Monitoring strategy for lead in drinking water at consumer’s tap: field experiments in France

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Abstract: Following the outcome of a European project for developing a new protocol for the monitoring of lead in drinking water, field experiments have been carried out in five supply zones in France in order to test and develop practical tools for assessing compliance/non-compliance for lead. A number of properties in each zone were randomly selected and random daytime (RDT), 30 minutes stagnation (30MS) and fully flushed (FF) samples taken. The results confirm that, at zone level, RDT or 30MS samples taken in a sufficient number of properties give almost identical results. RDT is more practical and acceptable to the consumer whereas 30MS is more reproducible and should be preferred for assessment at an individual consumer’s tap. Random selection of properties appears to be a good solution for assessing the actual situation in a zone and help in the definition of priorities and type of actions to implement. Copper and nickel have also been controlled in three zones and the monitoring strategy for lead could also be used for these parameters.

Keywords: Lead; drinking water; sampling; domestic plumbing; copper; nickel

Introduction
Following recommendations of the World Health Organization for drinking water quality, in November, 1998 the European Commission adopted a new drinking water directive (DWD) (EC 98/83) which lowered the parametric value (PV) for lead from the then current value of 50 µg/l in running water to 10 µg/l. The PV refers to water as it emerges from the consumer’s tap, assessed on the basis of “representative” monitoring and should be met 15 years after the DWD came into force (i.e. by December 2013). For an interim period of 10 years, starting in 2003, the parametric value is set at 25 µg/l.

The contamination of drinking water by lead occurs mainly through contact with materials and mainly lead pipes in domestic plumbing installations. The contamination level is influenced by a number of factors including water characteristics, plumbing design and water usage patterns (stagnation time) and may vary widely and rapidly. Consequently, the sampling protocol and the monitoring strategy are of major importance for the control of lead at a consumer’s tap. In recent years, many studies have been conducted on the factors influencing lead concentration at the tap (Leroy, 1993; Schock, 1980; Kuch and Wagner, 1983), on sampling protocols (Van den Hoven, 1987; Randon, 1996; Baron, 1997; European Commission, 1999) and on the implications of a change of the MAC (European Commission, 1995).

In 1997, a European study showed that two sampling methods (random daytime (RDT) and 30 minutes stagnation (30 MS)) are appropriate for statutory monitoring purposes.

In France, it has been estimated that nearly 40% of properties have lead service pipes and also that about 40% have lead pipes in domestic plumbing installations. The implementation of the new directive will necessitate remedial actions (central water treatment, replacement of lead pipes and consumer information). In 1998, on behalf of health authorities, a working group was formed by Association Générale des Hygiénistes et Techniciens Municipaux (AGHTM) in order to study and develop practical tools for the control and monitoring of lead. This work was based on the results of the European study (European...
Commission, 1999) and of previous work carried out in France by the AGHTM (Baron, 1987; Randon, 1996). The objective was to provide complementary information to help in the transposition of the European DWD into French regulation with regard to practical aspects and performances of sampling protocols and monitoring strategies at the level of supply zones or of individual consumers.

Methods

Test areas

Experiments for the assessment of sampling strategies and sampling protocols were carried out in five supply areas in France. Each supply area was a geographical unit (a city or a grouping within a city or of villages in a region) supplied by a uniform water quality. The main characteristics of the areas are given in Table 1.

Areas A1 and A2 were two distribution units of a city supplied with water from different origins (A1 with ground water and A2 with treated surface water) but with almost identical characteristics.

D1 and D2 were single distribution units which were supplied alternatively (depending on resource availability) with a soft water (D1) or with a medium mineralized water (D2).

B and C were groups of small distribution units (40 in total) in the same region. B corresponded to distribution units supplied with soft aggressive waters and C corresponded to distribution units supplied with neutralized soft waters.

Selection of sampling points

A random selection of at least 60 addresses was made in each area (A1 + A2, B + C and E). For area D, only 30 points were selected each of which were sampled twice, a first time when the area was supplied with soft water (D1) and for a second time when it was being supplied with the medium mineralized water (D2). More points were selected in area B + C and the points split into the two categories (B = aggressive waters and C = neutralized soft waters).

Addresses were selected at random from lists of inhabitants and the selected “candidates” informed that a sampler would visit them over a given period to take water samples. Only for area A were fixed appointments (day and time) made.

For each point, information on the property (date of construction, plumbing and service pipe material and number and age of inhabitants) were collected to help in the interpretation of results and for further assessment of the representativity of the selected points in the area.

Sampling protocols and analysis

Three samples were taken in each property at kitchen cold water taps using the protocols described in the European study on lead monitoring:

Table 1 Main characteristics of test areas

<table>
<thead>
<tr>
<th>Area</th>
<th>Inhabitants</th>
<th>pH</th>
<th>Conductivity (µS/cm)</th>
<th>Hardness mg/l CaCO₃</th>
<th>Alkalinity mg/l CaCO₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>~500,000</td>
<td>7.6</td>
<td>480</td>
<td>280</td>
<td>230</td>
</tr>
<tr>
<td>A2</td>
<td>~130,000</td>
<td>7.6</td>
<td>480</td>
<td>250</td>
<td>190</td>
</tr>
<tr>
<td>B</td>
<td>5.5 - 7.5</td>
<td>50 - 200</td>
<td>2 - 11</td>
<td>100 - 160</td>
<td>20 - 60</td>
</tr>
<tr>
<td>C</td>
<td>7.6</td>
<td>180</td>
<td>42</td>
<td>280</td>
<td>220</td>
</tr>
<tr>
<td>D1</td>
<td>~11,000</td>
<td>7.7</td>
<td>350</td>
<td>168</td>
<td>165</td>
</tr>
<tr>
<td>D2</td>
<td>~11,000</td>
<td>7.7</td>
<td>630</td>
<td>280</td>
<td>220</td>
</tr>
<tr>
<td>E</td>
<td>~21,000</td>
<td>7.7</td>
<td>350</td>
<td>168</td>
<td>165</td>
</tr>
</tbody>
</table>
1. **RDT.** A single 1 l sample is taken without flushing any water from the tap beforehand.

2. **Fully flushed sample (FF).** A sample is taken after prolonged flushing (at least 3 pipe volumes from meter to the tap) or 3 minutes.

3. **30 MS.** After prolonged flushing (FF), water is allowed to stand in the pipework for 30 minutes after which a 2 l sample is taken without flushing the tap beforehand.

**Analysis.** All analyses were performed by local laboratories in each area.

**Lead** concentrations were determined in all RDT and 30 MS samples for all areas. FF samples were not always analysed (when RDT and 30MS were below 10 \( \mu g/l \)) but were always taken. **Copper and Nickel** concentrations were determined in the three samples from areas A, B and C. **pH and temperature** were measured after flushing at all sampling points. **Conductivity and alkalinity** were measured when necessary (areas B, C and D) in order to check the water quality.

**Results**

**Characteristics of selected properties**

One of the objectives of the study was to check whether a random selection of properties would give a good representation of the actual situation in the area. For this purpose, information collected about the properties were compared with existing data (age of properties, type of properties (single or multiple occupancies), population, percentage with lead service pipes and geographic distribution of the selected properties in the area). However, some information, like the percentage of properties with lead plumbing, are not well known (which is another reason for using random sampling). As a first approach, the maximum expected percentage of properties with lead plumbing was estimated using dates of construction (lead was used for domestic plumbing until about 1945–1950).

Table 2 gives a summary of the information collected for each area.

Generally, the estimated and observed information were in good agreement (percentage of lead service pipes, type of properties, date of construction and geographic distribution of properties) and it can be concluded that the random selection of properties gives a satisfactory representation of the area.

As regards domestic lead plumbing, the comparison between the date of construction and the presence of lead pipes showed that, for some areas (D and E), most of the properties built before 1949 did not actually have lead pipes. For area A, there was a better correlation between the date and lead plumbing (85% of properties built before 1949 had lead pipes). These differences between areas D and E and area A can be explained by the type of properties: in area D and E, most of the properties were individual houses where lead pipes had often been completely removed, whereas in area A all properties were in multiple occupancy buildings where only partial renovations had been made.

These results show that the information collected in randomly selected properties was useful and necessary in assessing the actual proportion of properties with lead plumbing and, consequently, the risk of having lead concentrations at the tap exceeding the PVs.

**Comparison of sampling protocols**

**Lead.** The results of the lead analysis for all the test areas with the different sampling protocols are summarized in Figure 1 (percentages of compliance/non-compliance for 10, 25 and 50 \( \mu g/l \)) and Table 3 (median, 3rd quartile and 90th percentile of the distribution of the results).

Figure 1 and Table 3 show that RDT or 30 MS lead to almost identical outcomes for each area. RDT generally tends to produce slightly more severe results than 30 MS (i.e. higher frequencies of non-compliance). These results confirm the conclusions of the European study (European Commission, 1999).
Figure 1 also shows that the non-compliance frequencies are quite low for areas C, D and E. This can be explained by the low percentage of properties with lead pipes in these areas (Table 2). But even in properties with lead pipes (Figure 1B), non-compliance levels remain low. This is probably for two reasons: the waters have low or medium plumbosolvency and the properties have only short lengths of lead pipes (individual houses).

Non-compliance frequencies are higher in both areas A and B but for different reasons. In area A, the water has medium plumbosolvency but more than 70% of properties have lead pipes (service pipes or internal plumbing) of sometimes long lengths (multiple occupancy buildings). In area B, waters have high plumbosolvency (soft acidic waters) but less than 30% of properties have lead pipes. In this area, lead concentrations (by RDT or 30 MS) always exceeded 10 µg/l for properties with lead pipes.

Results with FF samples (Table 3) confirm that flushing is an efficient way of reducing lead concentrations. However for areas with lead problems (A and B), more than 25% of the results exceeded 10 µg/l and more than 10% exceeded 25 µg/l.

![Figure 1 Lead concentrations in the different test areas using 30 MS or RDT sampling protocols](image-url)
Copper and Nickel. Most of the properties had copper pipes in their domestic plumbing. Table 4 gives a summary of the results. The parametric value for copper of 2000 µg/l (new European directive) was never exceeded in areas A or C. In area C, all results were below 100 µg/l and, in area A, less than 10% exceeded 1000 µg/l (French limit). Higher concentrations were measured in area B (soft acidic waters), exceeding 2000 µg/l for more than 10% of properties with RDT samples.

In contrast, in area C, which has similar characteristics to area B except that the water has been remineralized and neutralized, copper concentrations are very low. This comparison shows the efficiency of the treatment in reducing corrosivity toward metallic materials.

Comparison between RDT and 30 MS samples show that, for copper, at the area level, the RDT protocol produces significantly higher concentrations. The greater “severity” of RDT compared to 30 MS samples is more significant than the case for lead. This could indicate that the 30 MS protocol underestimates the average concentration (or that the RDT protocol overestimates the average). However, as no data on the actual average concentrations for copper exists, it is difficult to make a decision on this point.

Nickel. For nickel, concentrations exceeding 20 µg (parametric value of the new European Directive) were detected in only two properties in area B and no result exceeded 50 µg/l.

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**Table 3** Comparison of the statistical distribution of the results for lead with the three sampling protocols

<table>
<thead>
<tr>
<th>Area</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
<th>C</th>
<th>D1</th>
<th>D2</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (50%)</td>
<td>RDT</td>
<td>13</td>
<td>9</td>
<td>7</td>
<td>1</td>
<td>&lt;2</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>30MS</td>
<td>13</td>
<td>10</td>
<td>10</td>
<td>1</td>
<td>&lt;2</td>
<td>&lt;5</td>
</tr>
<tr>
<td></td>
<td>FF</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>&lt;2</td>
<td>-</td>
<td>&lt;5</td>
</tr>
<tr>
<td>3rd quartile (75%)</td>
<td>RDT</td>
<td>22</td>
<td>16</td>
<td>35</td>
<td>7</td>
<td>6</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>30MS</td>
<td>25</td>
<td>26</td>
<td>31</td>
<td>6</td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>FF</td>
<td>15</td>
<td>16</td>
<td>19</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>90th percentile (90%)</td>
<td>RDT</td>
<td>43</td>
<td>30</td>
<td>69</td>
<td>13</td>
<td>9</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>30MS</td>
<td>48</td>
<td>67</td>
<td>55</td>
<td>15</td>
<td>16</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>FF</td>
<td>33</td>
<td>28</td>
<td>28</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Table 4** Comparison of the statistical distribution of the results for copper with the three sampling protocols

<table>
<thead>
<tr>
<th>Area</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (50%)</td>
<td>RDT</td>
<td>230</td>
<td>196</td>
<td>490</td>
</tr>
<tr>
<td></td>
<td>30MS</td>
<td>177</td>
<td>162</td>
<td>227</td>
</tr>
<tr>
<td></td>
<td>FF</td>
<td>53</td>
<td>72</td>
<td>76</td>
</tr>
<tr>
<td>3rd quartile (75%)</td>
<td>RDT</td>
<td>404</td>
<td>635</td>
<td>1363</td>
</tr>
<tr>
<td></td>
<td>30MS</td>
<td>243</td>
<td>264</td>
<td>760</td>
</tr>
<tr>
<td></td>
<td>FF</td>
<td>209</td>
<td>115</td>
<td>114</td>
</tr>
<tr>
<td>90th percentile (90%)</td>
<td>RDT</td>
<td>719</td>
<td>953</td>
<td>2300</td>
</tr>
<tr>
<td></td>
<td>30MS</td>
<td>580</td>
<td>303</td>
<td>1393</td>
</tr>
<tr>
<td></td>
<td>FF</td>
<td>421</td>
<td>174</td>
<td>278</td>
</tr>
</tbody>
</table>

Properties with copper pipes

100% 100% 61% 84%
Discussion

Sampling protocols

The experiments carried out in France broadly confirmed the conclusions of the European study (European Commission, 1999). For compliance assessment at supply area level, RDT and 30 MS protocols lead to comparable results. RDT is slightly more severe but, above all, it is more practical and acceptable to the consumer. However, at an individual level (one consumer tap), the European study showed that RDT is not sufficiently reproducible for the assessment of the average concentration based on a single sample. The 30 MS (2 l) protocol is more reproducible and representative (for lead) and is to be preferred in this situation. With the 30 MS protocol, sampling conditions can be fully controlled by the sampler (total time needed is 45 minutes to 1 hour in the property) and acceptable to the consumer when they are fully informed. A longer stagnation time would be less practical and acceptable. However, in some cases, a single 30 MS sample could be insufficient (e.g. in determining the individual contributions of service pipe and domestic plumbing to the total lead figure) and a more extended appraisal may be necessary (e.g. series of 30 MS sampling, FF, detailed examination of the water usage patterns, etc.).

As regards copper, at an area level, the RDT protocol appears to be more severe than 30 MS. As no comparisons with results obtained by the reference protocol (flow proportional sampling, representative of mean concentration) have been made, it is not possible to conclude which is the most “representative” protocol. However the RDT approach would provide a better “margin of safety”. Experiments in three areas in France show that the non-conformity level ([Cu] >2 mg/l) is very low and linked mainly to water corrosivity (soft acidic waters).

FF sampling is not representative of the average concentration; it gives an indication on the minimum lead (or copper) concentration at the tap. This result is useful mainly for consumer information and when a recommendation to flush the tap before using water for drinking or foodstuff preparation is contemplated where the concentrations are high in either RDT or 30 MS samples. A high concentration (e.g. >20 µg/l) in FF samples indicates a need for confirmation sampling and/or implementation of remedial action and providing advice to the consumer.

Monitoring strategy

Field experiments have shown that the random selection of sampling points in a supply area is a practical and efficient way of assessing the compliance/non-compliance level (using RDT or 30MS sampling protocols). When the information regarding domestic plumbing and/or service pipe materials is not available or is unreliable, which is often the case, random sampling in a sufficient number of properties is probably the best way of obtaining an accurate initial assessment. Comparison of the results from such assessments can allow the prioritization of areas for action and, in each case, the identification of the most appropriate remedial solution (replacement of lead pipes, central water treatment, recommendation to the consumer to replace domestic lead plumbing, to flush the tap before use, etc.).

Two specific aspects of the assessment procedure also need to be considered: the definition of the “supply” area and the minimum number of sampling points. The supply area should be homogeneous in terms of water corrosivity to lead/copper. In France, many distribution systems (i.e. single water supply) are too small (<500 inhabitants) to allow the selection of a sufficient number of properties for an assessment, for practicality and cost reasons. In such cases the best solution is to group several distribution systems in a geographic area (as was done in the current work for areas B and C) using criteria based mainly on water characteristics.
As was concluded in the European study, a sufficient number of samples need to be taken in order to provide statistically valid information on the lead concentrations within a supply zone. Twenty properties is a reasonable minimum number which should be sampled but more (up to 60) can be necessary if the frequency of non-conformity ([Pb] > 10 µg/l) is low (<5 – 10%). If copper and nickel also have to be controlled, a minimum of 60 properties in the supply zone can often be necessary for an accurate assessment covering all three parameters. This can be done only if the supply zone is of sufficient size and reinforces the need for grouping small distribution systems in order to reach a sufficient minimum size (number of properties/inhabitants) for the zone.

Conclusions
Field experiments carried out in five supply zones in France have produced more background information on sampling protocols and monitoring strategies for lead with respect to practicality, representativity and accuracy of the assessment. Some guidance as to a monitoring strategy to meet the requirements of the new European DWD can be given (e.g. initial or periodic assessments). A random selection of properties and RDT sampling give good results in term of representativity for a given zone and practicality and can also be used to control copper and nickel. A sufficient number (20 – 60) of properties need to be sampled for a valid statistical assessment of the conformity/non-conformity level in a given zone. For that purpose, the grouping of different distribution systems, with similar water characteristics, to produce “supply zones” large enough to select a sufficient number of sampling points at an acceptable cost is proposed.

The outcome of such assessments allows the prioritization of areas for action and, in each case, the identification of the most appropriate remedial solution (replacement of lead pipes, central water treatment, recommendation to the consumer to replace domestic lead plumbing, to flush the tap before use, etc.).

Periodic repetition of the assessment would not be necessary for zones where no problems are detected or as long as no remedial action has been taken in zones where problems have been detected.

At the individual (consumer’s tap) level, the RDT protocol is not sufficiently reproducible to produce a reliable result with a single sample and the 30MS protocol is to be preferred if the objective is to inform the consumer about the lead concentration at their own tap. FF samples may also be useful for providing advice to the consumer.

Acknowledgement
The experiments described in this paper were designed and carried-out by a working group involving health authorities (Direction Générale de la Santé, Directions Départementales de l’Action Sanitaire de Sociale de la Gironde, de Meurthe et Moselle, de Paris et du Rhône), water suppliers (Vivendi-Générale des Eaux and Lyonnaise des Eaux) and laboratories (Centre de Recherche et de Contrôle des Eaux de Paris and Laboratoire d’Hygiène et de Recherche en Santé Publique de Nancy). Special thanks to Roger Oliphant (WRc) for assistance with the English used in this paper.

References


