default values and in interpreting results. Measurements can also be helpful to estimate this contamination.

5.4 Exposure to asbestos in soil

It is important to recognise that anthropogenic deposits are often contaminated with asbestos or asbestos containing materials that can present serious risks for human health and safety. Appropriate risk assessments should be carried out prior to any sampling

NOTE General guidance on safety during sampling is provided in ISO 18400-103.

6 Sampling for site characterization

6.1 Site characterization

An exposure assessment of contaminated sites as well as soil in general depends on the information available about the characteristics of the site in question, including substance sources, migration pathways and the potential receptors that might be at risk. It is important to determine where to investigate and which matrices should be sampled. Table 1 can be used to identify the media to be sampled in order to take into account different exposure pathways.

For the purposes of this document, site characterization can thus be defined as the source identification and characterization component of the exposure assessment.

Investigations should be thorough enough to locate, quantify and characterize contamination. They should be both lateral (sample area) and vertical (sample depth) to evaluate the degree and extent of contamination. Sampling standards should be considered to obtain a detailed description of the relevant types of site investigation, sampling, and assessment. In particular, the guidance in ISO 18400-104 on investigation and sampling strategies in general and that in ISO 18400-203 on potentially contaminated sites should be followed.

NOTE When accidents occur (e.g. accidental discharge of chemical products), priority is usually given to removing the spilled products and managing the potential receptors (environmental and human), with site characterization as the second step of management.

For practical and economic reasons, the investigation of contaminated sites cannot include sampling and analysis for all substances. A phased approach is usually the best way of providing the required data in the most cost-effective and efficient manner. At the initial stage of the assessment, the (types of) substances likely to be found – and their pattern(s) of distribution in the soil – can often be identified by characterizing the possible sources of contamination of the site. This is typically a part of what is often called a historical survey of the activities carried out on the site. At this stage, it could be relevant to also include the characterization of the general exposure pattern in the area under consideration (e.g. old waste disposal sites, proximity to industrial activities) as well as the identification and characterization of possible former activities on the site that could have led to specific contaminations (e.g. gasoline stations, specific industries). It could be relevant to identify different sources (substances and location) for the different exposure pathways. Such preliminary investigations should be carried out in accordance with ISO 18400-202.

The aim of the detailed site investigation is to define the extent and level of contamination and to assess the exposures associated with the identified hazards and receptors, as identified in the CSM. It is of major importance to the assessment of human exposure that the extent (concentrations and physical extent) of contamination in all relevant media is determined in the site investigation.

A number of general site characteristics are necessary to assess possible exposure patterns. Relevant characteristics of the site that can be determined are listed in Table 2.

Table 2 — Parameters useful for site description

Parameters	Description	ISO Standard
Landform and topography	topography, landform, land element, position, slope, micro-topography	ISO 25177
Land use and vegetation	land use, human influence, vegetation, buildings, etc.	ISO 19144-2
Geology	origin of parent material, effective soil depth	ISO 25177, ISO 14688-1, ISO 14689
Surface characteristics	rock outcrops, coarse surface fragments, wind and water erosion, surface sealing, surface cracks, other characteristics	ISO 25177
Hydrology	surface water balance, rainfall, evapotranspiration, surface runoff, groundwater recharge, presence and depth of water table, moisture conditions	
Meteorological conditions	wind speed, predominant wind direction, temperature	
Soil type/ soil horizon description	soil type with respect to the classification system used, sequence and depth of diagnostic horizons, soil colour (matrix, mottling), organic matter, texture, coarse elements, pedofeatures, carbonates, field-pH, structure, fracturing, inhomogenities, presence of non-soil material, compactness, total estimated porosity, geochemistry, roots, worm channels, biological activity	ISO 25177, ISO 14688-1
Hydrogeology	number of aquifers, depth, flow direction, flow variation	

6.2 Soil ingestion

The amount of soil and hence the amount of potentially harmful substances ingested given a particular concentration in the soil depend primarily on activities/uses identified in the CSM (children playing with and on the soil, gardening, etc.).

Depending on the activity/use the most appropriate layers/depths for sampling will vary: e.g. topsoil (first few centimetres) for children playing or deeper soil directly linked to ploughed depth for gardening.

It should be noted that in gardens, parks and playgrounds occasional activities can bring soil from deeper layers to the surface. For instance, planting and replacing trees and bushes can involve digging holes, and some of the soil from the bottom of the hole can be brought to the surface. Earthworms and other soil fauna can also transport soil from deeper layers to the surface.

The soil texture should be taken into account. Soil particle size influences ingestion: the smaller particles sizes stick on the fingers of children and can therefore be ingested, contrary to large size particles.

The characteristics of substances, such as volatility, water solubility and soil sorption, should also be considered as these influence the distribution of substances in soil, e.g. in the topsoil. The natural background concentration of metals and metalloids should also be considered when interpreting the results.

The choice of sampling method, e.g. spot samples, cluster samples, should be made following the guidance in ISO 18400-104. Systematic regular sampling in which spot or cluster samples are taken is usually preferable although composite sampling can sometimes be used to assess surface soil quality with regard to soil ingestion exposure pathway.

6.3 Vapour and dust inhalation

6.3.1 Inhalation of vapour

The quality of groundwater and deep soil can alter air quality inside buildings located above and to a lesser extent, the outdoor areas.

Based on current measurements and conservative model calculations, impacts from vapours in outdoor air seldom occur unless the substances are very close to the surface and present in gas or easily released phases. Indoor impacts due to the vaporization of volatile substances (organic or inorganic such as mercury) can occur if the concentration in the source medium (groundwater or soil) is sufficient.

Soil assessments to characterize vapours should be carried out at relevant depths and on relevant layers of soil. Modelling can help to target the relevant points of exposure. The assessor should pay attention to the depth and location of the samples. It depends on the aim of the assessment: characterization of historical contamination linked to a former activity or characterization to assess future or current use.

Two other factors need to be taken into account because of their potential impacts on measurement and results. They are:

— climatic factors (for example weather conditions, humidity, temperature, ventilation), and

— other emission sources near points of measurement that might disturb the results (for example fuel tank).

Particular vigilance is required to prevent the loss of substances during sampling, transport and analysis (for more details, see for example ISO 18512, ISO 15009 and ISO 22155).

In case of vapour contamination from groundwater or soil, results can be overestimated or underestimated by modelling. The quality and reliability of the results of a substance transport modelling study will depend on the data that have been used to develop the CSM and to construct and refine the mathematical model. If the data are inadequate the model results will be unreliable. The data used should be site-specific and characterize the site and area being modelled (ISO 21365). Even in this case, the results remain uncertain. Uncertainties can be reduced by measuring soil gas concentrations in addition to performing measurements on soil and groundwater.

6.3.2 Inhalation of dust

Dust transport is mainly relevant in areas where the soil is stripped of plant cover for certain periods (e.g. gardens, cultivated agricultural land, and former mining sites) and in areas of intense activity (e.g. gardens, parks and sports facilities). Dust originally comes from the top layers of the soil and mainly consists of the finer fractions.

A separate analysis of the finer soil fraction (the fraction less than 30 µm diameter is usually considered respirable) could be relevant if dust inhalation is considered as a relevant exposure pathway.

Alternatively and preferably, direct measurements of suspended particles should be made so as to take into account field conditions. Sensors or samplers can be installed on the site or in its vicinity. Sensors allow the quantification of suspended particles in ambient air. Samplers allow the quantification of suspended particles in air and determination of their chemical composition (see ISO 7708 which refers to particle size fraction definitions for health-related sampling).

Weather conditions (for example, rainfall, winds) should be taken into account. Suspended particulate matters measurements require a simultaneous on-site weather monitoring. Attention should be paid to the duration and the choice of measurement period to have results representative of exposure conditions.

6.4 Cutaneous contact

Cutaneous contact with contaminated soil could be caused by dust reaching the skin through atmospheric deposition, by playing or by working with the soil.

Dust involved in dermal contact can be determined by several techniques: wet wipes and/or swabs on a surface (usually 1 m^2) or vacuuming to collect dust in a bag. Both are used in indoor dust determination. For outside dust, measurements are carried out by using gauges or samplers depending on exposure time.

Dermal contact with outdoor dust can also be assessed. In this case, topsoil is sampled and the relevant depth indicated in the CSM.

6.5 Intake of substances via plants

Garden and agricultural plants generally have a root depth of less than 30 cm; they can however reach 60 cm but rarely exceed 160 cm. Trees can have roots reaching down several metres although they take up the majority of nutrients from the first 40 cm in the temperate zone. For trees, the volume of roots is related to the volume of branches. The orientation of the roots (horizontal or vertical) depends on the type of tree.

Garden cultivation and agriculture (hoeing, digging and ploughing) usually affect soil at depths up to 30 cm and very rarely reach greater depths except with subsoiling which can reach 60 cm.

The amounts of substances taken up and accumulated by plants depends on the physico-chemical characteristics of the substance, the type of soil (including soil characteristics), the type of plant, and even climate. It should be noted that plants are contaminated by surface adherence to roots, root uptake and deposition on leaves. Intake by humans also depends on how a plant is treated before consumption (washing, peeling, cooking, packaging, etc.). Sampling of plants should be carried out taking into account parameters such as botany and how the plants are prepared for consumption by persons to ensure the representativeness of the exposure.

NOTE 1 Uptake by plants differs not only between species but between races, varieties or cultivars within species.

NOTE 2 Concentrations in plants will usually vary between roots, stems, leaves, fruits, etc.

6.6 Intake of substances via the consumption of animal products

As mentioned in 5.3.8, intake of potentially harmful substances by animals is mainly due to direct ingestion of soil from the surface layer or drinking water. The consumption of fodder comprising plants which have taken up and accumulated PHSs, or which have soil adhering to them, can also contribute to overall exposure via ingestion.

Soil sampling should be related to food chain assessment: for example, top soil in barnyards for eggs and poultry meat consumption; top soil in pastures for animal fodder, milk, and meat.

NOTE It might also be desirable to sample water used to feed animals or for irrigation because this might be contaminated if it comes from local streams or ponds, for example, rather than a public water supply.

Direct sampling of animal products (milk, eggs and meat) should be given priority over trying to model uptake and accumulation given the uncertainties inherent in such modelling.

Physicochemical behaviour of substances should be taken into account. For example, bioaccumulation in eggs is a very significant pathway for some substances.

6.7 Synthesis for site sampling in relation with human exposure

Table 3 summarizes the link between site uses, exposure pathways and soil depth for sampling.

The sampling depths suggested Table 3 relate to the site in its present condition. It is important to recognise that when the use of a site is being changed, e.g. an old industrial site is to be used for housing, construction activities can result in soil from much greater depths being brought to the surface. In any particular instance, sampling depths should be decided on following the guidance as appropriate in ISO 18400-104, ISO 18400-203 and ISO 18400-205.

It is important to recognise that the site under investigation might be the result of past redevelopment of a contaminated site. Thus, the easily accessible surface soils could overlay contaminated soils, and there could be a potential for upward movement of contaminants due to moisture movement, plant growth and decay, and activity of burrowing animals including worms. A preliminary investigation in accordance with ISO 18400-202 and subsequent development of a conceptual site model in accordance with ISO 21365 should lead to identification of when such issues might need to be taken into account.

Table 3 — Link between uses, exposure pathway and sampling depth

Use	Exposure pathway	Example of depth of sampling
Private gardens (ornamental)	Inhalation of dust (outdoor)	Topsoil (first centimetres)
	Ingestion of soil and dust	Topsoil (first centimetres)
	Cutaneous contact	Topsoil (first centimetres)
Private gardens (kitchen), agricultural zones	Ingestion of contaminated vegetables	Plant root zone (root depth) depends on type of vegetables
	Ingestion of soil and dust	Ploughed depth soil[a]
	Dust inhalation	Ploughed depth soil[a]
	Cutaneous contact	Ploughed depth soil[a]
Playgrounds, parks, sport facilities	Inhalation of dust	Topsoil (first centimetres)
	Inhalation of vapour	Source depth
	Ingestion of soil and dust	Topsoil (first centimetres)
	Cutaneous contact	Topsoil (first centimetres)
Consolidated surfaces	Inhalation of vapour	Source depth
Industry (including consolidated and unconsolidated areas, park-like areas, and buildings)	Inhalation of dust	Topsoil (first centimetres)
	Inhalation of vapour	Source depth
	Ingestion of soil	Topsoil (first centimetres) (depending on soil availability)
Farming	Food consumption	Plant root zone (root depth) depends on type of vegetables
Poultry farming	Food consumption (eggs)	Topsoil (first centimetres)

[a] Ploughed depth usually is about 30 cm, but it can vary, depending on what plants are being cultivated.

7 Characterization of soil as a matrix hosting physical, chemical and biological processes

7.1 Relevant soil processes and parameters

Soil is a mixture of three phases: liquid and gas present in a solid matrix. Soil characteristics depend on the original rock or geological deposit from which the soil comes, and on other parameters such as the organisms living in and on it, and climatological factors. With time, they modify the original material, giving distinct horizons within the profile. This modification results in a wide variety of soils with different physical and chemical characteristics. Even within one soil type, large variations can occur within a short distance. On a site on which anthropogenic materials are present, the soil might also contain ash, clinker, bricks, rubble, etc.

NOTE On some contaminated sites the liquid phase might comprise both water and a non-aqueous phase.

Substances present in soil can be bound to the soil matrix by sorptive and binding mechanisms which can affect availability with respect to uptake and/or metabolization by living organisms, e.g. in the case of inhalation and ingestion. The binding of substances can change with time, due to alteration of the soil or to alteration of the binding mechanism. To quantify human exposure to substances present in soil, information regarding the total content of each substance in the soil might therefore not be sufficient. For some substances, the evaluation of human exposure can be based on contents measured by analytical techniques, resulting in data expected to be adequate for the evaluation of the (bio) available portion of these substances. Investigators may also take into account available knowledge on the resorption and metabolism of the substances in the organism, and the related differences between individuals and population groups (e.g. children versus adults).

The possibility of substance mixtures can also be considered. The substances to be evaluated can be considered one by one, based on experience gained from other site investigations. In general, there is a considerable need to develop tests capable of assessing over a broad range the impact of contamination of the soil complex on human health. It should also be kept in mind that synergistic or antagonistic-type interactions between substances can affect the actual impact of exposure.

The following paragraphs focus on soil characteristics affecting the sorption and movement of substances in soils and, consequently, their availability, in relation to the assessment of human exposure. The choice of relevant parameters depends on the purpose of the characterization, e.g. a general classification or the characterization of a specific site for a specific use. The characterization of soil requires determining physical, chemical and biological properties although, depending on the specific assessment, not all soil parameters are relevant in all cases.

During the transport of substances in soil, the substances are affected by a number of physical, and reactive geochemical and biological processes that could attenuate, concentrate, immobilise, release, degrade or otherwise transform the substances. Since these transformations affect both substance concentrations and exposure pathways, information on the parameters governing these processes is important for the exposure assessment. It should be noted that the relative importance of the different parameters for the processes is not yet fully understood.

The potential processes involved in the fate and transport of the substances in the soil depend on the type of soil and the type of substance, and include:

- sorption/desorption;
- binding;
- dispersion;
- solubilisation;
- diffusion, including intraparticle diffusion;
- complexation;

- precipitation/dissolution;
- volatilization;
- chemical transformation;
- photo-degradation;
- uptake by plants and other organisms;
- biological transformations including microbial, soil, animal and plant metabolisms.

Fate and transport analysis does not normally include all the above processes but should at least include the key processes. In Tables 4 and 5 a number of parameters governing the above-mentioned processes and the overall transport processes are listed and linked to the potentially relevant exposure pathway.

Table 4 — Physical parameters of matrix of soil relevant for different exposure pathway

Soil parameter	Soil ingestion	Dermal contact	Inhalation of dust	Inhalation of vapours (outdoors)	Inhalation of vapours (indoors)	Intake via plants	Intake via animals
Particle density	X	X	X	X	X	X	X
Particle size distribution	X	X	X	X	X	X	X
Sand content				X	X	X	X
Clay content				X	X	X	X
Silt content				X	X	X	X
Air permeability				X	X		
Bulk density				X	X	X	X
Depth of vadose zone				X	X		
Dry matter content		X	X	X	X	X	X
Organic matter content	X	X		X	X	X	X
Porosity		X		X	X		
Temperature				X	X		
Water content		X	X	X	X	X	X

NOTE 1 Table 4 is intended to be indicative rather than exhaustive.

NOTE 2 The real impacts vary between the different substances. Inhalation of vapours usually refers to organic substances for all practical purposes.

Table 5 — Chemical parameters of matrix of soil relevant for different exposure pathways

Substance content	Soil ingestion	Dermal contact	Inhalation of dust	Inhalation of vapours (outdoors)	Inhalation of vapours (indoors)	Intake via plants	Intake via animals
Carbonate content	X					X	X
CEC						X	X
Exchangeable acidity						X	X
Organic carbon fraction		X		X	X	X	X

NOTE Table 5 is intended to be indicative rather than exhaustive.

[a] Various partitioning coefficients can be relevant, see 8.2.5.

Table 5 *(continued)*

Substance content	Soil ingestion	Dermal contact	Inhalation of dust	Inhalation of vapours (outdoors)	Inhalation of vapours (indoors)	Intake via plants	Intake via animals
pH						X	X
Redox potential						X	X
Partitioning coefficient[a]				X	X	X	X
Soil oxygen						X	X

NOTE Table 5 is intended to be indicative rather than exhaustive.

[a] Various partitioning coefficients can be relevant, see 8.2.5.

7.2 Measurement/analysis of soil characteristics

7.2.1 Physical characteristics of soils

A number of physical soil parameters are relevant to the assessment of human exposure caused by contamination in soil. Several physical characteristics are listed below together with comments on their relevance in exposure assessments. The choice of parameters should be based on preliminary knowledge of the site's geology, pedology and substances that might be present.

— Particle density: Particle density depends on the elements composing soil (for example, minerals, organic matter). Particle density together with porosity and water content define the bulk density and are thus relevant in connection with the estimation of phase partitioning in the soil.

— Particle size distribution: Particle size distribution is the distribution of soil mineral particles in relation to particle diameters. Four fractions are commonly distinguished: clay, silt, sand, gravel/stones. The particle size distribution determines the soil texture and also the surface area of a soil, the finest fraction having the largest specific surface (area per unit mass). The surface area influences the actual sorption of substances onto the soil. It should be noted that the particle size <0,002 mm, usually defined as clay, can contain other materials which are not clay minerals.

NOTE 1 There are a variety of particle size classification systems. It is therefore important to be careful when using terms such as "clay", "silt", "sand", etc. ISO 18400-104 uses the classification in ISO 14688-1.

NOTE 2 ISO 14688-1 establishes the basic principles for the identification and classification of soils on the basis of those material and mass characteristics most commonly used for soils for engineering purposes. ISO 14688-1 is applicable to natural soils in situ, similar man-made materials in situ and soils redeposited by man. Named particle groups are defined in Table 6.

— Sand: Particles with a diameter between 0,063 mm and 0,2 mm (for fine sand) and 0,2 mm and 2 mm for medium to coarse sand, usually consisting of quartz but can also contain fragments of feldspar, mica and occasionally heavy minerals.

— Clay: Clay particles (<0,002 mm) affect the reactive properties of soil due to their large specific surface (for sorption) and (electrical) properties. Depending on the type of clay mineral, the charge can be positive, negative or neutral.

— Silt: It has an intermediate particle size between sand and clay (0,002 mm to 0,063 mm).

— Air permeability: Air permeability in soil is a function of porosity, grain size and water content. Air permeability influences the exposure pathway for the inhalation of vapours.

— Bulk density: The bulk density is directly related to porosity, water content, grain density and the proportion of solid particles. It is relevant for estimating phase partitioning in soil.

— Dry matter content: Dry matter content is the proportion of the total mass of soil taken up by soil particles compared to the total mass of the sample. Chemical analysis often relates the amount of a substance to the dry matter content, so knowing this parameter is necessary to correctly estimate the partitioning of a substance in the soil.

— Organic matter content: Organic matter content influences biotransformation processes, especially for organic compounds that are difficult to biodegrade and which primarily degrade under co-metabolic processes. It also influences the sorption of substances and thus their availability.

— Porosity: Porosity is the volume of pore space in the total volume of soil. The pore space is usually occupied by air and water (or sometimes other permanent gases such as methane and carbon dioxide, and non-aqueous liquids).

— Temperature: Soil temperature can affect the volatility of organic compounds present and also the possible biotransformation processes in the soil.

— Water content: The proportion of pore space occupied by water influences the binding and the diffusion of substances in the soil matrix. Water content is usually measured in terms of the mass of water in relation to the total mass of the wet sample.

Physical characteristics for which International Standards are available are listed in Table B.1. Note that some properties can only be measured in situ and some on laboratory samples.

Table 6 — Defined particle size ranges from ISO 18400-104 (based on ISO 14688-1)

Name	Size mm	Name	Size mm
Large boulder	>630	Coarse sand	0,63 – 2,0
Boulder	200 – 630	Medium sand	0,2 – 0,63
Cobble	63 – 200	Fine sand	0,063 – 0,2
Coarse gravel	20 – 63	Coarse silt	0,02 – 0,063
Medium gravel	6,3 – 20	Medium silt	0,006 3 – 0,02
Fine gravel	2,0 – 6,3	Fine silt	0,002 – 0,006 3

7.2.2 Chemical characteristics of soil

A number of basic chemical parameters influence the soil processes that affect how substances behave in soil, e.g. sorption, precipitation and complexation. Some are described below.

— Carbonate content: Free carbonates such as calcite, aragonite and dolomite, greatly affect soil physical and chemical properties. Many chemical methods exist to quantify carbonate content in soil.

— Cation exchange capacity (CEC): CEC describes the capacity of the soil to bind positively charged substances and is thus especially important for the evaluation of metal sorption and thus availability, e.g. for plant uptake. CEC essentially reflects the amount and character of the soil organic matter and clay particles.

— Exchangeable acidity: In soil, acidity is the number of positive ions [hydrogen ions (H^+), aluminium ions (Al^{+3}), aluminium mono $Al(OH)^{+2}$ and di-hydroxide ions $Al(OH)_2^{+1}$]. Because they have a positive electrical charge these ions participate in cation exchange reactions, and they are called exchangeable acids because they cause soil acidity. Exchangeable acidity is therefore the number of meq/100 g of soil which consist of these ions.

— Organic carbon fraction: Organic matter in soil is present as humic substances (predominantly aromatic polymers with high molecular weight and acidic properties). These molecules can bind organic substances as well as some inorganic elements/substances. Binding can be covalent (strong) or electrostatic (weaker). Due to the properties described, organic matter in soil also contributes to its CEC and pH. The organic carbon fraction is typically measured as total organic carbon (TOC).

- pH: The acidity of the soil is expressed as the log10 of the hydrogen ion concentration. pH affects the availability of charged ions and is thus relevant for assessing the availability of metals and ionisable organic substances. For most elements, solubility increases as the pH falls (i.e. as acidity increases) but some elements are amphoteric (e.g. zinc) and can occur as both cations (positively charged ions) and anions (negatively charged ions). The solubility of these elements (and hence availability to plants) increases at both low (acid) and high (alkaline) pHs with an optimum pH at which solubility is at a minimum.
- Redox potential: The redox potential indicates the degree to which soil conditions are aerobic or anoxic and thus determines the oxidation state of a compound in soil which also influences its availability. Redox potential is of specific importance for the precipitation of certain metal-ions in soil, thus affecting their availability.
- Soil oxygen: The presence of oxygen in soil is important to the respiration of soil organisms and thus for the degradation of organic substances. Lack of oxygen in the upper soil layers could be a sign of the presence of degradable substances and of organic matter in general. Oxygen depletion also occurs if carbon dioxide and/or methane is permeating upwards from underlying strata (e.g. from coal mine workings or an old landfill).

Chemical characteristics that it might be desirable to measure and for which International Standards exist are listed in Annex B.

8 Analytical strategy

8.1 Characterization of contamination

Substances likely to be present are linked to the past use of the site. A list of possible substances linked to different types of industrial activity is given in ISO 18400-202:2018, Annex A. It is stressed that this is a minimum list and the assessor should consider the actual situation. An assessment should be made on a case-by-case basis.

The procedures set out in ISO 18400 have been developed to define how to characterize substances in different matrixes (soil, gases, water).

Before any laboratory analysis, samples should be subjected to pre-treatment (e.g. sub-sampled, appropriately dried for substance type) compatible with the methods of analysis to be employed. The guidance on the pretreatment of samples in the laboratory provided in ISO 11464 and ISO 14507 should normally be followed. Some methods for extraction or analysis include their own requirements regarding the pre-treatment of samples, and they should always be followed unless there are sound technical reasons not to do so, in which case these reasons should be reported with the analytical results.

NOTE Guidance on the pretreatment of samples in the field is provided in ISO 18400-201.

Nutrients in the soil are often studied because of their agronomic soil characteristics and capacity to biologically degrade organic substances. As they are seldom of primary importance in connection with direct human exposure, methods for their detection are not included in this document.

8.2 Characterization of contamination in relation to exposures

8.2.1 General

Lists of potential contaminants and methods for their identification and quantification relevant for different types of exposure pathways are given in Annex B. Certain parameters require measurement in almost all situations: others only require measurements for certain intended uses of the soil. However, judgement should be made on a case-by-case basis. Inorganic substances and organic substances are listed in Annex B. The range of organic substances that could be present is very wide, thus, only a few are listed in Annex B; essentially those for which International Standards exist or are in preparation.

8.2.2 Metals and metalloids

Metals and metalloids can be contaminants or be present naturally. In both situations, the risk depends on the concentrations and intrinsic danger of the substance.

To evaluate availability for direct uptake (i.e. ingestion or inhalation), plant uptake or leaching, for example, it could be necessary to distinguish between the chemical availabilities of the substance in question, such as solubility in strong acid, weak extractants, or water. Although the extractants are different, it is often possible to use the same methods to analyse the extract.

Total concentration is the total of the element present in all chemical forms and irrespective of its location in the soil material, including that incorporated in silicate minerals. The determination of these “true” total concentrations requires using techniques such as X-ray fluorescence analysis or a powerful solvent combination such as a mixture of hydrofluoric and perchloric acid. The use of this solvent mixture presents many practical problems and pseudo-total concentrations suffice for many purposes in environmental assessment. These are determined using a strong acid or combination of acids, but they typically leave a small insoluble residue with some soil materials. Depending on the element and the matrix these solvents typically yield 70 % to 90 % of the “true” total concentration (it can be lower for those elements which are present and predominately bound to silicate or aluminate lattices). When comparisons are to be made with guideline values for specific soil uses, it is essential to determine whether “pseudo-total” or “total” concentrations are required. Speciation of metals and metalloids such as As or Cr oxidation states should be determined to assess the effects of substances in case of exposure.

Concentrations extractable with complexing agents, weak extractants such as salt solutions or with water, can be relevant for assessing different kinds of bioavailability, including plant uptake or exposure pathways related to the pore water concentration of the substance. As for water extractable concentrations, it is important to recognize that when compounds of limited solubility are present (e.g. gypsum) the apparent amount soluble depends on the soil/water ratio employed in the tests. A detailed discussion of soil leaching and extraction tests is provided in ISO 15175.

There are several extraction methods to evaluate the degree and extent of human exposure to potentially harmful substances including total and partial extraction of the substances. Generally total extraction method gives very important information on human exposure, while the relationship between total concentrations of harmful substances and degree of human exposure is not exactly matched. Therefore, various extraction and leaching methods can be used to assess the availability of substances in soil.

Guidance on available International Standards for measuring metals and metalloids in soil and their applicability to different extractants is given in Annex B.

NOTE 1 Pseudo total concentrations mean that the method used does not extract all of the component from the soil matrix. These methods are used in many countries due to tradition and/or to ensure better health and safety in the laboratory.

NOTE 2 There are many different methods for obtaining water extracts based on batch processes, e.g. shaking with a fixed amount of water, sequential extractions or columns. For a detailed discussion of methods see ISO 15175.

NOTE 3 There are various analytical methods for water specified in International Standards. However, it is important to ensure that they work with the extracts obtained from a particular (contaminated) soil material.

8.2.3 Bioaccessibility and bioavailability

For health risk assessments, the bioavailability (see 3.3) value equal to 100 % is often used: i.e. it is assumed all ingested substances are absorbed by the body and reach the bloodstream. However, this is seldom true and in practice only a part of the substance is absorbed though the gastro intestinal tract membrane while the other part is eliminated directly during digestion.

It is difficult to know/determine the actual bioavailability of a substance from a particular soil but it is possible to get a measure of the bioaccessibility (see 3.2), i.e. the fraction that is liberated from a soil in (human) gastrointestinal juices and thus available for absorption. It has been shown that for certain elements (arsenic, cadmium and lead) bioavailability can be correlated with bioaccessibility as measured for example using the method in ISO 17924. Studies have also been carried out using a generally similar method for at least certain PAHs and certain other elements.

Thus, use of bioavailability allows a more realistic estimate of exposure through the ingestion route, thus improving the estimation of risk levels enabling more proportionate actions.

8.2.4 Organic contaminants

The range of organic substances that might be present is very wide. The groups of organic contaminants listed in the tables in Annex B are some of those more commonly encountered, but the list is not complete. Besides the groups of organic contaminants mentioned, it can often be relevant to look for specific organic substances, e.g. individual aromatic hydrocarbons, both volatile and polycyclic, specific solvents, specific chlorophenols. Some of the potentially relevant organic substances are mentioned in documents which suggest lists of contaminants related to different types of industrial activity (see ISO 18400-202:2018, Annex A).

Organic chemical analysis often focuses on looking for any substance which might be present. For example, it takes two forms: determining what is present (qualitative analysis) and determining how much of a specific compound or class of compounds is present (quantitative analysis). The detection of “adventitious” or unexpected substances, particularly when complex mixtures of organic chemical species are present, requires screening methods such as gas chromatography/mass spectrometry. It is also customary to employ analytical methods aimed at measuring total concentrations of classes of compounds such as phenols, PAHs, total petroleum hydrocarbons (TPH) and chlorinated hydrocarbons. Care is required in both the use and the interpretation of the results of such methods. Qualitative analysis is frequently carried out prior to quantitative analysis. Class analysis frequently precedes specific compound analysis.

In the case of petroleum hydrocarbons, risk assessment is usually based on a consideration of a number of aromatic and aliphatic fractions based on the number of carbon atoms in the compounds present. The guidance in ISO 11504 should be followed when deciding what fractions and individual compounds to determine.

Sampling and analyses of soil to assess volatile organic compounds (e.g. benzene, chlorinated solvents) presents particular analytical difficulties to obtain representative results.

The ISO 18400 series suggests that even under ideal conditions of sampling, transport, and sample preparation, etc., substantial losses can occur. A variety of techniques are used to make measurements in situ or obtain samples of volatile substances ready for laboratory analysis: for example, using adsorption tubes, percussive window sampling and windowless drilling rigs or soil corers (see ISO 18400-204). In addition, it should be noted that different laboratory methods (e.g. purge-and-trap and head-space analysis) can give substantially different results.

It is important to recognize that organic compounds might be extracted from naturally occurring organic materials (e.g. humus, decaying vegetation, peat, coal) and that non-specific analyses could, therefore, give misleading results.

International Standards relating to analyses of organic compounds in soil are listed in Annex B.

NOTE For the water-soluble part of organic components a variety of methods can be used to obtain water extracts based on batch processes, e.g. shaking with a fixed amount of water, sequential extractions or columns. For details see ISO 15175.

8.2.5 Soil/substance related parameters

Relevant substance parameters are listed below, it is not practical to determine these on a site-specific basis. References should be made to authoritative sources (a useful listing related to petroleum hydrocarbons is provided in ISO 11504).

- Organic carbon partition coefficient, K_{oc}: The organic carbon partition coefficient, K_{oc}, is used to describe the binding of an organic substance to the organic carbon fraction in the soil.
- Soil/water partition coefficient, K_D: The soil/water partition coefficient describes the ratio between the amount of a substance present in solution in the soil water and the amount of substance sorbed to the soil particles.
- *n*-Octanol/Water Partition Coefficient, K_{ow}: it is defined as the ratio of the concentration of a chemical in n-octanol and water at equilibrium at a specified temperature. It is a relative indicator of the tendency of an organic compound to adsorb to soil and to predict the distribution of a substance in various environmental compartments (water, soil, air, biota).
- Henry's constant, *H*: Henry's constant describes the ratio between the amount of a component present in the soil air and the amount present in the soil water.
- Bioconcentration factors (BCF) for plants: Plant/soil concentration factors vary depending on the specific plant species, the substance, the climatic factors, the soil type and the plant component investigated, e.g. roots or leaves, and age.
- Vapour pressure: The pressure exerted by a vapour in a confined space. Vapour pressure controls the volatility of a chemical from soil.
- Degradation rate: The degradation rate of a specific compound in the soil is also related to the specific soil conditions, e.g. water content and soil oxygen content. Some compounds might only be degraded under aerobic conditions, while others might only be degraded under anaerobic conditions. Degradation can be biological, chemical, and/or physical. The degradation rate is generally expressed as DT_{50} and/or DT_{90}, i.e. the time needed for 50 % and 90 % degradation respectively, see ISO 11266.

9 Management of results

In the case of contaminated soil, management depends on the situation:

- either the site is occupied for residential or industrial use, or
- the site is a brownfield site, with a development plan.

Regarding the first situation, the characterization of exposure media (e.g. topsoil, air, plants) can involve direct measurements without the use of modelling. Then, the interpretation can be based on comparison with existing reference values such as national public management values or natural environmental values. Guidance on how this might be done is provided in ISO 18400-104.

When measured concentrations are below or near reference values, the environment is considered compatible with use. The soil management process can be stopped if contamination sources are dealt with. Environmental monitoring could be required to verify evolution over time.

If media concentrations exceed these reference values, simple actions might be enough such as removing concentrations from the contaminated area, covering contaminated soil or restricting access.

A health risk assessment can be carried out with specific exposure parameters. If these solutions are insufficient, actions should be implemented so that the risk related to the exposure of persons and the environment is acceptable.

Regarding the second situation, for a brownfield with a development plan, a specific and proportional approach is required. The environmental assessment of soil, water and gas will facilitate site characterization and help identification of the best remediation treatment strategy. Site management will ensure that all the contamination sources are dealt with.

A cost/benefit analysis can help in choosing the best specific technical solution. This solution can be confirmed by feasibility and treatability tests. After the completion of remediation, residual health risks should be assessed. This validates that remediation actions are sufficient and that the residual concentrations are acceptable.

10 Data handling, evaluation and quality

A fairly large amount of uncertainty is associated with the characterization of soils because soil is inherently heterogeneous, and the distribution of contaminants is also heterogeneous. This uncertainty also concerns human exposure. The sufficiency of the data to be used shall be evaluated before any judgement can be made about risk to humans. The data shall be sufficient in terms of:

— type of soil;

— quantity;

— analytical/testing quality.

Before investigation of the site is started it is essential to:

— define the objectives of the investigation;

— establish a sampling strategy in terms of types of sample to be obtained, sampling locations, and how samples are to be handled in accordance with these objectives;

— establish an analytical and testing strategy that takes into account the guidance provided in this and other relevant International Standards;

— set data quality objectives consistent with the assessment procedure to be used.

It is essential to have sufficient data. The confidence that can be attached to any judgements made, for example, through comparison with the requirements of a published standard (the requirements in such standards regarding sampling shall always be followed) or a site-specific risk assessment, is equivalent to the confidence placed in the representativeness of the data.

Care shall be taken in deciding what statistical expression(s) of the data is to be used in the characterization, as this could affect the choice of sampling procedures.

The quality of the data to be used can be assured by:

— setting formal analytical data quality objectives (e.g. for accuracy, reproducibility);

— using standard analytical and testing methods such as those listed in this document, or where International Standard methods are not available, those published by national standardization or equivalent bodies;

— using accredited laboratories that apply standardised methods;

— using laboratories that take part in relevant proficiency testing schemes;

— the commissioning agent employing its own quality assurance procedures.

To analyse the results, uncertainties shall be considered at each step of the method. Reflection is essential to understand the uncertainties and their impact on the results. Various types of uncertainty can be identified: “epistemic uncertainties” due to a lack of knowledge and “aleatory uncertainties” related to temporal and spatial variability. The approach used to manage these two kinds of uncertainties is different and should be clearly explained. This uncertainty assessment is a tool used to place the conclusions in perspective. Often, the reports presenting the results of assessments are scrutinised by regulators and other interested parties, including the general public. It is important, therefore, that such reports are of a high technical standard and also take account of a wide and often non-technical readership. Use should therefore be made of tabular summaries, graphics and other means to present the data in ways that will make the data as easy as possible to understand and assess.

Annex A
(informative)

Exposure pathways depending on the site use

Exposure-site uses and respective ways of exposure are listed in Table A.1.

Table A.1 — Exposure pathways connected with site uses

Exposure site use	Inhalation		Cutaneous contact	Ingestion	
	Dust	Vapours		Soil/Dust	Crops
Kindergartens (mainly children)	x	x	x	x	x
Domestic vegetable gardens (adults and children)	x	x	x	x	x
Agricultural areas (adults and children)	x	x	x	x	x
Ornamental gardens (adults and children)	x	x	x	x	
Parks (adults and children)	x	x	x	x	
Sports facilities (mainly adults)	x	x	x	(x)	
Industrial/commercial areas, non sealed (mainly adults)	x	x	(x)	(x)	
Industrial/commercial areas, sealed (mainly adults)	(x)	x		(x)	
Building, indoor climate (adults and children)	(x)	x		(x)	
NOTE A parenthesis around the x indicates that this exposure pathway is of less importance or not always relevant for the specific site use.					

NOTE 1 Inhalation and ingestion of dust in indoor areas is related to soil tracked into the buildings by footwear and to a lesser degree soiled clothes.

NOTE 2 Ingestion of crops in kindergartens and, for example, play grounds in parks is related to for example growing of crops for educational purposes or the like in such areas, which is not uncommon.