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Guidance on sampling and monitoring for lead in drinking water

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Photo cover page:

Lead pipe to supply water to the Great Bath at Bath Roman Baths – Photograph © Andrew Dunn, 15 September 2005; Creative Commons Attribution ShareAlike 2.0; source Wikimedia Commons

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1. Scope

The Task Group on Indicators and Monitoring has recommended that lead should be one of the key health indicators under the Protocol on Water and Health. The Parties will need to establish their baseline position within nine months of the July 2009 meeting of the Working Group on Water and Health and then determine any initial improvement plans that may be warranted by July 2010. This Guidance Document provides a recommended method for each Party to establish its baseline position for lead in drinking water. Within this timescale it is not considered feasible to survey all water supply systems within the Country. Rather, a risk based approach is proposed to identify representative water supply systems to enable each Party to ascribe appropriate priorities to the lead health indicator. Subject to initial findings, the Parties may wish to undertake further assessments to determine improvement plans in greater detail.

This Guidance Document has been prepared by an Expert Group comprising representatives of the World Health Organization (WHO), the European Commission's Joint Research Centre and COST Action 637, a research network on metals and related substances in drinking water. It is consistent with recent formal advice to the European Commission in relation to the planned revision of the current Drinking Water Directive (98/83/EC) [1,2] and draws widely from European experience.

2. Background

Our exposure to lead is declining owing to different regulations, especially from air and food. Therefore the contribution of drinking water to our total exposure increases. The main sources are lead pipes, solders and brass fittings. Minor sources are PVC pipes containing lead stabilisers and galvanised steel pipes. The toxicity of lead is well established. WHO has established a provisional tolerable weekly intake of 25 µg/kg body weight. Using the weight of an infant of 5 kg, a consumption of drinking water of 0.75 L/day and an exposure contribution of 50% from drinking water, WHO has established a guideline value of 10 µg/l for lead in drinking water [3].

The purpose for sampling and monitoring for lead in drinking water is to check the quality of source water, and to validate the operation of the water treatment plant, the distribution network and the domestic distribution system up to the tap. One can distinguish four types of monitoring:

1. Inventory monitoring is the monitoring to get a picture of a water supply zone in which the concentrations of lead at the consumers' tap is not well known. This Guidance document focuses on this type of monitoring.
2. Operational monitoring is the monitoring that checks the concentration of lead in view of the daily operation of the water supply zone. This type of monitoring is generally carried out by the organisation that is responsible for the supply of drinking water.
3. Compliance monitoring is the monitoring that checks whether the supplier fulfils its duty to supply safe drinking water. This type of monitoring is generally carried out by the competent authorities.
4. Investigative monitoring is the monitoring that is performed when the concentration of lead in a sample exceeds the limit value and the origin of the failure needs to be investigated.

Within the European Region of WHO, the Member States of the European Union have to comply with the Drinking Water Directive (DWD) [4]. It regulates in its Art. 6(1) that "the parametric values set in accordance with Article 5 shall be complied with: (a) in the case of water supplied from a distribution network, at the point, within premises or an establishment, at which it emerges from the taps that are normally used for human consumption". Art 7(1) regulates that "samples should be taken so that they are representative of the quality of the water consumed throughout the year" [4]. Annex I specifies the sample for lead more detailed in note 3 of Part B.

> "The value applies to a sample of water intended for human consumption obtained by an adequate sampling method [1] at the tap and taken so as to be representative of a weekly average value ingested by consumers. Where appropriate the sampling and monitoring methods must be applied in a harmonised fashion to be drawn up in accordance with Article 7(4). Member States must take account of the occurrence of peak levels that may cause adverse effects on human health" [4].

The parametric value of lead is 25 µg/l until 2013 after which the values lowers to 10 µg/l. The parameter lead is subject to compliance monitoring. "The purpose of compliance monitoring is to provide the information necessary to determine whether or not all of the Directive's parametric values are being complied with. All parameters set in accordance with Art. 5(2) and (3) must be subject to compliance monitoring unless it can be established by the competent authorities, for a period of time to be determined by them, that a parameter is not likely to be present in a given supply in concentrations which could lead to the risk of a breach of the relevant parametric value" [4].

According to Art. 6(2) non-compliance due to the domestic distribution system in private premises is not the responsibility of the Member States. However Member States need to make the property owners aware of the problem and need to advise on possible remedial action to be taken.

In order to harmonise the sampling and monitoring the Drinking Water Directive foresees the preparation of Community guidelines. Attempts have been made to prepare Community guidelines for copper, lead and nickel [6]. Recently proposals have been prepared to clarify the Directive for its revision [2]. Some of these proposals could be considered as Community guidelines for the current Directive and are presented here. Other issues have not been solved yet and this guide proposes some approaches.

[1] To be added following the outcome of a study [5]

3. Definitions

It should be noted that the sample volume in the definitions is not fixed. The sampling volume depends on the purpose of sampling and should be mentioned in the report.

COMPETENT AUTHORITY

The definition of ***competent authority*** is the organisation that is responsible for the safety of drinking water, either at national or at local level.

MONITORING – COMPLIANCE

The definition of ***compliance monitoring*** is the monitoring at the point of compliance to verify that water supplied for human consumption is in compliance with its quality requirements.

MONITORING – INVENTORY

The definition of ***inventory monitoring*** is the monitoring to estimate the lead problem in a water supply zone or country.

MONITORING – OPERATIONAL

The definition of ***operational monitoring*** is the monitoring activity to check the quality of source water, and to validate the operation of the water treatment plant, the distribution network and the domestic distribution system up to the tap.

POINT OF EXIT

The definition of the ***point of exit*** is that point where the water leaves the water treatment plant or point of abstraction where there is no treatment.

POINT OF SUPPLY

The definition of the ***point of supply*** is that point in the distribution network where the responsibility of the water supplier ends and the responsibility of the property owner for the internal plumbing system starts. The exact definition of point of supply should be defined in national law. Examples of point of supply are the water meter or the stopcock at a premises' border (or curtilage). In certain cases it is equivalent to the point of entry.

POINT OF ENTRY

The definition of the ***point of entry*** is that point in the distribution network where the water enters the property, public or private. In certain cases it is equivalent to the point of supply.

POINT OF COMPLIANCE

The definition of the ***point of compliance*** is the point within premises or an establishment at which water emerges from the tap where the water is normally used for human consumption. For compliance sampling purposes and practical reasons this is normally the cold water tap in the kitchen.

SAMPLING – FIRST DRAW

The definition of a ***first draw sample*** is a sample that is taken first in the morning before the tap in the premise has been used for other purposes. During the stagnation period no water should be drawn from any outlet within the property (this includes flushing of toilets). If any water is drawn during the stagnation period the result will be invalid. It is common practice for such samples to be taken by consumers. There is no control over the quality of the samples. When the sample is taken the tap should be fully opened or as open as possible without losing sample.

The stagnation of water in the domestic distribution system influences the concentration of lead.

SAMPLING – FULLY FLUSHED

The definition of a ***fully flushed sample*** is a sample that is taken after prolonged flushing of the tap in a premise in such way that stagnation of water in the domestic distribution system does not influence the concentration of lead. In practice a sample is taken after flushing at least three plumbing volumes. In cases where the temperature of the water from the distribution network is cooler than the ambient temperature, an alternative method is monitoring the temperature of the water during flushing until it stabilises.

SAMPLING – PROPORTIONAL

The definition of a ***proportional sample*** is a sample that is taken during the use of tap water for human consumption in a property. The sample is an approximation of the concentration of lead that is consumed in that property. This sampling method requires a special consumer-operated device to be fitted to the tap that splits off a small constant proportion of every volume of water drawn for dietetic purposes. There is no control over the quality of the samples. The proportional sample is normally collected during a 1-week period.

SAMPLING – RANDOM DAYTIME

The definition of a ***random daytime sample*** is a sample that is taken at a random time of a working day directly from the tap in a property without previous flushing. When the sample is taken the tap should be fully opened or as open as possible without losing sample.

The stagnation of water in the domestic distribution system influences the concentration of lead in a random manner.

SAMPLING – STAGNATION

The definition of a ***stagnation sample*** is a sample that is taken after prolonged flushing the tap in a premise (see fully flushed sampling) and successive stagnation of a predefined period before the sample is taken from the tap. During the stagnation period no water should be drawn from any outlet within the property (this includes flushing of toilets). If any water is drawn during the stagnation period the result will be invalid. When the sample is taken the tap should be fully opened or as open as possible without losing sample.

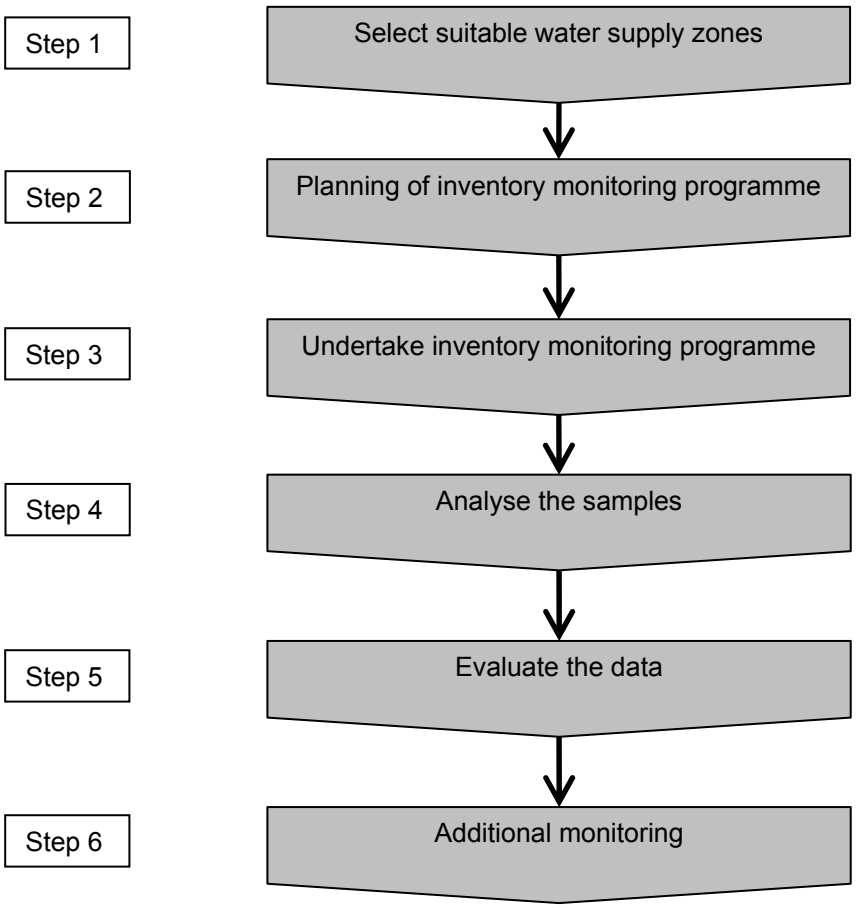
The stagnation of water in the domestic distribution system influences the concentration of lead in a predefined way. A stagnation time of 0.5 or 2-4 hours is commonly used.

WATER SUPPLY ZONE

A ***water supply zone*** is a geographically defined area within which water intended for human consumption comes from one or more sources and within which water quality may be considered as being approximately uniform.

4. Approach

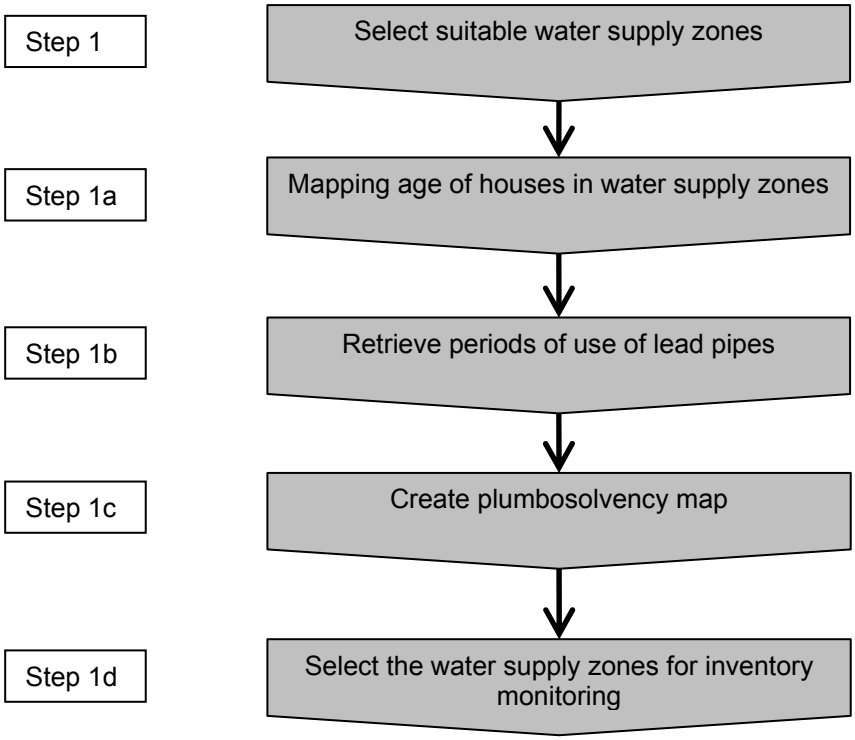
The five steps to determining the baseline for the lead health indicator are:



The sixth step is optional and aims at studying the water supply zone in further detail. Each step is described in greater detail in the following sections.

5. Selection of water supply zones

The selection of water supply zones for inventory monitoring can be done using the following steps:



House age and lead pipe usage period

The occurrence of lead pipes is usually associated with the age of the buildings. In order to prepare inventory monitoring well, the competent authority is advised to prepare an inventory of

- The age of the housing in each water supply zone in the country. Generally buildings that are at least 30 years old can be suspected to have lead pipes. However this may vary between countries.
- The period(s) in which lead pipes have been used. The inventory can be extended to lead-containing solders, brass fittings, galvanised steel pipes/fittings and unplasticised PVC containing lead-stabilisers.

Plumbosolvency map

The information of the age of the housing stock and the period(s) that lead pipes have been used, can be combined on a plumbosolvency map of each water supply zone. The most basic map will indicate areas were lead pipes are expected and were not. The more details are available on other lead-releasing materials, the more detailed maps can be produced.

The plumbosolvency maps can be refined by including information of the water composition of the water that is supplied. Plumbosolvency is promoted by low alkalinity (<50mg/l $CaCO_3$), pH below 7, high organic content (colour >10° Hz) and reddish iron-containing water.

The creation of plumbosolvency maps at national level is a substantial amount of work and this work should preferable be delegated to local authorities. For European Union Member States the exercise should at least include all water supply zones that produce more than 1000 m^3 per day. Non-compliances of these supplies are obliged to be reported to the European Commission in the framework of the Drinking Water Directive.

Selection of the water supply zones for inventory monitoring

Based on the plumbosolvency maps water supply zones can be grouped according to similar expected lead problems, i.e. the percentage of houses in the water supply zone that might have a lead pipes. A minimum of three lead problem groups can be distinguished: water supply zones having

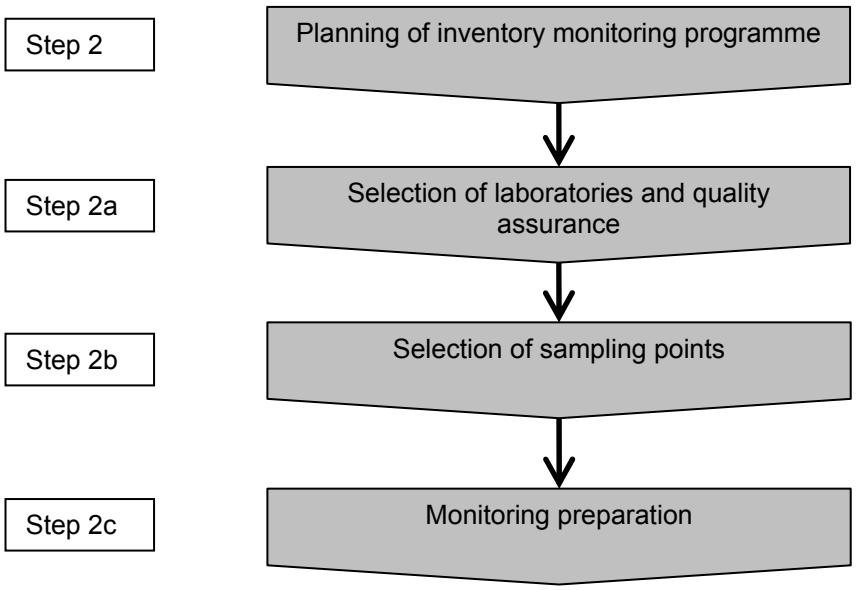
- More than 50% of the properties that may contain lead pipes
- 10-50% of the properties that may contain lead pipes
- Less than 10% of the properties that may contain lead pipes

It is recommended that for the inventory monitoring a minimum of three water supply zones from each lead problem group are selected. The size of the selected water supply zones should be representative for:

1. the other zones in the same lead problem group
2. a substantial amount of population

6. Planning of inventory monitoring programme

The planning of the inventory monitoring programme can be done using the following steps:



Selection of laboratories and quality assurance

The laboratory must operate a system of analytical quality control (AQC). The laboratory should be well organised and the quality and performance of instruments should be traceable including precision, bias and reproducibility. It is recommended to participate regularly in proficiency test schemes for lead analysis in water.

The sample handling and analysis of lead should preferably be undertaken under laboratory conditions that do not lead to detection of lead in blank samples. In particular attention should be given to the reagent blanks and the air quality.

The quality of sampling and monitoring is assured by employing skilled personnel, clearly written procedures and an external auditing process.

It is important that the personnel used in sampling are adequately trained and competent to carry out the tasks required. Preferably, such personnel should have their training certified by a competent assessor.

Clear written procedures must be available and used to assist sampling personnel. Such procedures should cover all aspects of sampling, including both planning and implementation.

Sampling activities should be audited by a competent external person during the complete inventory monitoring exercise. Any defects can than be resolved quickly.

Selection of sampling points

Sampling points should be selected randomly. There should be a right balance between public and private buildings, e.g. conform to the ratio between them. Consumers' taps in individual buildings are chosen at random from billing lists, electoral registers, post code lists or other similar and suitable lists. A house cannot be selected twice in one year. In order to achieve an adequate level of statistical confidence in the results obtained, it is recommended that the numbers of samples in the following table are taken. The reference is the production volume of the production plant(s) in the water supply zone because some zones may suffer from substantial losses during distribution.

On each day of sampling an additional sample should be taken at the point(s) of exit of the water production plant(s) that serve the water supply zone. This to establish a baseline of the concentration of lead in the water supplied to the distribution network.

Production volume in water supply zone (m^3/day)	Total number of samples in each survey	Number of samples per month over a 6 month period
<10,000	180	30
10,000 to <15,000	240	40
>15,000	300	50

The appropriate number of samples should be taken evenly over a period such that seasonal factors are taken into account. Normally the minimum sampling period should be six months that spans equally both higher and lower water temperatures. This is because lead dissolution into water will have approximately twice the concentration in the summer than in the winter.

The recommended numbers of samples are necessary because of the inherent variation in lead concentrations at consumers' taps and the need to minimise the reproducibility problems of smaller sampling numbers.

Monitoring preparation

Sampling bottles should be made of colourless polypropene (PP), polyethene (PE) or fluorinated ethene propene (FEP) and should have a volume sufficient to take 1 litre. The bottles should not leach any detectable amount of lead. The sample bottle cleaning should preferably take place in a clean laboratory of which the incoming air is well filtered. A common cleaning procedure of the bottles is by rinsing first with an organic solvent or suitable detergent solution. Next the bottles should be filled with hydrochloric acid (6 mole/l) and successively with nitric acid (7 mole/l), each for one week at ambient temperature or for 24 h at 48±2°C. The bottles are conditioned by filling with nitric acid (0.1 mole/l), each for one week at ambient temperature. Between the rinsing and filling steps the bottles are rinsed with ultra-pure water.

It should be feasible for a sampler to take at least 10 samples during a normal working day. Therefore, a water supply system with a production volume of <10,000 m^3/day will require 3 days of sampling work per month, up to 5 days of sampling work per month for a water supply system with a production volume of >15,000 m^3/day.

An example of the total sampling workload that could be involved for a Party is shown below. In this example, the sampling workload is equivalent to 2 persons over an assumed six-month period (i.e. 1 Full Time Equivalent person).

Production volume in water supply zone (m^3/day)	Number of water supply systems to be sampled and the numbers of samples	Number of sampling days
<10,000	4 systems = 720 samples	72
10,000 to <15,000	2 systems = 480 samples	48
>15,000	3 systems = 900 samples	90
Total	9 systems	210

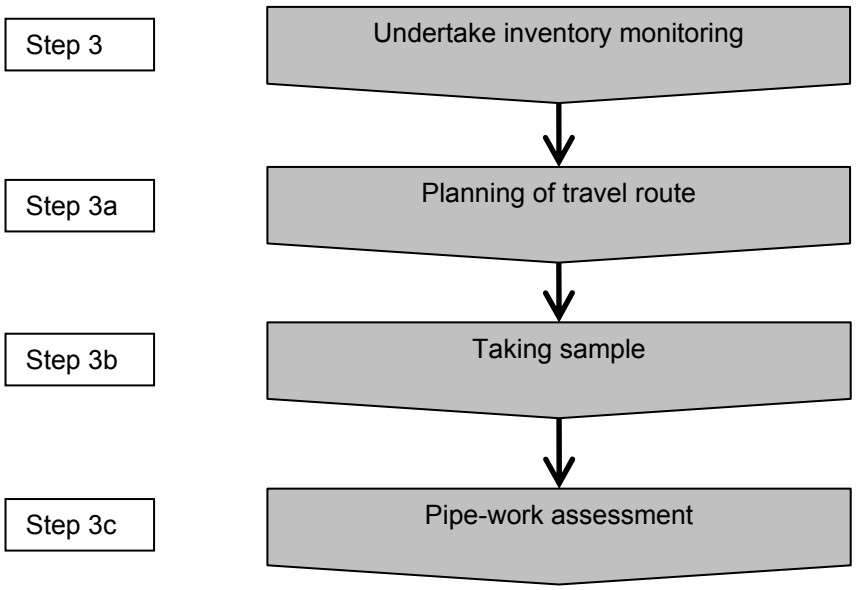
It is recommended that samplers carry formal identification and an official warrant that permits them to seek access to consumers' premises.

It would also be advisable for an explanatory leaflet to be available which can be handed to the house owner when access for sampling is being requested.

It is recommended that the sampler takes blank and/or spiked samples with them for quality control of the sampling procedure.

7. Undertake inventory monitoring

During the actual inventory sampling the following actions should be carried out:



Planning of travel route

On a particular sampling day it is common practice to optimise the route of travelling between the sampling points. The selected sampling locations may be sampled at any time during normal working hours. This means that the sampler should ensure taking samples evenly distributed over the working hours [7]. In case of the absence or refusal of a property owner for taking a sample, the sampler should instead sample an adjacent property.

Taking samples

The point for sampling should be a cold water tap from which drinking water is regularly obtained within the building. In private houses this tap is normally the kitchen tap. In public buildings the sampler should judge which tap is mostly used for drinking and food preparation purposes.

The sample is taken according to the method of random daytime (RDT) sampling. After selection of the tap being sampled, the first 1 litre of water from the tap is sampled. This means that the tap is not flushed before taking the sample. Samples should be taken with the tap opened as much as possible to allow for turbulent flow. However care should be taken that the sample should not escape the sample bottle.

In case the tap consists of a single lever mixing tap the sampler should ensure that only cold water is sampled and not a mix with hot water.

Each sample container should be labelled with a unique sample number, the date and time of sampling, and the sampling location. The use of bar codes and electronic logging can be considered. Whether paper based or electronic systems are used, the objective should be to maintain the traceability of the samples taken.

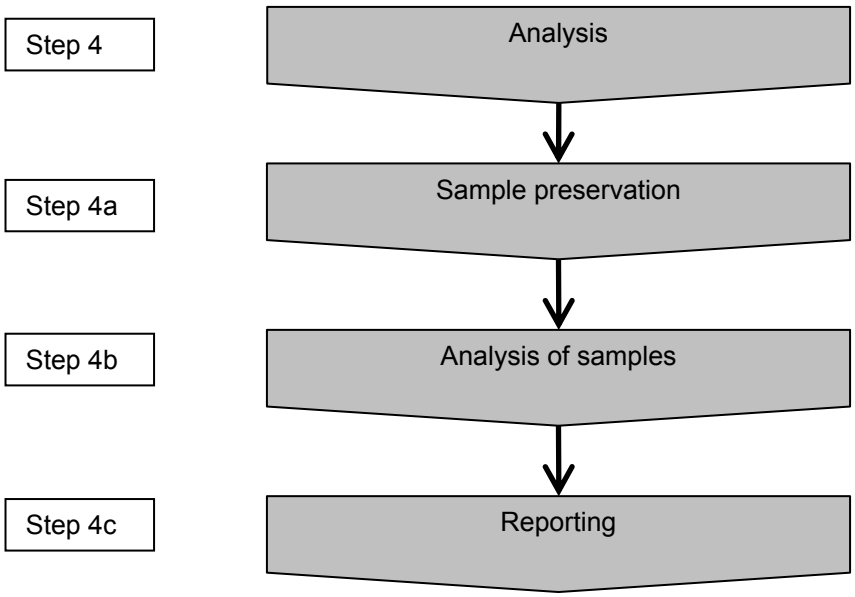
After the samples have been taken the samples should be protected from any environmental contamination. It is not necessary to cool the samples down to ±4°C during transportation [14]. Samples should be crated for ease of transportation and safety and normally delivered to the laboratory for analysis within 24 hours.

Pipe-work assessment

It is recommended that the materials and dimensions of the pipe-work, that serves the consumer's tap that has been sampled, should be assessed by visual inspection and noted. This will assist in the interpretation of the results obtained.

8. Analysis

During the phase of analysis the following actions should be carried out:



Sample preservation

Upon arrival in the laboratory the samples should immediately be preserved by adding nitric acid to achieve a pH less than 2. Generally this can be achieved by adding 0.5 ml concentrated nitric acid ($\rho(HNO_3)$ = 1,4 g/ml) per each 100 ml of sample. It is not necessary to cool the samples down to ±4°C during storage before analysis [14].

Analysis

Samples should be analysed for their total lead content. The method of analysis should have a limit of detection of 1 µg/l. Besides analysing internal control samples it is recommended to analyse a certified reference material containing concentrations near the limit of detection and/or at the limit/guideline value of 10 µg/l.

Four ISO standards for the determination of low levels of lead in drinking water exist:

1. Inductively coupled plasma mass spectrometry (ICP-MS) [9, 10]. Samples are analysed with an inductively coupled plasma mass spectrometer. The method should be able to reach a limit of detection of 0.1-0.2 µg/l depending on the mass selected for detection.
2. Atomic absorption spectrometry using graphite furnace (GF-AAS) [11]. Samples are analysed with an atomic absorption spectrometer using a graphite furnace. In order to check whether spectral and non-spectral interferences influenced the analytical result the analysis can be repeated by adding chemical modifiers to the sample including blanks and calibration standards. The method should be able to reach a limit of detection of 1 µg/l.
3. Inductively coupled plasma atomic emission spectrometry (ICP-OES) [12]. This method has a typical limit of detection of 2-5 µg/l and may only be used if the laboratory can show that a limit of detection of 1 µg/l can be achieved.
4. Flame atomic absorption spectrometry (F-AAS) [13]. This method is not state-of-the-art. It describes 3 methods of which method C may be used if the laboratory can show that a limit of detection of 1 µg/l can be achieved. The method is based on the chelation of lead with hexamethyleneammonium-hexamethylenedithiocarbamate, extraction by a mixture of diisopropylketon and xylene and analysis by flame atomic absorption spectrometry. The range of determination is typically 2-200 µg/l.

Reporting

The test report should include:

1. reference to ISO standard or other standard used; deviations from the standard should be reported
2. identification of sample
3. date of sampling and analysis
4. information of sample pre-treatment
5. amount of preservation acid added to the sample
6. results of the analysis, i.e. samples, limit of detection etc.

9. Data evaluation

At the end of the sampling period, the results for each water supply system should be assessed on the basis of the percentage of samples that exceed the health based target for lead of 10 µg/l. Agreement of the results with the assessment of the pipe work in the corresponding property should be checked. Houses having lead pipes but their corresponding samples did not fail the target of 10 µg/l have the potential to do so if another random daytime sample is taken. Therefore these houses need to be added to the houses that fail the standard in order to have a complete picture of the potential problem. The following basis for prioritisation is recommended for each water supply system:

Percentage of houses exceeding 10 µg/l incl houses with Pb pipe but no exceedance	Priority for attention
< 2.0	low priority
2.0 to <5.0	investigate any localised clusters
5.0 to <10	system-wide measures may be required in addition to resolving any localised clusters
10 to <20	system-wide measures required
20 to <50	significant problems require attention
>50	very significant problems require urgent attention

The results from the representative water supply systems can then be extrapolated to the country as a whole, to provide an initial assessment of the extent of any problems with lead in drinking water within the Party, and the their prioritisation for attention.

10. Additional monitoring

10.1. Investigative monitoring

The design of and the materials used in the service pipe and domestic distribution system are important factors that contribute to the lead concentrations in drinking water. If lead components are present, secondary factors such as chemical and physical characteristics of the water supplied, flow regime and consumer behaviour (stagnation and consumption volume) determine the lead exposure through drinking water.

The steps for resolving the exceeding lead concentration in an individual house are to assess:

- The type of materials used in the service pipe and the domestic distribution system by inspection
- The volume of water between the point of supply and the point of compliance including a lower and higher estimate
- The source of lead by stagnation sampling

There are two options to determine from which section the lead problem arises:

1. The property has a sampling tap at the point of supply. The tap should be flushed extensively (see fully flushed sampling) followed by a 30 minute stagnation during which no water can be used in the property. After stagnation a sample is taken at the point of supply (volume dependent on local situation of service pipe) followed by a sample at the point of compliance (volume dependent on higher estimate of the volume of water between the point of supply and the point of compliance). The results will indicate from which part lead is released.
2. The property has no sampling tap at the point of supply. The tap should be flushed extensively (see fully flushed sampling) followed by a 30 minute stagnation during which no water can be used in the property. After stagnation three successive samples representing 1) the lower estimate of the volume of water between the point of supply and the point of compliance, 2) the volume calculated as the difference between the lower and higher estimate and 3) a volume representing the service pipe (volume dependent on local situation of service pipe) are taken [8]. The results of the first and the third successive sample will show from which part the lead is released. When lead is released from the second successive sample the problem is caused at the border of responsibility. The best approach to clarify the problem is to install a tap at the point of supply and to sample according the first option.

In both options the 30-minute stagnation results only indicate in which part of the water supply the source of lead is located. The lead concentration in a 30-minute stagnation sample is about 50% of the lead solubility for a 10 mm lead pipe whereas it is only about 20% of the lead solubility for a 25 mm lead pipe. In case the piping is only partly made of lead, e.g. only fittings or lead solder, these percentages are lower due to dilution. It could happen that the random daytime sample taken for the zone compliance programme did not comply with the parametric value whereas the 30-minute stagnation sampling does not detect any lead release. This phenomenon can be caused by 1) a real stagnation time of the random daytime sample of longer than 30 minutes and 2) lead particles that were present in the random daytime sample.

In order to see whether non-compliance in an individual property persists, regular random daytime sampling according to the monitoring protocol for compliance of lead at zone level and a well pre-defined monitoring programme should be performed during at least a year in order to capture any seasonal effects.

In the case lead is released from the domestic distribution system the property owner should be notified and informed about possible remedial action to solve the lead problem.

10.2. Operational monitoring of lead at zone level

The random daytime sampling protocol is also a useful tool to apply in operational monitoring. However the frequency should be much higher than that is required for compliance monitoring and can be lower than inventory monitoring.

10.3. Compliance monitoring of lead at zone level

The pan-European study by Van den Hoven *et al*. [5] found, for zonal survey purposes, that RDT sampling gave similar results to proportional sampling, and that it had fewer logistic constraints. A more recent study [15] using computational modelling also concluded that RDT sampling was an adequate surrogate method. The ***daytime sampling protocol*** is also proposed to be included in the revised Drinking Water Directive of the European Union [2] [2]. Non-compliance for lead always needs to be investigated (see Chapter 10.1). The frequencies for compliance monitoring are given in the table below.

Volume of water distributed [1]	Number of compliance samples
m^3/day	n/year
≤ 10	[3]
> 10 − ≤ 100	[3]
> 100 − ≤ 1000	1
> 1000 – ≤ 10,000	1 + 1 for each 3300 m^3/day and part thereof of the total volume
> 10,000 − ≤ 100,000	3 + 1 for each 10,000 m^3/day and part thereof of the total volume
> 100,000	10 + 1 for each 25,000 m^3/day and part thereof of the total volume

1 Minimum frequencies for compliance monitoring should depend on the risk assessment made in the water risk management strategy and could be higher.

2 As far as possible, the number of samples should be distributed equally in time and location.

3 The frequency is to be decided by the Member State concerned.

[2] Note: Compliance monitoring is the monitoring to check that the legal obligations are fulfilled. In the EU the Member States have to comply with the Drinking Water Directive which requires representativeness of a sample for the weekly average value of lead ingested. A random daytime sample is not representative for that. This issue is proposed to be discussed in the art. 12 committee on the EU Drinking Water Directive in view of its revision

11. References

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Abstract

This report gives guidance on the assessment of lead in drinking water at national level in the framework of the work agreed by the Parties of the Protocol Water and Health. The guidance focuses on the case that nothing is known about the lead problem in water supply. The guidance proposes creating plumbosolvency maps of every water supply zone on which basis representative zones are selected for monitoring. The Random Daytime sampling protocol is the key method. On the basis of the monitoring results an estimate of the lead problem at national level can be made.

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