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Soil quality — Sampling —

Part 204:
Guidance on sampling of soil gas

Qualité du sol — Échantillonnage —

Partie 204: Lignes directrices pour l'échantillonnage des gaz de sol

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Foreword

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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).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 190, *Soil quality*, Subcommittee SC 2, *Sampling.*

This first edition of ISO 18400-204 cancels and replaces ISO 10381-7:2005, which has been technically and structurally revised. The ISO 18400 series is based on a modular structure and cannot be compared to ISO 10381-7 clause by clause.

A list of all parts in the ISO 18400 series can be found on the ISO website.

Introduction

This document is one of a group of International Standards to be used in conjunction with each other where necessary. The ISO 18400 series deals with sampling procedures for the various purposes of soil investigation. The roles/positions of the individual standards within the total investigation programme are shown in Figure 1. The stated soil gas and landfill-gas measurements do not give any quantitative statement of the total quantity of material detected in soil gas or soil. The measurement results can be influenced by, e.g. temperature, humidity, air pressure, minimum extraction depth, etc.

The general terminology used is in accordance with that established in ISO/TC 190 and, more particularly, with the vocabulary given in ISO 11074.

Toxic, asphyxiating and explosive soil gases can enter buildings and other built development on and below ground and variously pose potential risks to occupants and users and to the structures themselves.

Such gases might be present in the ground naturally, or be present as a result of contamination of the ground, or arise from buried wastes. In addition to the main components found in air (nitrogen and oxygen), soil gas can contain volatile organic compounds (VOCs), inorganic vapours (e.g. mercury) and a wide range of other gases (e.g. methane, carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, helium, neon, argon, xenon, radon, etc.).

These gases can have several origins such as: landfilled wastes; contaminated soils on a brownfield site; plume of contaminated groundwater; spill or leakage of chemicals products, leaks of mains gas (natural gas); sewer gas, etc.

In order to complete an assessment of the risks posed by the presence of permanent and other soil gases like VOCs, it is necessary to understand and characterize the potential sources of gas in and around a site.

Guidance on installations for soil gas sampling (equipment and instruments, methods of sampling, requirements of controls, etc.) and other relevant information (e.g. on environmental conditions) are provided in this document.

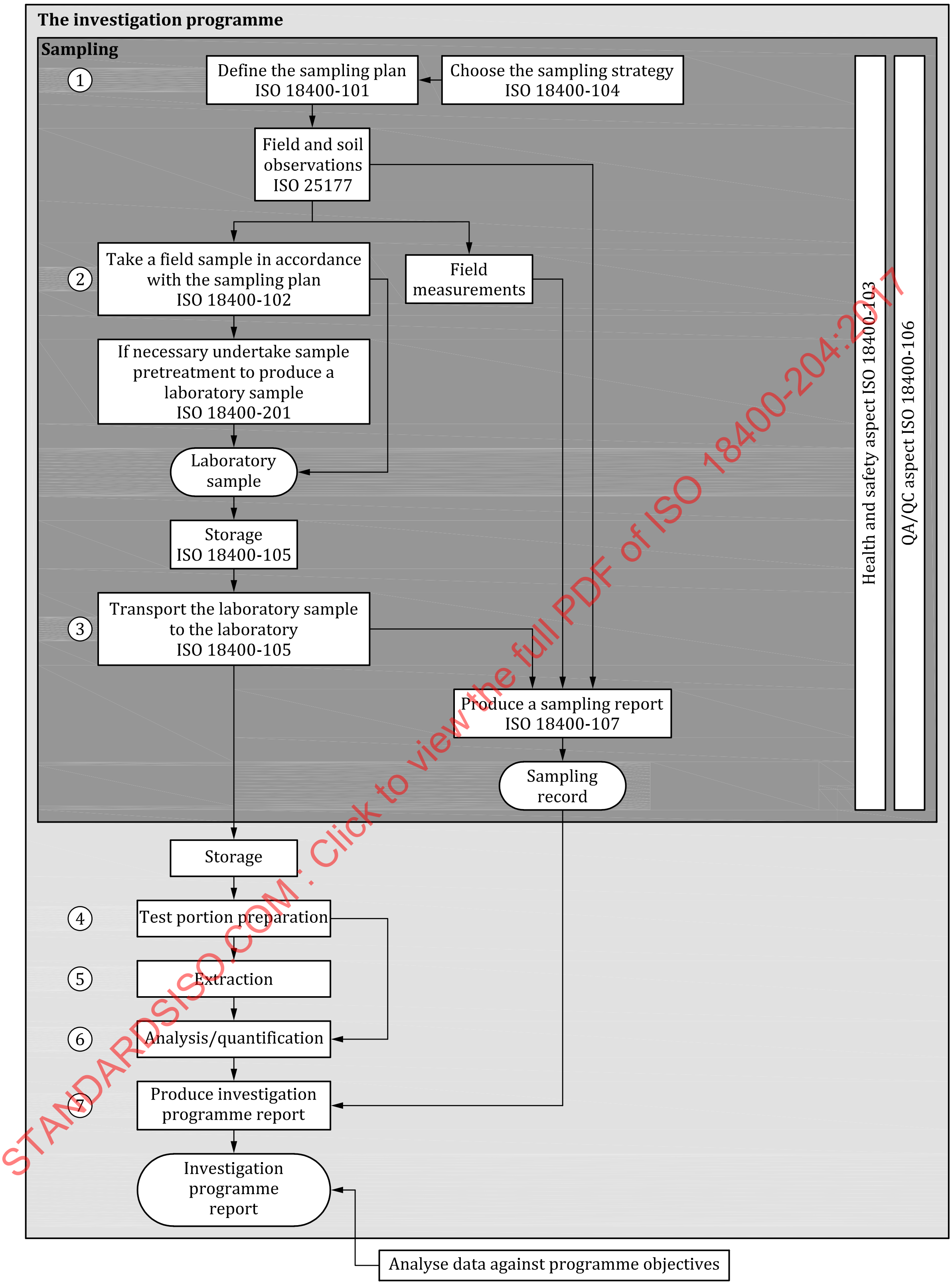


Figure 1 — Links between the essential elements of an investigation programme

NOTE 1 The numbers in circles in Figure 1 define the key elements (1 to 7) of the investigation programme.

NOTE 2 Figure 1 displays a generic process which can be amended when necessary.

Soil quality — Sampling —

Part 204:
Guidance on sampling of soil gas

1 Scope

This document contains guidance on soil gas sampling using

— active sampling (adsorbents, filters, air containers), and

— passive sampling

applied at permanent or temporary monitoring wells or other installations in soils or underneath buildings (sub-slab).

It provides guidance on:

— development of a sampling plan;

— construction of monitoring installations;

— transport, packaging and storage soil gas samples;

— quality assurance.

This document also gives basic information about

— soil gas dynamics, and

— identification of soil gas sources

relevant to permanent or temporary boreholes in soils or underneath buildings (sub-slab).

The compounds covered by this document are:

— volatile organic compounds (VOCs);

— inorganic volatile compounds (e.g. mercury, HCN);

— permanent gases (i.e. CO_2, N_2, O_2, CH_4).

This document does not give guidance on:

— risk evaluation and characterization;

— selection and design of protective measures;

— the verification of protective measures, although the site investigation methodologies described can be used when appropriate;

— the sampling of atmospheric or indoor gases;

— the measurement of gases from the soil entering into the atmosphere;

— monitoring and sampling for radon.

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 18400-107, *Soil quality — Sampling — Part 107: Recording and reporting*

3 Terms and definitions

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

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

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

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

3.1
active soil gas sampling
sampling by extracting a certain volume of soil gas

3.2
breakthrough
detection of an adsorbent control section of one or more compounds having a mass greater than 5 % of the mass quantified on the measuring section

3.3
dead volume
volume which is present between the suction opening of the soil gas probe and the sampling vial, including the volume of the sampling vial or of the adsorption tube

3.4
dense non aqueous phase liquid
DNAPL
liquid of a group of organic substances which is relatively insoluble in the water and denser than the water

3.5
direct method
direct measuring method
method of analysis where the soil gas sample (aliquot) is directly introduced into a suitable equipment without first being concentrated and subjected to analysis

3.6
direct-reading detecting tube
glass tube filled with reagents which, after drawing through certain gaseous compounds, show concentration-dependent chromophoric reactions and which are thus used for qualitative and semi-quantitative analyses as well

Note 1 to entry: It is important that attention be paid to cross-sensitivities.

3.7
gas migration
movement of gas from the source through the ground to the adjoining strata or to emit to atmosphere

Note 1 to entry: Examples of sources include e.g. wastes within a landfill or spill of hydrocarbons.

3.8
gas monitoring well

standpipe suitably installed inside a borehole from which gas samples can be taken to measure soil gas concentrations and to monitor changes in composition of soil gas or soil *gas migration* (3.7)

3.9
gas sampling

collection of a volume of soil gas contained in the pore space of the soil

3.10
landfill

deposition of waste into or onto the land as a means of disposal

3.11
landfill gas

mixture of permanent gases (main components), dominated by methane and carbon dioxide, formed by the decomposition of degradable wastes within landfill sites

Note 1 to entry: It can also include a large number of VOCs (trace components).

3.12.1
lower explosive limit
LEL

lowest percentage (volume fraction) of a mixture of flammable gas with air which will propagate an explosion in a confined space at 25 °C and atmospheric pressure

3.12.2
upper explosive limit
UEL

uppermost percentage (volume fraction) of a mixture of flammable gas with air which will propagate an explosion in a confined space at 25 °C and atmospheric pressure

3.13
light non aqueous phase liquid
LNAPL

liquid of a group of organic substances which is relatively insoluble in the water and less dense than the water

3.14
method by adsorption

method in which substances to be determined are concentrated adsorptively on an adsorbent, subsequently desorbed and analysed

Note 1 to entry: The adsorbent can be e.g. activated charcoal or XAD-4 resin.

3.15
monitoring installation

permanent or temporary device used for soil gas sampling

EXAMPLE Sub-slab, soil gas probe.

3.16
non aqueous phase liquid
NAPL

liquid of a group of organic substances which is relatively insoluble in the water

3.17
one-stage soil gas sampling

sampling of soil gas directly from a soil gas probe placed in soil, without pre-drilling

3.18
passive soil gas sampling
sampling based on the adsorption of gases of the ground on an adsorbent placed in the ground, without using artificially reduced pressure

3.19
permanent gas
element or compound that is a gas at all ambient temperatures likely to be encountered on the surface of the earth

EXAMPLE Gas like mine and landfill gases.

Note 1 to entry: Permanent gas can also be defined as “element or compound that is a gas at all ambient temperatures likely to be encountered on the surface of the earth”; see ISO 11074:2015, 3.6.11.

3.20
soil gas
gas and vapour in the pore spaces of soils

3.21
soil gas monitoring device
borehole finished with suitable material for stabilisation of the borehole wall and/or for limiting the sampling area

Note 1 to entry: Depending on the type and stability of fitting, a distinction is made between temporary (for single or short-term repeated soil sampling) and stationary and semi-permanent or permanent soil gas monitoring points (for long-term observation).

3.22
soil gas probe
soil gas sampling probe
probe, generally a tube, which is installed directly into soil (one-stage soil gas sampling), or in a borehole (two-stage soil gas sampling) to take soil gas samples

Note 1 to entry: By applying a negative pressure to the upper end of the soil gas probe (head), the soil gas at the lower end (tip) is drawn through the suction opening(s) and transferred to a gas collecting equipment and online measurement equipment (direct measuring method) or to an absorbent (concentration method), which are installed either in or at the head of the soil gas probe or subsequently used.

3.23
soil gas sample volume
volume of soil gas taken to form the sample

3.24
continuous soil gas sampling
sampling from a monitoring well over a controlled longer period of time (mostly several hours up to days) to observe the variations over time of the gas concentrations and of the pressure distribution in the soil

3.25
sub-slab
soil gas sampling location just below the foundation slab of a building, within the unsaturated zone

3.26
subsoil
layer of soil beneath the surface soil and overlying the bedrock (called also “undersoil”)

3.27
two-stage soil gas sampling
sampling done firstly through installation of a borehole with the aid of a drilling instrument or by small boring, and secondly by sampling of soil gas from a soil gas probe installed in the borehole

3.28
volatile organic compound
VOC
organic compound that is volatile under normal environmental/atmospheric conditions, although it can be found in the ground in the solid, liquid and dissolved phase form as well as in gaseous phase

Note 1 to entry: VOC can also be defined as "organic compound" which is liquid at room temperature (20 °C), which generally has a boiling point below 180 °C"; see ISO 11074:2015, 6.1.24.

Note 2 to entry: Examples include single-ring aromatic hydrocarbons and other low boiling halogenated hydrocarbons, which are used as solvents or fuels, and some degradation products.

4 Preliminary items to be considered

Soil vapour monitoring is a faster and cheaper method to detect contamination of VOCs in soils and/or in groundwater and for mapping the plumes than soil boreholes and/or the installation of groundwater monitoring wells. The method permits establishment of a much denser network of soil gas monitoring points than is usually possible for groundwater monitoring wells and soil boreholes.

The choice of sampling technique should be consistent with the requirements of the investigation (including subsequent analytical procedures, conceptual site model, investigation objectives, etc.). Consideration should also be given to the nature of ground under investigation, as well as the nature and distribution of contamination, the geology and the hydrogeology. Every effort should be made to avoid cross-contamination and creation of preferential pathways to avoid contamination of underlying aquifers.

Before intrusive works begin, a comprehensive check should be made of the ground to ensure that no services or structures are at risk and no hazards are present (for more information on sampling techniques and safety, see ISO 18400-102 and ISO 18400-103).

When sampling soil gas close to the surface, the effect of ambient air penetration needs to be considered. The sampling depth is determined by the presence of impermeable cover over the ground surface, the soil type (porosity, clay content, etc.) and the depth of bedrock.

NOTE 1 A preliminary condition for soil gas sampling and monitoring is the prior recording of the geological soil profiles/pedological layers. For some sites, this can be done whilst taking soil samples from borings.

Cold conditions make soil gas sampling difficult in many ways. Ground frost greatly limits the mobility of gas in soil and should be considered in planning and carrying out sampling as well as in interpreting the measurements results. Water saturation (total or partial) of unsaturated layer (e.g. after rainfall) can significantly reduce the soil gas emission rates, limit soil gas mobility, and lead to high levels of humidity can severely reduce the adsorption capacity of some sorbents.

The main problem with soil gas sampling below the frozen ground is the loss of air-filled porosity due to the high moisture content in the zone between frozen and unfrozen parts of the ground. Consequently, the samples should be taken from greater depths (but compatible with investigation objectives).

All buildings constructed on unfrozen ground act as pathways or barriers for upwards soil gas migration. Lower pressures and differences in concentration in the buildings can also assist gases to penetrate the basements of buildings.

NOTE 2 Causes of differential pressure effects include the rise of warm air within buildings and the operation of air-conditioning systems. Gas can enter through:

- cracks and openings in concrete ground slabs such as cracks due to shrinkage;
- construction joints/openings, e.g. at wall/foundation interface with ground slab;
- cracks in walls below ground level present due for example to shrinkage or movement;
- gaps and openings in suspended concrete or timber floors;

- gaps around service pipes and ducts;
- cavity walls;
- staircases, elevator shaft.

Gas migration into other structures also needs to be considered, especially below ground structures such as manholes, culverts, lift pits, mine shafts, access to underground services, etc.

This document specifically deals with the sampling of soil gas. Related exhaust or interference sources in ambient air (industrial or more generally anthropogenic activities) are not considered apart from the constitution of a field blank.

Pressure effects caused by the rise of warm air within buildings can assist the entry of gases into buildings.

Some organic pollutants in the gas phase in soil and subsoil can present toxicological risks of varying severity. Due to this possibility, personnel should be provided with appropriate gas detection equipment and should be equipped, according to the potential toxicity (assumed or measured), with suitable personnel protective equipment (PPE).

Certain organic fumes (as well as methane, for example) can form explosive mixtures with air (explosivity limits and self-ignition temperatures should be taken into account). It is therefore appropriate to use electrical equipment and tools which are suitable for use in explosive atmospheres.

Health and safety issues should be considered at all times. Training should be given to ensure that personnel understand the necessary precautions (for more information on safety, see ISO 18400-103).

5 Basic principles

5.1 Physical and chemical principles

5.1.1 Permanent gases

Potentially hazardous permanent gases (see 3.19) such as methane and carbon dioxide occur most commonly in “landfill gas” and “mine gases”.

Wherever biodegradable material is present in landfill sites or within the soil matrix of the ground beneath a brownfield site, microbial activity will produce methane and/or carbon dioxide. These gases can similarly be produced in alluvial deposits and by degrading natural organic material. Landfill gas consists primarily of methane and carbon dioxide (at a ratio of approximately 60:40). Depending on microbial activity, this ratio can change. A number of additional trace gases can be present.

Mine gas, also called coal mine methane (CMM), is a set of various vapours produced during mine operations. It is a mix of methane (essentially, more than 90 %) and carbon dioxide (nearly 10 %). Some minor gases are also present: carbon monoxide (product of incomplete combustion of carbon), hydrogen sulfide and nitrogen.

Abandoned mine methane (AMM) refers to mine gas after exploitation, which is trapped in the former galleries, boosted and propelled to the surface throughout the flooding of the mine. It usually contains less methane and more air than CMM (50 % to 60 % of methane, depending on the sealing of the mining voids and former works).

Permanent gases can also originate from coal deposits, peat, natural deposits (e.g. chalk and alluvial deposits), from leaks of mains gas (natural gas) and from sewer gas. Information on techniques for identifying the origin of gas can be found in 5.4.

Methane is explosive at concentrations of between 5 % and 15 % (volume fraction) in air; below 5 % [the lower explosive limit (LEL)] there is insufficient gas to support combustion and above 15 % [the upper explosive limit (UEL)] there is insufficient oxygen to support combustion. These both explosive limits are changed by the presence of other gases (e.g. carbon dioxide).

Carbon dioxide is an asphyxiant and also toxic. It can cause adverse health effects in concentrations greater than about 0,5 % (volume fraction).

The LEL of a mixture of explosive gas is equal to the lowest LEL among the components of the gaseous mixture. In the same way, the UEL of a mixture of explosive gas is equal to the highest UEL among the components of the gaseous mixture. Thus, other alkanes concentration (ethane, notably) should be considered in the calculation of LEL/UEL.

Landfill gas is usually saturated with moisture and is corrosive. It can cause vegetation to die back due to the elimination of oxygen from the plant’s root zone or to the presence of phytotoxic compounds. Its density depends upon the ratio of carbon dioxide to methane: the higher the ratio of carbon dioxide, the greater the density.

Gas pressure within the subsurface is dependent on the gas generation rate, the atmospheric pressure, the permeability of the waste mass and the surrounding strata, changes in the level of leachate or groundwater within the site and the temperature.

Depending upon site engineering and local geology, gas can migrate considerable distances and can present a hazard to nearby developments.

In the particular case of mine gas, the cessation of water pumping leads to a rise in water table levels which increases the gas pressure in mine voids, and consequently increases the probability of surface gas emissions, through the ground or former mine works. It is, therefore, important to gain an understanding of gas concentrations and flow rates to establish the potential for gas migration off-site or atmospheric emissions. Usually, decompression boreholes are drilled to avoid this phenomenon. They are good monitoring and sampling points to monitor mine gas composition, pressure, flow and water level.

5.1.2 Volatile organic compounds

Depending on the pressure and temperature conditions, VOCs enter into soil pore space as either a liquid or a gaseous phase. They are present in soil as gaseous and liquid phases, dissolved in soil water, adsorbed on solid (organic and inorganic) soil particles or enclosed in capillary cavities.

Dynamic distribution equilibriums are established according to the prevailing conditions and bound forms of the pollutants. Owing to the diversity of the possible substance distributions and the time-dependent effects on the equilibrium, each determination of the contaminant concentration can provide only a “point-in-time” description of the status. Every interference, with the soil and/or groundwater, affects the distribution equilibrium in a different way, which is difficult to assess.

A saturation equilibrium between the liquid and gaseous phases is established in the contaminated zone independent of the amount of substance present. A soil gas saturation concentration of a VOC develops in the immediate surroundings of the polluted area, irrespective of whether it is a very small drop of the substance or a large deposit. The concentrations measured in the soil gas should not be used as an index of the actual amount of substance present in the soil. VOCs disperse in soil gas by convection (i.e. in the direction of the pressure gradient) and diffusively (i.e. in the direction of the concentration gradient). VOCs in the soil can be transported as flowing non-aqueous-phase liquids (NAPLs and/or DNAPLs), or together with another flowing liquid phase (e.g. groundwater, or dissolved in mineral oil), from which they can be transferred back into the soil gas.

5.2 Environmental conditions

It is important that atmospheric conditions, before and during the sampling, be recorded. It will generally be sufficient to record the conditions about a week prior to sampling, but rainfall up to a couple of weeks before may affect soil gas sampling, depending on, e.g. temperature, soil type and sampling depth. Local climatic conditions at the time of monitoring should also be recorded. This information can help in the interpretation of the data. The most important parameters to record are:

- atmospheric pressure:

due to the pressure difference between soil pores and atmosphere, rapid falling atmospheric pressure increases soil gas emission rates. Rapid rising atmospheric pressure can have the opposite effect. The magnitude of this effect depends upon the soil permeability and the rate at which the pressure changes. It is also considered that atmospheric pressure under 1 013 hPa (depression condition) will increase emission rates;

- rainfall:

a long or a strong period of rainfall can lead to accumulation of soil gas under the water front. Gas can be dissolved in water and the sampling, even with pumping device, will not be enough to free the gas. The measurement will not also be representative;

after rainfall, a water logging effect will occur in the unsaturated layer and change the ground's water saturation, reduce the movement and reduce emission rates of soil gas.

Other useful parameters are:

- outdoor temperature:

outdoor temperature have a significant effect on evaporation, which in turn will affect the infiltration and percolation of water and thus the mobility and concentration of soil gas;

soil temperature also affects the concentration of gases e.g. biological production of CO_2 (and consumption of O_2) through root and microbial respiration is higher at higher temperature especially in well vegetated areas. Other gas producing reactions may also be temperature dependent;

temperature influences volatility of chemicals. High temperature will raise the volatile potential of chemicals and increase emission rates;

NOTE 1 The temperature in the soil tends to remain relatively consistent, until near sub-surface (1,0 m to 1,5 m depending on climate and of the soil nature). At this depth, outdoor temperature has low or no influence on the volatilisation in the subsurface and emission of VOCs.

- indoor temperature:

when a building is heated, if the indoor temperature is higher than outdoor temperature, a “chimney effect” can occur, leading to a reduction in pressure relative to atmospheric pressure outside and consequently induce a flow of soil gas into the building;

- humidity (ambient air and soil gas or sub-slab gas):

humidity can severely reduce the adsorption capacity of some sorbents;

- wind speed/direction:

depending the direction and intensity of the wind, it can lead to a reduction in pressure relative to atmospheric pressure outside and consequently induce a flow of soil gas into the building;

wind passing over the soil surface lowers the gas pressure in the upper reaches of the soil creating a gradient for gas flow toward the surface. The extent to which this occurs depends on a variety of factors, including whether the surface is “sealed” by freezing or water logging;

- water table depth and any hydrogeological perturbation nearby (e.g. groundwater pumping, excavation, tide influence):

a water table rising (e.g. caused by rainfall, tide effect), can put the gas under pressure and force it to the surface; however, it can also block migration pathways. The saturation of superficial soils can restrict the venting of soil gas to atmosphere. This can result in variations in gas pressure and concentrations;

NOTE 2 After coal exploitation, gas still desorbs from source rock. In the same time, water pumping stops and a flooding occurs in the remaining mining voids. The rising water table involves an overpressure of coal gas, which can then migrate to the surface through former mine works or the fractures in the upper geological formations induced by the exploitation. This phenomenon is constrained thanks to decompression boreholes, offering a controlled pathway to the gas from the deep reservoir to the atmosphere.

— ground conditions (e.g. dry, wet, frozen) and heterogeneity:

the clay will sometimes become wet and swell thus resealing (healing) the cracks but this does not always happen depending on the clay minerals present and whether the cracks become filled with sand or other detritus. This will lead to an increase in gas emissions at the surface. In periods of wet weather, the clay will become wet and swell, and cracks will be sealed. This will reduce surface gas emissions and can lead to increased gas concentrations and increased lateral migration. A measurement of intrinsic soil permeability and moisture content can be helpful in assessing these effects according to the nature of the soil;

depending upon site engineering and local geology, or meteorological conditions (e.g. frozen soil), gas can migrate considerable distances (metres to tens of metres) within the unsaturated zone through preferential pathways (anthropic or naturals) and when it enters a permeable layer that is confined by an overlying impermeable layer or perched groundwater.

In general, it can be difficult to establish the cause of changes in concentrations and emissions since they may be due to a combination of the above factors.

However, a qualitative evaluation of sampling conditions should be provided with justification for each sampling campaign in order to draw a conclusion as to its likely representativeness character (underestimating, inflating or neutral conditions).

NOTE 3 For permanent gases, the main factor is atmospheric pressure.

5.3 Soil gas dynamics

The migration of volatile compounds in soil gas can be via three primary mechanisms:

- diffusive flow (movement of constituent along a concentration gradient);
- advective flow (movement of constituent due to motion of a transporting fluid);
- dispersion (transport resulting from local variations in fluid flow, e.g. due to friction effects in the matrix).

Factors which influence the migration of VOCs in the unsaturated zone include the chemical/physical properties of the VOCs, the geologic conditions (e.g. ground permeability) and chemical/biological conditions (e.g. whether microbial degradation is active).

5.4 Identifying the source of soil gas

Identifying the origin of the gas is important when making decisions regarding its monitoring and control. In a contaminated land context, a site history study, a preliminary diagnostics and a conceptual site model are necessary to identify the compounds likely present in soil, non-aqueous phase liquids on/in/under groundwater and/or soil gas. Possible degradation products should be identified so as to be able to properly determine the impact of the contamination that is being investigated.

The composition of a gas may help identify the source. The following examples are given for permanent and landfill gas:

- gas from a geological source may have a higher proportion of methane than landfill gas;

- geologically-derived gas generally contains up to 15 % ethane and higher hydrocarbons, while biogenic methane contains only trace amounts;
- it may be possible to distinguish mains gas from other gases if the exact composition of the local mains gas is known.

Mains gas may have odour compounds such as sulfides and mercaptans added to give the gas a distinctive odour; it may also contain long chain hydrocarbons such as octane and nonane. Helium is often removed from mains gas.

Landfill gas may also contain higher than normal concentrations of higher hydrocarbons if the waste contains substances that generate or release such gases and vapours.

Identification of different components may, however, be limited as the components may be affected by chemical changes occurring in the ground during migration, by solution in groundwater and by adsorption onto clays, etc.

Ratios of permanent gases can be useful to distinguish the origin of/processes producing gases such as CO_2 and methane. This can be achieved by plotting the concentrations of these gases against O_2 and N_2.

Biogenic (formed by microbiological activity) methane and thermogenic (formed by thermal degradation of organic matter at higher temperatures and pressures) methane have different proportions of carbon isotopes carbon 12 and carbon 13 which can be measured to identify the origin of the gas. The technique, however, requires specialist laboratories.

In a contaminated land context, volatile compounds can come from:

- solid or liquid compounds present in the soil;
- non-aqueous-phase liquids on or in groundwater;
- groundwater impacted with dissolved volatile compounds.

In this context, some tools may help to identify the source, including:

- concentration gradients study in soils, groundwater and/or soil gas;
- ratio comparison of different compounds for multi-compounds contamination in soils, groundwater and/or soil gas;
- ratio comparison of a compound and its degradation products in soils, groundwater and/or soil gas;
- isotopic analyses.

Identified sources should be included in the conceptual site model.

6 Requirements for sampling plan

6.1 General considerations for sampling plan

6.1.1 Objectives and general recommendations

6.1.1.1 Objectives

The main objectives of soil gas sampling are as follows:

- qualitative determination of substances present in the unsaturated soil layer (inventory);
- quantitative determination of substances present in the unsaturated soil layer (evaluation);
- determination of spatial and temporal variability of local concentrations;

- determination of the place(s) of input and location of the contamination centres (= areas of highest concentration measured/hot spot);
- determination of the horizontal and vertical distribution of concentrations;
- mapping of groundwater contamination (pollutant plumes);
- observation of spatial distribution over the time;
- determination of soil gases contribution to ambient, indoor and/or outdoor air in a risk assessment context;
- measurements to evaluate the feasibility of remediation measures (e.g. gas extraction potential);
- measurements to evaluate the effectiveness of remediation measures.

Development of the investigation strategy should include decisions about:

- phasing of the investigation;
- the location, pattern and number of monitoring points required for the site as a whole or for individual zones;
- the design of monitoring wells or monitoring points including the response zone(s);
- what on-site measurements are to be made and how these are to made (choice of instruments, etc.);
- the frequency and timing of monitoring and the period over which monitoring is to be carried out;
- the type and number of samples to be collected for laboratory analysis;
- the methodology by which samples for laboratory analysis should be collected, transported, stored and preserved;
- the laboratory analyses requirements; (e.g. transport conditions, number of supports, maximum flow rate);
- the laboratory analysis required;
- any safety measures needed to protect the personnel or the environment;
- what quality assurance measures are required.

When preparing the sampling plan, consideration should be given to any planned invasive activity (excavations, vibrations, etc.) that might create pathways for gas migration or otherwise affect migration patterns.

6.1.1.2 General recommendations

In addition to gas monitoring, boreholes are also useful for obtaining geological hydrogeological, geotechnical and contamination information and are therefore a useful multi-purpose tool.

When monitoring results, especially those obtained from standpipes, are to be compared with one another, the techniques used to obtain them should be consistent to ensure comparability between different operators, techniques and over different monitoring periods or between different laboratories. To achieve this, quality assurance measures as given in Clause 11 should be followed.

Gas concentration measurements may be taken using portable equipment (see Annex B) or samples may be taken for off-site laboratory analysis. It is advisable to collect gas samples, to be submitted for confirmatory analysis in a laboratory, in order to verify the on-site monitoring results.

NOTE For permanent gases, especially with an “infrared” method, it is advisable to implement a specific methodology taking into account the characteristics of the gas (detection of methane before carbon dioxide).

If samples cannot be taken according to the plan (e.g. because of obstacles on the site or in the ground, higher groundwater level than expected), this shall be recorded in the sampling report. It is wise to define certain procedures for such contingencies (e.g. relocate the sample, leave it out). In the absence of properly documented procedures, sampling personnel can make wrong decisions, rendering the investigation useless.

The strategy should be specific and should be based upon the particular conditions on the site in question, as revealed by the preliminary investigation and any intrusive investigation carried out to date (see ISO 18400-202[1]). There is no single strategy which can be generally applied. Therefore, some typical examples are given in the following parts.

6.1.2 Initial explorations (field screening)

The aim of an initial exploration is to determine the substances present and/or their concentration range. At this stage, data on concentrations are generally not known, so there is the risk that the measuring range selected may be not appropriate. Detection limits can be too high, raising the possibility of breakthrough, in the case of adsorbents. In the case of contaminants present at low levels, the extraction of large volumes (e.g. 20 l to 100 l) allows gathering of information on a more comprehensive range of substances.

When effectively used, screening methods can provide a comprehensive overview of substances present and thus result in considerable cost saving as regards the subsequent detailed investigation.

The use of a photoionization detector (PID), a multi-gas analyzer (O_2, CO_2, H_2S, CH_4, CO), without prior use of a gas chromatograph, as well as direct-reading detector tubes, serve for labour protection, workplace monitoring and for rough mapping of pollutant plumes (e.g. for determining effective starting points for establishing groundwater or soil gas measuring sites).

They do not supply exact concentrations of single VOCs but give the range of concentration present in soil gases. This permits the measurement procedure subsequently used to be fitted to the concentration levels (e.g. lower the sample volume). Considering the relative precision of field equipment (non-quantitative measurements, variability of results) and transport hazards for this type of equipment, it is strongly recommended to duplicate soil gas sampling whenever possible.

6.1.3 Known contamination centre

If the contamination centre is known, the extent and limits of the contamination can be investigated using point screening. The screening is carried out on selected profiles both horizontally and vertically according to the nature of the site and the objectives. Starting with large distances between sampling locations and increasing sample density stepwise, if appropriate, will provide a cost-effective strategy.

6.1.4 Determination of the contamination hot spots (areas showing highest concentrations) and gas monitoring wells location

If the contamination centre is not known or when there is doubt about the presence of contamination, screening is carried out using a coarse regular grid pattern. All available information from historic enquiries or previous investigations should be taken into account.

In this case, light tools and equipment are generally combined with analytical/measurement methods, allowing detection of a wide range of concentrations. A large number of measurement points should be used to reduce the risk of not finding suspected contamination.

Once a contamination centre has been found, follow the strategy of 6.1.3.

---

1) Under preparation.

6.1.5 Determination of horizontal and vertical distribution of VOCs

This is essentially the same process given in 6.1.3. Screening or collection of soil samples for headspace examination over horizontal and vertical profiles is carried out to establish the distribution of the contaminant in the soil gas.

Point sampling (small sampling volumes of soil gas taken from defined sampling depths) along profiles can also be used to determine spatial distribution. Care shall be taken that ambient conditions (see 5.2) and consistent sampling techniques and instruments are achieved to enable comparable measurements.

On-site analysis can help to minimize interferences and can allow an effective intensification of the sampling point screen.

6.1.6 Observation of spatial distribution of VOCs in the course of time

Repeated sampling under almost the same conditions is possible only for homogeneous and well defined ground conditions. Therefore, it is useful to establish permanent soil gas monitoring devices for permanent continuous observations.

The disadvantage of such monitoring devices is that they present a limited picture of the situation as regards soil gas on the site. In particular, the geometry and surface of the monitoring device, as well as the potential for gas exchange, are significantly different from the corresponding properties of soil pores.

Particular attention shall be paid to ambient conditions (variations in temperature, humidity, air pressure, water content, etc.).

6.1.7 Evaluation of soil gases contribution to ambient, indoor and/or outdoor air

When a risk assessment is needed in advance (for a building in construction) or for a building that is not accessible, it should be based on measured soil gas concentrations, emission rates and adoption of suitable models to predict indoor air concentrations.

When a risk assessment is needed for buildings already existing on a site, it should preferably be based on concentrations determined on the exposure media (ambient, indoor and/or outdoor air) rather than on concentrations derived by modelling from soil gas concentrations or directly from pollutants concentrations in soil.

In indoor air, there are some VOCs emitted by building materials and furniture. When indoor air measurement is needed, it is important to determine the contribution of soil gases concentrations to the levels measured in the exposure medium (e.g. indoor air) in order to differentiate it from other contributions (e.g. ambient air pollution, indoor domestic pollution). In this context, soil gas sampling should be carried out underneath the indoor sampling locations (or as close as practicable) at the same time and with the same method as used to determine concentrations in the exposure medium.

6.2 Working ranges of measurement methods

The aim of spatially localizing or delineating soil contamination provides for a relative quantitative comparability of the concentration values determined. The soil gas concentration values range according to the corresponding substance and method-specific detection limits (several micrograms per cubic metre, µg/m^3) up to the corresponding saturation concentrations (in some cases, up to >100 000 000 µg/m^3, i.e. >100 g/m^3). In order to cover the whole concentration range, sampling techniques and measuring methods adapted to the relevant problem should be used.

NOTE When using adsorption methods, the capacity of adsorbents can readily be exceeded. The volumes at which breakthrough occurs differ from chemical to chemical. In the case of high concentrations in soil gas, direct measurement methods are useful to give the range of concentration present. This permits the measurement procedure subsequently used to be fitted to the concentration levels (e.g. avoiding breakthrough by lowering the sample volume).

6.3 Monitoring well options

Soil gas can be monitored and/or sampled using:

- driven probes;
- permanent gas-monitoring wells, ports or sampling probes;
- mine shafts, decompression boreholes and gas safety works.

Although each technique has its uses, in situations where a detailed, long-term understanding of the site is required, permanent gas monitoring wells or sampling probes installed in boreholes should be used.

If gas concentration measurements are required at different depths, grouped, nested or multi-level installations should be used.

Selection of the installation(s) to be used should take into account health and safety and potential environmental impacts, and where known, the geology. Some techniques also preclude the collection of soil samples for examination.

Options for sampling and measuring soil gas are listed in Table 1.

Table 1 — Options for sampling soil gas

Sampling techniques	Temporary or permanent monitoring	Description	Advantages	Disadvantages
Passive sampling	temporary	A passive sampler is buried in the ground at low depth (generally 1 m or 2 m) or set in a soil gas monitoring well for a predetermined lapse of time.	Very quick and easy to install. Low cost. Allow to screen an area and to map a plume of volatile compounds in soil gases.	Give only qualitative information.
Sub-slab probe	temporary/ permanent	Drilling a hole in the hard-standing or foundation slab and pushing a hollow tube through the slab which can be connected to a gas detector or a sampling device.	Very quick. Cheap. Easy to install. Allows sampling of gases immediately below a building.	Care is needed to avoid creation of preferential pathway between indoor air and sub-slab air. Damages any under-lying damp proof or gas control membrane (this applies to all through slab exploration).

Table 1 *(continued)*

Sampling techniques	Temporary or permanent monitoring	Description	Advantages	Disadvantages
Driven probes with lost cone	temporary	Hollow tube with solid nose cone. Mechanically driven into the ground. Monitoring pipe installed inside tube. Tube extracted leaving behind a sampling chamber above the nose cone.	Minimal ground disturbance Easily portable thus access problems unlikely Allows soil gas profile through the ground to be determined	Will not penetrate obstructions. Can cause smearing in clayey soils which restricts gas ingress into the probe hole. Max. depth of 2 m. Can become blocked. Risk of cross contamination if the same pipe is used several time without cleaning. Better for low levels of soil pollution.
Driven probes with retractable nose cone		Hollow tube with a solid and retractable nose cone. Mechanically driven into the ground with a hydraulic or pneumatic hammer. Monitoring pipe installed inside tube. Tube partially extracted liberating a sampling chamber above the nose cone.		

Table 1 *(continued)*

Sampling techniques	Temporary or permanent monitoring	Description	Advantages	Disadvantages
Driven probes with screened part		Hollow tube with plain part of generally at least 1 m, and with screened part of at least 50 mm. The tube is mechanically driven into the ground with a hydraulic or pneumatic hammer. Monitoring pipe installed inside the tube to capture the air from the screened part of the tube.		
Gas monitoring well (without flushing device)	permanent	Cased borehole is sunk by one of the following techniques: cable percussion techniques; percussive window and windowless drilling rigs; using continuous flight auger; sonic drilling. A screened standpipe is installed in the borehole. The pipe is surrounded with gravel, and the casing withdrawn. A cement layer is provided on the top of the device.	Great depths attainable Minimal disturbance to ground Can install several standpipes in one borehole to measure at different depths Can take samples of strata at different depths during drilling. Controls the absence of water in the device (avoid influence on sampling of soil gas). Allows soil gas vertical profile through the ground to be determined.	Relatively slow and expensive. May have access problems. Brings contaminated material to the surface. Care is needed to avoid enabling contamination of an underlying aquifer.

Table 1 *(continued)*

Sampling techniques	Temporary or permanent monitoring	Description	Advantages	Disadvantages
Mine Shaft	temporary/ permanent	Monitoring or sampling device simply connected to the well head or its vent using quick couplings and a set of adapters if needed.	Deep reservoir characterisation. Different reachable depths, from 1 m to 1 000 m or more, or water level at least (if not fully backfilled). Water table measurable (if not fully backfilled). Its large diameter (3 m to 10 m) allows any kind of probe to fit in (water level indicator, gas/water canister, camera).	When the shaft is backfilled : dust may come in the device while sampling; gas pressure and composition are not representative of the reservoir; water table cannot be monitored. Gas pressure may not be compatible with all devices. Devices strictly have to be EX-labelled (self-protected against explosive gas). Equilibrium time before representative sample is obtained (linked to the significant volume to purge). Some may be old and their seals damaged, so gas tightness may be questioned.
NOTE 1 Gas monitoring well made with flushing device is not recommended because air or water flush can spread contamination. Air flush can also cause migration of soil gas. NOTE 2 All lubricants used should be such that they will not interfere with the measurements to be made, either whilst the work is in progress or during later monitoring (e.g. it might be preferable to use vegetable rather than mineral oils as lubricants when VOCs are to be monitored). Similarly, care should be taken during storage and handling of lubricants, fuels and hydraulic fluids for drillings rigs, etc. that they do not leak into the ground.				

6.4 Sampling plan

6.4.1 Horizontal location of sampling devices

The location and design of monitoring wells or other chosen technique should be planned well in advance, in accordance with:

- the aims of the site investigation (see 6.1);

- the conceptual site model, including:
  - the knowledge from historic study and former diagnostics;
  - the geological context (e.g. nature of soil, heterogeneities);
  - the hydrogeological context (nature of aquifer, flow direction and variations of the water table in time);

    Geological and hydrogeological context should be known before soil gas sampling in order to prevent implantation of the probe or well in groundwater, or in different and/or unknown soil layers.
  - the location and number of potential on- and off-site sources;
  - the nature and behaviour of the contaminants (e.g. solubility, levels and heterogeneity of pollution in the unsaturated zone);
  - migration pathways such as more permeable zones of soil or rock and close to service ducts and trenches;
  - permeability of the ground (which affects the zone of influence of the wells, especially if the wells are connected together by the same layer, a drain, a driftway, etc.);
  - locations of underground services, etc.;
  - the locations of existing buildings (including location, form and depth of foundations) and other structures;
  - the locations of proposed buildings and services;
  - the extent of proposed excavations and other earthworks;
- the sensitivity of the (proposed) end use;
- need to assess potential off-site migration;
- radius of action of monitoring well;
- drilling constraints (e.g. access, location of underground services);
- other considerations including health and safety.

Each site presents a specific combination of these elements and there is no generic sampling strategy applicable to all sites.

A sampling plan should be drawn up in detail containing all the elements listed above as appropriate with justification of the approach that is to be adopted.

Any changes to this plan should be noted with justification.

6.4.2 Monitoring depths

In areas where contamination is thought to be severe, the drilling of boreholes can produce preferential pathways and as a result information should be sought on specialist drilling precautions.

The depth from which samples are taken depends on the objectives. Information on concentrations at different depths is useful, as it allows for a better understanding of the propensity for the gas to migrate.

Depth of soil gas sampling also depends on information required and on site conditions such as structure of the ground, location of the groundwater table, migratory pathways, etc. These conditions shall be established prior to planning of soil gas sampling. Soil profiles of all of the soil gas sampling bores shall be recorded in detail depending on the heterogeneity of the ground and the objectives of the investigation.

The following three points should be taken into account when determining monitoring depths:

a) owing to increasingly uncontrolled influence of ambient air at shallow depth the minimum sampling depth should not be less than about 1 m below ground surface;

   If there is good reason for sampling from closer to the surface (e.g. below sealed sites), this should be indicated in the sampling report;

   For VOCs, if the sampling depth is less than 1 m, in the absence of sealing surface in good condition (concrete, asphalt, etc.), the ground surface for about a 5 m diameter around the sampling point should be sealed against air entry with a suitable flexible membrane (only inert materials should be used).

   For sub-slab sampling, the sampler should check the slab state to identify all the preferential pathways between indoor air and sub-slab air. The airtightness of the sampling points will be guaranteed with a seal made of inert material. If there is any doubt as the likely airtightness of the slab, it may be sealed (or at least improved) by sealing cracks and superimposition of a suitable flexible membrane.

b) sampling point should be at least 1 m above the water table so that the screened section is always above the groundwater and ingress of capillary water is inhibited. Therefore, this should be taken into account when deciding the monitoring depth;

   For a permanent well, the base of the monitoring well should be set 1 m above the highest known groundwater level.

   NOTE Maximum sampling depth is limited by the accessibility, by the availability of techniques to secure gas-tightness of the probe system and limit dead volumes, and by the level of the water saturated soil zone.

c) the screened part (or sampling chamber) of the sampling well should be in a unique geological bed;

   it is recommended that the length of the screened part (or sampling chamber) of the sampling well does not exceed 0,5 m.

If concentration gradients have to be investigated (e.g. when delineating hot spots), multi-depth sampling (see 7.2.4) and small sampling volume should be preferred. In this case, techniques that allow collection of soil gas samples from small sampling volumes (i.e. from holes less than 0,1 m in diameter) should be used.

For soil gas sampling linked to risk assessment, sampling at shallow depths is recommended.

Multiple wells formed to different depths (grouped installation) or nested wells (nested installation) may be used to monitor gas concentrations at different depths. Where nested wells are used, the installation should be closely supervised to ensure gas-tight seals are achieved within the borehole.

Monitoring wells should have response zones that intercept gas in a single source or pathway. The response zones should not normally span across different sources or pathways.

6.4.3 Timing and frequency of monitoring

Monitoring should be carried out starting from shortly after installation of the monitoring equipment for a period commensurate with the objectives of the investigation.

When a monitoring well is installed in a borehole, sampling should not be carried out for at least 24 h after formation of the well to permit settlement of the well pipe within the bore and to permit the bentonite seal to properly set.

Monitoring should be sufficient to allow prediction of worst case conditions when soil gases and/or permanent gases emissions to atmospheric air are likely to be high. For permanent gases, monitoring should be carried out on tens of days during a period of low atmospheric pressures. For other soil gases, monitoring should be carried out during a period of low atmospheric pressures, dry air (no rainfall) or high outdoor temperature.

Justification should be provided for the monitoring period and frequency that is adopted. This should be based on the preliminary conceptual site model.

Factors that should be taken into account in the decision process include:

- periods of rising, falling and stable barometric pressure;
- rainfall;
- water table depth and any hydrogeological conditions;
- ground conditions (e.g. dry, wet, frozen);
- the need to be able to predict the nature and timing of worst case conditions.

Due to the variability of soil gases over time, it is recommended to realize at least two sampling campaigns in different environmental conditions (e.g. winter/summer) (see 5.2).

NOTE This recommendation of two sampling campaigns in different environmental conditions is a minimum. Due to the level of risk, urgency, lack of knowledge of soil gas variations, more frequent sampling campaign can be realized especially in dynamic systems (rapid changes or evolutions). It is common to have monthly or three-monthly sampling campaign.

In the case of long monitoring (several days, several weeks, etc.) additional factors may be taken into account: risk of degradation, switchgear monitoring, revegetation, energy consumption, etc.

Higher frequency monitoring can be applied depending on the objectives (e.g. soil gas investigation linked with risk assessment) and the expected variability of gas emissions.

For each sampling campaign, an assessment of the gas emission conditions should be carried out. This assessment should include consideration of the environmental conditions (see 5.2) (e.g. generally a period of high atmospheric pressure, heavy rain and low temperature generates low to very low gases emissions).

6.4.4 Sample volumes and sampling rates

The flow rates and sampling volumes depend on the nature of the compounds sought, nature of sampling (e.g. adsorbent, pressurized container), concentration range expected, breakthrough volumes, recommendations from the laboratory (quantifications limits) or the material supplier, and soil intrinsic permeability. The overlying land use shall not be considered.

The extraction of soil gas during sampling reduces pressure in the pore space and hence influences phase and solution equilibria. To limit these influences, especially when taking point samples, flow rates up to a maximum 2 l/min are recommended for a monitoring well. For soils exhibiting a low gas permeability and a small gas pore volume, even lower flow rates should be used.

When a qualitative determination of the substances present is required (e.g. during preliminary investigations), a large soil gas volume should be extracted. This will provide a more volume-related diffuse sampling zone.

The incorporation of atmospheric air shall be avoided. Appropriate controls (see leakage test in 8.2.2) are essential.

For active sampling on sorbent, if an insufficient flow rate or sampling time is used, there is the potential for an increased laboratory detection limit as insufficient sorption of the VOCs to the sorbent medium will occur. Conversely, if too great a flow rate or sampling time is used, the sorbent medium might become saturated early in the sample collection process. Therefore, the flow rate and sampling time depends on site conditions, the expected concentrations of VOCs in the soil gas and the detection limit required. Flow rate is also a function of the geology. In tight (e.g. clayey) soils, a lower flow rate needs to be used (compared with granular soil) to minimize the potential for VOC desorption (since the VOC concentration in the soil pores space is required) and atmospheric air entrainment into the sample. The flow rate is typically between 20 ml/min and 500 ml/min but can be higher depending on the mass and nature of the sorbent. In indoor air sampling, the duration of the sampling is linked to the exposition of a population (e.g. sample needs 8 h for workers). That is not the case with soil gas sampling.

In the case of point soil gas sampling, a small volume is taken within the horizon layer (about 10 ml) for a possibly non-influenced detection of the pore volume filled with gas. When sampling larger volumes (up to several litres), the sampling area is diffuse and its location cannot be determined. Soil gas sampling from a borehole with diameter greater than that of the probe is called “integrating”, as the gas might be delivered over its entire length.

Instruments for the measurement of gas flow rate are listed in Annex C.

7 Construction of monitoring installations

7.1 General

7.1.1 Environmental conditions

The installation of soil gas monitoring wells should be carried out in boreholes or driven boreholes. Installation should not be carried out in a trial pit with subsequent backfilling due to the disturbance and aeration of the ground and the uncertainty of the period necessary for original ground conditions to re-establish before monitoring can continue.

The strata encountered should be recorded during the installation of wells when the selected method permits this to be done. The descriptions of the strata encountered should include reference to the presence of any biodegradable material or other material that might give rise to gas, including the proportion of such material when this is practicable. If the method of installation does not allow the strata to be recorded, the ground conditions around the response zone should be inferred from other nearby investigation points, such as other boreholes.

Each part of the sampling system which is in contact with the soil gas sample should be properly cleaned between each use.

NOTE The equipment of the monitoring well depends on different factors like context, objectives, environmental conditions, safety conditions like risks of explosive atmosphere, etc.

7.1.2 Instruments

The standard equipment for soil gas sampling generally includes the instruments given in Annex A.

Different instruments measure different gases over different concentration ranges, and each has its own advantages and limitations. It is important for the operator to obtain a good understanding of gas monitoring equipment and which type should be used in a given situation. In Annex B, the operational advantages and disadvantages of several portable instruments, along with the gases analysed, are given.

Portable instruments which are to be used on gas-contaminated sites should be intrinsically safe; this is particularly so if the instrument is to be used within a confined space.

7.2 Soil gas sampling devices

7.2.1 Passive soil gas sampling

Passive soil gas sampling can be done by burying a passive sampler in soil or putting it in a soil gas monitoring well.

For the first method, a hole is to be made to a depth adapted to the objectives (e.g. for mapping a pollution a depth about 1 m is generally adapted). Then the passive sampler is buried and recovered with the ground extracted. After a predefined lapse of time (a few days to a few weeks), the passive sampler is dig up and sent to laboratory.

For the second method, the passive sampler is set in a soil gas monitoring well, at the screened part level.

The passive samplers are maintained in place for a duration adapted to the expected concentration level.

7.2.2 Sub-slab

A hole should be drilled (hole diameter: 0,01 m minimum) to a depth of 0,10 m to 0,20 m beneath the slab, creating a sampling chamber immediately underneath the slab. A screened tube is inserted into the hole, and a bentonite seal provided at the top of the sub-slab. The tube (screened or not) can be connected to a gas detector or a sampling device.

The state of the hardstanding or the slab next to the sampling point should be inspected to determine whether potential preferential pathways such as cracks, etc. are present.

If preferential pathways are identified near the monitoring well, they should be sealed with bentonite (or other suitable and inert material) before sampling begins.

After sampling, the hole (if it is not a permanent installation) shall be sealed carefully to avoid creating a preferential circulation pathway. In sensitive contexts (housing, schools, etc.), the absence of residual emissions should be controlled.

If the slab is covered with a carpet, plastics material (e.g. vinyl), or other flooring material (e.g. linoleum), this should be carefully removed from around the intended sampling point. The floor covering should be restored once sampling has been completed.

7.2.3 Driven probes

7.2.3.1 General

Driven probes should not be used where there will be significant smearing of the ground along the pipe as it is driven in (e.g. in very high plasticity clay soils). Smearing can be minimized by using a drive cone that has a larger diameter than the pipe.

Care should be taken when driven probes are used on sites known or suspected to be contaminated to avoid cross contamination when the same driven probe is used several times in succession. Meticulous cleaning should be carried out (without any chemical product) between each use (see ISO 18400-102).

7.2.3.2 Driven probes with screened part

The driven probe is made of a metallic hollow tube with:

- a diameter less than 0,05 m;
- a plain part of at least 1 m;
- a screened part of at least 0,05 m.

The tube is driven into the ground (manually or with a hydraulic or pneumatic hammer) to a minimum depth of 1 m. The top of the well should be provided with a gas tap and a bentonite seal should be provided at the top of the well.

7.2.3.3 Driven probes with retractable nose cone

The driven probe is made of a metallic hollow tube with:

- — a diameter less than 0,05 m;
- — a plain part of at least 1 m;
- — a solid and retractable nose cone allowing a sampling chamber of at least 0,05 m.

The tube is driven into the ground (manually or with a hydraulic or pneumatic hammer) to a minimum depth of 1 m then the tube is partially extracted to liberate the sampling chamber above the nose cone. The top of the well should be provided with a gas tap and a bentonite seal should be provided at the top of the well.

7.2.3.4 Driven probes with lost cone

The driven probe is made of a metallic hollow tube with:

- — a solid nose cone;
- — a diameter less than 0,05 m;
- — a plain part of at least 1 m.

The tube is mechanically driven into the ground (manually or with a hydraulic or pneumatic hammer) until a minimum depth of 1 m then the tube is partially extracted for 0,05 m to 0,10 m creating a sampling chamber above the lost cone.

The top of the well should be provided with a gas tap and a bentonite seal should be provided at the top of the well.

7.2.4 Gas-monitoring standpipe in a borehole

After creating the borehole using cable percussion, percussive window or windowless drilling rigs, continuous flight auger, sonic drilling or hand auger techniques, a pre-slotted pipe should be installed to the required depth within the borehole.

The pipe material and its thickness should provide sufficient strength and chemical resistance for the proposed installation [high density polyethylene (HDPE) is normally used]. The pipe should be un-slotted (full) at least within the first metre under the ground surface. The pipe should comprise sections which can be fitted together with screw threads, as this avoids the need for organic compounds and solvents to seal the lengths together (i.e. pipes should be joined without using glue or adhesive tape because such materials emit volatile compounds that could contaminate the soil gas samples). The slotted section should be in the required response zone (see 6.4.2).

A cap should be at the bottom of the well's pipe. If the well does not extend to the base of the borehole, the backfill below the base of the well should be well compacted (with bentonite or cement bentonite grout or pellet seal) immediately below the monitoring well.

The annulus between the outer wall of the borehole and the slotted pipe should be filled in with non-calcareous single size gravel or similar inert material, of a suitable grain size in relation to the size of the annulus and the slot of the perforated screens. The annulus around the plain un-slotted pipe should be filled with bentonite or cement bentonite grout. The top of the hole (generally 1 m from the ground surface) should be sealed with an impermeable plug (bentonite grout/bentonite cement, etc.), while at least the upper 0,2 m from the ground surface should be sealed with concrete or mortar to support and secure a cover.

Bentonite or cement bentonite grout should be placed so that it forms an effective seal. It should be mixed on the surface and put in place.

An air tight screw top or bung should be fitted to the top of the standpipe to allow access into the pipe in order to check the absence of ground water in the borehole, before soil gas sampling. The sampling point should be closed after the control. Determination of water levels within wells should be made before all gas measurements and/or before taking any samples for laboratory analysis. If water is detected, soil gas sampling will not be considered as representative.

The cap (i.e. airtight screw top or bung) shall be fitted with at least one gas tap through which gas samples can be taken. A flexible tube should extend at least a short distance from the tap into the well so that gas is not drawn only from the zone immediately beneath the cap. Care should be taken to ensure that the tube(s) extending from the tap(s) are above the highest expected groundwater level.

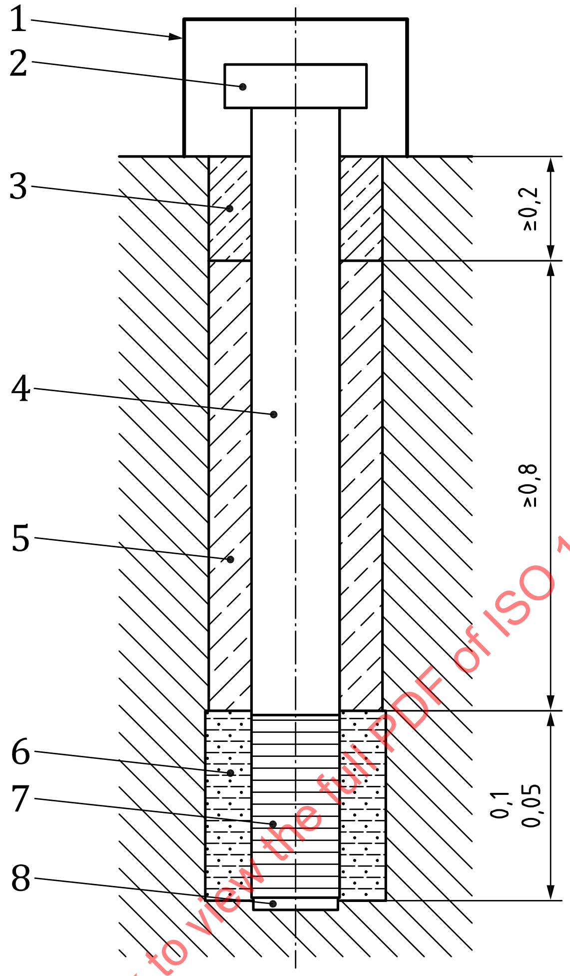
The tap(s) should usually be closed between monitoring events (there may be occasions when it might be left open for an extended period to provide information to better understand the gassing regime).

It is often preferable to provide two gas taps, one from which gas is extracted and one through which gas is returned to the well. Doing so, gas is removed from and returned to the well at different depths thus promoting mixing. However, one should take care of the gas modification induced by the analysis (e.g. katharometer) and apply this method while insuring gas remains exactly the same after the analysis.

NOTE In the very special case of mine gas, the gas is sampled from mining well or survey in which the presence of water is known and measured. However, unlike soil gas measurements, the water level measurement is performed after the physicochemical measurements of gas and do not constrain the representativeness of the measurement. Indeed, the differential pressure between the mine workings and atmosphere are such (sometimes several bars) they induce significant exhaust gas flow rates (several m^3/h) when released to the air. Pressure Controls and gas composition are made and before any inspection within his works, including the statement of the groundwater level. Otherwise, these measures are considered not representative. The gas is fed to the analyzer by simply pressing play, no pumping is required; therefore, no risk of transmission of liquid water in the measuring hoses is to be expected.

Monitoring wells should be provided with sufficient protection to prevent tampering and vandalism. Suitable measures can include the installation of a lockable cover (e.g. stop-cock cover) set in concrete. Where possible, pipes should terminate above ground level as this prevents surface water (e.g. rainwater) infiltrating in the well and makes them easier to identify (this might not be possible on sites with public access). If in-borehole monitoring equipment is to be left in place, the head works should provide sufficient space to install the equipment with an air tight seal. Wells should be clearly and permanently marked with the well reference number.

Dimension in metres



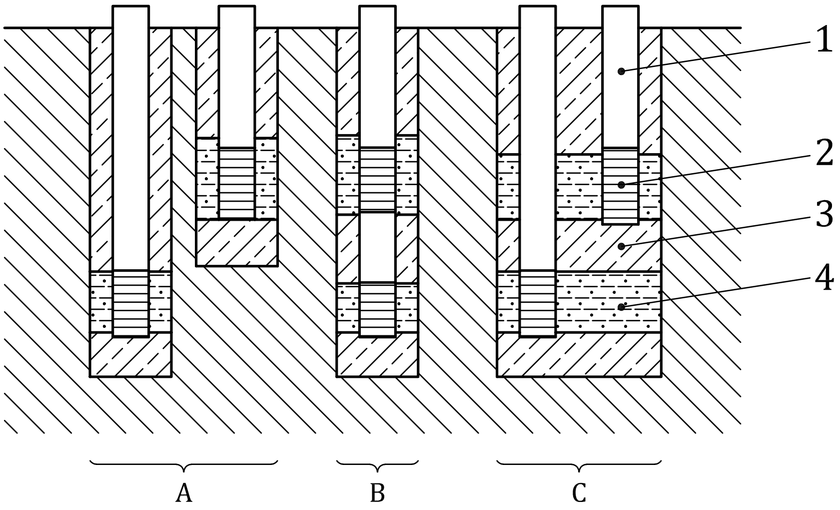
Key

1	lockable cover
2	gas tap/cap
3	concrete/mortar
4	plain pipe
5	bentonite/cement-bentonite
6	gravel/sand
7	slotted pipe
8	bottom sealing cap

Figure 2 — Schematic sectional view of a gas monitoring well

Multiple depths sampling

Depending on the objectives and site context, multiple depths may be investigated for soil gas. In that case, several designs are possible. Figure 3 presents three main designs for multiple depths soil gas sampling.



Key

1	standpipe plain part
2	standpipe screened part
3	bentonite
4	gravel/sand
A	Design A consist of two different boreholes equipped with standpipes with one response zone.
B	Design B consists of a unique borehole equipped with a single standpipe containing two response zones. The two screened sections are separated by bentonite. Response zones should be isolated during sampling by using a packer. Care should be taken with respect to the type of packer used with particular regard to the materials from which it is made so as to avoid emission and absorption of volatile compounds during sampling;
C	Design C consists of a single borehole equipped with several standpipes (with a maximum of four, otherwise sealing around the tubes becomes a problem) with one response zone each. The different response zones are separated by bentonite.

NOTE The sphere/field of action (vertical and horizontal) of each response zone should be known for the sampling flow rate that will be applied. Distances between response zones and bentonite thickness should be adapted to the field of action in order to prevent any connection between the response zones during sampling.

Figure 3 — Different designs for multiple depths soil gas sampling

8 Sampling

8.1 Generic consideration

Soil gas samples for analysis can be taken using a variety of methods. Equipment for collecting gas samples is often quite specialized and requirements should be clearly understood and advice on sampling requirements and procedures obtained from the test laboratory before use.

Samples may be taken using active sampling or passive sampling methods.

Active sampling involves either:

- collection of a small volume of gas, or
- accumulation on a specific filter with an absorbent solution that traps the volatile compounds and subsequent dissolution in the laboratory to allow analysis.

  The filter is contained within laboratory-prepared tubes or similar devices and the soil gas passed through the filter using a pump;

- sorption of volatile compounds onto a sorbent medium and subsequent de-sorption in the laboratory to allow analysis.

  The sorbent medium is contained within laboratory-prepared tubes or similar devices and the soil gas passed through the tube using a pump.

In passive sampling, a sorbent medium is exposed to a gas for a period of time defined, and volatile compounds are adsorbed through diffusion or permeation alone. Passive sampling in soil gas can be used, typically through burial of a passive sampler within the ground, although suspension of a passive sampler to target a subsurface void (e.g. within a sub-floor void) or monitoring well may also be undertaken dependent on the objectives of the investigation (for further guidance on the use of passive samplers including limitations and advantages, see 8.4).

Some passive samplers can provide only qualitative information about the soil gas concentrations. The results obtained are expressed in amount of the volatile compound adsorbed by the device, but it cannot be related to its concentrations in soil gas. This kind of device can be useful to detect and map plumes of VOCs. Table 2 lists containers and adsorbent devices for sampling soil gas.

Some other passive samplers can provide qualitative information about the soil gas concentrations. The results obtained are expressed in mg/m^3. Some research and development works are in progress for this kind of device and accurate passive samplers adapted for soil gas can be expected in future years.

In the case of permanent gases (including mine gas or landfill gas), it should be noted that the gas pressures in wells are generally above atmospheric. It is often possible to carry out passive sampling or to measure gas concentrations using on-site instrumental techniques, in the resulting flow without the need to apply vacuum. In the other cases (pressure in the well less than or equal to the atmospheric pressure or there is only a very low flow), it will be necessary to pump gas from the well to enable active sampling or measurements of gas concentrations to be made.

Table 2 — Containers and adsorbent devices for sampling soil gas

Type of device	Description	Advantages	Disadvantages
Sorbent tubes or impregnated filters	A gas flow is passed through a sorbent medium in a tube or through an impregnated filter. Volatile compounds are trapped. The tubes or filters are sent to laboratory for analysis.	Small. Low detection limits possible. Provide time weighted average concentrations. Can allow high sampling volume (>100 l). Some tubes have a control section to evaluate breakthrough. Multilayer tubes are available which enable a wide selection of compounds (heavier and lighter) to be sampled. Method widely used and validated.	Relatively large above ground sample train. Breakthrough testing required to make sure sorbent not saturated. Calibrated pump required for active sampling. Potential competition between compounds (and humidity for hydrophilic sorbent) during adsorption.
Sampling bags	A small volume of gas is trapped in a container by pumping. The container is sent to laboratory for analysis.	Wide range of bags available. Lightweight. Quick.	Requires pump with an exhaust port to draw gas into bag. Often fragile and easily punctured. Difficult to store and transport once full. Potential for interaction/ sample loss for some bags. Small sampling volume.
Sparging	A gas flow is passed through a liquid solution that absorbs the volatile compounds. The liquid is sent to laboratory for analysis.	Small. Low detection limits possible. Can allow high sampling volume.	Care should be taken during transport to avoid any loss of the liquid solution. Calibrated pump required for active sampling.
Pressurized containers	A small volume of gas is trapped in a container by pressure difference. The container is sent to laboratory for analysis.	Easy to use. Robust. Low detection levels possible. No pump requirement/ limited above ground sampling chain. Method widely used and validated.	Higher cost. Heavier than other containers. Less readily available. Small sampling volume. Needs an advanced cleaning between each sampling. Use of a holder is needed.
Glass or stainless steel sampling tubes	A small volume of gas is trapped in a container by pumping. The container is sent to laboratory for analysis.	Relatively easy to use. Sample collected using manual pump. Quick.	Limited sample size. Higher detection limits.

8.2 Preparation of the monitoring installations

8.2.1 Preparation of the sampling point

Sampling points should be prepared as described in 7.2 before samples are taken.

NOTE Monitoring installations commonly used for permanent gases have a larger diameter than monitoring installations commonly used for VOC monitoring. Mine shafts can be several meters in diameter (6 m on average). Checks at backfilled wells are performed above the embankments, in a square tube 30 cm. The wells are inspected not backfilled by pipes 80 mm to 120 mm in diameter. Surveys have tubes whose cross-sectional average of the order of 100 mm

Different connecting devices can be used: quick couplings, hose insert, system nut/olive for (further guidance see 8.3.2).

There should be no water in a monitoring port when samples are taken. If water is present, the measurements will not be representative.

8.2.2 Leakage test

An installation leakage test should be completed prior to collection of the first sample to provide confidence that atmospheric entrainment will not occur, thereby diluting the sample with a second source of air.

These leakage tests concern all monitoring installations and can be realized by one of the following methods:

- pump soil gas from the monitoring point and analyse on-site for the concentrations of oxygen and carbon dioxide.

  If concentrations are comparable with those expected in ambient air, atmospheric entrainment might be occurring;
- use of a tracer:
  - a tracer gas (e.g. helium) is introduced at the ground beneath a shroud placed over the sampling point;
  - a liquid compound or mixture of compounds is introduced at the ground surface around the sampling point;

    the ground gas sample is collected and either tested on-site for the presence of the tracer gas, or sent for laboratory analysis for the tracer gas or specific components present in the liquid compound introduced at the ground surface. Propane and helium are examples of gaseous compounds and alcohol, pentane or freons are sometimes used as liquid compounds. In the case of the detection of the volume concentration of the tracer less than 10 % of the total volume, the tightness of the device will be considered acceptable;
- the suction opening of the sample probe shall be sealed gas-tight. The entire extraction system is evacuated with the pump which will be used for sample extraction.

  Then, the system is shut off in front of the suction opening of the pump and the negative pressure is measured. The measured (negative) pressure should remain constant for at least the amount of time planned for the sampling process. Then the apparatus is gas-tight according to this document.

8.2.3 Purge

The objective of a soil gas monitoring installation is to control the quality of the soil gases by measuring or by taking samples for analysis. So, a soil gas monitoring installation should be representative of the soil gas quality and not the air which could stay in the borehole. Thus, it is necessary to purge the monitoring installation before sampling or measuring. Two modes of determination of the purge volume are possible:

- the first is to eliminate at least 5 times the volume of air present in the monitoring installation;
- the second is to purge until some relevant soil gas parameters (e.g. PID for VOCs, O_2, CO_2, H_2S, Humidity) became stable.

This purge must be performed at a rate comparable to the sample flow to be subsequently applied.

NOTE Purging of large diameter wells such as commonly used for permanent gases, are not usually performed before sampling although there can be special circumstances when this might be helpful (e.g. to determine how rapidly soil gas enters the well from surrounding ground). In this very specific case, purging could be carried out using inert gas (e.g. nitrogen).

8.3 Active sampling

8.3.1 General

Care should be taken so that atmospheric entrainment through the above ground sampling train does not occur. A range of tests can be carried out prior to and/or during sampling to document that atmospheric entrainment is not occurring (see 8.2.2).

Gas samples should either be analysed directly using appropriate instrumentation, or absorbed into liquids, or adsorbed on to solids prior to analysis or identification of individual constituents, in the laboratory. The adsorption/desorption method can introduce bias (for example, by incomplete recovery of the vapour), so account of this should be taken when reporting results.

The collected volume during active sampling depends of the specifications of the sorbent or filter, the expected concentrations, the soil moisture (especially for hydrophilic sorbents), the desired quantification limits. Two main approaches can be distinguished:

- High sampling volumes, this approach should be implemented:
  - to increase the chance of detecting a contaminant in a field screening context; or
  - to lower the quantification limits in a risk assessment context (evaluation of soil gases contribution to indoor air).

  NOTE 1 For high sampling volumes, the radius of action of the monitoring well is important, and care is needed to avoid connection with ambient air (more important depth of the monitoring well, low sampling flow rate).

  NOTE 2 For high sampling volumes, if the source of volatile compounds is very localized and far away from the monitoring installation, a high risk of dilution can occur.

- Small sampling volumes: this approach should be used:
  - when the sampling methods (pressurized container, sensitive sorbents, etc.) require small volumes;
  - when the concentration expected in soil gas is very high.

  NOTE 3 For small sampling volumes, the radius of action of the monitoring is very small and can reduce the chance of detecting pollution in a field screening approach.

NOTE 4 Collection of a small volume of gas, which might take only a few minutes, results in data relating to the soil gas quality at the point in time when the sample was collected. Sampling using a sorbent medium is likely to take a greater length of time, for example a number of hours and provides a time-averaged view of the soil gas quality over the sampling period. Equipment is available to sample for short periods at fixed intervals over an extended time period. Sampling duration depends on the conceptual site model, the exposure mechanism and possible temporal effects. Sampling trains are available for sampling into pressurized containers over different time periods (e.g. one hour, three hours, eight hours or one week). The size of the sample can affect the detection/reporting limit of the laboratory method.

NOTE 5 Whatever method is used to collect the gas sample, it is vital that there are no leaks in the sampling system that could draw gas into the sampling chamber from the surrounding air as this might give erroneous results.

NOTE 6 Attention needs to be paid during active sampling to the effects of high humidity on instruments and adsorbent devices, for example, condensation in cells and poor recovery, saturation of some types of sorbent, blocking of cold traps used for GC analysis.

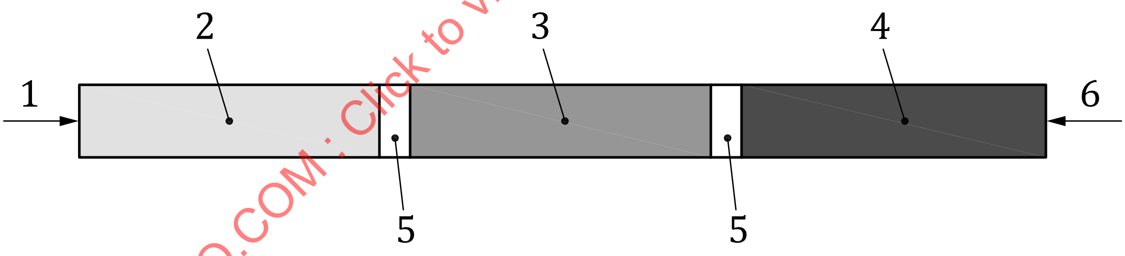
All material should be chemically inert. High density polyethylene (HDPE), PTFE (polytetrafluoroethylene) or polypropylene (PP) is recommended for connections. Use of polyvinyl chloride (PVC), silicon or polyethylene (PE) should be avoided for VOCs sampling.

8.3.2 Sorbent tubes or filters

8.3.2.1 General

This method is widely used to sample soil gases, indoor air or ambient air. An air flow is passed through a stainless steel tube filled with a specific sorbent (carbon) or through an impregnated filter and volatile compounds present in the air are adsorbed or absorbed on it. They are sent to laboratory for analysis.

NOTE Multi-sorbent tubes are available and allow sampling light and heavy volatile compounds with a unique tube.



Key

1 desorption flow direction

2 carbon molecular sieves, strong adsorbent

3 graphitized carbon, medium adsorbent

4 graphitized carbon, week adsorbent

5 glass wool

6 direction of the incoming flow of soil gas

Figure 4 — Schematic representation of a multisorbent thermal desorption tube

Figure 4 represents a multisorbent thermal desorption tube made of a stainless steel tubes packed with a graphitized carbon (a weak sorbent), another graphitized carbon (a medium sorbent) and carbon molecular sieves (a strong sorbent). This multibed tube can be used for a broad range of target compounds: (vinyl chloride to pyrene).

This sampling method needs specific care to limit interferences and to guarantee a complete control of the volume of soil gas that passed through the sampling medium because any mistake made in the sampled volume will impact the calculated concentration of the analysed compounds.

8.3.2.2 Sampling line

Figure 5 gives an example of a soil gas sampling line, with the location of its different components.

A sampling line is composed of:

- connection hoses made of inert material (stainless steel, PTFE, etc.);
- dust filter: depending on field observations, the need of dust filter should be evaluated.

  Consideration should be given to the type of dust filter used, as this can affect sampling (i.e. dust filter should not adsorb or emit compounds that could interfere with the analyses);
- moisture trap: humidity can severely reduce the adsorption capacity of some sorbents, and in order to evaluate and prevent this effect the following measures should be adopted:
  - hydrophobic adsorbents should be used when practical;
  - sample tubes should not be at a lower temperature than the sampled gas to avoid condensation forming in the sorbent tubes or associated connecting pipework;
  - the temperature and humidity levels of the gas to be sampled should be determined before sampling to see if a moisture trap or drying agent should be used in advance of the sorbent tube;

    Consideration should be given to the type of drying agent used, as this can affect sampling. Silica gel is not recommended for gas sampling as it adsorbs polar molecules. In most cases, either calcium chloride or anhydrous calcium sulphate is recommended. For sensitive analysis, magnesium perchlorate is probably the most suitable. Instrument manufacturers often supply proprietary hydrophobic filters, but care should be taken that only specified filters should be used. Alternatively, a gas cooling device, e.g. with a Peltier element and fixed water separator, can be used;

    When a moisture trap is used, justification for the choice should be provided to prove the absence of interference of the selected moisture trap and the compounds analyzed.

    When both moisture and dust trap are used, the dust trap should be set in front of the moisture trap.
- flow regulator system;
- flowmeter adapted to the flow range (see Annex C);

  NOTE 1 A flowmeter can be set on each sampling line during all the measurement, or a single flowmeter can be used for simultaneous sampling and moved from one sampling line to another for flow rate controls (e.g. each 4 h).
- sampling media (sorbent tubes or filters):

  NOTE 2 Some sampling media have a front section and a back section, to evaluate the breakthrough. Adsorbents are sensitive to pollutants competition. The analysis of the control layer also allows to take into account this phenomenon.
  - when the sorbent tube (or filter) includes a back section a unique cartridge is set (each section should be analyzed);
  - when the sorbent tube (or filter) does not include a back section, a second tube (or filter) should be set between the first one and the pump, this second tube (or filter) is used as back section and should be analyzed.

  When several sorbent tubes (or filters) are needed:
  - they should not be set in series, except when they do not have a back section.

In that case, a second tube (or filter), similar to the first one, can be set in series between the first one and the pump to evaluate breakthrough;

- they should be set in parallel and related to only one pump per tube or filter, or to use flow regulators to be able to control the flow rate passing through each tube accurately.

  When several sorbent tubes are set in parallel with only one pump, flow regulators should be used to control the air flow for each tube.

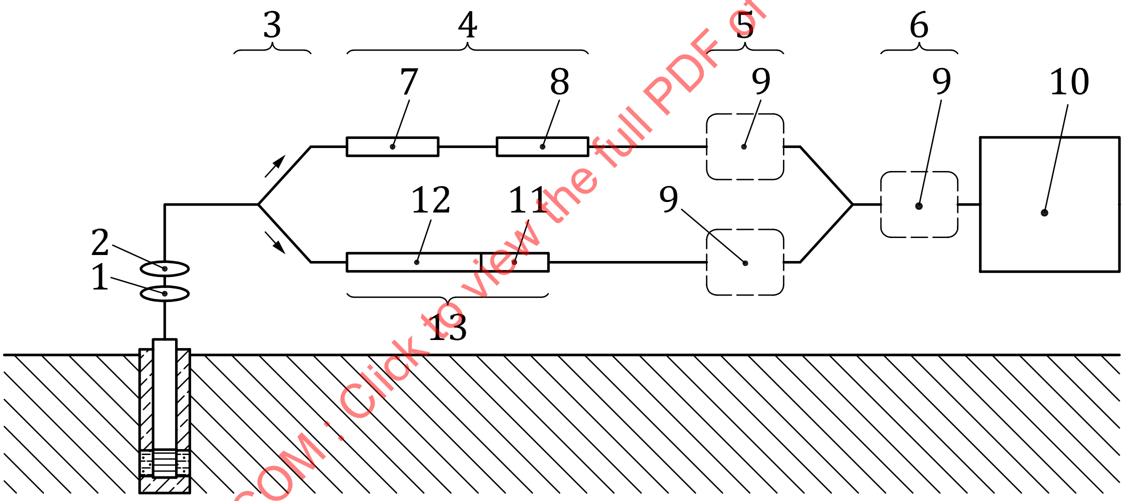
  Use of simple “T” connection is not recommended as there is no way to adjust accurately the flow rate on each branch;

- air pump adapted to the flow range.

All materials used should be inert.

For each sample, a sampling line should be set up for each family of compounds and/or type of trap (sorbent tube and filter). Tubes or filters are set at the end of the sampling line, upstream of the pump. The orientation of the tubes and filters should be checked (generally, an arrow shows the required orientation of gas flow through the tube) in order to avoid a reversal of the sampling support.

This part of the sampling line should be kept to a minimum, in general no more than 1 m.



Key

1	dust trap
2	moisture trap
3	flow regulator system
4	sampling tube without back section
5	flowmeter location for one line control
6	flowmeter location for total flow control
7	front tube
8	back tube
9	flow meter
10	air pump
11	back section
12	front section
13	sampling tube with back section

Figure 5 — Example of a soil gas sampling line

8.3.2.3 Flow calibration and control

A flowmeter appropriate to the flow range (see Annex C) should be employed for the flow rate controls.

When sampling using a sorbent tube combined with a pump, the pump should be placed at the end of the sampling train so that air is drawn through the sorbent tube at a low flow rate.

When several sorbent tubes are needed the tubes should be set in parallel and it is advisable to use one pump per tube, or to use flow regulators to be able to control the flow rate passing through each tube accurately.

The flow rate should be controlled for all the tubes individually, and the total flow rate also needs to be controlled to check the coherence with the sum of the flow rates of each sorbent tube.

The flow rate should be measured on the complete sampling line to integrate all the pressure loss (e.g. ground permeability influence), and at least at the beginning and at the end of the sampling.

It is advisable to place the flowmeter after the sorbent tubes on the sampling line to avoid cross contamination and, in the case of a soap bubble flowmeter, to avoid humidity transfer from the flowmeter to the sorbent tubes. If this is not possible, and the flowmeter is set in front of the sampling medium, the use of a blank sampling medium for the flow calibration is recommended.

If the flow rate fluctuates by less than 5 % between flow rate controls (e.g. between the beginning and the end of the sampling), the sampling shall be considered as representative, and the average flow rate, based on flow rate measurements at the beginning and at the end of the sampling (and any other intermediary controls), is to be used to determine the soil gas volume sampled.

If the flow rate fluctuates by more than 5 %, but less than 10 % between flow rate controls, the sampling shall be considered as representative, and the minimum flow rate measured among beginning, intermediary and final flow rate controls, used to determine the soil gas volume sampled.

If the flow rate fluctuates by more than 10 % between flow rate controls, the sampling shall not be considered as representative.

When several sorbent tubes are used, and if the total flow rate is different by more than 10 % than the sum of the flow rates of each sorbent tube, the sampling shall not be considered representative.

8.3.3 Sample containers — Sampling bags

Different types of sample bags are available and the appropriate sampling bag should be selected taking into account the compounds that are known to be present, or might be present, in the gas to be sampled. Several compounds could be analysed with a single sample bag.

NOTE 1 Care is needed in the choice of the bag, in particular to avoid adsorption of volatile compounds on the inner surface of the bag.

Sample bags should not be damaged or show signs of wear and tear (they are often suitable for one sampling event only).

Sample bags require a pump to pull the vapours from the soil through the sampling installation (see 8.2.4 for sampling line and flow calibration protocol).

NOTE 2 The pumps used need an exhaust port to fill up the bag.

The sample bag should not be filled more than 2/3 full. The sample bag size can be adjusted depending on the volume of gas necessary for the analysis. Volumes from some millilitres to several dozen litres are available. Then, depending on soil characteristics, soil gas installation designs and the targeted quantification limits, sampling duration and pumping flow are determined.

After sampling, the sample bags should be stored out of sunlight, at room temperature, and in a specific container to avoid piercing.

The sample should be delivered to the laboratory within 24 hours and the analysis completed within 24 hours of receipt.

NOTE 3 Some methods recommend that the contents of the bags are analysed within a few hours of sample collection (i.e. ≤4 h for benzene according to method NIOSH 7300).

8.3.4 Sparging

Different sort of liquid solutions are available and the appropriate liquid solutions should be selected depending on their properties.

The liquid container should not be damaged or show signs of leaks.

Sparging requires a pump to pass the gases through the liquid solution installation (see 8.2.4 for sampling line and flow calibration protocol).

NOTE Sparging in this context is the passage of a gas through an absorbent liquid.

After sampling, the liquid container is properly closed and should be stored out of sunlight, at room temperature.

The sample should be delivered to the laboratory within 24 hours and the analysis completed within 24 hours of receipt.

8.3.5 Sample containers — Pressurized containers

Pressurized containers are stainless steel containers which have the internal surfaces treated to avoid adsorption of compounds. Pressurized container volume is usually around 1 l to 6 l.

Pressurized containers should be checked on receipt to confirm that the container pressure has been maintained at the preparation level during transport. All containers which could be susceptible to cross-contamination during transport (i.e. all those except the overpressurized containers) should be stored and transported in a manner that will minimize the potential for cross-contamination to occur.

The pressurized container is equipped with an air pressure regulator and plugged to the monitoring port. The valve is opened at the beginning of the sampling and the gas enters into the pressurized container spontaneously due to the difference of pressure between the container and soil gas. The valve can be equipped with a flow controller for filling at a targeted flow rate. Filling the pressurized container is controlled by the pressure gauge fitted on it. Usually, sampling duration is around 1 h to 24 h, depending on the sampling flow and the device volume. When sampling is over, the valve is closed and the whole system is sent to the analytical laboratory.

During sampling, the pressure should be checked regularly to prevent any problem with the air pressure regulator.

Between each sampling event, advanced cleaning shall be carried out to ensure the absence of unwanted compounds before the next sampling event.

8.4 Passive sampling

This method refers to passive samplers installed in fixed installation, in below-slab voids or placed directly in the ground (see 7.2). In this last case, a hole is made to a depth of about 1 m. The passive sampler is buried and the hole backfilled with the excavated material or, the passive sampler can also be set directly in a soil gas monitoring well. After a predefined time (a few days to a few weeks), the passive sampler is dug up and sent to laboratory.

NOTE 1 This method permits installation quickly of a larger number of sampling devices (40 to 100 samplers a day) at relatively low cost.

NOTE 2 The advantage of this technique is that the results are not affected by the soil texture, moisture or changes in soil conditions. Adsorption of vapours over a prolonged period of time enables detection of very low concentrations which might not be detectable with short-term active monitoring. All these benefits make this technique very useful for the detection and mapping of plumes of VOCs in deep aquifers.

Passive diffusive samplers also have some potential limitations relative to the current conventional sampling methods.

- Starvation effect: If the air to which the sampler is exposed is stagnant, the sampler might remove VOC vapours from the air faster than they are replenished, in which case, the sampler itself imposes a reduction in the concentrations it is intended to measure.

  This is referred to as the “starvation effect”, and it depends on the uptake rate of the sampler and the face velocity past the sampler.

- Saturation/Competition: If passive samplers are exposed to high concentrations for extended periods of time, the adsorbent media might become saturated, in which case, the uptake rate might diminish, or more strongly adsorbed compounds might displace less strongly adsorbed compounds (i.e. competition for adsorptive sites), which could impose a bias on the concentration measurements.

  This can be managed if there is some advance information about expected concentrations (e.g. via field screening or historical data).

- Matching adsorbent media to target compounds: Different chemicals have different adsorption coefficients, and a variety of adsorbent media are available, so it might be necessary to match the adsorbent to the compounds of interest to provide a high degree of retention during sampling, and good recovery during analysis.

  It might not be practical to design a single passive sampler suitable for the range of vapour intrusion investigations. This is similar to the challenges of conventional active ATD tube sampling methods.

8.5 Sampling for on-site measurements

Where portable instruments are used, they should be connected securely to the sample point and gas should be allowed to flow through the instrument until a steady reading is obtained. A reading should be taken of both peak and steady-state concentrations.

Any instrument used in the field should be calibrated and achieve appropriate limits of detection. In addition, the limitations associated with the sampling point installation should be clearly understood (see Annex B).

Monitoring ports should be prepared as described in 7.2 before any measurements are made. There should be no water in a monitoring port when measurements are made. If water is present, the measurements will not be representative.

When taking a gas measurement from a monitoring point or port, a length of tubing (sample line) is usually required to connect the borehole to the gas analyser. This should be kept to a minimum, in general no more than 1 m. All material should be chemically inert. High density polyethylene (HDPE), polytetrafluoroethylene (PTFE) or polypropylene (PP) are recommended for connections. Use of polyvinyl chloride (PVC), silicon or polyethylene (PE) should be avoided for VOCs sampling.

A column of drying agent might need to be placed along the sampling line to prevent the moisture contained within the soil gas from damaging the instrument (see 8.2.2).

Flow rates can be measured using a variety of dedicated instruments or using flow meters integral to gas analysers. Where little or no gas flow is expected, the equipment should be capable of measuring low flow rates in the order of few litres per hour. Reports of flow results should state clearly which method has been used (see Clause 10). Negative flow rates should also be measured and recorded.

NOTE 1 Measurement of ambient gas concentrations provides a check on the correct functioning of instruments and, in the case of VOCs, background concentrations. The latter might be important when the investigation is on a site where VOCs are likely to be present in the atmosphere (e.g. fuel service stations).

NOTE 2 It can be beneficial to record the gas concentrations and flow rates observed in a borehole using a data-logging device. In most cases, the gas analyser will have a data logger connection. This can be used to log at predefined frequencies. When monitoring from a borehole, it is advisable to log every few seconds. This will show the steady-state concentrations, as well as the range of concentrations. In most cases, the data logger can be downloaded onto a computer software package for further analysis and data storage.

9 Identification, packaging and transport of samples for laboratory analysis

9.1 Identification

Self-adhesive labels, glue or marker pens should not be used when labelling sampling devices, especially sorbent tubes, in order to avoid traces of residual glue or ink contaminating the samples, especially during scans by thermal desorption.

To guarantee the integrity of the samples and prevent contamination of the sorbent tubes, it is recommended to

- seal correctly tubes and sampling devices in order to avoid any leaching after sampling,
- gather all the sampling devices from the same sampling point in an individual bag correctly identified, and
- label sorbent tube caps (and not the tube/sampling device itself), or put labels on a bag in which the collection of capped tubes has first been placed.

9.2 Packaging and transport

Immediately after the end of the collection, the sorbent tubes should be closed with the plugs provided by the laboratory. These plugs should be sufficient to ensure the tightness of the medium during transport. In addition, the tubes can be packed in aluminium foil containers so as, in particular, to protect them from the light. All samples should be packaged in the cool box provided by the laboratory taking all measures to protect them from damage or external influences during transport (avoid breakage in case of packaging “in bulk”) and using inert materials (not likely to release volatile compounds during transport).

In the case of pressurized containers, it is recommended to remove the tap to facilitate packaging.

Gas samples should be gathered in a different cool box than samples of soil or water to prevent contamination during transport.

Samples should be packed in cool atmosphere (e.g. cool bow with iced packs) and away from the light.

Samples should arrive at the laboratory no more than 24 h after sampling and analysis should commence within the following 24 h.

10 Sampling report

The requirements outlined in ISO 18400-107 apply in general to the soil gas sampling report.

A report should be prepared following each monitoring or sampling event containing the following:

- location;
- photos or video;
- date and time of sampling/measurement(s);
- who took the sample;
- pressure differences between soil gas and ambient air;

- sampling depth;
- gas flow rates;
- instrument(s) and technique(s) used;
- ground conditions, e.g. wet, water-logged, dry with vegetation showing no signs of stress, cracks in the soil;
- details of leak tests and calibrations carried out on site;
- the nature of the ground at each location (if known);
- expected gas concentrations (as information for subsequent laboratory analysis) or results of direct measurements;
- for laboratory analysis, time and conditions of transport and storage.

When on-site measurements are to be made or samples taken for laboratory analysis, at least the following should be recorded to aid data interpretation:

- the results of instrument checks;
- weather conditions (temperature, pressure, wind, rainfall) for at least three days before, during, and after the monitoring event;
- activities that could affect the measurements made or samples taken, e.g. dewatering from nearby excavations or tidal effects on groundwater levels.

In addition, any of the following that are appropriate to the type of installation and the circumstances of the investigation should be recorded:

- atmospheric pressure for the preceding several days (to show the change, if any, in pressure);
- ambient gas concentrations;
- wind (speed and direction);
- ambient temperature;
- pressure in (and gas flow from) the monitoring well (if determined);
- temperature and humidity in the monitoring well;
- presence or absence of water in the monitoring well;
- condition of the monitoring well, diameter and depth of response zone;
- visible or audible indications of gas migration from or around the installation (e.g. hissing sounds);
- any unusual odours in or around the monitoring installation.

An example of information sheet that can be filled out for each sample is provided in Annex D.

11 Quality assurance

11.1 General

Following are listed some essential elements of quality assurance for the sampling of soil gas:

- during sampling, transport and storage of the samples it is important to ensure that they do not become contaminated, e.g. through exhausts, cigarette smoke, solvents or materials that contain volatile organic compounds (e.g. polystyrene products, pesticides, sunscreen products, skin care products);

- field blank and trip blank shall be performed regularly, e.g. before and after each examination phase or at the beginning of each sampling day;
- the purge should be sufficient before sampling and performed at a similar flow rate to that of the sample;
- the "carry-over" of contamination shall be avoided [parts made of rubber or plastic (e.g. packer, PTFE insets, sealant rings) can carry over substances into other boreholes/samples];
- the drilling instruments shall be cleaned thoroughly with clean water and then dried in order to avoid carry-over of contaminated soil;
- the sampling apparatus shall be cleaned regularly;
- the tightness of the sampling apparatus shall be checked regularly;
- an instrument log shall be kept for the sampling apparatus.

  In this document, the projects, the time periods of use, as well as the substances examined, shall to be recorded. Additionally, maintenance work, leak checks, date and type of cleaning performed on the parts of the apparatus shall be recorded;
- the adsorption tubes to be used in sampling shall be checked regularly according to their type with respect to their rate of leakage, e.g. per batch;
- the flow rate applied to sorbent tubes should be checked regularly (see 8.2.2);
- the shelf-life of loaded adsorption tubes or filled sampling containers under typical storage conditions (temperature, light conditions, location, container, duration) shall be checked for each substance;
- the influence of typical transport conditions (temperature, light conditions, location, container, duration) for loaded adsorption tubes or filled sampling containers on sampling results shall be examined for each substance.

  The use of trip blanks is recommended (see 11.2);
- if general conditions change considerably during the sampling series (e.g. strong rain storms), an additional sample shall be taken within the suspected area of contamination (this shall be recorded in the sampling report);
- a complete sampling record shall be kept for each sample.

Actions to be taken, when deviations from predetermined procedures are observed, should be considered prior to sampling.

NOTE The requirements outlined in ISO 18400-106 apply in general to soil gas sampling.

11.2 Quality control samples

11.2.1 General

Quality control samples are taken to evaluate the quality of the sampling programme, in addition to the samples taken from predetermined sampling points. They provide information which ideally discounts any errors due to possible sources of cross-contamination, inconsistencies in sampling and checks on the analytical techniques used. In accordance with the data quality objectives of the sampling and investigation programme, consideration should be given to implementing each of the quality control procedures described below. Table 3 presents recommendations for quality control samples frequency.

11.2.2 Blind replicate samples

These samples can be used to identify the variation in analyte concentration between samples collected from the same sampling point and/or the repeatability of the laboratory's analysis. For every 20 samples taken, one set of blind samples should be collected. These samples should be submitted to the laboratory as two individual samples and no indication given that they are duplicates.

11.2.3 Split samples

These samples provide a check on the analytical proficiency of the laboratories. For every 20 samples, one set of split samples should be taken. The split samples should be set in parallel, from the same sampling point in a single operation. One sample from each set should be submitted to a different laboratory for analysis. The same analytes should be determined by both laboratories, using identical analytical techniques.

NOTE In common studies, for many reasons (time, flow, etc.), split samples are rarely taken and analyzed.

11.2.4 Trip blanks

These blanks are used to detect cross-contamination of samples during transport. A container or sorbent cartridge or other collection medium, identical to the ones being used for the samples, is sealed as for a real sample, placed with the samples and transported back to the laboratory.

No pumping will be applied on trip blanks.

It is essential that trip blanks are packaged in the same conditions as the other samples in order to be able to draw conclusions about possible influences of the container on the adsorbent tubes (so the tube should be capped during transportation in the same way as the other tubes).

The trip blank is then analysed along with the collected samples.

11.2.5 Field blanks

These blanks are used to detect cross contamination of samples during sampling. The blank tubes are opened at the same time as the tubes to be used for the actual sampling. They are closed during the pumping phase and then reopened whilst the actual sampling tubes are being removed from the sampling train. No pumping is done on field blanks.

The field blanks will be finally closed and packed in the cooler box as a set of sample tubes. It is essential that the field blanks are packaged in the same conditions as the other samples to be able to draw conclusions about possible influence of field conditions on the samples.

The field blank is then analyzed along with the collected samples.

11.2.6 Other quality control samples

Other quality control samples to be considered include resubmission of a previously analysed sample to the same laboratory or to a different laboratory.

11.2.7 Evaluation of quality control sample results

The analytical results and quality control data should be evaluated following recognized procedures to allow the interpretation of accuracy, precision and representativeness of the data. Typical variations which can be expected from acceptable quality control samples are shown in Table 3.

Table 3 — Acceptance criteria for quality control samples

Quality control samples	Minimum number of samples	Typical RPD for quality control samples[a,b]
Blind replicate sample	One per 20 samples collected	30 % to 50 % of mean concentration of analyte
Split sample	One per 20 samples collected	30 % to 50 % of mean concentration of analyte determined by both laboratories[c]
Trip blank	One per box used to contain samples	The significance of the trip blank results should be evaluated in terms of those obtained for the actual field samples
Field blank	One per day	The significance of the field blank results should be evaluated in terms of those obtained for the actual field samples

[a] The relative percent difference (RPD) is [(relative difference between two samples expected to be similar) divided by the mean result] times 100.

[b] The significance of the RPDs of the results should be evaluated on the basis of sampling technique, sample variability and absolute concentration relative to criteria and laboratory performance.

[c] This variation can be expected to be higher for organic analytes than for inorganic and low concentration analytes.

11.2.8 Chain of custody

This process details the links in the transfer of samples between the time of collection and their arrival at the laboratory. Several transfers can take place in this process, but details of each transfer should be recorded on a chain of custody form. The minimum information that shall be included on the form is the following:

a) name of the person transferring the samples;

b) time and date that samples are taken;

c) time and date that samples are received by the laboratory;

d) analytes to be determined;

e) other specific instructions in the handling of the samples during analysis, e.g. special safety precautions;

f) samples that are expected to contain high levels of the analyte in question or other substances that can interfere with the analysis.

11.2.9 Equipment

All equipment should be calibrated and demonstrated to meet the calibration specifications prior to use. There are a number of reasons for this:

a) gas analysers have a tendency to drift over time;

b) some instrument types have a limited life and can fail suddenly without warning;

c) landfill gas contains trace gases that can “poison” the monitoring equipment.

The instrument should be calibrated using a standard gas with appropriate concentration and a zero gas such as nitrogen. The frequency of calibration will depend on how regularly the instrument is used. Advice on how to carry out calibration should be provided with the instrument. Regular servicing should be carried out according to the manufacturer’s recommendations. Regardless of whether the