

PLASTICS POISON THE WORKPLACE II: CHEMICAL EXPOSURES TO PLASTIC WASTE AND RECYCLING WORKERS IN KENYA AND THAILAND

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for a toxics-free future

IPEN is a network of non-governmental organizations working in more than 100 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.

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Arnika is a Czech non-governmental organization established in 2001. Its mission is to protect nature and a healthy environment for future generations both at home and abroad.

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EARTH is an independent non-governmental organization striving for social and environmental sustainability and justice in Thai society and promoting climate justice, good governance and accountability of governmental and international agencies. EARTH focuses on the impacts of hazardous substances on ecosystems, local communities, and workers' health.

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CEJAD is a registered public interest Non-Governmental Organization in Kenya working to promote sound management of chemicals and waste in order to protect the environment and human health, especially vulnerable populations.

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KEY FINDINGS

Plastics are made with thousands of chemicals, mostly petrochemicals derived from fossil fuels, many of which are known to be hazardous to our health, and many more that have little or no hazard information.

Hazardous chemicals are released throughout the life cycle of plastics, including when plastic wastes are handled during waste processing or recycling.

IPEN members EARTH in Thailand and CEJAD in Kenya coordinated with plastic recycling workers, plastic waste workers, and workers in other settings without occupational exposures to plastic waste, such as office settings or other settings, to assess their exposures to chemicals in plastics.

Participants from the three groups in each country (6 groups total) wore silicone wristbands for five days that capture environmental exposures to organic chemicals. The wristbands were analyzed at an independent lab for 73 chemicals in six chemical groups: polycyclic aromatic hydrocarbons (PAHs), phthalates, phthalate alternatives, organophosphate flame retardants (OPFRs), benzotriazole UV stabilizers, and phenols and bisphenols (eg, BPA).

The study found that:

- All participants experienced a mixture of chemical exposures to all six types of chemicals. In Thailand, each participant was exposed to at least 21 chemicals, and in Kenya at least 30 chemicals. Across the studies in both countries, 11 chemicals were found in every wristband tested. The findings are consistent with previous studies showing that we are all at risk of exposure to toxic plastic chemicals.
- Plastic waste and recycling workers were exposed to more chemicals than the other workers. Plastic recycling workers were exposed to the highest number of chemicals in Thailand and plastic waste workers to the highest number of chemicals in Kenya.
- Phthalates that are known endocrine disrupting chemicals (EDCs) were detected at the highest concentrations of all the chemicals. Participants in Kenya were generally exposed to higher levels than participants from the same groups in Thailand.
- All workers across the three groups were exposed to the phthalate DEHP, confirming them as “the everyone and everywhere chemicals.” Plastic waste workers were exposed to the highest levels. DEHP is an EDC banned in certain products in the EU, US, Australia, and China but unregulated in many countries across Africa, Asia, and Latin America.
- All workers across the three groups were exposed to phthalate alternatives, chemicals used to replace regulated phthalates but likely to have similar hazards. The study shows the dangers of toxic (so-called “regrettable”) substitution.
- Polycyclic aromatic hydrocarbons (PAHs) are cancer-causing chemicals found in plastics and generated when burning plastics and other materials. Both plastic recyclers and plastic waste workers were exposed to higher concentrations and higher numbers of PAHs than the other workers.
- Exposures to organophosphate flame retardants (OPFRs), chemicals linked to neurodevelopmental issues and endocrine disruption, were higher in recycling workers compared to the plastic waste workers and office workers in Thailand. In Kenya, all participants were exposed to a similar number of OPFRs as in the wristbands of the Thai recyclers.

Most plastic chemicals are not regulated through international agreements and would not be covered by current global Conventions. Since chemicals from plastics and plastic wastes cross national boundaries, national regulations alone cannot protect human health or the environment from their toxic hazards. Therefore, controls on hazardous chemicals should be an essential component of the Plastics Treaty.

BACKGROUND

Plastics are mixtures of various types of chemicals, most of which are produced from fossil fuels (petrochemicals). Plastic chemicals include monomers, polymers, chemical additives, and non-intentionally added substances (NIAS).

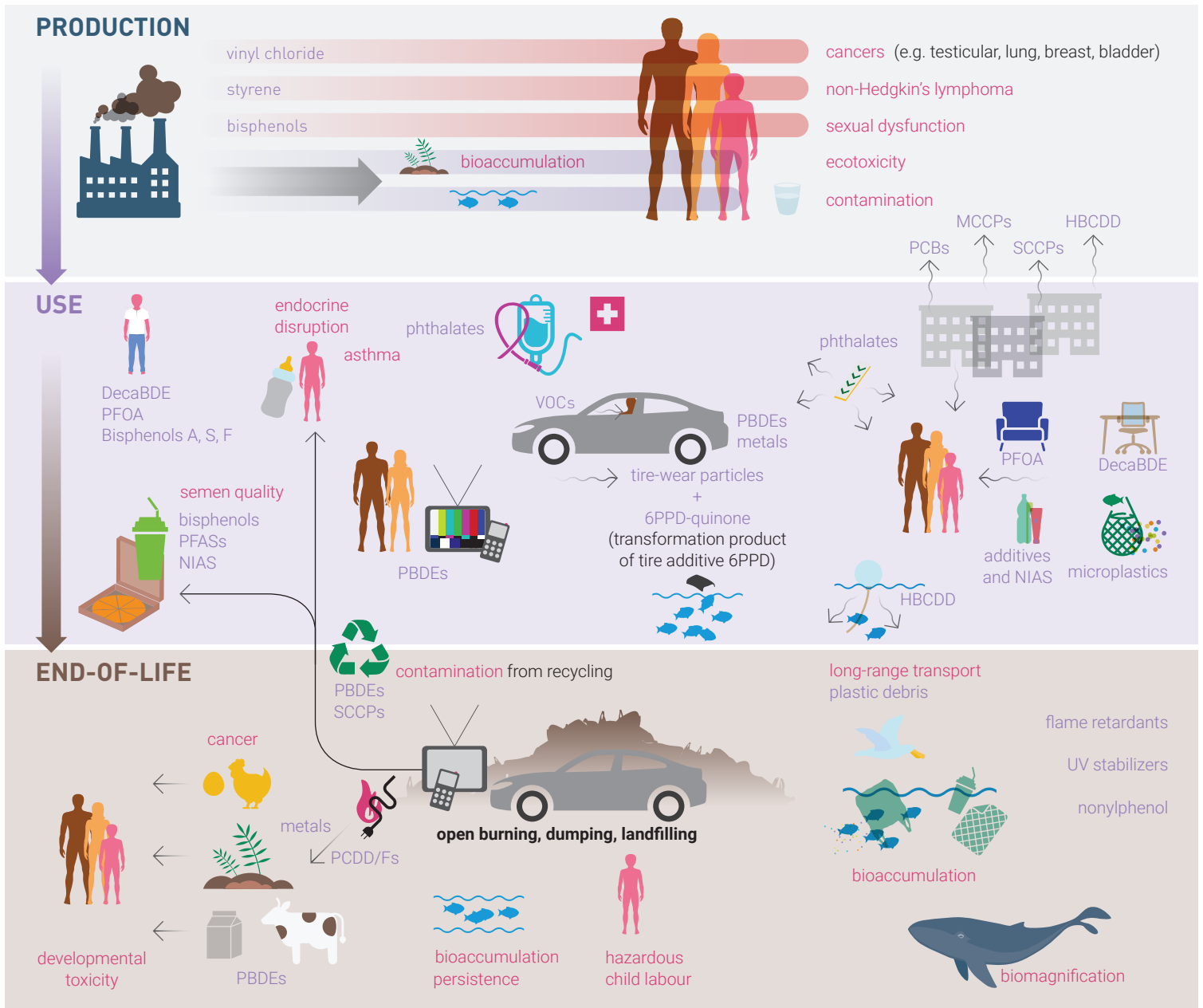
Most plastic chemicals are not regulated, and little is publicly known about the health impacts of the majority of these chemicals. Many reports and studies have provided evidence of the multitude of plastic chemicals, including highlighting the thousands of plastic chemicals of concern. For example, a recent report identified more than 16,000 chemicals potentially used or present in plastic materials and products. There is little or no information about the potential impacts on human health or the environment for over 10,000 of these chemicals. More than 4,200 plastic chemicals were categorized as of concern and the report concluded that more than 400 chemicals of concern can be present in each major plastic type, such as PVC, polyurethanes, PET, polyethylene and other types (Wagner et al., 2024). Chemicals present in plastics are generally not bound to the material but will be released during production, use, recycling, and disposal of the plastics (Hahladakis et al., 2018).

When plastics are recycled, these chemicals will be uncontrollably carried over into the new plastic material together with any new chemicals formed in the recycling process, including into consumer products made from recycled plastics. This is why highly toxic chemicals like dioxins have been found in toys and kitchenware made from recycled plastic in Kenya and elsewhere (Petrlik, 2021). Plastic materials can also be contaminated by chemicals during use and carry these chemical contaminants into the recycling process. A study of chemicals in recycled plastic pellets detected traces of more than several hundred chemicals, including pesticides, pharmaceuticals, industrial chemicals, and plastic additives (Carmona et al., 2023).

Health impacts caused by plastic chemicals include cancers, neurotoxicity, immunotoxicity, skin and respiratory conditions, and many more (Azoulay et al., 2019). Many plastic chemicals are endocrine disrupting chemicals (EDCs), which means that they can interfere with our hormones natural functioning in the body, leading to disease or even death (Gore et al., 2024). A recent study of PVC toys from Kenya identified several known EDCs present in all analyzed products, including phthalates at high concentrations (Jelínek et al., 2025).

Exposure to plastic chemicals is general, widespread, and occurs directly through many pathways including from extraction of fossil fuels, during production, use, recycling, and final disposal of plastics – in short, throughout the plastics life cycle. Exposure is also due to environmental contamination caused by plastics, for example, when plastic chemicals pollute soil, water, and air. This means that we can be exposed to plastic chemicals both from direct contact with the plastic and from air, food, water, dust, and other media that have been in contact with plastics (Gore et al., 2024). While many chemicals are excreted from the body within days or weeks of exposure, some can be stored in fat, bone, or are attached to proteins and can remain in the body for months, years, or even decades (Wagner et al., 2024). However, it is important to be aware that even though some chemicals are excreted faster from the body, that does not mean that they are safer.

Some countries have started addressing certain plastic chemicals and in January 2025, a law banning imports of plastic scrap came into force in Thailand. However, the problems related to plastic chemicals are not national but global. The plastic materials, products, and wastes that enter a country have often been traded and shipped internationally, often through complex trade routes, with no transparency, traceability, or ability for the consumer or waste worker to know what plastic chemicals they contain. Therefore, new global controls are needed to protect human health and the environment from plastic chemicals. To date, less than 1% of the chemicals used in plastics are regulated under existing international multilateral environmental agreements.



Source: United Nations Environment Programme and Secretariat of the Basel, Rotterdam and Stockholm Conventions (2023). Chemicals in plastics: a technical report. Geneva

Some groups are especially impacted by plastic chemicals. These include communities living near fossil fuel extraction and processing sites and areas of plastic production, recycling, and disposal. Workers in both the formal and informal sectors engaged in these activities are also at greater risk. The International Labour Organization has identified a wide range of health impacts to workers caused by plastic chemicals, including cancers, cardiovascular disease, and respiratory conditions, and highlighted that more research is needed to provide information on exposures and impacts of plastics to workers (ILO, 2023). A recent study conducted in Thailand showed that e-waste recycling workers have high levels of the toxic flame retardants polybrominated diphenyl ethers (PBDEs) and dechlorane plus (DP) in their bodies and in their food and surroundings. Compared to the average levels of the chemical found in samples from a group of organic farm workers and agriculturalists, who had trace levels of Dechlorane Plus in their blood, the Thai recycling workers on average had nearly 40 times higher levels of the harmful substance in their blood (Walaska, et al., 2024).

The use of silicone wristbands as passive samplers has become a common tool for assessing exposure to chemicals that people are exposed to via dermal contact or inhalation. The wristbands adsorb the same chemicals that the participant's skin comes in contact with and can therefore be used to determine the complex mixture of chemicals study participants are exposed to during a certain amount of time when the wristband is worn.

Previous studies have shown that such wristbands provide reliable information about which type of chemicals participants were exposed to from their environments. This includes both occupational exposure studies, but also studies of everyday exposures outside the workplace. While the wristbands cannot predict the exact concentration of the chemicals in the body, previous studies have demonstrated that they accurately show that the same chemicals or their breakdown products are present in the body for a wide range of chemicals such as flame retardants, pesticides, phthalates, polycyclic aromatic hydrocarbons (PAHs), and others (Dixon *et al.*, 2022; Hammel *et al.*, 2016; Hamzai *et al.*, 2022; Levasseur *et al.*, 2021; Samon *et al.*, 2022).

AIM

Workers who are engaged in collection, sorting, handling, shredding, recycling, and final disposal of plastics are believed to be more highly exposed to plastic chemicals than the general population. Therefore, the purpose of this study was to assess exposures of plastic waste workers and recyclers to plastic chemicals and to compare these exposures with others who do not face such occupational exposures.





OVERVIEW OF STUDY SET-UP AND APPROACH

The results from the study in Thailand presented below and used for comparison with the new results from Kenya were previously published in the report *Plastics Poison the Workplace: Chemical Exposures to Plastic Waste and Recycling Workers* (Brosché, S., et al. 2024).

Silicone wristbands, precleaned as described in Annex III at an accredited laboratory of the University of Chemistry and Technology, Prague (Czechia), were shipped to the NGOs the Centre for Environmental Justice and Development, (CEJAD) in Kenya, and Ecological Alert and Recovery in Thailand (EARTH). Until their use, the wristbands were contained in closed tin cans, which were stored in sealed bags.

In preparation for the study, representatives of the NGOs met with groups of potential study participants to explain the aim and procedure of the wristband study, the intended use of the data, and the voluntary nature of the study. Individuals who agreed to participate in the study were asked to sign an informed consent form, ensuring the anonymous use of their wristband data and noting that all participants had the right to withdraw from the study at any point. This approach was approved in ethics approval for the study by the ethical Committee of University of Chemistry and Technology, Prague (Czechia) and Jaramogi Oginga Odinga University of Science and Technology (JOUST) in Kenya.

The following groups of participants were included in the study, identified by the type of work they do:

	KENYA		THAILAND	
	WOMEN	MEN	WOMEN	MEN
Control group	7	2	6	4
People engaged in plastic waste work	7	2	6	4
People engaged in the plastic recycling industry	6	1	7	3

At the start of the study, each of the participants was given a wristband in a tin can with an assigned sample code to ensure that their data remained anonymous. The participants put on the wristbands, noted the time and day, and wore wristbands for 5 days (120 hours). The first day, each participant filled in a questionnaire about their lifestyle, working environment, and working conditions to provide information about possible exposure sources. At the end of each study day, participants filled in daily logs about their activities during the day to enable identification of potential sources of exposures that might impact the results. After the five days, participants took off their wristbands, put them back in the tin can and put the can back into their original bag. All the bags were then shipped to the NGO Arnika Association in Czechia, who delivered them unopened to the lab.

A field blank was also included in the study to capture any contamination during the handling of the wristbands before or after the start of the study. This was opened for a brief time at the start of the study when the wristbands were handed out. It was then put back into its tin, the tin put back in its original bag, and it was shipped to the lab together with the other wristbands at the end of the five days.

The results from the wristband analysis, including the field blanks, are provided in Annex I for Thailand and Annex II for Kenya.

PLASTIC WASTE AND RECYCLING WORK IN THAILAND

In rural Thailand, small-scale, informal recycling operations process plastic and electronic waste. Typically family-run, these operations take place within household-based workshops, where locals engage in tasks like sorting, dismantling, and shredding waste materials to extract valuable components, such as metals. Recycling has become a crucial source of income, with a significant portion of the population in some villages involved in this type of work.

Waste pickers typically work in local waste management centers associated with sub-district municipalities, where they collect plastic waste from various sources, compress plastic bags into compact lumps, and prepare the materials for recycling processes.

Plastic recyclers generally work in local collection and processing centers, where they handle and sort various plastic materials, with occasional tasks in dismantling and use of shredding equipment. While these activities provide economic benefits, they also bring environmental and health challenges due to the lack of regulated waste management practices. Non-valuable plastic waste is often openly burned or dumped, leading to significant pollution of the surrounding land, air, and food sources. Additionally, some communities run small shredding enterprises, grinding down plastic waste for further processing or sale. The use of basic, often unsafe equipment and personal equipment combined with limited awareness of potential hazards exposes workers and their families to toxic substances. Manually handling waste without protective measures releases hazardous materials, including persistent organic pollutants (POPs) and heavy metals, which can accumulate in the environment and increase health risks, particularly respiratory and endocrine issues.



This situation highlights the urgent need for safer waste processing practices and regulatory oversight to reduce chemical exposure in Thailand's recycling communities.

PLASTIC WASTE AND RECYCLING WORK IN KENYA

A majority of waste pickers in Kenya work informally in open dumpsites where the majority of municipal waste is often disposed. These dumpsites hold mixed waste constituting; organic waste, plastics, glass, metals, construction materials, paper, cardboard, and e- waste. In order to recover valuable materials from mixed waste, waste pickers carry out sorting activities, however this is often done with limited access to protective clothing or personal protective equipment (PPEs) leading to exposure to toxic chemicals used during the production of different products including plastics. Similarly, the waste pickers are often exposed to toxic smoke that emanates from the dumpsites that often combust intentionally or unintentionally. Even those who wear PPE are exposed through inhalation.

Waste recyclers included in the study, on the other hand, carry out plastic shredding in semi-open areas. The recyclers come into contact with PET plastics during the collection, sorting, and removal of bottle tops and labels from the plastics. The recyclers occasionally wear PPEs but other times use bare hands during the sorting and shredding process.

Both the waste pickers and recyclers pursue this line of work of collecting materials including plastics in order to sustain their livelihoods. However, this comes at a high cost related to the environmental and health burdens including pollution of nearby communities, food chain contamination, respiratory issues, and reproductive health issues as reported by the impacted waste actors.

CHEMICALS INCLUDED IN THE STUDY

Six types of chemicals were included in the study. These chemicals were selected due their association with plastics, concerns about their health impacts, and the lack of global, legally binding instruments to address these chemicals. Some of these chemicals are regulated in Thailand as described below. In Kenya, although general provisions have been in place since 2024 through the Environmental Management and Coordination (Management of Toxic and Hazardous Chemicals and Materials) Regulations, action on specific chemicals still needs to be taken.

A total of 73 chemicals were included:

1. Phthalates: 12 chemicals;
2. Other plasticizers (phthalate alternatives): 2 chemicals;
3. Polycyclic aromatic hydrocarbons (PAHs): 24 chemicals;
4. Benzotriazole UV-stabilizers: 8 chemicals;
5. Phenols and bisphenols: 6 chemicals; and
6. Organophosphate flame retardants (OPFRs): 21 chemicals.

PHTHALATES

Uses: Phthalates are a large group of chemicals that are most commonly used in PVC plastics to make them flexible and durable. PVC is used for a wide range of plastic products such as consumer products, food packaging, children's products, and medical plastics. Some phthalates also have additional uses in personal care products, cosmetics, and other non-plastic consumer products.

Exposures: Due to their extensive use, people are widely exposed to phthalates from use of products and also, for example, from contaminated house dust, food, and water.

Health impacts: Many phthalates are confirmed or suspected endocrine disrupting chemicals (EDCs), leading to a multitude of health impacts. They are toxic for reproduction, lower testosterone and estrogen levels, and can affect fertility across multiple generations. They are also associated with elevated blood pressure, obesity, anemia, and higher miscarriage rates (Flaws *et al.*, 2020).

Regulations: In Thailand, the phthalates DEHP, DBP, DEP, BBP, DINP, DIDP, and DNOP are not allowed in toys above a threshold of 0.1% (weight). Similar restrictions for use in toys are in place in many other Asian countries, including Indonesia, Vietnam, China, the Philippines, as well as in countries in other regions such as the US, EU, and Australia. In the EU, some phthalates require authorization before use in any product.

OTHER PLASTICIZERS

Uses: Trioctyl trimellitate (TOTM) and bis(2-ethylhexyl) adipate (DEHA) are used instead of phthalates to make plastics softer and more flexible. Plastics containing DEHA and TOTM are used in a wide variety of products, including food packaging, toys, electronics, fabrics, personal care products, and many more.

Exposures: Because of their widespread use, TOTM and DEHA have been widely detected in household dust and found to contaminate soil and sediment. People are exposed to these substances from the use of products containing them, but also, for example, from contaminated house dust, food, and water.

Health impacts: TOTM has been reported to cause endocrine and reproductive toxicity and cell damage (cytotoxicity), and DEHA has been linked to harmful effects on the brain, heart, and liver tissues due to oxidative stress, inflammation, and apoptosis (cell death) (Tan *et al.*, 2023).

Regulations: The use of TOTM and DEHA are not regulated in Thailand or banned in any other country. TOTM is under evaluation in the EU to assess the need for regulatory controls.

POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

Uses: Polycyclic aromatic hydrocarbons (PAHs) comprise a group of more than 100 chemicals that are generally not intentionally used in plastics but occur naturally in fossil fuels and can also be generated when, for example, coal, oil, gas, wood, plastics, and tobacco are burned.

Exposures: Most people are exposed to PAHs in their everyday lives from contaminated air, water, soil, and food sources. Occupational exposure to PAHs is common and widespread, for example, among firefighters, road workers, steel industry workers, workers in rubber and other plastics industries, and many other industries and occupations.

Health impacts: Exposure to PAHs causes a wide range of health impacts, including cancer, reproductive- and endocrine-disrupting effects, immunotoxicity, and neurotoxicity (Sun *et al.*, 2021).

Regulations: In Thailand, PAHs are not regulated. Many other countries have also established thresholds for occupational exposures, food, and environmental contamination, and have restricted levels of PAHs in children's products and other consumer products.

BENZOTRIAZOLE UV-STABILIZERS

Uses: Benzotriazole UV stabilizers (BUVs) are a group of chemicals that are widely used in plastics to prevent the plastics from degrading when exposed to UV radiation from sunlight. Some of the chemicals in this group are also used in sunscreen and skincare products to prevent damage to skin from UV radiation.

Exposures: Because of their widespread use, BUVs have been shown to contaminate all environmental media, including soil, air, and water and have been detected in human breast milk. UV stabilizers can also leach from packaging materials into our food. Exposure to BUVs occurs during use of products containing them and from contaminated house dust, food, and water.

Health impacts: BUVs have been linked to harm to human health, including endocrine disruption, damage to liver and kidney functions, and impacts on the immune system. (Khare *et al.*, 2023; Zhou *et al.*, 2023).

Regulations: Thailand is a Party to the Stockholm Convention, where the BUV UV-328 is listed for global elimination. No other BUV is regulated in Thailand, similar to most other countries in the world. However, in the EU, the use of three additional BUVs (UV-327, UV-350, and UV-320) require authorization.

PHENOLS AND BISPHENOLS

Uses: The two alkylphenols (octylphenol and nonylphenol) included in the study are used as antioxidants in plastics. Other uses include latex paints, pesticides, and industrial cleaners. Bisphenols are used as chemical building blocks in polycarbonate plastics and epoxy resins and also, for example, in the linings of food cans and thermal paper receipts.

Exposures: Sources of exposure to phenols and bisphenols are contamination of household dust, food, water, and other beverages. The sources of dietary exposure to bisphenol A have been extensively studied, and shown to be caused by leaching from carbonate plastics food and drink containers and food can liners.

Health impacts: Alkylphenols are linked to male infertility, low sperm count, and disrupted prostate development. Studies of occupational exposures have shown that exposures are associated with heightened risk of male and female breast cancers. One of the most well studied EDCs is bisphenol A (BPA), a chemical that causes a wide range of health impacts. These include impacts on brain development, adverse reproductive outcomes, reduced fertility, increased risk of diabetes, and associations with breast, prostate, ovarian, and endometrial cancers. Scientific studies show that other bisphenols have similar effects (Gore *et al.*, 2024).

Regulations: BPA is banned for use in infant food containers in Thailand and infant and children's tableware containing BPA must carry a warning label. Many other countries have also banned the use of BPA in baby bottles and food contact materials for children.

ORGANOPHOSPHATE FLAME RETARDANTS

Uses: Organophosphate flame retardants (OPFRs) include more than 130 chemicals that are increasingly used as replacements for brominated flame retardants, for example, in furniture, textiles, building materials, and electronics. They can also be used as plasticizers to make plastics softer and more flexible.

Exposures: The main source of human exposure to OPFRs is through contaminated indoor air and dust, since they are used widely in consumer products. They have also been shown to pollute water, biota, sediment, and soil.

Health impacts: Growing scientific evidence shows that OPFRs are toxic replacements for brominated flame retardants and have similar health impacts, such as endocrine disruption and developmental and neurodevelopmental toxicity (Blum *et al.*, 2019). Individual OPFRs have also been linked to reproductive toxicity, neurotoxicity, respiratory effects, and eczema (Chupeau *et al.*, 2020).

Regulations: Similar to most countries, Thailand does not have any regulations to control the use of organophosphate flame retardants. In the EU, several OPFRs are restricted for use in toys.



THE STUDY: MOST SIGNIFICANT RESULTS

Concentrations of the different chemicals detected in the wristbands varied within the participant groups, where levels in individual wristbands in some instances were far higher than the levels in other wristbands in the same group. Given the small sample size, comparisons between groups were therefore primarily based on median values, i.e., the middle value rather than averages. To facilitate readability and make results easier to compare, results are rounded in the text but provided in detail in Annex I for Thailand, and Annex II for Kenya.

1. ALL PARTICIPANTS WERE EXPOSED TO A COMPLEX MIXTURE OF CHEMICALS

All six types of chemicals were detected in all wristbands. Of the 73 chemicals included in the chemical analysis in total, the wristbands in Kenya contained between 30-41 chemicals, and the wristbands in Thailand between 21 – 40 chemicals. Eighteen chemicals were detected in all wristbands in the study in Kenya and 14 in all wristbands in the study in Thailand, indicating that there is general exposure to some chemicals irrespective of occupation. Also, the results indicate that exposures to these types of chemicals are not determined by location since 11 chemicals in total, including one or more chemical from each type, were detected across all wristbands in all participant groups in both countries.

The chemical exposures for each participant were slightly different since no two wristbands contained the exact same set of chemicals. The results also indicate that some individuals have specific point sources of exposure to certain chemicals, since some of the wristbands contained very high levels of certain chemicals. Still, some general differences between the different participant groups and countries could be identified.

2. PHTHALATES WERE DETECTED AT THE HIGHEST CONCENTRATIONS IN ALL WRISTBANDS

Six of the twelve phthalates included in the chemical analysis were detected in wristbands from both Kenya and Thailand: dimethyl phthalate (DMP), diethyl phthalate (DEP), di-isobutyl phthalate (DiBP), di-n-butyl phthalate (DBP), butyl benzyl phthalate (BBP), and bis(2-ethylhexyl) phthalate (DEHP). Three of these phthalates were detected in all the wristbands in both countries: DEP, DBP, and DEHP (see Figure 1). DEHP was detected at the highest levels of all chemicals in all wristbands from both countries.

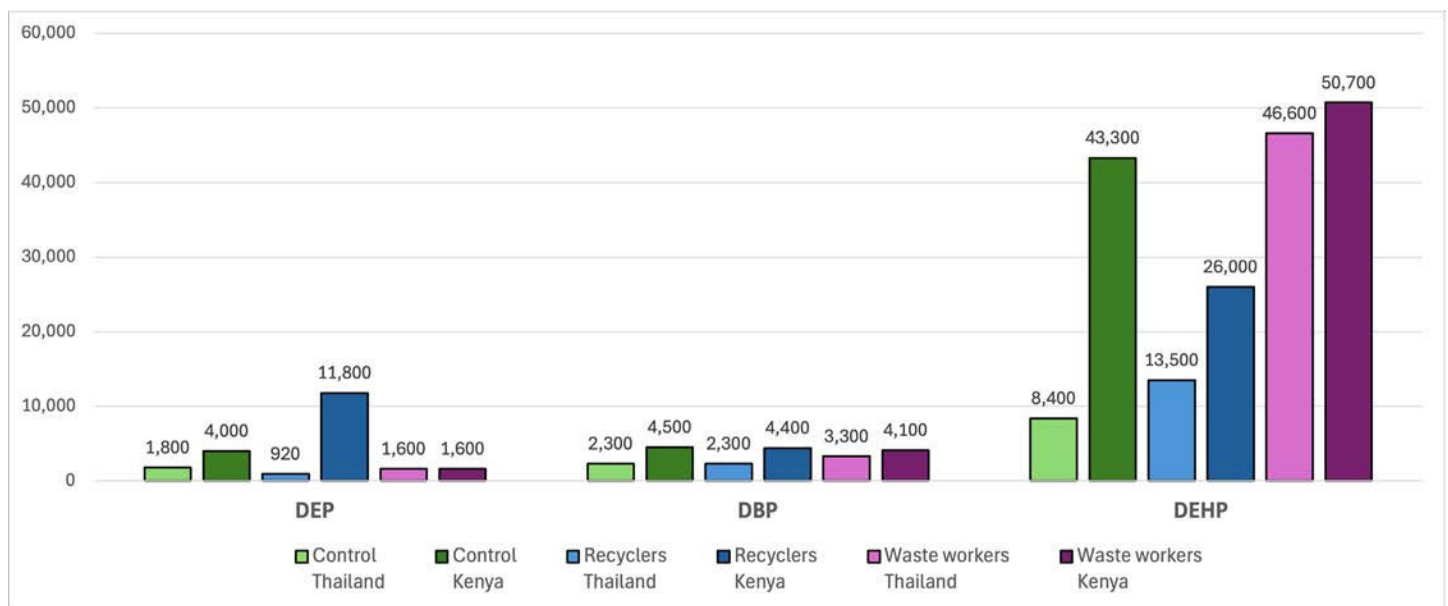


Figure 1. Median concentrations (ng/g) of the phthalates detected in all the wristbands. Numbers rounded for readability.

When comparing median concentrations of phthalates detected in the wristbands, there is no clear trend of exposure between the different groups in each country. However, exposure to these phthalates were generally higher in Kenya than in Thailand.

In Thailand, dimethyl phthalate (DMP) was detected in all the wristbands of the participants of the control group but only in one other wristband. In Kenya, DMP was detected in all wristbands, but the concentrations in the control group's wristbands were in most cases tenfold higher. Since DMP is also used in cosmetics, skin care products, and insect repellants, it could be hypothesized that the measured levels came from such uses rather than from plastics.

3. THE PLASTIC WASTE AND RECYCLING WORKERS WERE EXPOSED TO A HIGHER NUMBER OF CHEMICALS, AND WERE MORE EXPOSED TO POLYCYCLIC AROMATIC HYDROCARBONS (PAHS)

The participants in the control groups were in general exposed to fewer chemicals than the plastics waste workers and recycling workers in both countries (see Figure 2): In Thailand, between 21-33 chemicals was detected in the control group wristbands compared to 23-40 chemicals in the wristbands of the plastic recyclers and 27 – 38 chemicals in the wristbands of the plastic waste workers. In Kenya, between 31-38 chemicals was detected in the control group wristbands compared to 30-39 chemicals in the wristbands of the plastic recyclers and 34 – 41 chemicals in the wristbands of the plastic waste workers.

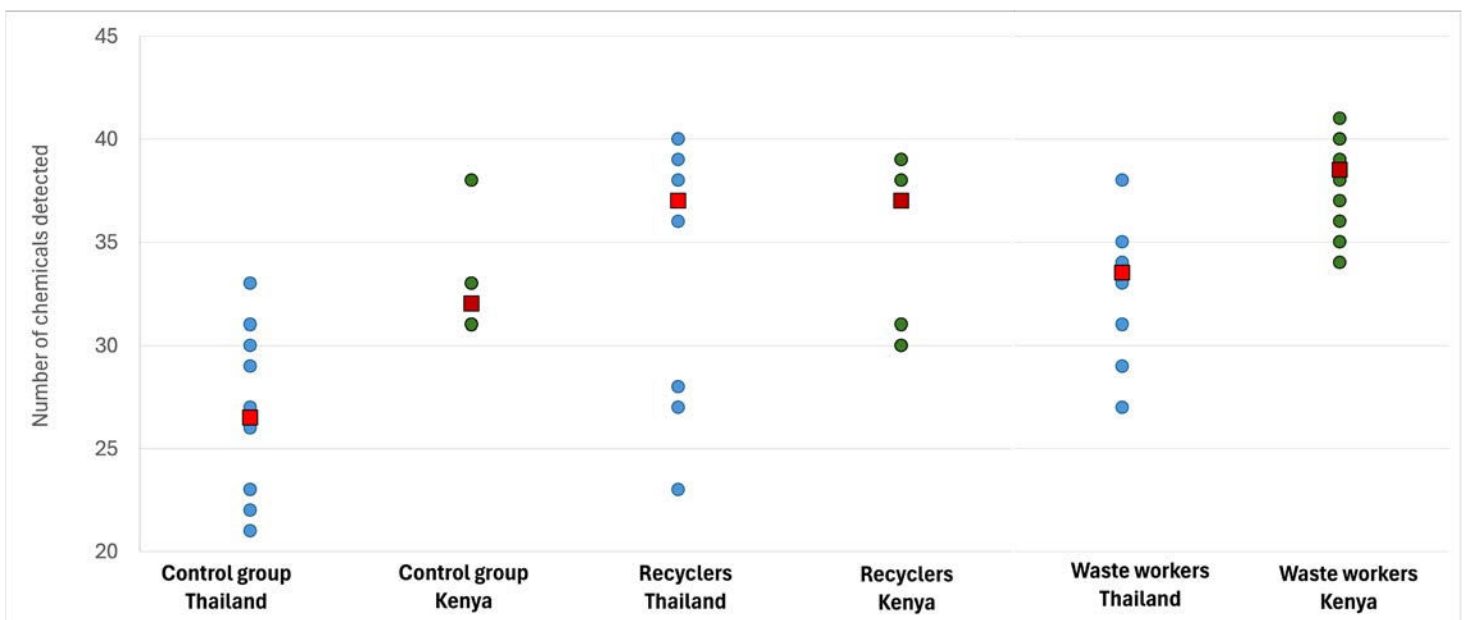


Figure 2. Number of chemicals detected in the wristbands, including medians marked in red.

Out of the 24 PAHs included in the study, 16 were detected in one or more wristband in both Thailand and Kenya. In Kenya, phenanthrene was detected in all wristbands, and in Thailand, phenanthrene, fluoranthene, and pyrene were detected in all wristbands. Overall, plastic recyclers and plastic waste workers were exposed to a higher number and higher concentrations of PAHs in both Thailand and Kenya) (see Table 1).

	THAILAND			KENYA		
	CONTROL	RECYCLERS	WASTE WORKERS	CONTROL	RECYCLERS	WASTE WORKERS
Nr of PAHs	6 (range: 4–15)	13 (range: 6–14)	13 (range: 8–16)	6 (range: 5–10)	12 (range: 6–13)	12 (range: 9–14)
Sum PAHs (ng/g)	60 (range: 31–679)	191 (range: 87–356)	153 (range: 68–1,545)	92 (range: 50–147)	188 (range: 26–1,096)	388 (range: 187–936)
Phenanthrene (ng/g)	28 (range: 17–190)	48 (range: 34–140)	42 (range: 28–460)	48 (range: 30–66)	46 (range: 21–389)	181 (range: 104–346)

Table 1 Median number, total concentration of PAHs, and concentration of phenanthrene, including range (min-max).

4. ALL PARTICIPANTS IN KENYA WERE EXPOSED TO A SIMILAR NUMBER OF ORGANOPHOSPHATE FLAME RETARDANTS (OPFRs) AS PLASTIC RECYCLERS IN THAILAND.

Sixteen of the 21 OPFRs included in the analysis were detected in one or more wristbands in Thailand, and eighteen in one or more of the Kenyan wristbands. Four OPFRs were detected in all wristbands in Thailand and six in all wristbands in Kenya. Three OPFRs were detected in all wristbands from both Thailand and Kenya: tri-isobutyl phosphate (TiBP), tri-n-butyl phosphate (TnBP), and triphenyl phosphate (TPhP).

In Thailand, recyclers were exposed to higher concentrations and a higher number of OPFRs than the other participants (see Table 2). In Kenya, the same trend was not seen since no group was generally exposed to a higher total concentration of OPFRs. However, exposure to OPFRs seems more widespread, since all Kenyan participants were exposed to a similar number of OPFRs as the Thai recyclers.

In addition, two individuals in the control group were exposed to high concentrations of cresyl diphenyl phosphate (CDD) at 171 ng/g and 547 ng/g, and one individual in the control group to tris(2-chloropropyl) phosphate (TCIPP) at 438 ng/g. While it is difficult to pinpoint the point sources for these exposures given the widespread uses of OPFRs. For example, TCIPP is marketed for use in polyurethane foam that is used in upholstered furniture. CDD is marketed as a flame retardant and plasticizer additive for general use, for example in plastics, coatings, and adhesives.

	THAILAND			KENYA		
	CONTROL	RECYCLERS	WASTE WORKERS	CONTROL	RECYCLERS	WASTE WORKERS
Nr of OPFRs	6 (range: 4–8)	12 (range: 6–11)	8 (range: 5–9)	11 (range: 10–12)	11 (range: 8–12)	11 (range: 9–12)
Sum of OPFRs (ng/g)	18 (range: 6–82)	71 (range: 23–176)	20 (range: 10–55)	17 (range: 9–723)	15 (range: 8–25)	18 (range: 9–77)

Table 2 Median number and total concentration of OPFRs, including range (min-max).

5. ALL PARTICIPANTS WERE EXPOSED TO THE PHTHALATE PLASTICIZER ALTERNATIVES

Two alternative plasticizers were included in the study, Bis(2-ethylhexyl) adipate (DEHA) and Trioctyl trimellitate (TOTM). Both were detected in all wristbands from both countries (see Figure 3). However, no clear exposure trends could be identified. In Thailand, median concentration levels to TOTM were slightly lower in the control group compared to the recyclers and plastic waste workers, but slightly higher in the control group in Kenya. Median levels of DEHA were much higher in the control group in Thailand compared to the plastic recyclers and plastic waste workers, whereas the wristbands of the plastic waste workers in Kenya contained the highest levels.

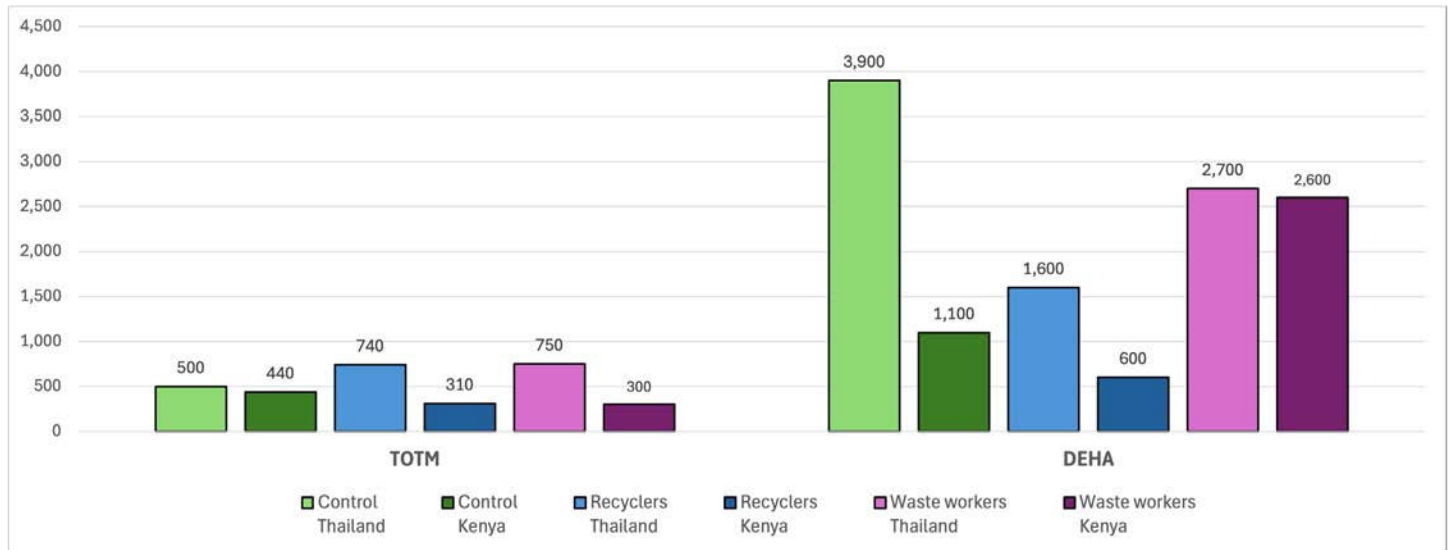


Figure 3. Median concentrations (ng/g) of the alternative plasticizers TOTM and DEHA. Numbers rounded for readability.

6. THE RESULTS FOLLOWS PREVIOUS STUDIES SHOWING WIDESPREAD EXPOSURE TO TOXIC CHEMICALS IN MANY COUNTRIES

This study provides further evidence of the widespread exposure to toxic plastic chemicals and the results are in line with other studies using wristbands as passive samplers. While many wristband studies focus on the United States (US), a few studies also provide insights from other regions. Since exposure levels and patterns may be different in different countries and regions depending on consumer habits, population density, and regulatory controls, the results from this study were compared to available wristband studies with a broader geographical spread.

A study by Dixon and colleagues assessed chemical exposure in 14 communities in Africa (Senegal, South Africa), North America (United States (U.S.)) and South America (Peru) (Dixon et al., 2019). The same 14 chemicals were detected in over half of the wristbands, including six phthalates and one organophosphate flame retardant. Of these 14 chemicals, 13 were defined as potential endocrine disrupting chemicals (EDCs). The number of potential EDCs ranged from 4 to 30 per wristband, and of the 191 chemicals detected in one or more wristbands, 96 were classified as potential EDCs. The chemical exposures for each participant were slightly different since no two wristbands contained the exact same set of chemicals.

In a study evaluating exposures to office workers in the USA, UK, China, and India after 32 hours of exposure, 94 of the 99 measured targeted chemicals were present in at least one of the wristbands. In addition, 793 unknown chemicals were present on average in each wristband. All wristbands contained at least one organophosphate flame retardant and one or more phthalate. Most of the samples (98%) contained one or more PAH (Young *et al.*, 2021). When a piece of each wristband was screened for endocrine disrupting properties in different bioassays, they all exhibited hormonal activity (Young *et al.*, 2023).

In a study of exposures in students in Italy and France, 74 of their 92 targeted chemicals were detected in at least one wristband. Organophosphate flame retardants and PAHs were extensively detected in this study (Wang *et al.*, 2020).

Many studies show widespread exposure to phthalates, even in rural communities (Bergmann *et al.*, 2017; Dixon *et al.*, 2019). Phthalates were the most abundant class of chemicals detected in the study evaluating exposures to office workers in the USA, UK, China, and India (Young *et al.*, 2021). In a study of wristbands worn by around 150 undergraduate students at the University of California for 5 days, DBP, DEHP and DEP were detected in all wristbands (Reddam *et al.*, 2024). The concentrations detected in both studies were generally within the same range as seen in the control groups in this study.

In the EU, the use of alternative plasticizers has become more common than the use of phthalates, due to increasing regulation of phthalates. The alternatives are therefore commonly detected in, for example, household dust (Jung *et al.*, 2024). This study shows a similar situation, since all participants were shown to be exposed to the plasticizer alternatives. In fact, the control group in Thailand and Kenya were exposed to higher levels of the plasticizer alternatives than in other studies (see Young *et al.*, 2021; and Reddam *et al.*, 2024).



CONCLUSIONS AND RECOMMENDATIONS

The results from this study show that all participants were exposed to a wide range of plastic chemicals, all of which have associated health concerns. These included many chemicals that are confirmed or suspected endocrine disrupting chemicals. It is very concerning that the highest concentrations detected in the wristbands were of the phthalates DEHP, DiBP, and DPB, all chemicals that have been strictly regulated in the EU because of their harm to human health.

In addition, the number of chemicals detected in each wristband raises concerns of combined effects, since mixture effects can be higher than the effects of each individual chemical. It should also be noted that this study did not include other widely used chemicals of concern such as pesticides, parabens, brominated flame retardants, and others. It is therefore very likely that participants in this study, as well as everyone else, are exposed to a higher number of hazardous chemicals in our everyday lives.

Workers have the right to a safe and healthy working environment and need good, decent, safe, and green jobs. However, plastic waste recyclers and plastic waste workers were exposed to a higher number and higher concentrations of some of the plastic chemicals included in the study. This supports the hypothesis that their work makes them more highly exposed to plastic chemicals than the general population and therefore they must be considered a group in an especially vulnerable situation.

A recent report from the European Federation of Public Service Unions (EPSU) on “Emerging health and safety risks in the waste sector” (Wegmann, 2025), provides recommendations on Occupational Safety and Health. These include stringent exposure controls, effective local exhaust ventilation, enclosed processing areas, and regular air quality monitoring, as well as enhanced inspections and enforcement of OSH regulations. It also underscores the importance of worker representation through trade unions and health and safety committees.

Not even the wealthiest country has the capacity on its own to protect its people from toxic plastic chemicals, and low- and middle-income countries are the most impacted, even though most are not major plastic producers.

IPEN recommends:

- Legally binding, global controls on plastic chemicals throughout their full life cycle and across sectors must be established in the new Plastics Treaty.
- The overproduction of plastics leads to higher exposures to toxic plastic chemicals. Therefore, plastic production and use must be reduced.
- Replacing one toxic plastic chemical with a similar chemical, so-called regrettable substitution, must be prevented by regulating groups of chemicals.
- Recycling of plastics containing or generating toxic chemicals must be prohibited. These plastics should instead be destroyed using non-combustion technologies.
- Producers must be required to disclose the chemicals in their plastics and plastic products and ensure that the information is publicly available throughout the full product life cycle.
- Workers’ fundamental rights must be upheld, including rights to information, training, representation, and collective bargaining, as well as the right to refuse work where there is a serious and/or imminent danger.
- Employers must fulfill their obligations to protect their workers from harm from plastic chemicals, prioritizing elimination, and where this is not possible, substitution of toxic plastic chemicals as established in the occupational safety and health hierarchy of controls.
- Personal protective equipment, including gloves and respiratory masks must be made available as a last line of defense and a complement to other preventative measures. In addition, changing and washing facilities must be made available to all workers.

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ANNEX I - RESULTS OF THE CHEMICAL ANALYSIS OF THE WRISTBANDS FROM THAILAND

Minimum, maximum and median concentrations of the chemicals detected in wristbands of the three groups of participants, and concentrations detected in the field blank (ng/g).

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	
Dimethyl phthalate	DMP	6.89	2,254	10.8	30.4*	30.4*	30.4*	BLQ	BLQ	BLQ	BLQ
Diethyl phthalate	DEP	140	9,170	1,804	72.1	2,130	924	78.7	10,159	1,641	BLQ
Di-n-propyl phthalate	DnPrP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-isobutyl phthalate	DiBP	144	107,107	453	114	817	366	300	2,433	474	BLQ
Di-n-butyl phthalate	DnBP	746	23,880	2,266	457	8,035	2,321	1,191	16,017	3,346	37.8
Di-isopentyl phthalate	DiPeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
N-pentyl-isopentyl phthalate	nPiPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-n-pentyl phthalate	DnPeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-n-hexyl phthalate	DnHP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dicyklohexyl phthalate	DcHP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Butyl benzyl phthalate	BBzP	9.52	577	69.4	7.79	1,547	41.4	71.8	2,152	113	BLQ
Bis(2-ethylhexyl) phthalate	DEHP	3,486	64,748	8,365	5,466	73,945	13,457	9,759	157,142	46,594	BLQ
Triooctyl trimellitate	TOTM	423	828	501	391	3,132	744	353	4,187	751	12.4
Bis(2-ethylhexyl) adipate	DEHA	586	8,601	3,946	424	8,482	1,611	1,215	5,682	2,664	217
4-n-octylphenol	4-OP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
4-n-nonylphenol	4-NP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Naphthalene	NA	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Acenaphthylene	ACY	1.20	18.0	3.75	1.31	15.0	3.47	2.63	99.8	3.24	BLQ
Acenaphthene	ACE	3.21	48.7	35.3	46.3*	46.3*	46.3*	31.6	93.3	56.7	BLQ
Fluorene	FLN	6.92	18.5	12.7	8.97	21.7	15.3	3.39	67.9	13.3	1.32
Phenanthrene	PHE	16.9	192	27.7	34.1	139	47.7	27.6	456	41.7	BLQ
Anthracene	AN	3.95	36.9	7.41	4.60	78.5	14.0	7.57	102	12.3	2.23
Fluoranthene	FLT	4.33	155	9.85	24.4	79.1	32.7	12.1	290	30.1	1.57
Pyrene	PY	2.24	156	6.84	19.7	75.3	38.5	12.2	274	28.3	BLQ
Benzo[c]fluorene	BcFl	0.79	9.75	1.34	0.94	5.17	1.86	0.73	14.3	2.22	BLQ
Benzo[a]anthracene	BaA	1.84	12.7	2.98	2.25	12.5	5.80	0.64	23.1	3.07	BLQ
Cyklopenta[cd]pyrene	CPP	2.56	17.8	10.2	1.67	23.5	7.49	0.97	53.7	6.99	BLQ
Chrysene	CHR	0.51	15.0	1.47	1.23	18.2	4.17	0.92	31.8	4.55	BLQ
5-methylchrysene	5MC	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	
Benzo[b]fluoranthene	BbFA	0.64	3.58	1.72	0.77	18.6	6.85	0.59	10.3	3.02	BLQ
Benzo[k]fluoranthene	BkFA	0.72	1.31	1.02	0.63	8.51	2.98	1.14	5.59	2.29	BLQ
Benzo[k]fluoranthene	BjFA	0.51	2.36	1.31	1.39	11.3	4.38	3.04	8.13	5.39	BLQ
Benzo[a]pyrene	BaP	0.66	1.24	0.83	0.70	7.59	2.58	1.18	8.66	2.52	BLQ
Indeno[1,2,3-cd]pyrene	IP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ah]anthracene	DBahA	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Benzo[ghi]perylene	BghiP	0.00	0.00	BLQ	1.31	7.58	5.39	0.82	5.28	2.97	BLQ
Dibenzo[al]pyrene	DBalP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ae]pyrene	DBaeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ai]pyrene	DBaiP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ah]pyrene	DBahP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Drometrizole	UV-P	32.2	80.2	46.6	18.0	36.3	25.6	16.3	17.0	16.7	BLQ
Tinuvin 234	UV-234	1.10	17.4	2.30	1.20	31.9	3.18	1.30	21.4	3.05	BLQ
Tinuvin 320	UV-320	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bumetrizole	UV-326	8.33	53.2	20.1	7.33	92.4	48.6	9.33	547	20.2	5.23
Tinuvin 327	UV-327	12.3	14.1	13.2	0.70	4.75	2.20	1.10	2.70	2.20	BLQ
Tinuvin 328	UV-328	3.40	24.8	10.4	3.10	17.9	8.65	3.00	8.80	4.50	BLQ
Octrizole	UV-329	1.80	8.40	4.00	0.80	7.80	1.55	0.70	24.0	0.90	BLQ
Tinuvin 350	UV-350	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol A	BPA	0.85	25.4	2.01	0.94	12.4	6.49	2.23	15.3	4.75	0.93
Bisphenol B	BPB	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol F	BPF	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol S	BPS	0.05	1.47	0.12	0.06	1.59	0.17	0.09	2.23	0.36	BLQ
Triethyl phosphate	TEP	0.52	0.52	0.52	0.70	2.31	1.09	0.52	1.07	0.70	BLQ
Tri-n-propyl phosphate	TPrP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tri-isobutyl phosphate	TiBP	0.76	30.9	2.96	0.91	36.4	9.61	0.60	19.0	3.05	BLQ
Tri-n-butyl phosphate	TnBP	3.76	30.2	9.84	5.70	35.8	23.3	2.40	23.3	7.93	0.12
Tris(2-butoxyethyl) phosphate	TBOEP	0.26	6.54	1.26	0.25	6.48	0.55	0.52	3.31	1.98	BLQ
Tris(2-ethylhexyl) phosphate	TEHP	0.11	8.89	0.44	0.10	1.69	0.69	0.16	6.27	0.66	BLQ
Triphenyl phosphate	TPhP	0.44	2.03	1.08	1.29	8.33	5.73	0.29	3.36	1.28	BLQ
Cresyl diphenyl phosphate	CDPP	0.45	0.57	0.48	0.64	18.4	6.96	0.78	1.80	1.03	BLQ
Tricresyl phosphate (sum of isomers)	¼TCP	0.18	0.35	0.27	0.84	41.9	3.83	0.18	13.1	0.50	BLQ

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	
Ethylhexyl diphenyl phosphate	EHDPhP	3.21	3.92	3.56	3.70	31.07	6.93	3.53	8.80	3.73	BLQ
Isodecyl diphenyl phosphate	iDDPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tris(2-isopropylphenyl) phosphate	TIPPP	BLQ	BLQ	BLQ	0.73	2.10	1.14	0.22	0.39	0.39	BLQ
Tris(p-tertbutylphenyl) phosphate	TtBPP	BLQ	BLQ	BLQ	0.09	0.38	0.14	BLQ	BLQ	BLQ	BLQ
Trixylenyl phosphate	TXP	BLQ	BLQ	BLQ	13.7*	13.7*	13.7*	BLQ	BLQ	BLQ	BLQ
Tris(2-chloroethyl) phosphate	TCEP	BLQ	BLQ	BLQ	0.68*	0.68*	0.68*	BLQ	BLQ	BLQ	BLQ
Tris(2-chloropropyl) phosphate	TCIPP	BLQ	BLQ	BLQ	61.1	61.9	61.5	BLQ	BLQ	BLQ	BLQ
Tris(1,3-dichloroisopropyl) phosphate	TDCIPP	0.49	3.76	0.61	0.32	1.53	0.67	0.26	0.86	0.37	BLQ
Tris(tribromopentyl) phosphate	TTBNPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tetrakis(2-chlorethyl) dichloroisopentyl diphosphate	V6	BLQ	BLQ	BLQ	0.05	0.10	0.07	BLQ	BLQ	BLQ	<0.05
Resorcinol-bis(diphenyl) phosphate	RDP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol A-bis(diphenyl) phosphate	BPA-BDPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ

BLQ = Below limit of quantification

*only detected in one wristband in the participant group

ANNEX II - RESULTS OF THE CHEMICAL ANALYSIS OF THE WRISTBANDS FROM KENYA

Minimum, maximum and median concentrations of the chemicals detected in wristbands of the three groups of participants, and concentrations detected in the field blank (ng/g).

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MAX	MIN	MEDIAN	MAX	MIN	MEDIAN	MAX	MIN	MEDIAN	
Dimethyl phthalate	DMP	605	106	420	41.0	6.41	12.0	38.4	8.96	16.8	25.3
Diethyl phthalate	DEP	23,460	231	3,999	7,460	709	11,837	4,199	183	1,624	30.4
Di-n-propyl phthalate	DnPrP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-isobutyl phthalate	DiBP	7,936	881	2,616	2,942	704	1,640	4,233	1,024	2,219	145
Di-n-butyl phthalate	DnBP	9,004	1,588	4,540	6,077	1,455	4,442	1,048	1,250	4,088	208
Di-isopentyl phthalate	DiPeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
N-pentyl-isopentyl phthalate	nPiPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-n-pentyl phthalate	DnPeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Di-n-hexyl phthalate	DnHP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dicyklohexyl phthalate	DcHP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Butyl benzyl phthalate	BBzP	249	49.0	57.9	423	15.4	40.2	139	18.1	53.7	BLQ
Bis(2-ethylhexyl) phthalate	DEHP	97,675	10,180	43,275	1,872	7,135	25,969	9,932	15,695	50,729	212
Triooctyl trimellitate	TOTM	6,390	70.1	438	3,814	174	311	4,960	94.6	299	BLQ
Bis(2-ethylhexyl) adipate	DEHA	5,524	552	1,092	3,288	255	598	4,647	471	2,632	97.8
4-n-octylphenol	4-OP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
4-n-nonylphenol	4-NP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Naphthalene	NA	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Acenaphthylene	ACY	20.6	1.93	3.32	62.8	3.22	4.58	64.8	8.49	15.0	BLQ
Acenaphthene	ACE	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Fluorene	FLN	11.6*	11.6*	11.6*	69.3	5.88	10.4	68.5	40.0	54.3	BLQ
Phenanthrene	PHE	65.9	30.2	48.0	389	20.9	46.1	346	104	181	BLQ
Anthracene	AN	5.83*	5.83*	5.83*	16.9	10.3	13.6	41.8	14.1	28.0	BLQ
Fluoranthene	FLT	27.9	7.83	14.9	222	13.7	48.9	200	31.9	86.4	BLQ
Pyrene	PY	27.6	6.94	18.5	230	16.5	52.4	210	31.2	86.6	BLQ
Benzo[c]fluorene	BcFl	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Benzo[a]anthracene	BaA	0.81*	0.81*	0.81*	32.5	0.83	7.81	20.2	1.51	8.28	BLQ
Cyklopenta[cd]pyrene	CPP	4.61*	4.61*	4.61*	0.52*	0.52*	0.52*	17.8	2.41	13.1	BLQ
Chrysene	CHR	4.22	0.56	1.71	44.8	1.03	11.0	27.7	2.67	13.3	BLQ
5-methylchrysene	5MC	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	
Benzo[b]fluoranthene	BbFA	0.66	0.51	0.53	15.4	0.63	4.35	15.2	0.85	4.59	BLQ
Benzo[k]fluoranthene	BkFA	BLQ	BLQ	BLQ	6.50	1.01	1.64	5.62	0.57	2.71	BLQ
Benzo[k]fluoranthene	BjFA	BLQ	BLQ	BLQ	9.7	0.60	2.18	8.75	0.97	3.80	BLQ
Benzo[a]pyrene	BaP	0.67	0.51	0.59	7.26	0.62	1.38	5.62	0.70	1.97	BLQ
Indeno[1,2,3-cd]pyrene	IP	BLQ	BLQ	BLQ	2.63	0.91	1.77	4.90	0.71	2.41	BLQ
Dibenzo[ah]anthracene	DBahA	0.65	0.53	0.56	0.85*	0.85*	0.85*	BLQ	BLQ	BLQ	BLQ
Benzo[ghi]perylene	BghiP	BLQ	BLQ	BLQ	4.99	1.07	1.99	12.7	0.53	3.96	BLQ
Dibenzo[al]pyrene	DBalP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ae]pyrene	DBaeP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ai]pyrene	DBaiP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Dibenzo[ah]pyrene	DBahP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Drometrizole	UV-P	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tinuvin 234	UV-234	1,268	3.05	17.9	31.2	1.50	11.0	55.2	2.89	14.1	BLQ
Tinuvin 320	UV-320	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bumetrizole	UV-326	141	6.31	18.6	80	9.40	25.3	166	7.95	24.2	BLQ
Tinuvin 327	UV-327	3.96	1.02	2.70	4.03	2.99	3.51	7.56	1.18	3.67	BLQ
Tinuvin 328	UV-328	57.6	1.28	7.20	26.9	1.12	19.7	23.3	3.13	7.02	BLQ
Octrizole	UV-329	40.3	0.68	5.89	2.36	0.54	1.59	4.98	0.61	3.40	BLQ
Tinuvin 350	UV-350	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol A	BPA	8.54	0.88	3.17	7.41	0.19	1.15	22.0	1.56	3.50	0.08
Bisphenol B	BPB	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol F	BPF	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Bisphenol S	BPS	1.09	0.05	0.12	0.45	0.07	0.15	2.43	0.05	0.23	BLQ
Triethyl phosphate	TEP	5.36	0.89	1.75	4.48	0.89	1.79	3.56	0.65	1.71	BLQ
Tri-n-propyl phosphate	TPrP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tri-isobutyl phosphate	TiBP	3.73	0.20	0.61	5.46	0.20	0.82	3.20	0.52	1.02	BLQ
Tri-n-butyl phosphate	TnBP	4.40	0.16	0.65	0.62	0.09	0.23	10.8	0.96	2.09	BLQ
Tris(2-butoxyethyl) phosphate	TBOEP	3.84	0.40	1.19	4.53	0.63	1.53	3.34	0.66	1.32	BLQ
Tris(2-ethylhexyl) phosphate	TEHP	0.57	0.12	0.30	5.03	0.03	0.94	2.51	0.05	0.80	BLQ
Triphenyl phosphate	TPhP	85.4	1.22	4.72	7.84	1.88	4.86	51.1	3.75	5.61	BLQ
Cresyl diphenyl phosphate	CDPP	547	0.38	0.87	8.55	0.30	1.88	2.68	0.32	0.64	BLQ
Tricresyl phosphate (sum of isomers)	¼TCP	53.7	0.06	0.55	1.13	0.12	0.34	48.9	0.09	0.49	BLQ

		CONTROL			RECYCLERS			WASTE WORKERS			FIELD BLANK
CHEMICAL	ACRONYM	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	MIN	MAX	MEDIAN	
Ethylhexyl diphenyl phosphate	EHDPhP	2.56*	2.56*	2.56*	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Isodecyl diphenyl phosphate	iDDPP	2.80	0.29	0.41	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tris(2-isopropylphenyl) phosphate	TIPPP	0.18	0.03	0.08	0.24	0.03	0.07	0.17	0.04	0.08	BLQ
Tris(p-tertbutylphenyl) phosphate	TtBPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Trixylenyl phosphate	TXP	BLQ	BLQ	BLQ	0.03	0.03	0.03	2.33	2.33	2.33	BLQ
Tris(2-chloroethyl) phosphate	TCEP	0.51	0.12	0.31	0.10*	0.10*	0.10*	BLQ	BLQ	BLQ	BLQ
Tris(2-chloropropyl) phosphate	TCIPP	438*	438*	438*	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tris(1,3-dichloroisopropyl) phosphate	TDCIPP	61.0	0.56	1.04	1.67	0.18	0.83	4.82	0.62	1.04	BLQ
Tris(tribromopentyl) phosphate	TTBNPP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ
Tetrakis(2-chlorethyl) dichloroisopentyl diphosphate	V6	BLQ	BLQ	BLQ	0.05*	0.05*	0.05*	0.06*	0.06*	0.06*	BLQ
Resorcinol-bis(diphenyl) phosphate	RDP	BLQ	BLQ	BLQ	BLQ	BLQ	BLQ	2.34	2.34	2.34	BLQ
Bisphenol A-bis(diphenyl) phosphate	BPA-BDPP	1.14	0.39	0.71	0.39	0.11	0.11	0.29	0.09	0.15	BLQ

BLQ = Below limit of quantification

*only detected in one wristband in the participant group

ANNEX III – DETAILS OF THE PRECLEANING AND ANALYSIS OF THE WRISTBANDS

A. Method of preparing silicone wristbands for sampling

Before sampling, the silicone wristbands (SWs) were pre-cleaned with solvent mixtures ethyl acetate:hexane (1:1, v/v) for 3x2 hours ethyl acetate:methanol (1:1, v/v) for 2x2 hours. The SWs were then placed in pre-baked aluminium foil (450 °C, 5 h) and dried for 2 hours (450 °C). The SWs were then stored in prepared aluminium boxes.

B. Method for isolating target polar analytes from SWs (organophosphate flame retardants and bisphenols)

The target analytes were extracted from the SWs with basic methanol (1% NH₄OH in methanol) by ultrasound-assisted extraction (3x30 min). The combined extract was evaporated to dryness and redissolved in methanol with internal standards and analysed by UHPLC-MS/MS after filtration.

C. Method for isolating target non-polar analytes from SWs (phthalates, polycyclic aromatic hydrocarbons, UV stabilisers)

The target analytes were extracted from SW with the solvent mixture hexane:dichloromethane (1:1, v/v) by ultrasound-assisted extraction (3x30 min). The combined extract was redissolved in hexane.

A half aliquot was used for the analysis of UV stabilisers after the solvent was change to methanol containing internal standards and analysed by UHPLC-MS/MS after filtration.

The second part of the extract was purified with silica SPE. The purified extract was evaporated and redissolved in isooctane with internal standards and analysed by GC-MS/MS.

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