# DETAILED MONITORING OF HUMAN EXPOSURE TO FOUR GROUPS OF CONTAMINANTS USED IN CONSUMER PRODUCTS: THE A-TEAM SAMPLING CAMPAIGN

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## Introduction

The A-TEAM (**A**dvanced **T**ools for **E**xposure **A**ssessment and Bio**m**onitoring) project is a multi-partner Marie-Curie Initial Training Network funded by the EU FP7 programme. Its aim is to enhance knowledge and substantially improve the currently used approaches to monitor external and internal human exposure to targeted chemicals, based upon a detailed study of a well-characterized human study group. The groups of organic chemicals that the A-TEAM project is focused on have found use in a variety of consumer products: perfluoroalkyl substances (PFASs), "emerging" brominated flame retardants (EBFRs), organophosphate esters (OPEs) and phthalate esters (PEs).

Perfluoroalkyl substances (PFASs) are man-made chemicals with a partially or fully fluorinated alkyl chain and diverse functional groups attached. PFASs have been used for the last 50 years in a wide range of industrial and consumer products, such as water and oil repellents for leather, paper, textiles and in inks, varnishes, waxes, lubricants, hydraulic oils and fire-fighting foam[1]. Brominated flame retardants (BFRs) are added in a broad range of commercial products such as televisions, computers, textiles, carpeting, building insulation and furniture[2]. The ban of production and use of widely used BFRs (i.e PBDEs) have led to the production of new chemicals, with similar chemical properties, as replacements ("emerging" brominated flame retardants (EBFRs)). Organophosphate esters (OPEs) are either non-halogenated, which are mostly used as plasticizers, or halogenated, which are mostly used as flame retardants in several products including textiles, rubber, polyurethane foam, antistatic agents, cotton and electronic equipment[3]. Phthalate esters (PEs) are dialkyl or alkyl/aryl esters of 1,2-benzenedicarboxylic acid, that are high-production-volume chemicals used in plastics and other common consumer products such as personal-care products, paints and pharmaceuticals.

Humans can be exposed to environmental contaminants from food, drinking water, house dust, ambient air and direct contact with consumer products. Food consumption has been suggested as a major source of exposure to PFASs, while indoor sources, such as house dust and indoor air have been increasingly related to considerable human exposure[4,5]. The main routes of human exposure to the well-known BFRs, which might be similar for EBFRs, are diet, ingestion of indoor dust and inhalation of indoor air, while the contribution of these three pathways varies substantially[Error! Bookmark not defined.,6]. Several possible routes of exposure have been suggested for OPEs, while empirical data on sources, pathways, and routes of exposure are lacking. Humans are exposed to PEs through food consumption, inhalation of air, and dermal exposure, while the main exposure route is highly dependent on the specific compounds studied[Error! Bookmark not defined.]. Despite increasing evidence of the toxic effects of several contaminants, the major human exposure pathways for many chemicals are not well characterised. Also, following the ban of some formulations, alternative chemicals have been introduced in consumer products as replacements, of which the exposure pathways and health effects are unknown.

The aim of the A-TEAM sampling campaign was to recruit a study group of 60 adults and to collect a wide variety of biological and environmental samples from the participants and their homes, using several sampling approaches. The main research objectives of the A-TEAM project are to further understand how and to what extent chemicals used in consumer products enter humans, and how we can best monitor their presence in our bodies, diet and indoor environment. To our knowledge this is one of the most comprehensive sampling campaigns conducted in the field of environmental contaminants.

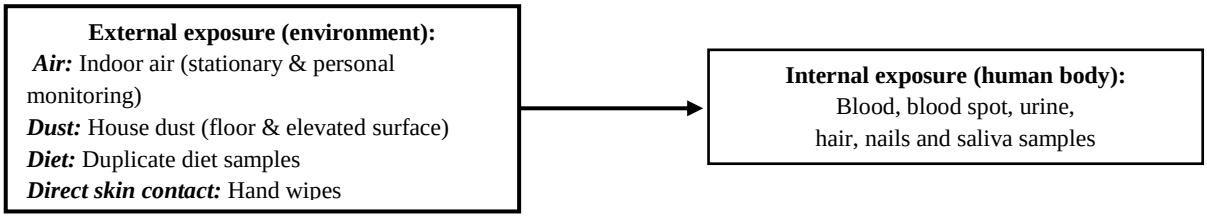
## Materials and methods

### *Underpinning rationale of A-TEAM*

We established a study group of 60 households from Oslo, Norway. As our intention was to evaluate a variety of approaches to sample external and internal exposure to consumer chemicals and their relationship, rather than

obtain estimates of such exposure representative of a given population; participants were recruited from staff of the Norwegian Institute of Public Health (NIPH). Sample collection was conducted during the winter period when the proportion of time spent indoors is at a maximum and building ventilation is at a minimum. To characterise as many exposure pathways as possible, samples relevant to both external and internal exposure of male and female adults were collected. **Figure 1** illustrates the rationale underpinning sample collection. Sampling of each individual occurred over 2 days during 2 researcher visits (1 visit per day) to the participant's house. Some samples were collected by the participants themselves, such as urine and saliva, and others by the researchers, such as dust from the living room. Additionally, detailed information about dietary habits, indoor domestic environment and other lifestyle characteristics of the participant was collected by questionnaires. The project was approved by the Regional Committees for Medical and Health Research Ethics in Norway, and all participants completed a written consent form before participating.

**Figure1. Rationale of human exposure and sample collection**




***Indoor environment***

Indoor Air: Stationary and personal air samples were collected to compare their efficacy as indicators of human exposure via inhalation. Air samples were collected using specific sampling media, which varied according to the contaminant targeted. For stationary air sampling, fixed point samplers/pumps were put up 1 m above the floor in the participant's living room to collect air for 24h. For personal air, the participant carried a backpack with the pump for 24 h. The sampler was attached to participant's shoulder in order to collect air from all the different environments where the participant might be exposed during one day.

Indoor Dust: Elevated surface and floor dust samples were collected by researchers from the participant's living room to explore which one best reflects the human exposure through dust. For settled dust, all surfaces above 1 m in the living room were vacuumed, including window, door and picture frames, shelves, furniture, and books. The dust collected by the researchers was the accumulated dust in the participant's living room for a period of 2-3 weeks. Vacuum cleaner bags were also collected from the participant's personal vacuum cleaners in order to investigate whether this dust better reflects long-term exposure, as it represents dust collected over a longer time frame than the researcher collected dust.

Hand Wipes: Hand wipe samples were collected from the participants to explore whether these samples are related to internal and/or external exposure.

***Dietary exposure***

Our target contaminants enter food through environmental contamination of the food chain, and/or via transfer from food contact materials during food processing, or storage. In the A-TEAM project we will estimate dietary exposure by: i) a duplicate diet study, where dietary replicates over 2 consecutive 24 h periods are analysed, ii) a food diary, where food consumption over the same 2 x 24 h periods is reported and the contribution of specific foods to overall exposure can be estimated, and iii) a food frequency questionnaire, where long-term habitual diet is assessed. Conducting such thorough dietary assessment provides an opportunity to evaluate the ability of different dietary exposure assessment methods to reflect the contribution of diet to human body burdens of the target chemicals. For the duplicate diet study, participants were asked to weigh and collect duplicate portions of food and drink consumed. Solid and liquid foods were collected in separate bottles. The type, weight and other details related to the food contact material of the consumed foods and drinks were reported in the food diary. After collection, the solid food samples were homogenised using a food processor. The ability of the food processor to homogenize composite food samples was tested by measuring natural conductivity after adding NaCl and processing the sample. The sample was considered sufficient homogeneous since the relative standard deviation of the conductivity is below 3%.

***Internal exposure***

Venous blood and blood spots were collected from the A-TEAM participants by trained researchers. According to the sampling plan, around 40 mL of whole blood was collected and serum separated after clotting and centrifuging. After venous blood collection, blood spots were collected from participant's fingertip on 2 blood spot cards and left to dry for approximately 3 hours. Participants were requested to collect 3 urine samples over the 2 day duration of the sampling campaign; one in the afternoon of the 1st day, one in the morning of the 2nd day and one in the afternoon of the 2nd day. As for blood spots, hair, saliva and fingernail samples were collected in order to study whether non-invasive samples can be adequately used to assess the human body burden of the targeted chemicals. The collection of hair samples was based on the COPHES protocol[7].

***A-TEAM rating form of sampling campaign***

In order to record the experience of the volunteers during their participation in the A-TEAM project, a short rating form of the sampling campaign was developed and administered. Participants were asked to complete the form anonymously and send it to the project leader.

**Results and discussion**

The A-TEAM sampling campaign started in November 2013 and ended in April 2014. The A-TEAM researchers conducted 122 home visits in 61 households of the A-TEAM study participants. Regarding household locations, 41 out of 61 (67%) were located inside Oslo municipality area (0.5-13 km away from the NIPH). The rest, 21 out of 61 (33%), were located outside Oslo municipality area (14-180 km away from the NIPH) encompassing neighbour municipalities and counties. The average visiting rate was 4 participants per week (8 visits). The home visits were scheduled according to the participant's convenience during the afternoon. The study population included 16 men (26%) and 45 women (74%).

The weights of the collected biological, food and dust samples are presented in **Table 1**. The weight of the morning urine sample was significantly higher than both afternoon urine samples (Wilcoxon signed rank test for paired samples: p-value<0.05). Approximately 40 mL of venous blood was collected and 12 mL of serum were obtained per participant on average (30% of the venous blood volume, range = 15-38%). We collected 116 blood spots cards. For two participants it was not possible to collect 2 cards due to low blood flow, and for one participant the blood sample was collected by his/her general practitioner and blood spot cards were thus not collected. Regarding the other non-invasive samples, we collected hair, nails and saliva for more than 93% of our study group (57 hair, 59 nail and 61 saliva samples). Further, the daily weight of the solid food collected as duplicate portions of foods, ranged between 0.3 and 1.8 kg, while the daily weight of liquid food collected as duplicate portions of drinks was weighing up to 4 kg. For both solid and liquid food, the mass collected by the participants on the 2nd day was less than the 1st day.

The mass of collected floor dust exceeded significantly that of the dust from elevated surfaces in the same living rooms (Wilcoxon signed rank test for paired samples: p-value<0.05). We collected 15 personal air samples for analysis of PFASs, 13 samples for EBFRs, 16 samples for OPEs and 17 samples for PEs. The average operating time of the personal pumps was 23 hours with small variations by contaminant. By comparison, the average sampling time of the stationary pumps in the participants' living rooms was 23.5 hours, with 95% of the samples capturing 20 to 24 hours sampling time. The participants collected 243 hand wipe samples.

Serum, urine, food and dust samples were further aliquoted in subsamples in order to be distributed and analysed by the collaborating research groups of the A-TEAM network. We prepared 297 aliquots of serum samples, 737 aliquots of solid food and 737 of liquid food samples, 916 aliquots of urine samples and 1084 aliquots of dust samples (both collected dust and dust from the vacuum cleaner bags).

***A-TEAM rating form of sampling campaign***

We received 38 responses to the A-TEAM rating form (62% response rate). The gender-specific response rate was similar to the participation rate in the sampling campaign. Regarding their motivation to participate, most of the participants chose all three options given (i.e "project gives valuable information for society", "want feedback for personal chemical levels", "support studies in my work place"). Participants were also asked to rate as either "very easy", "easy", "not easy-not hard", "hard", or "very hard", the 20 tasks that were performed during their participation in the A-TEAM sampling campaign. Completing the food frequency questionnaire, collecting duplicate portions of food and drinks and keeping the food diary were rated as "hard" or "very hard"

by 34%-47% of the respondents. Most of the respondents reported that completing the indoor environment and the food frequency questionnaires, as well as keeping the food diary were time consuming, while collecting duplicate portions of food and drinks was both time consuming and tiring. Surprisingly, not cutting the fingernails for at least 2 weeks before the visits of the researchers was "hard/very hard" for 42% of the respondents. Even though carrying the personal pump or having the stationary pump in the living room were not rated as "hard/very hard" by many respondents (18-26%); some reported that performing these tasks was tiring and invasive. Nevertheless, 92% of the respondents were positive about participating in a similar project in the future. Overall, based on the feedback from the participants as well as our success in collecting nearly complete sets of all samples envisaged at the outset, we consider this sampling campaign highly successful.

**Table 1. Amounts of urine, serum, food and dust collected from 61 participants during the A-TEAM sampling campaign.**

| | Mean | (SD) | Min | Max |
|---|---|---|---|---|
| **Biological samples** | | | | |
| *Gross weight of urine (g)* | | | | |
| Sample 1 | 180 | (87) | 39 | 410 |
| Sample 2 | 192 | (91) | 15 | 413 |
| Sample 3 | 166 | (81) | 26 | 388 |
| *Serum volume (mL)* | 11.7 | (1.5) | 6.0 | 15.0 |
| **Food samples** | | | | |
| *Weight of solid food (g)* | | | | |
| Sample 1 | 970 | (361) | 270 | 1841 |
| Sample 2 | 689 | (279) | 159 | 1277 |
| *Gross weight of liquid food (g)* | | | | |
| Sample 1 | 1915 | (736) | 540 | 4030 |
| Sample 2 | 1619 | (754) | 470 | 4254 |
| **Dust samples** | | | | |
| *Weight of dust collected by the researchers(mg)* | | | | |
| Elevated surface dust | 0.59 | (0.38) | 0.12 | 2.02 |
| Floor dust | 1.07 | (1.01) | 0.11 | 6.39 |
| Dust from participant's vacuum cleaner bag (g) | 65.9 | (82.4) | 1.0 | 380.0 |

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