# Childhood lead exposure in the home. Plomb-Habitat (Home-Lead) project (2008-2014): principal results, impacts and perspectives

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# Childhood lead exposure in the home

# Plomb-Habitat (Home-Lead) project (2008-2014): principal results, impacts and perspectives

Philippe Glorennec [1,2]

Jean-Paul Lucas [3]

Anne Etchevers [2]

Youssef Oulhote [1,2]

Corinne Mandin [3,2]

Joël Poupon [4]

Yann Le Strat [5]

Philippe Bretin [5]

Francis Douay [6]

Barbara Le Bot [1,2]

Alain Le Tertre [5].

[1] Ecole des Hautes Etudes en Santé Publique (EHESP)
Sorbonne Paris Cité
Avenue du Professeur Léon Bernard
35043 Rennes Cedex
France
[2] Irset (Institut de Recherche sur la Santé, l'Environnement et le Travail)
INSERM UMR 1085
Rennes
France
[3] Université Paris-Est
Centre Scientifique et Technique du Bâtiment (CSTB)
Champs/Marne
France
[4] Hôpital Lariboisière (AP-HP)

Laboratoire de Toxicologie Biologique
2 rue A. Paré
75010 Paris
France
[5] Institut de Veille Sanitaire (InVS)
12, rue du Val d'Osne
94410 Saint Maurice
France
[6] ISA Lille,
Laboratoire Génie Civil et géoEnvironnement (LGCgE)
48, boulevard Vauban
59046 Lille Cedex
France

## Résumé

Les niveaux d'exposition au plomb ont beaucoup baissé mais demeurent une préoccupation de santé publique du fait d'une grande prévalence de l'exposition et d'effets à faibles doses, sans seuil connu. Le projet Plomb-Habitat avait pour objectif de décrire les sources de plomb dans l'habitat, leur association avec la plombémie, et de tester des techniques de mesure et repérage des sources. Il reposait sur un sous échantillon de l'enquête de prévalence du saturnisme infantile *Saturn'Inf.* Pour la première fois en France, des mesurages environnementaux menés au sein de 484 foyers, représentatifs des 3,6 millions de logements abritant au moins un enfant âgé de six mois à six ans, ont permis de décrire la contamination en plomb dans l'eau du robinet, les poussières déposées au sol, les peintures, les aires de jeux extérieurs, les parties commumes et les plats et cosmétiques traditionnels. Le projet Plomb-Habitat a également permis d'identifier les déterminants environnementaux des plombémies, d'étudier dans quelle mesure la détermination des ratios isotopiques du plomb dans les compartiments environnementaux et le sang permet d'identifier les sources d'exposition, de comparer les informations apportées par les analyses des fractions totales et acido-solubles. L'élaboration d'un modèle de prédiction des plombémies a conduit à la proposition de valeurs limites en plomb dans l'eau de boisson, les poussières déposées et le sol extérieur. Le corpus de données et de résultats ainsi constitué dans le cadre de Plomb-Habitat est aujourd'hui utilisable pour fonder les décisions publiques en vue de la poursuite des efforts de réduction des expositions au plomb.

Mots clés : plomb ; saturnisme ; eau ; poussière ; peinture ; sol.

## Abstract

Exposure levels to environmental lead have dropped significantly over the past years in France. Nevertheless it remains a public health concern due to the high exposure prevalence and the absence of a known threshold for effects. The objectives of the “Plomb-Habitat” (Home-Lead) project were to identify the sources of lead in French dwellings, their association with blood lead levels, and to test measurement techniques, as well as methods for sources’ identification. For the first time in France, environmental measurements conducted in 484 households, representative of the 3.6 million dwellings with at least one child from six months to six years of age, have made it possible to describe the lead contamination in tap water, settled dust, paints, outdoor playgrounds, common areas and vernacular dishes and medicines. Along with the “Saturn’Inf” survey on prevalence of children lead poisoning, “Plomb-Habitat” has also contributed to: i) identify the environmental determinants of blood lead levels, ii) to study how the determination of isotopic ratios of lead in environmental compartments and blood may help to identify the exposure sources, and finally iii) to compare the information provided by the analysis of total and leachable fractions of lead. The development of a model to predict blood lead levels may help in the setting of guidelines values for lead in drinking water, settled dust and outdoor soil. This corpus of data and results is now used to inform public decisions for on-going efforts to reduce children’s lead exposure.

Key words: lead poisoning; water; dust; paint; soil.

Childhood exposure to lead has decreased significantly in recent decades, particularly in France (1). It nevertheless remains a public health concern because of the persistence of sources, in particular in housing (2), and the neurotoxic effects, in particular with no known threshold (3). Because of the higher frequency of low level lead exposure and the fact that no threshold has been identified for its health effects, the lowest exposures account for most of the health and economic impacts of lead exposure (4). Furthermore, given the decline in all exposures, the French High Council of Public Health is planning (5) to lower the intervention threshold requiring identification of lead sources from the current value of 100 µg/L (defining childhood lead poisoning) to the 98th percentile of the childhood blood lead level distribution, or approximately 50 µg/L in 2008-2009.

Clearly, it is important to identify lead exposure sources and their impacts on the current total exposure, to update the scientific knowledge, but especially to continue to reduce exposures and effectively identify the highest exposure levels. Given the lower exposure levels, it will be more difficult to identify sources during environmental surveys on childhood lead poisoning cases. The major lead poisoning cases diagnosed in the 1990s could often be traced to a single, easily identifiable source presenting high lead concentrations, whereas today, exposure levels are more complex. Consequently, more sophisticated identification tools such as isotopic ratios (6) may prove useful. Additionally, if the exposure reduction policy is based on compliance with environmental lead concentration standards, it is important to know the quantitative relationship between source concentrations and blood lead levels. However, the available empirical relationships involve higher exposures than those found today and measure total lead in dust (7), whereas in France the prescribed method measures acid-leachable lead, which is considered a better reflection of lead dissolved by gastric fluids and therefore the bioaccessible fraction of lead.

In this context, the "Saturn'Inf" childhood lead exposure survey conducted in 2008-2009 by the Institut de Veille Sanitaire [French Institute for Public Health Surveillance] provided an opportunity to go beyond the initial objectives of the survey, which aimed to describe the childhood blood lead level distribution, verify the reduction of the prevalence of lead poisoning as required by the 2004 French Public Health Act and study the determinants of blood lead levels collected by questionnaire. The "Plomb-Habitat" (Home-Lead) project joined "Saturn'Inf" with the following objectives:

- ✓ improve knowledge on the determinants of blood lead levels;
- ✓ identify sources and environmental compartments responsible for overexposure;
- ✓ compare total lead and acid-leachable lead analysis in terms of their explanatory and/or

predictive value for blood lead levels;

- ✓ establish an empirical model to predict blood lead levels based on lead concentrations in the home environment;
- ✓ provide an initial overview of the presence of lead in the French housing stock where children are present;
- ✓ identify the determinants of lead dust contamination;
- ✓ estimate the proportion of cases of overexposure for which isotopic ratio analysis of lead in the blood and the environment can help identify the source.

This article summarizes the different project components, which have already been subject to an external peer review of articles in the international scientific literature, which the reader may refer to for additional information.

## Material and methods

A **scientific consortium** led by the CSTB was formed for the project:

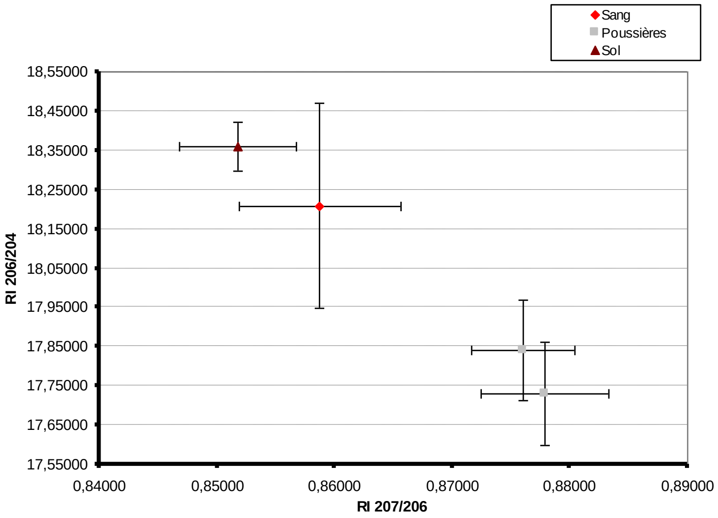
- Centre Scientifique et Technique du Bâtiment [French Scientific and Technical Building Centre] (CSTB): coordination of household surveys, management of the database, description of the contamination and the determinants in the homes;
- EHESP School of Public Health – Research Institute on Health, Environment and Labour (IRSET, Inserm UMR 1085): Development of analytical methods and analysis of environmental samples (Leres laboratory), interpretation of isotopic analyses, analysis of the determinants of blood lead levels;
- Institut de Veille Sanitaire: coordination with Saturn'Inf, analysis of the determinants of blood lead levels;
- Toxicology Laboratory of the Hospital Lariboisière (AP-HP): analysis of lead isotopes in the blood;
- ISA Lille: preparation of soil samples.

For the record, the main purpose of the **Saturn'Inf** (1) survey was to determine the blood lead levels of children aged 6 months to 6 years old living in metropolitan France, Guadeloupe, Martinique and Réunion. The 3831 children included were recruited from September 2008 to April 2009 in 143 hospitals. The study used a two-stage sample design. First, hospitals were selected randomly with intentional over-representation of hospitals in areas with a higher supposed prevalence of older homes and industrial sites, to include enough children with elevated blood lead levels in order to identify associated factors, as well as to improve the accuracy of prevalence estimates of high blood lead. Second, in these hospitals, children were included when a blood sample had already been ordered, excluding seriously ill children ("inappropriate" conditions not conducive to recruitment) and those hospitalized for lead poisoning. Because the probability of inclusion of children in each hospital in each region was known, it was possible to assign a sampling weight for each child, calculated as the inverse of the probability of inclusion. In other words, each child in Saturn'Inf represented a certain number of children from the original population. The potential selection biases were discussed and deemed minimal if any (1). The blood lead level of each child included was measured.

The target **populations** of Plomb-Habitat (Home-Lead) were children 6 months to 6 years living in mainland France and Corsica, and their primary residences. We took a random sample of 484 children and 484 homes from the 3831 children in Saturn'Inf.

**In-home surveys** of the children were conducted from October 2008 to August 2009, comprising a questionnaire and measurements. The questions focused on i) family composition, income, parental occupation; ii) the children's behaviour and activities; iii) the condition of the home, household habits, the presence of moisture, damage or pests; iv) the presence of risk factors for lead presence: hobby with risk of lead exposure, high traffic road, nearby lead-emitting industry, lead indoor water pipes, use of cosmetics or traditional cookware, and v) a description of the home (size, composition, ventilation, comfort, heating, etc.). The **environmental measurements** concerned mediums likely to contain lead and be in contact with children: paint (one per homogeneous unit of construction: measurement by non-destructive XRF and paint chip samples if surface load greater than 1 milligram of lead per square centimetre), settled dust on the floor of play areas inside the home (sampled by wipe in 5 rooms maximum per home), soil (sampled using a ring) or dust (sampled by wipe (8)) from play areas outside the home, water from the kitchen tap (water sampled after 30 minutes of stagnation), cookware and cosmetics if required. The paint measurements *in situ* were carried out according to the AFNOR 46-032 standard (9). The analysis methods of paint, soil and dust were specifically developed by Le Bot *et al*. for this project (10;11) to obtain, on the same sample, the concentrations of acid-leachable lead (regulatory reference method in France) and total lead (reference method in other countries such as the United States of America). The method involves a sequential digestion of the sample with an acid solution that simulates human digestion by its acidity, then a stronger acid attack for extracting the residual lead. The assays were performed by ICP-MS (*Inductively Coupled Plasma Mass Spectrometry*). The results of the measurements carried out during the project are summarized in Table 1. The in-home survey operators took a common training course to ensure uniform measurement and sampling protocols. All the measurement protocols were described in detail by Lucas *et al*. (12).

The **isotopic analyses** required specific assays of the different lead isotopes (Pb 204, 206, 207 and 208) both in blood and in the environmental samples. Isotopic analysis (13) identifies the likely sources of overexposure of children by comparing the relative abundance of the different isotopes in the blood and in the potential sources. It was therefore performed i) for children likely to be exposed to a specific source of exposure (blood lead levels above 25 µg/L); ii) for sources whose concentration (water, soil and dust) was (based on toxicokinetic modelling) capable of generating such blood lead levels (14). The isotopic analyses were performed by ICP-MS (13) after intercalibration of laboratories. Figure 1 shows an example of the application of Isotopic Ratios (IR) on a child included in the isotopic analysis. For example, for this child, the isotopic ratios excluded two potential sources (2 indoor dust samples), and identified a single source: outdoor soil.



| Sang | Blood |
|---|---|
| Poussières | Dust |
| Sol | Soil |
| RI 206/204 | IR 206/204 |
| RI 207/206 | IR 207/206 |

**Figure 1. Graph of Isotopic Ratios (IR) 207/206 *versus* 206/204 for one of the children included in the isotopic analysis. Plomb-Habitat (Home-Lead), France (2008-2009).**

The **quality control** of the analyses was performed using blanks and periodic analyses of certified reference materials in terms of concentration (or isotopic abundance). The quantitative assays of the environmental samples (water and dust) were conducted under COFRAC accreditation (French Accreditation Committee)().

All survey and analysis results were controlled and consolidated in an anonymous database.

The data collected were subjected to different **analytical strategies** according to the objectives. All the analyses included the sampling weights (inverse of the children's probability of inclusion, see above; an individual with a weight of 1000 in the sample represents 1,000 individuals in its population) to express the results either in terms of the population of children 6 months to 6 years living in metropolitan France, or in terms of the corresponding housing, and took into account the sample design to calculate variances from these estimates. The sampling weights were adjusted (construction period, region, etc.) by post-stratification to improve the estimates. Analyses were conducted simultaneously to determine both acid-leachable lead and total lead. Descriptive analysis (12) was performed on the contamination in the homes. Contamination of dust was modelled by a hierarchical linear model to take into account that several dust samples were collected in the same home (15). Regarding the relationship between blood lead levels and environmental risk factors, two types of models were used. First, an explanatory model (16) was developed to identify risk factors. To do this, a generalized additive model on the mean blood lead level was used, including all variables potentially associated with blood lead levels. Then a quantile regression on different quantiles (10, 25, 50, 75, 90) of blood lead levels was carried out to determine the effect of certain important variables. Second, a predictive model was used, again with a generalized additive model on the mean blood lead level. It estimated the effect of a change in environmental concentrations on blood lead levels, and therefore included as predictor variables, present together in the model, only the lead levels in the water, dust and soil; the other (non-environmental) variables were retained for the adjustment (17). Concerning the isotopic analyses, the interpretation was graphic and was based on the proximity of the ratios of the various isotopes, specifically on whether the ratios overlapped their uncertainty ranges (18).

**Table 1. Measurements taken for the Plomb-Habitat** (Home-Lead) **project, France 2008 to 2014.**

| | Type of measurement | Number | Comment |
|---|---|---|---|
| Child's blood | Lead concentration | 484 | |
| | Isotopic abundances | 1936 | |
| Tap water | Lead concentration | 472 | Pb = PbAS |
| | Isotopic abundances | 59 | |
| Floor dust in homes | Surface lead concentration | 1753 Pb; 1763 PbAS | 2 to 5 samples per home |
| | Isotopic abundances | 3684 | |
| Floor dust in common areas | Surface lead concentration | 208 Pb; 209 PbAS | 1 or 2 samples (landing outside the apartment and entrance hall) |
| | Isotopic abundances | 456 | |
| Dust on the ground of the outdoor play area | Surface lead concentration | 53 Pb; 53 PbAS | Hard surface *i.e.* a paved courtyard |
| | Isotopic abundances | 104 | |
| Soil in the outdoor play area | Lead concentration | 315 Pb; 315 PbAS | Loose soil *i.e.* a lawn |
| | Isotopic abundances | 644 | |
| Paint in the home | Surface concentration | 17893 | Non-destructive XRF measurement |
| Paint in common areas | Surface concentration | 1727 | Non-destructive XRF measurement |
| Paint chip | Lead concentration | 46 Pb; 46 PbAS | |
| | Isotopic abundances | 360 | |
| Cookware | Lead concentration | 14 | Pb = PbAS |

|  |  |  |  |
|---|---|---|---|
|  | Isotopic abundances | 112 |  |
| Cosmetics | Lead concentration | 16 Pb; 16 PbAS |  |
|  | Isotopic abundances | 116 |  |

**Legend.** Pb: Total lead; PbAS: Acid-leachable lead.

## Results and discussion

The **environmental lead concentrations** in tap water, and acid-leachable lead in indoor settled dust and outdoor dust (in the case of hard surfaces) and soil are shown in Table 2.

**Table 2. Lead concentrations in tap water, indoor settled dust and outdoor dust (in the case of hard surfaces) and soil. Homes of children 6 months to 6 years, France, 2008-2009. According to Lucas 2012 (12).**

|  | Tap water (µg Pb/L) | Indoor dust* (µg Pb/m²) |  | Outdoor dust (µg Pb/m²) |  | Outdoor soil (µg Pb/g soil) |  |
|---|---|---|---|---|---|---|---|
|  |  | acid-leachable | total | acid-leachable | total | acid-leachable | total |
| N (sample) | 472 | 471 (homes) | 471 (homes) | 53 | 53 | 315 | 315 |
| N (population) | 3461328 | 3449152 | 3453789 | 325646 | 325646 | 2518808 | 2518808 |
| P5 | <1 | 1 | <2 | 8 | 9 | 5 | 10 |
| P25 | <1 | 3 | 4 | 12 | 17 | 10 | 17 |
| P50 | <1 | 7 | 9 | 21 | 32 | 17 | 27 |
| P75 | 1.1 | 14 | 17 | 94 | 99 | 42 | 60 |
| P95 | 5.4 | 41 | 63 | 352 | 393 | 243 | 254 |
| Arithmetic mean | 1.8 | 14 | 19 | 79 | 96 | 58 | 74 |
| Geometric mean | <1 | 7 | 9 | 37 | 44 | 22 | 34 |

*arithmetic mean of the rooms surveyed (5 maximum)

In 2008-2009, 60% of children drank tap water. 58% (CI95 = 50-66) of French homes had lead concentration in water lower than the quantification limit of 1 µg/L. Approximately 2.9% (CI95 = 1.2 to 4.5) of children lived in a home with a lead concentration in water > 10 µg/L. The acid-leachable lead concentration, expressed as a geometric mean (GM), was 6.8 µg/m² in the dust on the floor inside the homes; the correlation between two samples from the same home was about 0.6 (12). Approximately 4.8% (2 to 7.6) of children lived in a home where the lead concentration exceeded 70 µg/m² (total lead) and 15.9% (10.2 to 21.6) in a home where the concentration exceeded 25 µg/m². According to the French High Council of Public Health (HCSP), if these values are exceeded, the children living in the homes in question must be screened, and information must be provided on how to reduce exposures, respectively (5). The acid-leachable lead concentration (GM) was 37 µg/m² in the dust of outdoor play areas outside the homes. The acid-leachable lead concentration (GM) was 22 µg/g in the soil of outdoor play areas outside the homes. Approximately 2.1% (0.5 to 3.6)% of children (corresponding to 2.1% (0.5 to 3.7) of homes) had lead concentration in the outdoor play area exceeding 300 µg/g (total lead) and 15% (8 to 21.9) (corresponding to 13.7% (7.5 to 19.9) of homes) had a concentration exceeding 100 µg/g. These values correspond respectively to those recommended by the HCSP to screen for blood lead levels higher than 50 µg/L and assess the health risks specific to the site. Note that the simultaneous measurement of total lead and acid-leachable lead showed that the median of the distribution of the lead ratio "acid-leachable/total lead" was 0.83 for indoor dust and 0.69 for outdoor soils.

Approximately 25% (CI95 = 19-30) of homes contained **paints containing lead** (*i.e.* at least one homogeneous unit area of the building had a lead concentration > = 1 mg/cm²); most of these paints were accessible to the children (XRF measurements were preferably carried out less than one metre from the floor) and 5% (CI95 = 2-7) were also damaged or peeling (19). Fifty percent of homes built before 1949 contain lead-based paint (paint on non-metallic surfaces to target white lead); the percentage is 38% if the threshold is set at 2 mg/cm² rather than 1 mg/cm². For homes built between 1949 and 1974, the proportion of lead-based paint is roughly 22% and roughly 13% for thresholds of 1 mg/cm² and 2 mg/cm², respectively. The number of homogeneous surfaces containing lead paint per home also decreased after 1949. The presence of lead paint is below 2% for homes built between 1975 and 1993 and is almost zero for homes built after 1993 (both for the 1 mg/cm² and the 2 mg/cm² thresholds). The indoor dust lead concentration is mainly associated with the lead content in dust on landings for apartments. It does not appear that dust on landings is particularly contaminated by paint in the common areas. The lead levels in indoor dust are mainly due to outdoor soil being brought in, possibly via shoes, clothing and pets. Damaged or peeling lead paint is rare in the national housing stock and is only a marginal source of indoor dust contamination (20).

The **associations with blood lead levels** are summarized in Table 3. Lead paint remains associated with mean blood lead levels in children as well as dust in the home and common areas, dust and soil of outdoor play areas, passive smoking, and the use of traditional cookware and cosmetics. Associations are positive but not always significant at the 5% threshold. The association between use of traditional cookware and cosmetics and blood lead levels is demonstrated for the first time in a national population-based study. Dust and water in the home among tap water drinkers are most strongly associated with the mean blood lead levels (see Table 3) but also with the highest 10% of blood lead levels (16). Note that for these highest 10% of blood lead levels, the association between blood lead levels and water is higher among tap water drinkers but not zero in bottled water drinkers, which suggests exposure through the water used in food preparation (16). For the record, dietary exposures other than water were not studied in this project. Concentrations in dust were positively correlated with all the quantiles of the blood lead level distribution, starting at the lowest levels (quantification limit: 1 µg/m²). Concentrations in water above 5 µg/L were associated with a rise in the mean and in the 75th and 90th quantiles of blood lead levels (16).

**Table 3. Associations of sources and lead vectors with the geometric mean of blood lead levels in children. France, 2008-2009. (according to** (16)**)**

| Type of exposure | Change in source | Change in blood lead levels in % (95% CI) |
|---|---|---|
| Indoor dust in the home | From 4 to 72 µg/m² (P25 to P99) | 34 (3; 74) |
| Dust in common areas | From 0 to 562 µg/m² (P25 to P99) – Note: 0 when no common areas | 21 (-13; 70) |
| Tap water for tap water drinkers | From 0.4 to 14 µg/L (P25 to P99) | 36 (2; 82) |
| Tap water for bottled water drinkers | From 0.4 to 21 µg/L (P25 to P99) | -11 (-38; 28) |
| Soil in the outdoor play area | From 0 to 407 µg/g (P25 to P99) | 16 (-9; 42) |
| Soil (hard surface) in the outdoor play area | From 0 to 187 µg/m² (P25 to P99) | 33 (8; 58) |
| Paint (sum of the XRF measurements divided by the surface area of the room) | From 0 to 3.3 (su) (P25 to P99) | 13 (-15; 45) |
| Passive smoking | < 1 h/d<br>1-2 h/d<br>2-5 h/d<br>> 5 h/d | 7 (-19; 43)<br>18 (-12; 58)<br>10 (-32; 79)<br>13 (-23; 65) |
| Uses of traditional ceramic cookware | Yes vs. no | 56 (4; 132) |
| Use of traditional cosmetics | Yes vs. no | 43 (-4; 113) |
| Parent occupationally exposed to lead | Yes vs. no | -1 (-14; 14) |

Thus water and dust are major factors underlying blood lead levels. For practical purposes, the theoretical efficacy of limiting concentrations in water, dust and outdoor soil was estimated by the model including only these variables as predictors of blood lead levels in the children. We observed (17) for all mediums an increasing monotonic relationship (for water above the quantification limit of 1 µg/L) between the lead concentration in the mediums and the mean blood lead level. For dust, the slope is stronger for lower values, while for water, it increases with the concentration. For dust, an increase from 0 to 100 µg/m² generates an increase in the mean blood lead level of 50 to 125%, or a blood lead level between about 20 and 30 µg/L. For loose soil, an increase of 100 µg/g generates an increase in the mean blood lead level of 10 to 75%, or a blood lead level between about 15 and 25 µg/L. For tap water, an increase of 50 µg/L generates an increase in the mean blood lead level of 0 to 150%, or a blood lead level between about 15 and nearly 40 µg/L. It is important to note that these relationships are established for the mean blood lead level of the population of children living in France and cannot be used to evaluate the individual consequences of a change in the contamination of a medium.

Note that the models developed using total lead and acid-leachable lead gave very similar results. For the predictive model, the predictions using the two measurement methods were highly correlated (Spearman r = 0.98).

To simulate the **impact of concentration limits (not to be exceeded) in the mediums studied** this model was used to predict blood lead levels that would result from the application of regulatory values limiting concentrations in these mediums. Values exceeding the concentration limits were replaced by this concentration limit. We thus simulate an intervention aiming to limit exposures to potential regulatory values. The results are presented by Oulhote *et al*. (17), for different concentration limits (total lead). For example, setting a concentration limit (guideline value for indoor dust) of 200 µg/m² in France for indoor dust would reduce the geometric mean blood lead levels of the 10,639 children exposed above this value by 3.8 µg/L, while the mean blood lead level of all children would remain unchanged. Setting this level to 10 µg/m² would reduce the geometric mean blood lead levels of 1,479,633 children by 1.4 µg/L. At the extreme, setting this level to 1 µg/m$^2$ would reduce the geometric mean blood lead levels of the 4,198,345 children concerned by 2.9 µg/L, while the geometric mean of all blood lead levels would fall to 10.9 µg/L. These results show that unless they are very low, concentration limits reduce exposure for only a small percentage of the population of children. They must therefore be accompanied by measures to reduce the exposure of the most children possible, given the absence of a threshold between dust and blood lead levels, and between blood lead levels and health effects.

Regarding the **isotopic analyses**, the differences in composition between the sources (relative to measurement uncertainty) were sufficient to be used for 57% of the children with blood lead levels > 25 µg/L and at least one potential source of exposure. For these children, the isotopic ratios suggested a single source in 32% of cases, and eliminated at least one potential source in 30% of cases. Accordingly, if environmental surveys were conducted for children with blood lead levels above 25 µg/L, isotopic analysis would have an added value for 30% of them. This added value increases with blood lead levels (statistically insignificant). Isotopic analysis confirmed that overexposure is not due to a single type of source; suspected sources identified may be tap water, soil, dust or paint. By analysing the compatibility of the isotopic ratios, we were able to investigate the source of lead in the dust (21). We observed that 81% (72-90%) of the homes have homogeneous dust (criterion: at least 90% of the dust from the same home had compatible 207/206 and 206/204 IRs). Outdoor soil is the main source of lead in the dust with the highest lead concentration in 65% (48-81%) of homes. For homes containing lead paint, paint is the main source of lead in the dust in the same room in 73% (38-100%) of homes. Dust in common areas is the source of lead in the dust (in the home) with the highest lead concentration in 87 % (70-100 %) of apartments. These results are thus consistent with those previously obtained on the concentrations, where the dust on the landing was the principal determinant of lead concentrations of dust inside the home.

## Conclusion and recommendations for prevention and identification

The Plomb-Habitat (Home-Lead) project, in association with the Saturn'Inf survey, contributed **original scientific knowledge** on residential lead exposure, with broad implications by extrapolation to all children and their homes in France. It complements the data from the national childhood lead poisoning surveillance system that collects the blood lead levels of children screened who are the most exposed. It quantitatively describes the presence of different sources of lead in the housing stock in France. Among these, water and dust have proved to be the sources most strongly associated with the mean blood lead levels as well as the highest 10% of blood lead levels. Because they have a measurable influence at low levels, it is important to reduce the concentration in these mediums. These results are consistent with the international literature, in particular North American, and provide original information at these blood lead levels. Although cases of exposure to cosmetics and traditional cookware have already been described, the extent of their contribution at the population level is new, as is the expression of the contributions of dust and water for different quantiles (levels) of blood lead levels. Several other aspects had never been addressed at such a broad population scale, such as the study of the determinants of dust lead levels or the comparison of isotopic ratios between sources and blood lead.

Beyond these scientific aspects, the project also had an operational role and helped to update the knowledge of risk factors for blood lead levels lower than those previously requiring management measures. The results of Plomb-Habitat may include the following **implications for risk reduction**. The value of reducing exposures via water should be examined, because although the vast majority of concentrations respect the limit value of 10 µg/L, the influence of water is measured below this level, even in non-tap water drinkers. Dust is an exposure medium for which there seems to be no observable threshold. Actions should aim to reduce exposure in all homes, and to avoid overly high exposures to lead in dust. The data collected here identified paint, soil and dust in common areas as contributors. They also provide quantitative relationships between dust concentrations and blood lead levels and could be used to develop a guideline value or concentration limit in dust. Plomb-Habitat also provides the prevalence of homes above a given value that may be recommended in the future. Regarding concentrations in dust, "acid-leachable" and "total" methods were found to have the same predictive capacity for blood lead levels. If the acid-leachable method is maintained, the ratios measured during the project can be used to convert the concentrations expressed in acid-leachable lead to total lead, instead of the default estimates used previously. Tableware containing lead should be used only for decorative purposes and the European limit of 4 mg/L is worth reconsidering, because the association is observable starting at the quantification limit of 1 µg/L. Similarly, the use of cosmetics containing lead (9 out of 16 samples in the study) should be avoided. If the blood lead levels requiring intervention are lowered, the intervention methods by the health services for case investigations could be updated in the light of new relationships between lead concentrations in the mediums and blood lead levels, as well as the now-quantified contribution of isotopic ratio analysis. Systematic measurements of lead in the homes indicated that lead could be present even in constructions built in the 1970s - and more rarely the 1990s, with a higher probability for homes built prior to 1949, especially for paint containing the highest concentrations. Accordingly, while the identification of at-risk housing should primarily target the oldest homes, it should not be assumed that those built after 1949 do not contain lead paint.

Regarding actions on exposure mediums, **the results of Plomb-Habitat** (Home-Lead) **should be completed** by studies of interventions and comparative studies of the effectiveness of different action strategies. The acid-leachable lead measurement method, which is relatively easy and inexpensive, should be compared to more complex and expensive methods of measuring bioaccessibility. If a study such as Plomb-Habitat were to be repeated, the experience gained could suggest some areas for improvement. Finally, in a broader context, this type of in-home survey could be combined with a system for biological measurement of exposure and other measurements (air) and questions (dietary habits) to achieve economies of scale and to obtain a more complete view of environmental and dietary exposures and be able to study the determinants.

The results of Plomb-Habitat have already been reinvested in the expertise since they have been used by the HCSP (5) and by ANSES for the Infant Total Diet Study (22). Moreover, additional potential uses have already been identified, for instance determining space-time budgets of children in France at the room level, optimizing the information collected during the Lead Risk Assessment Findings (CREP), updating the assessment of the economic costs of lead exposure reduction measures (5) and assessing residential exposures to other metals and metalloids measured simultaneously (23;24). Finally, the Plomb-Habitat in-home surveys were also the opportunity to take dust samples to measure semi-volatile organic compounds (25) under the ECOS project to evaluate the cumulative risk of these compounds (26).

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