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REPORT

Analysis of workplace air monitoring data for 4,4'-isopropylidenediphenol (Bisphenol A; BPA)

2023

Executive Summary

This report presents results from a voluntary initiative by the European producers of Polycarbonate (the PC/BPA group of Plastics Europe) and Epoxy resins (Epoxy Europe, a CEFIC sector group).

It summarises available air exposure data at workplace facilities involving BPA production and its transformation to Polycarbonate or Epoxy resins. The vast majority of BPA (98 %) is used to manufacture Polycarbonate and Epoxy resins.

In Europe, there are in total 22 plants which handle BPA among member companies of the aforementioned trade associations. Nine plants produce BPA, five plants produce Polycarbonate and eight plants produce base Epoxy resins. Out of these 22 plants, 17 provided exposure measurements for this report, amongst them seven BPA producing plants, all five Polycarbonate producing plants and five Epoxy resin producing plants. Exposure data from uses of Polycarbonate or Epoxy resins further downstream are not included in this data collection.

Regular exposure measurements are conducted in the contributing facilities, including sampling of ambient air during BPA handling activities. The use of personal monitors for the entire period of work shifts (8 hours) allows for an accurate determination of Time Weighted Average (TWA) exposures and provides input to risk assessment leading to the selection of suitable engineering controls such as Local Exhaust Ventilation (LEV) and, where required, the use of Respiratory Protective Equipment (RPE) for certain tasks, for example handling of solid BPA, where higher exposures are possible due to dust formation.

306 individual workplace air measurements were collected between 1997 and 2023. The data cover the following manufacturing steps:

- BPA production: 211 (69%)
- Polycarbonate production and compounding: 49 (16%)
- Epoxy resin production: 36 (12%)
- Laboratory uses of BPA for analysis: 10 (3%)

The data have been provided from multiple sources encompassing a range of activities and using different sampling and analytical techniques. The dataset includes mostly personal samples (89%) but also static sampling (11%). Most data were collected by dust samplers followed by quantitative BPA analysis. Simple dust monitoring by samplers or direct reading instruments were also used.

The reported workplace measurements show a degree of variability. The investigated activities can be broadly separated into two main exposure categories (see also table 1):

1) **Lower exposures** (Geometric Mean $\leq$ 0.01 mg/m³) were observed for processes running in closed systems or activities of operators in control rooms, during sampling and in laboratories (corresponding to REACH Process Categories (PROCs) 1, 2, 3 and 15). The related activities are demonstrably far below the EU binding Occupational Exposure Limit (OEL) of 2 mg/m³. Where appropriate, these activities are supplemented by Respiratory Protective Equipment (RPE).

2) **Higher exposures** (Geometric Mean 0.02 to 0.4 mg/m³) are observed with activities where solid BPA is handled and dust may be generated, such as cleaning, bagging, dosing and bulk transfer of BPA (corresponding to REACH PROCs 4, 8b and 9). The use of RPE against dust is reported across manual handling activities to further protect workers, most commonly with FFP2 and FFP3 particle masks.

When viewed in its totality across all covered activities and processes, the provided data demonstrate that exposure to BPA dusts/vapours and aerosols is generally well controlled at these facilities compared to the current EU Occupational Exposure Limit (OEL) value of 2 mg/m³ expressed as 8h-TWA.

Table 1: Summary of air measurement data per activity

Activity	Geometric Mean (GM) [mg/m³]	95th Percentile [mg/m³]	Grouping
Dosing	0.4	9.65	'Higher' exposure
Big-Bag Filling	0.34	2.5	
Bulk Transfers	0.13	5.83	
Solid BPA Handling	0.03	3	
Cleaning & Maintenance	0.019	6.75	
PROC 2 – Sampling	0.011	1.19	'Lower' exposure
PROC 1 – Closed Systems	0.004	0.29	
PROC 2 – Operator	0.004	0.14	
Laboratory Use	0.003	0.22	

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Background

Since March 2022, BPA is subject to an EU binding Occupational Exposure Limit (OEL) value of 2 mg/m^3 based on an 8h-Time-Weighted Average (TWA), which has been set under Directive (EU) 2022/431. EU Member States have to comply with this OEL by April 5, 2024. Previously, Germany, Switzerland, Finland and Austria operated with an OEL of 5 mg/m^3, while Netherlands had set an OEL of 3.3 mg/m^3. Denmark applied an OEL of 3 mg/m^3 for BPA, based on the general national OEL for organic dust. The EU binding OEL value of 2 mg/m^3 was used as reference in this report.

On 17th March 2023 the European Chemicals Agency (ECHA) formally began a process of assessing the potential need for revising the EU-wide binding OEL for BPA.

Epoxy Europe, a CEFIC Sector group, and the PC/BPA group of Plastics Europe formed a technical task force to collect and analyse relevant occupational exposure data. One of the objectives of this group was to gain a common understanding of the current levels of BPA occupational exposure at industrial BPA manufacturing, conversion and formulation sites of the task force members. They represent a significant fraction of plants producing BPA, Polycarbonate and base Epoxy resins in Europe (further details see below). An external consultant, acting as a data trustee, was retained to collect and analyse the available exposure data from member companies. The results are reported here and give an anonymised overview of typical exposure levels across various BPA handling tasks.

Data Collection

As a first step, the member companies were provided with an Excel survey questionnaire with agreed data points for collection. The Excel sheet was to be completed based on Industrial Hygiene data collected from monitoring of individual workers/operators at member company sites. The data request was for air monitoring and skin data but excluded biomonitoring data (BPA in urine samples). The data was handled by the data trustee in strict compliance with European competition guidelines.

For each operator, the data requested were:

- Year of sampling/analysis
- Task description based on REACH Exposure Scenarios (ES), Process Categories (PROCs) with the provision of activity details in a free text field.
- Control measures in operation, such as Local Exhaust Ventilation (LEV), Respiratory Protection Equipment (RPE) type, and Skin Protection type, where used.

- Air sampling and analytical methods used, including indication of the Limit of Quantitation (LoQ)
- Air measurement data, including sampling times, flow rates (L/min), sampling type (personal vs static), source temperature, and measured exposure value with units (mg/m^3 or $\mu g/m^3$)
- Dermal sampling data, including sampling and analytical method with LoQ, sampling source temperature, and highest surface concentration with units (mass/ area of skin)

Completed questionnaires were returned, representing 17 plants across seven member companies of PC/BPA group of Plastics Europe and Epoxy Europe, the CEFIC sector group. The data covered seven of a total of nine European BPA manufacturing plants, all five Polycarbonate manufacturing plants and five of a total of eight base Epoxy resin manufacturing plants. The data represents exposures in the manufacturing process of BPA, the use of BPA as a monomer for the Polycarbonate production and its subsequent compounding processes plus the use of BPA as a monomer for Epoxy resins (mainly BADGE (bisphenol A diglycidyl ether) production). Thus, the data are broadly representative for the main uses of BPA (Figures 1 and 2). For downstream uses of Polycarbonate, i.e. conversion into articles by either injection moulding or extrusion, no exposure data are included in this data collection. However, during these process steps there is no handling of BPA on its own, but handling of Polycarbonate which comprises only traces of residual BPA.

For Epoxy uses, there are additional downstream actors in the value chain handling BPA. These additional downstream uses have not been included in the data collection.

The activities involved in the report are described in Table 1 and detailed in Figure 2 below.

European Bisphenol A production in 2020 was approximately 950,000 tons (Figure 1).

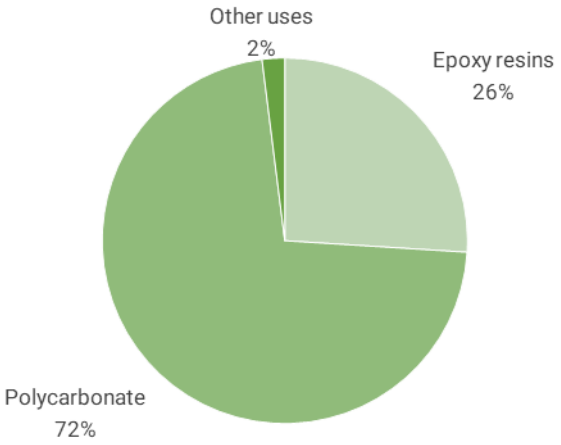


Figure 1: Uses of BPA in the European Union
Source: IHS Markit (2022)

Figure 2 below shows the uses of BPA and volumes and content of BPA in the given use. Volume data refers to the European Union and is based on the Assessment of Socioeconomic Value of Polycarbonate in Europe (IHS Markit, 2022).

In the main use, Polycarbonate, BPA is used as monomer to produce Polycarbonate with only small amounts of residual BPA left in the polymer. For the second significant use, Epoxy resins, BPA is used as monomer to produce several types of oligomeric Epoxy resins with only residual amounts of BPA left in the oligomer. A very small fraction of BPA volume is also used as component in hardeners of Epoxy resins. Approximately 2% of the volume is used in other uses not assessed in this report.

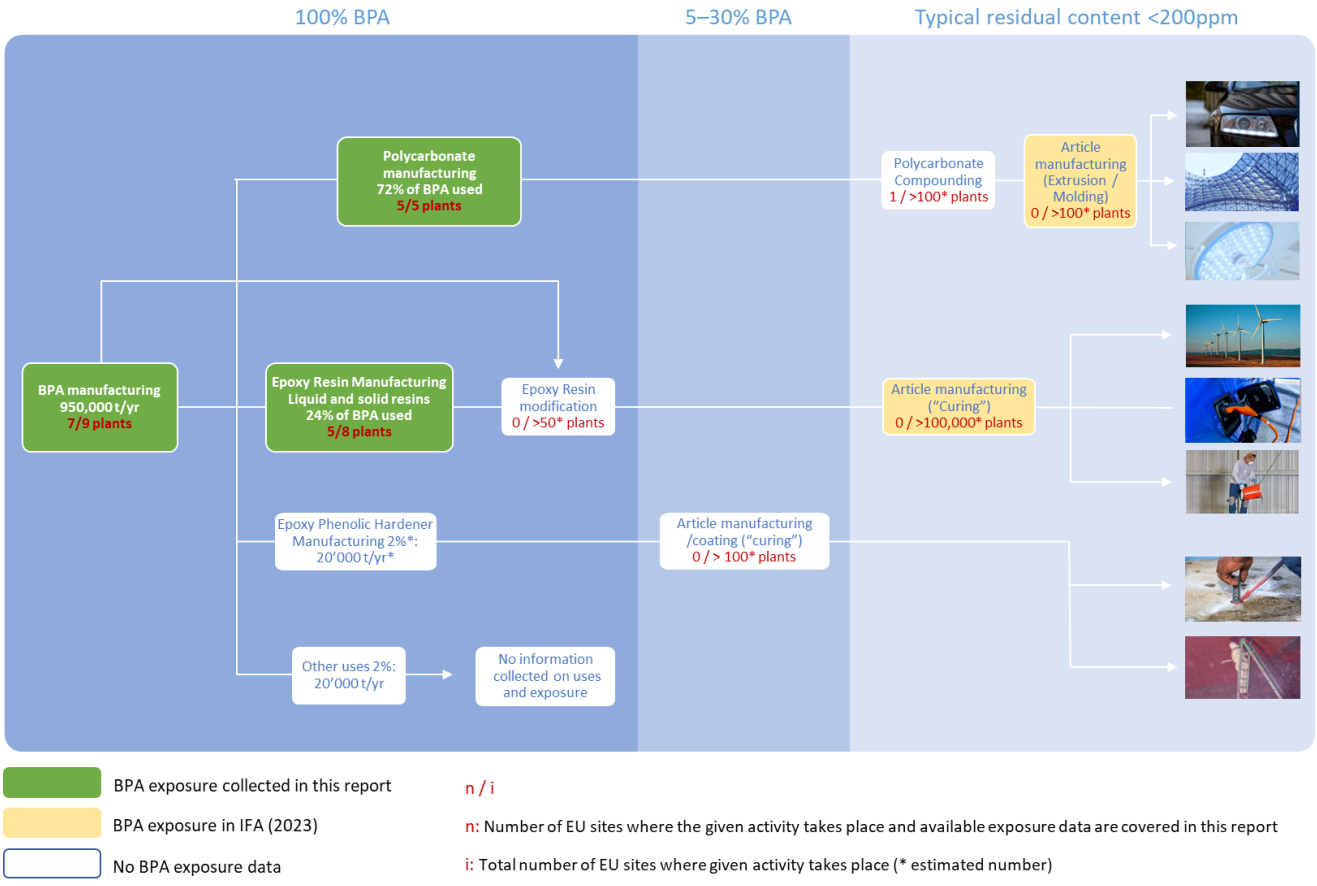
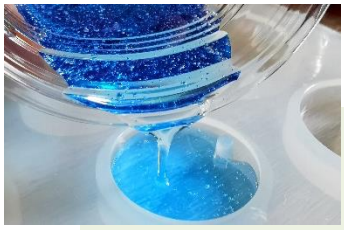


Figure 2: BPA value chain with indication of exposure data covered by this report

Polycarbonate

In the manufacture of Polycarbonate, BPA is used as a monomer to produce BPA-based Polycarbonate, which is a thermoplastic polymer. During polymerization BPA is chemically fully converted into the resulting polymer. In Polycarbonate, BPA is no longer present in its original chemical form except for technically unavoidable traces of unreacted residual monomer. Pure Polycarbonate is usually processed further by adding functional additives and/or blending with other polymers via a compounding step in an extruder. The resulting products, compounds and blends, are sold to the market as pellets. The content of residual BPA is typically well below 150 ppm.

Downstream, Polycarbonate pellets are converted into articles by either injection moulding or extrusion. In both processes, the Polycarbonate pellets are melted down in an extruder and are then either injected into a mould or extruded through a die and subsequently solidified. There is no handling of free BPA in these process steps.



Epoxy resins

BPA is used as monomer for modifying base Epoxy resins. In the resin, BPA is present only in minimal residual levels (typically less than 200 ppm), in a viscous or solid resin with minimal risks of exposure. BPA is also formulated in some Epoxy hardeners (phenolic hardeners). Epoxy Europe members have reformulated or are in the process of reformulating BPA-free hardeners in line with demand of specific markets. After curing, BPA is encapsulated in a complex, 3-dimensional polymeric network thus significantly reducing exposure potential.

Downstream uses

The data collected in this report do not cover downstream uses of Polycarbonate such as injection moulding or extrusion of Polycarbonate or downstream uses of Epoxy resins by industrial and professional applicators. Indicative exposures from downstream uses have recently been published by the German Institute for Occupational Safety and Health of the German Social Accident Insurance (IFA 2023), which reveals low exposures across a range of downstream activities, well below the current OEL.

Methodology

Data were provided for the years 1997 to 2023. No dermal exposure data were provided, only air measurement data were available.

Submitted data were of variable quality; there was a considerable number of blank fields across entries. Some data were provided in aggregated form (multiple data points per row), requiring separation into individual rows. Further data management was required to allow statistical analysis and graphing. For example, where values were provided as a range, or were indicated as less than (<) a named value, the upper value of the range was used, indicating worst case. When the value was below the Limit of Quantitation (LoQ), a default value of LoQ/2 was used. This approach was deemed acceptable as it aligns with the method employed for Diisocyanates by Creely et al (2006)[1], and considers that various sampling and analytical methods were used across multiple facilities. These refinements resulted in a set of 306 useable data rows for analysis.

All values were first converted to the common unit of mg/m^3, allowing for initial calculation of percentiles/quartiles as well as mean, geometric mean and standard deviations (Table 2).

Air measurement data are visualised in Microsoft Excel using bar charts of the geometric means (GM) for each activity, Lognormal distribution curves, as well as a Box and Whisker chart ('Boxplot') to give an overview of exposures per activity.

Geometric means, standard deviations, 95^{th} percentiles and 70% confidence intervals were calculated for the data, and separately for each activity.

Reference is made to the methods described in the European Standard, EN 689+C1[2], which specifies a strategy to perform representative measurements of exposure by inhalation to chemical agents to demonstrate the compliance with occupational exposure limit values (OELVs).

EN 689 also recommends approaches for testing compliance of the dataset against an OEL value. Where at least six exposure measurements are available for a particular Similarly Exposed Group (SEG) activity, a comparison is made between the 70% upper confidence limit (UCL) and the 95^{th} percentile of the distribution of the results. If the UCL is greater than the OEL value it can be concluded that there is an unacceptable probability of exceedance, and therefore the decision is non-compliance with the OEL. Where the UCL is below the OEL, the probability of exceeding the OEL value is deemed acceptably low, indicating compliance. For all activities, the current EU OEL of 2 mg/m^3 was the reference used.

[1] Creely, K. S., Hughson, G. W., Cocker, J. & Jones, K. 2006. *Assessing Isocyanate Exposures in Polyurethane Industry Sectors Using Biological and Air Monitoring Methods*. Ann Occup Hyg, 50, 609-621.
[2] https://connect.nen.nl/Standard/Detail/3609871

Initially, activities were clustered according to the REACH Process Categories (PROCs), as it was felt that these would broadly link with defined SEGs. However, this tended to over-represent some PROCs in a way that did not adequately describe the operator activities covered.

On this basis, the activities were instead split according to the provided free-text descriptions, providing a more 'granular' method to link exposure to operator tasks, therefore providing the equivalent of 'Similarly Exposed Groups' (SEGs). Activities were thus split according to the criteria in Table 1.

Table 2: Activity splits according to provided free text descriptions

Activity	Descriptions
Closed System	PROC 1 activities – normal operations, taking samples
Cleaning / Maintenance	PROC 2 activities - includes: equipment cleaning, maintenance work, cleaning lines / process equipment, background whilst cleaning BPA dust separator, nozzle plate exchange at PC extruder, filter change, opening BPA conveyor system
Controlled Exposure (Operator)	PROC 2 activities – monitoring of shift workers / supervisors / control room operators under controlled exposure conditions
Controlled Exposure (Sampling)	PROC 2 activities – sampling under controlled exposure conditions
Big-Bag Filling	PROC 9 activities - includes granulation of BPA and filling to Big-Bags, exchange pelletizer (BPA pellets), transfer from silos to Big-Bags in open dedicated facilities
Solid BPA Handling – other	PROCs 8b/9 activities – BPA packing, bagging of small samples, filling totes, bagging operations, closed automated feed line, manual lifting of bags to weigh station and loading pallets
Dosing	PROCs 3 and 8b activities – loading of bags of 25 kg of BPA in a hopper or proband mixer, manually charging bags of BPA into reactor vessel, formulation, filling the reactor with BPA, granulation
Bulk Transfer	Mostly PROC 8b activities – includes transfer from silo to trucks, forklift handling of Big-Bags of BPA. Opening of Big-Bags on the unloading equipment from the bottom. Transfer of empty Big-Bags to waste container, unloading truck, transport from storage areas, no description
Laboratory	PROC 15 activities – laboratory / analytical work

Data Analysis

All Activities

Air Measurement Values

Table 3: Calculated percentiles of Air Exposure Measurements (mg/m^3)
- All 306 Data points, with deriving formula

Descriptor	Excel Formula	Value [mg/m^3]
Minimum	=MIN(values)	<LoQ
10th Percentile	=PERCENTILE.INC(values,10%)	<LoQ
25th Percentile (Quartile 1)	=PERCENTILE.INC(values,25%)	<LoQ
50th Percentile (Quartile 2 - median)	=PERCENTILE.INC(values,50%)	0.030
75th Percentile (Quartile 3)	=PERCENTILE.INC(values,75%)	0.300
90th Percentile	=PERCENTILE.INC (values,90%)	1.400
95th Percentile	=PERCENTILE.INC (values,95%)	3.200
Maximum	=MAX (values)	12.400
Arithmetic Mean (Average)	=AVERAGE (values)	0.600
Geometric Mean	=GEOMEAN (values)	0.025
Standard Deviation	=STDEV (values)	1.700
Geometric Standard Deviation	=EXP (STDEV (LN (values/geometric mean)))	20.700
70% Confidence level with 95th percentile	=CONFIDENCE.T(alpha, STDEV.S(values), COUNT (values))	0.100
70% Upper Confidence Limit (UCL)	=Mean(Values)+70%Confidence Level	0.700

Air measurement data across all activities were plotted to reveal lognormal distributions (Figure 3). Lognormal distribution is often applied to occupational exposures as sampling data is often skewed to the right since occupational exposure values have a lower boundary (i.e., the measured exposure value cannot be less than zero), with the y-axis representing the relative probability of a given value occurring in the dataset. Taking the log of the variable often mitigates such skewness. In such cases, the distribution is then considered lognormally distributed—or lognormal—if the log of the variable is normally distributed. Unusually high geometric standard deviations can be explained by the very long distribution tails observed due to a small number of high value outliers.

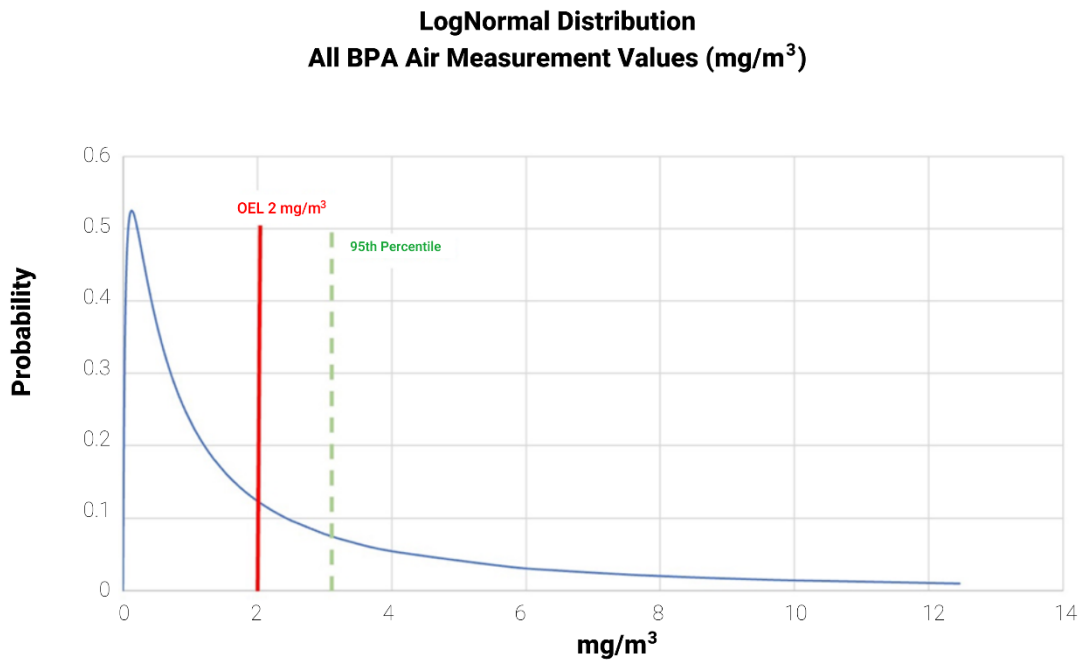


Figure 3: Distribution of all BPA Air Measurement Values (n=306)

With reference to the EU Occupational Exposure Limit (OEL) value of 2 mg/m³, it is evident that most of the provided air measurements (89%) fall below this value. A larger proportion (93%) is below the previous OEL of 5 mg/m³ used by some Member States. Furthermore, it is important to note that personal protective equipment (see Figure 7) is frequently used, especially in high exposure situations.

However, it can be more revealing to look at the air measurements across individual activities, with the large number of data points allowing a clear interpretation simply by comparing the OEL with descriptive statistics. Thus, Figure 4 confirms that controlled activities show lowest exposures indicating adequate exposure control, as expected. Activities involving the manual handling of BPA overall show higher exposures but are also generally well controlled. During these activities, Respiratory Protective Equipment (RPE) is generally used, providing an additional layer of worker protection. A simple comparison of geometric means (Figure 5) indicates general good exposure control across all activities.

In particular it can be seen that handling solid BPA by bagging, dosing and bulk transfer operations are targets for further investigation of opportunities to further reduce workplace exposures.

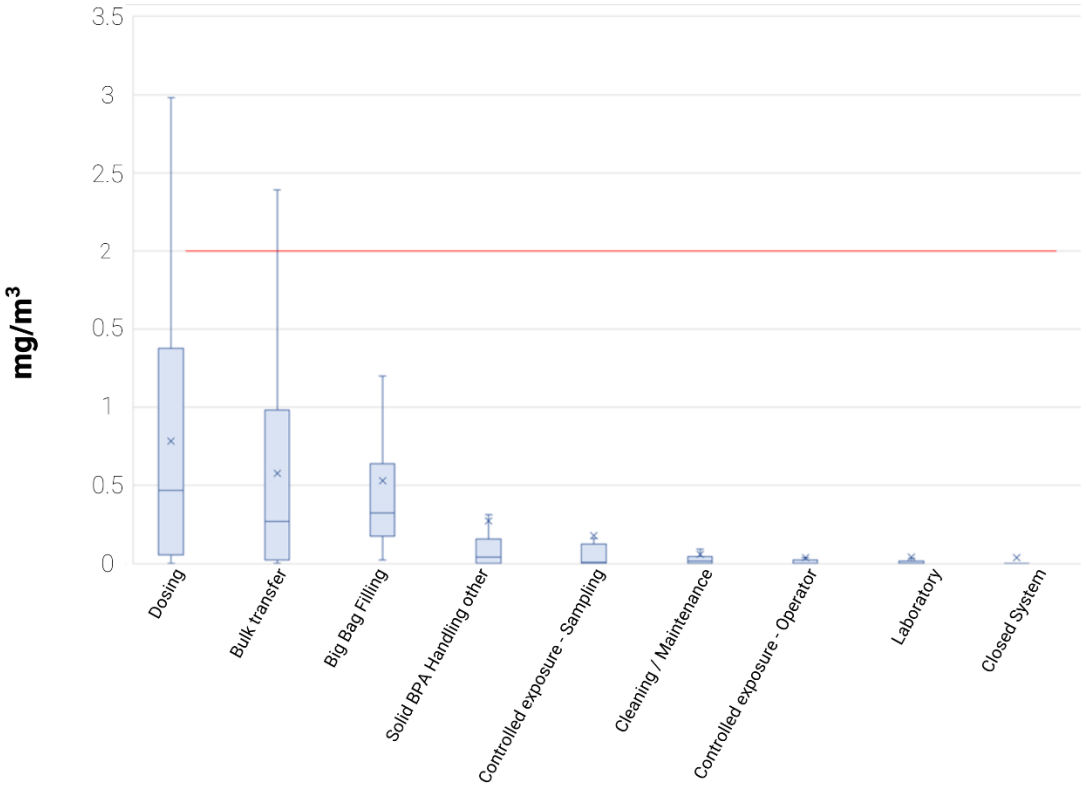


Figure 4: BPA Air measurements according to activity splits (see Table 2) – vs EU OEL (2 mg/m^3) - Values below 95th Percentile (n=290)

Table 4: Summary of Geometric Mean (GM), 95th Percentile and 70% Upper Confidence Limits (UCL) for each activity [mg/m^3]

Activity	**Geometric Mean (GM) [mg/m^3]**	**95th Percentile [mg/m^3]**	**70% Upper Confidence Limit (UCL) [mg/m^3]**	
Dosing	0.4	9.65	2.40	
Big-Bag Filling	0.34	2.5	0.99	
Bulk Transfers	0.13	5.83	1.54	
Bagging – other	0.03	3	0.58	'Higher' exposure
Cleaning & Maintenance	0.019	6.75	0.77	
PROC 2 – Sampling	0.011	1.19	0.216	
Closed Systems (PROC 1)	0.004	0.29	0.047	
Closed Systems (PROC 1)	0.004	0.29	0.047	'Lower' Exposure
PROC 2 – Operator	0.004	0.14	0.042	
Laboratory Use	0.003	0.218	0.05	

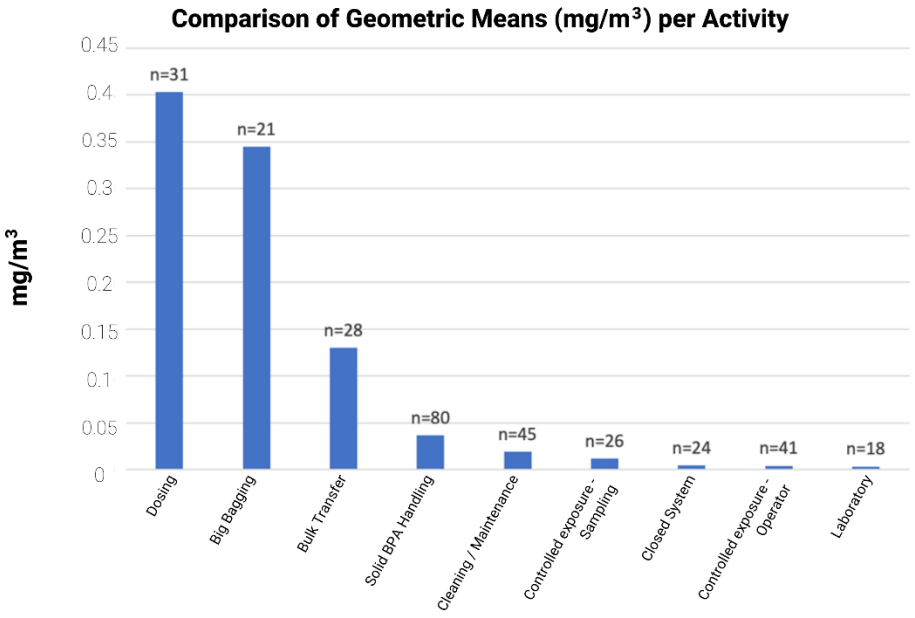


Figure 5: Comparison of geometric means across activities described in Table 2

Local Exhaust Ventilation Types and Efficiency

Use of Local Exhaust Ventilation (LEV) across all activities is perhaps surprisingly lower than one would anticipate but this can be explained by the extensive use of closed systems (PROC 1 / PROC 2) and the tendency to use LEV primarily where exposure, particularly to dusts, is anticipated (Figure 6). Indeed, for solid BPA handling operations there is a higher use of LEV during these activities (Figures 23, 26, 32) compared to closed systems (Figures 14, 17, 20).

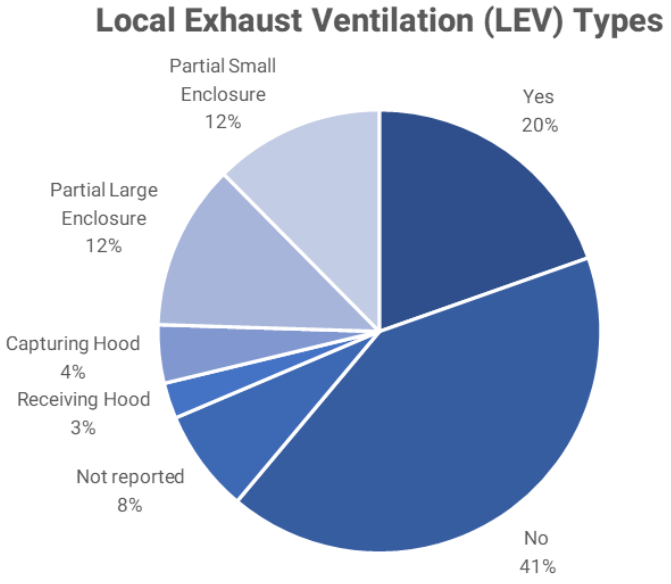
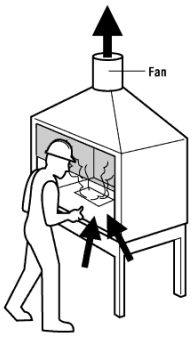
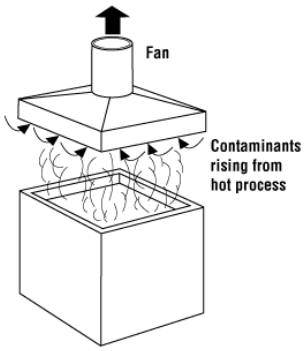


Figure 6: Local Exhaust Ventilation (LEV) types across all activities (n=306)

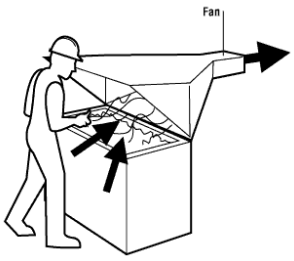
Enclosing hoods, or "fume" hoods, including partial enclosures are hoods surrounding the process or point where the contaminants are generated. Examples of completely enclosed hoods (all sides enclosed) are glove boxes and grinder hoods. Examples of partially enclosed (two or three sides enclosed) hoods are laboratory hoods or paint spray booths. The enclosing hood is preferred whenever possible.



Receiving Hoods are designed to "receive" or catch the emissions from a source that has some initial velocity or movement. For example, a type of receiving hood called a canopy hood receives hot rising air and gases, as shown.



Capturing hoods are located next to an emission source without enclosing it. Examples are a rectangular hood along the edge of a tank (as shown) or a hood on a welding or grinding bench table or a downdraft hood for a hand grinding bench.



Local Exhaust type used per activity was compared with air measurement to see if an indication of LEV efficiency could be determined, however the data variance prevent a firm conclusion at present.

Personal Protective Equipment

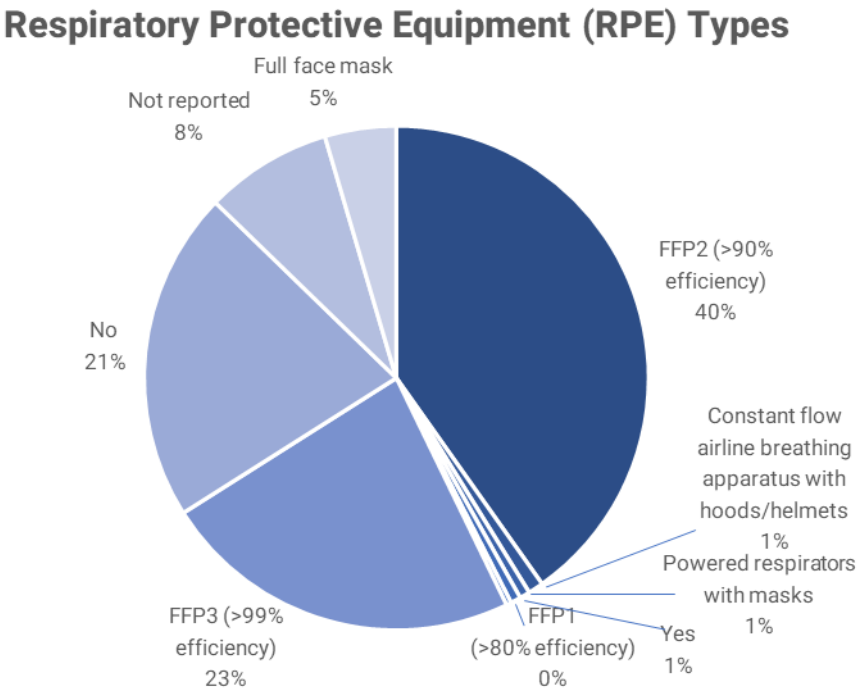


Figure 7: Reported Respiratory Protective Equipment (RPE) type across all activities (n=306)

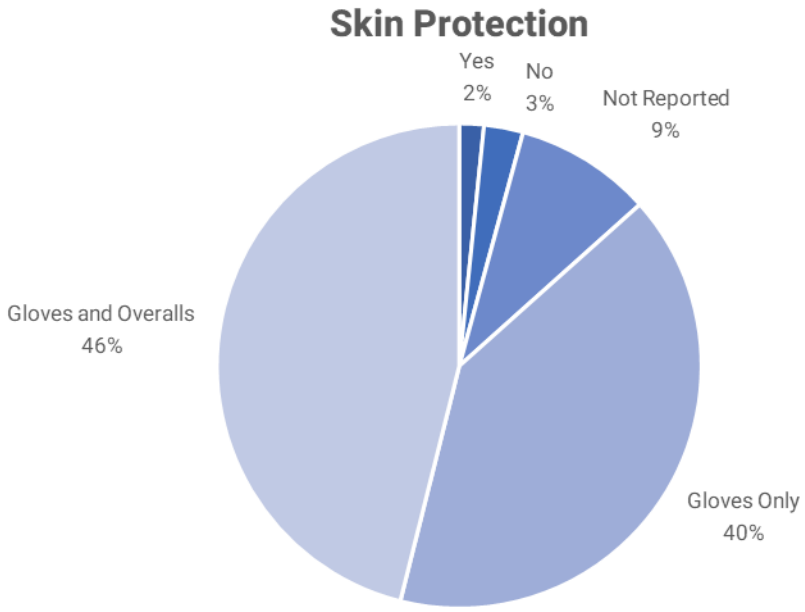


Figure 8: Reported Skin Protection methods across all activities (n=306)

There is a routine and consistent use of personal protective equipment – both respiratory (Figure 7) and skin protection (Figure 8) - across activities, in particular when viewed against those situations where collective protection from Local Exhaust Ventilation (LEV) cannot be assured, for example during dusty operations.

Sampling Types and Methods

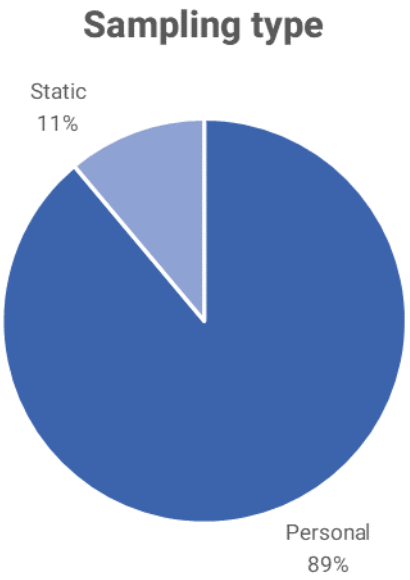


Figure 9: Prevalence of Personal vs Static/Stationary Sampling (n=306)

Sampling is primarily employed (Figure 9) via use of personal sampling devices for dusts, aerosols, and vapours. Most of the sampling is conducted for dust collected on glass or quartz fibre filters for subsequent analysis by High Performance Liquid Chromatography (HPLC). Direct IOM (Institute of Occupational Medicine) particle monitors[3] and Sidepack aerosol monitors[4] using light scattering measurements are also commonly used, whereas vapour collection makes up a small proportion of collection methods (Figure 10).

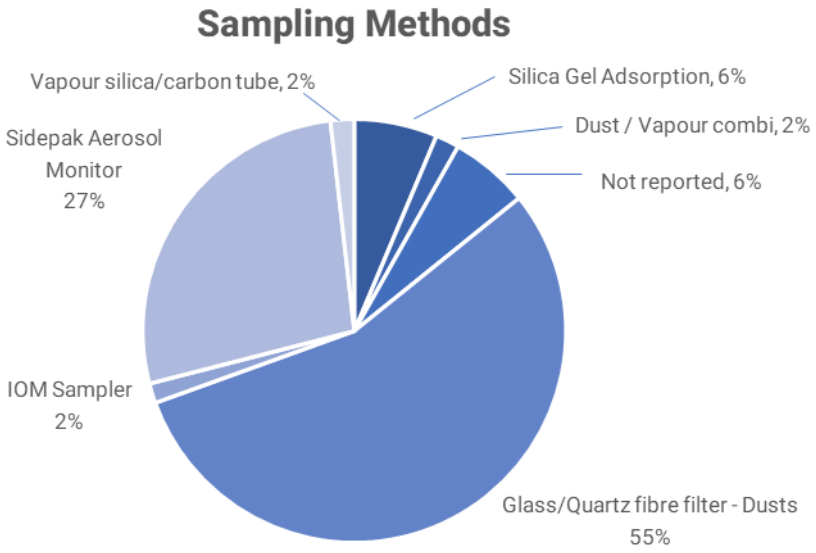


Figure 10: Sampling Methodologies applied across all activities (n=306)

[3] https://www.skcltd.com/products2/sampling-heads/iom-sampler.html

[4] https://tsi.com/products/aerosol-and-dust-monitors/aerosol-and-dust-monitors/sidepak%E2%84%A2-am520-personal-aerosol-monitor/

Analytical Methods

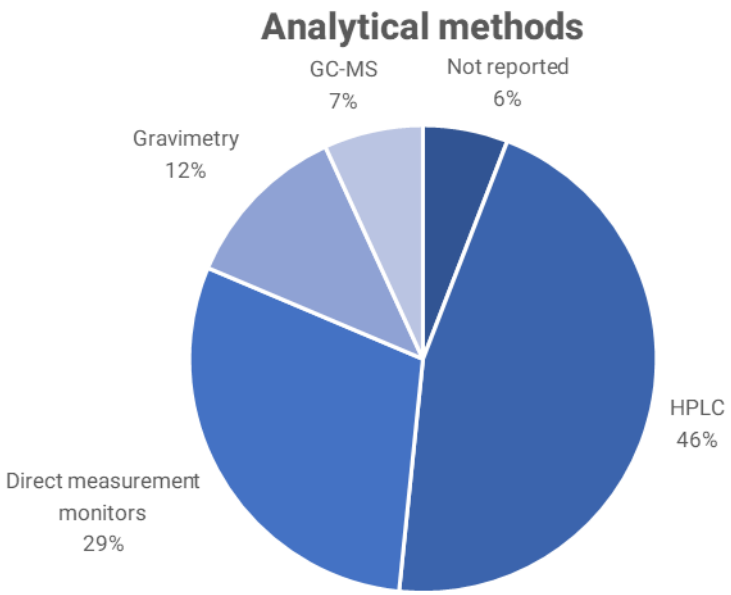


Figure 11: Analytical Methods applied across all activities

Different analytical methods are described across the reporting facilities, and even between activities at the same facility (Figure 11). Measurement of total dusts, for example using gravimetric methods and filter dust capture, was typically employed to confirm OEL compliance in some Member States (e.g., Denmark), however analysis for BPA itself is mostly achieved through use of HPLC measurements. Varying Limits of Quantitation (LoQ) are noted but are generally sufficiently sensitive (range of 0.001 to 0.09 mg/m^3). Direct measurement monitors for particles and aerosols is also common.

Closed Systems

Closed systems describe the general nature of processes taking place in the manufacture of substances or production of mixtures under closed process conditions as applied in chemical industry. Closed transfers inherent to the process including closed sampling are included. Open transfers to charge/discharge the system are not included.

As expected, exposure from closed systems is demonstrably low, with the maximum recorded concentration of 0.3 mg/m^3.

This activity is characterised by operations at room temperature using partial large enclosures, respiratory protection (FFP3 99% efficiency) and skin protection (gloves only), providing a remarkably elevated level of protection.

Only personal sampling methods are reported, either with an IOM sampler for gravimetric measurement of dusts or HPLC determination of vapours after silica gel absorption.

Table 5: Calculated percentiles of Air Exposure Measurements (mg/m^3)
Closed Systems based on 24 data points

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	<LoQ
25th Percentile (Quartile 1)	0.0026
50th Percentile (Median)	0.003
75th Percentile (Quartile 3)	0.003
90th Percentile	0.16
95th Percentile	0.28
Maximum	0.3
Arithmetic Mean (Average)	0.037
Standard Deviation	0.09
Geometric Mean	0.004
Geometric Standard Deviation	6.5
70% Confidence Level (95th Percentile)	0.01
70% Upper Confidence Limit (UCL)	0.047

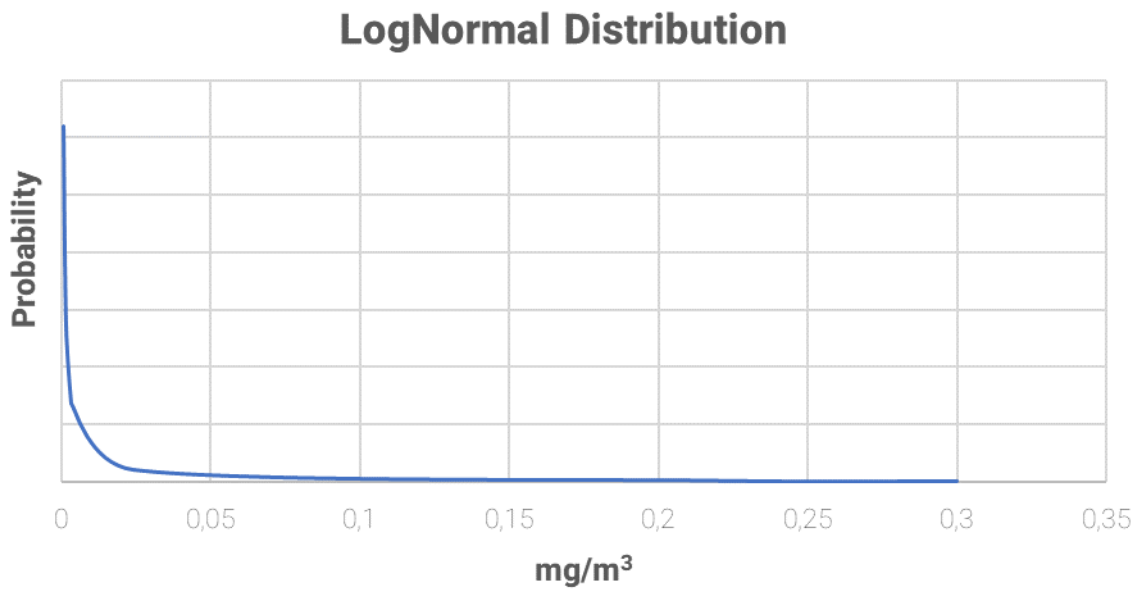


Figure 12: Closed systems – Data distribution (n=24)

24 individual air measurements corresponded to this activity, all of which were below the EU OEL of 2 mg/m^3. The calculated UCL is 0.047 mg/m^3.

Controlled exposure (PROC 2) – Sampling

26 individual data points describe PROC 2 activities involving sampling under conditions of occasional controlled exposure, with or without partially enclosed Local Exhaust Ventilation (LEV) (Figure 13).

Anticipated low exposure potential is confirmed, with additional Respiratory Protection Equipment (RPE) and skin protection typically used (Figure 15). Personal monitoring for dusts or aerosols is reported in all cases.

Table 6: Calculated statistics of Air Exposure Measurements (mg/m^3)
Controlled Exposure (PROC 2) Sampling with 26 data

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	<LoQ
25th Percentile (Quartile 1)	0.001
50th Percentile (Median)	0.01
75th Percentile (Quartile 3)	0.11
90th Percentile	0.57
95th Percentile	1.2
Maximum	1.5
Arithmetic Mean (Average)	0.18
Standard Deviation	0.4
Geometric Mean	0.01
Geometric Standard Deviation	15.9
70% Confidence Level (95th Percentile)	0.04
70% Upper Confidence Limit (UCL)	0.21

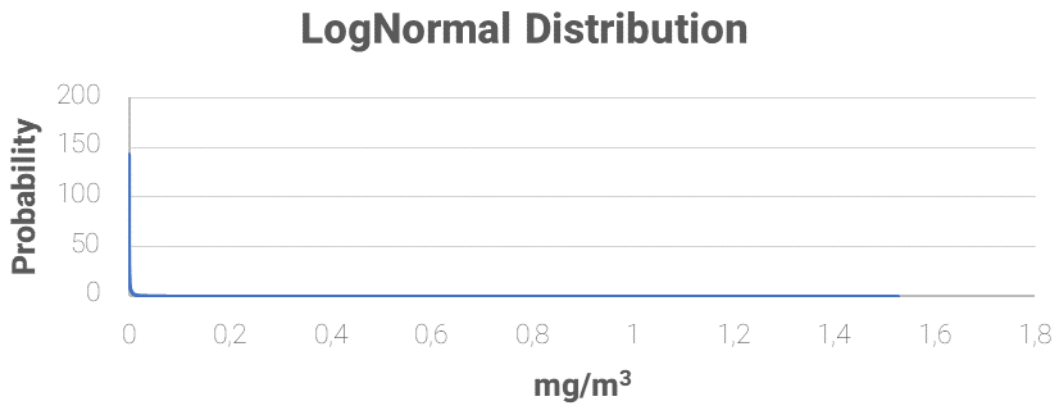


Figure 13: Controlled Exposure (PROC 2) Sampling – Data distribution (n= 26)

All air measurements fell below the EU OEL of 2 mg/m^3. The calculated 70% UCL is 0.21 mg/m^3.

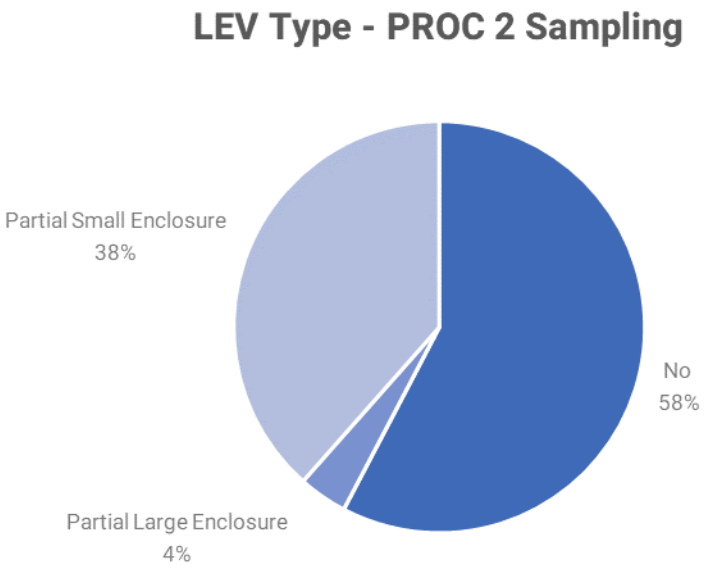


Figure 14: Local Exhaust Ventilation Types – Controlled Exposure (PROC 2) Sampling

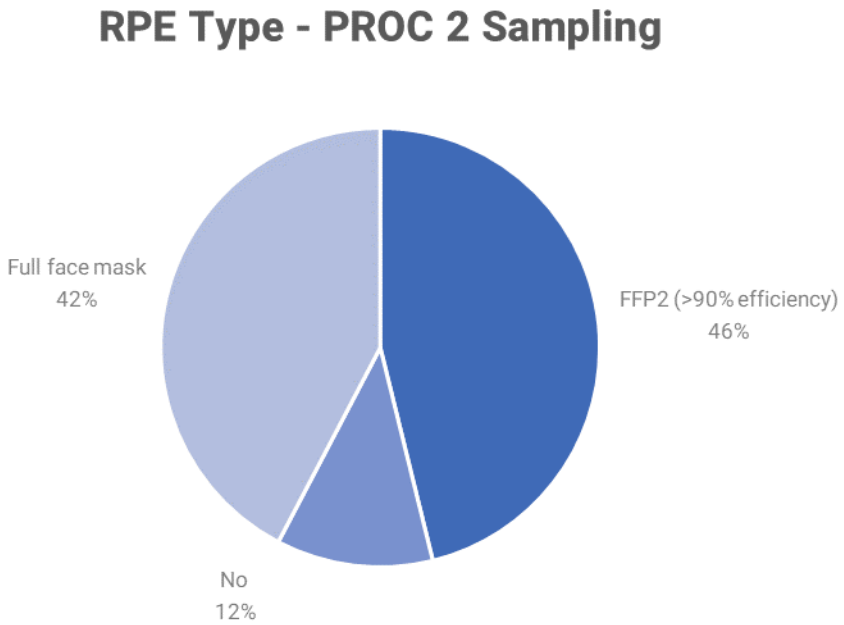


Figure 15: Respiratory Protective Equipment - Controlled Exposure (PROC 2) Sampling

Controlled exposure (PROC 2) – Operators

41 data points cover PROC 2 activities where the manufacture of substances or production of mixtures takes place (continuous processes that involve limited manual interventions). Both personal and static sampling, for BPA dusts, confirm the low exposure potential to shift workers / supervisors / control room operators under controlled exposure conditions. LEV and RPE are occasionally used.

Table 7: Calculated percentiles of Air Exposure Measurements (mg/m^3)
Controlled Exposure (PROC 2) Operators based on 41 data

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	<LoQ
25th Percentile (Quartile 1)	<LoQ
50th Percentile (Median)	0.003
75th Percentile (Quartile 3)	0.01
90th Percentile	0.09
95th Percentile	0.14
Maximum	0.46
Arithmetic Mean (Average)	0.038
Standard Deviation	0.09
Geometric Mean	0.0036
Geometric Standard Deviation	10.6
70% Confidence Level (95th Percentile)	0.0047
70% Upper Confidence Limit (UCL)	0.04

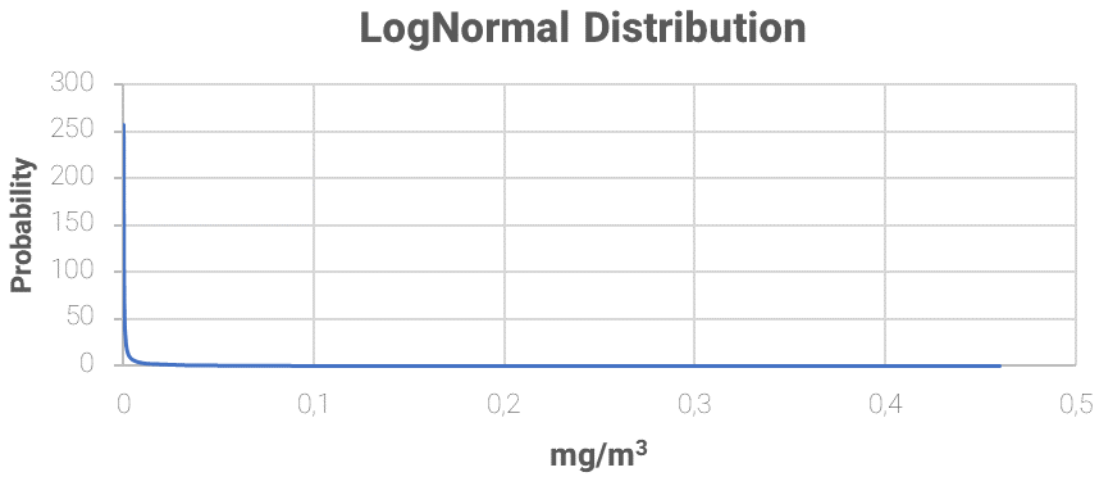


Figure 16: Controlled Exposure (PROC 2) Operators – Data distribution (n=41)

All 41 measurements fall below the EU OEL of 2 mg/m^3. The 70% UCL is 0.04 mg/m^3.

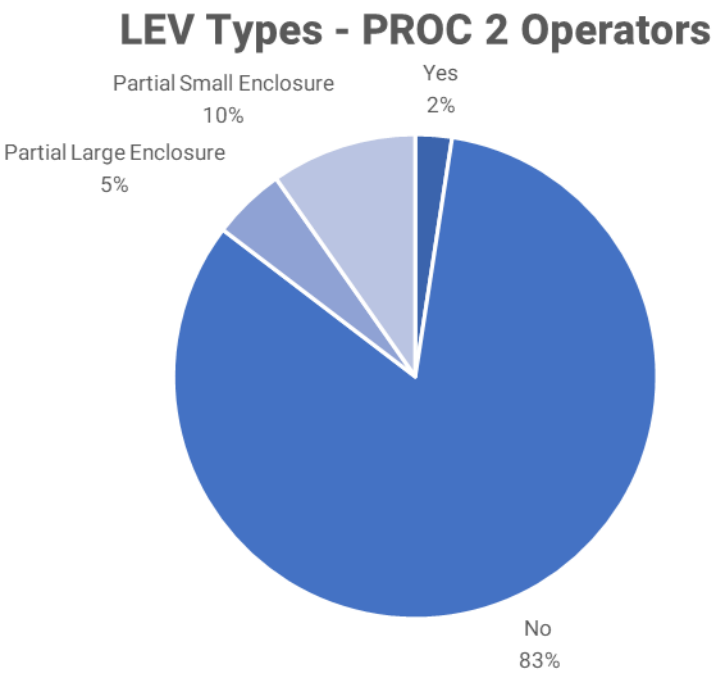


Figure 17: Local Exhaust Ventilation Types – Controlled Exposure (PROC 2) Operators

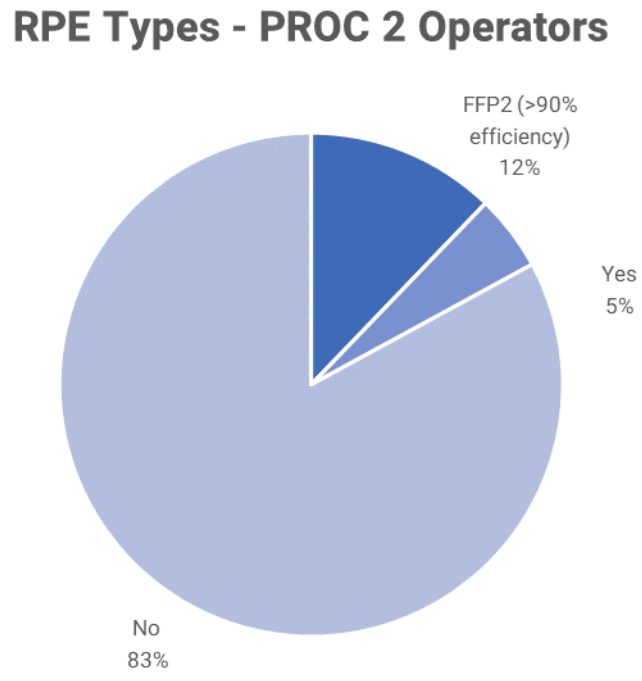


Figure 18: Respiratory Protective Equipment - Controlled Exposure (PROC 2) Operators

Cleaning and Maintenance

45 entries describing PROC 2 activities including: equipment cleaning, maintenance work, cleaning lines / process equipment, background whilst cleaning BPA dust separator, nozzle plate exchange at Polycarbonate extruder, filter change, opening BPA conveyor system.

LEV use is typically not reported, however high efficiency RPE and skin protection are used (Figures 20 and 21). 4 of the 45 values exceed the EU OEL of 2 mg/m^3, however all other measured values are well below 1 mg/m^3, indicating good exposure control. The 70% UCL is 0.77 mg/m^3.

Table 8: Calculated percentiles of Air Exposure Measurements (mg/m^3)
Cleaning and Maintenance (45 data sets)

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	<LoQ
25th Percentile (Quartile 1)	0.0035
50th Percentile (Median)	0.02
75th Percentile (Quartile 3)	0.05
90th Percentile	0.54
95th Percentile	6.75
Maximum	8.5
Arithmetic Mean (Average)	0.67
Standard Deviation	2
Geometric Mean	0.019
Geometric Standard Deviation	16.8
70% Confidence Level (95th Percentile)	0.1
70% Upper Confidence Limit (UCL)	0.77

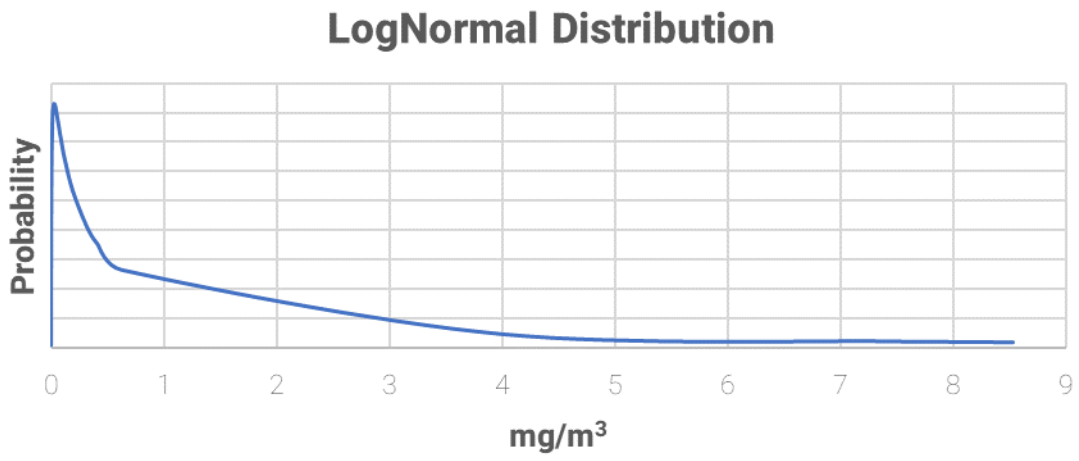


Figure 19: Cleaning & Maintenance – Data distribution (n=45)

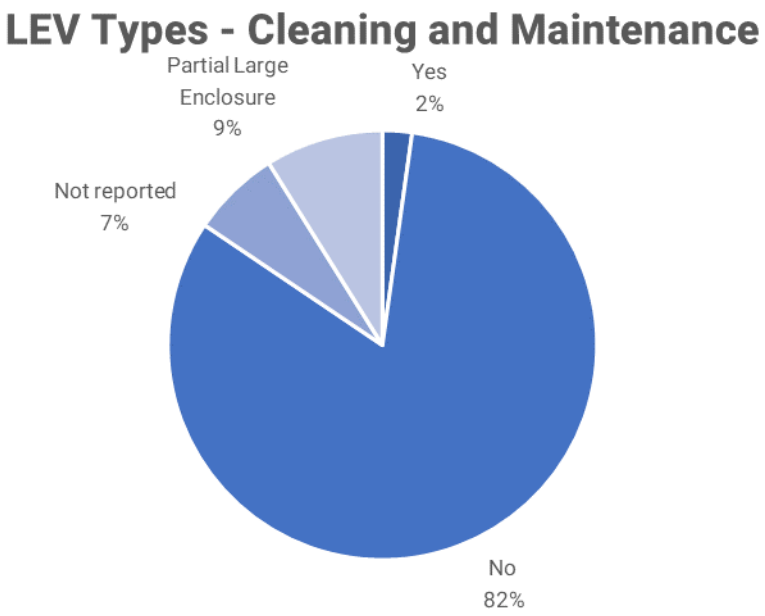


Figure 20: Local Exhaust Ventilation Types – Cleaning and Maintenance

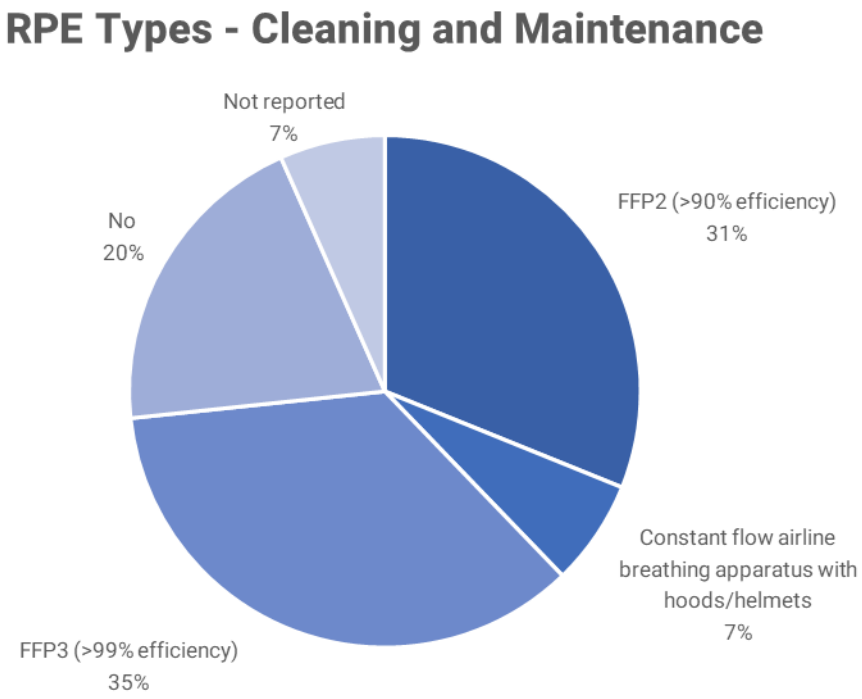


Figure 21: Respiratory Protective Equipment – Cleaning and Maintenance

Dosing

31 data entries describe dosing operations, mostly under PROC 8b conditions, including loading of bags of 25 kg of BPA in a hopper or proband mixer, manually charging bags of BPA into reactor vessel, formulation, filling the reactor with BPA and granulation.

Typically, partial small enclosures or fixed capturing hoods are employed to control dust, together with RPE (FFP2 >90% efficiency) or full-face masks / powered respirators and gloves. 9 of 31 exposure data reached or exceeded the EU OEL indicate that exposure is not controlled in all cases. The calculated 70% UCL (2.4 mg/m^3) is above the OEL of 2 mg/m^3.

Table 9: Calculated percentiles of Air Exposure measurements (mg/m^3) - Dosing (all 31 data)

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	0.03
25th Percentile (Quartile 1)	0.09
50th Percentile (Median)	0.72
75th Percentile (Quartile 3)	2.1
90th Percentile	6.4
95th Percentile	9.65
Maximum	12.46
Arithmetic Mean (Average)	1.9
Standard Deviation	3.2
Geometric Mean	0.4
Geometric Standard Deviation	11.1
70% Confidence Level (95th Percentile)	0.4
70% Upper Confidence Limit (UCL)	2.4

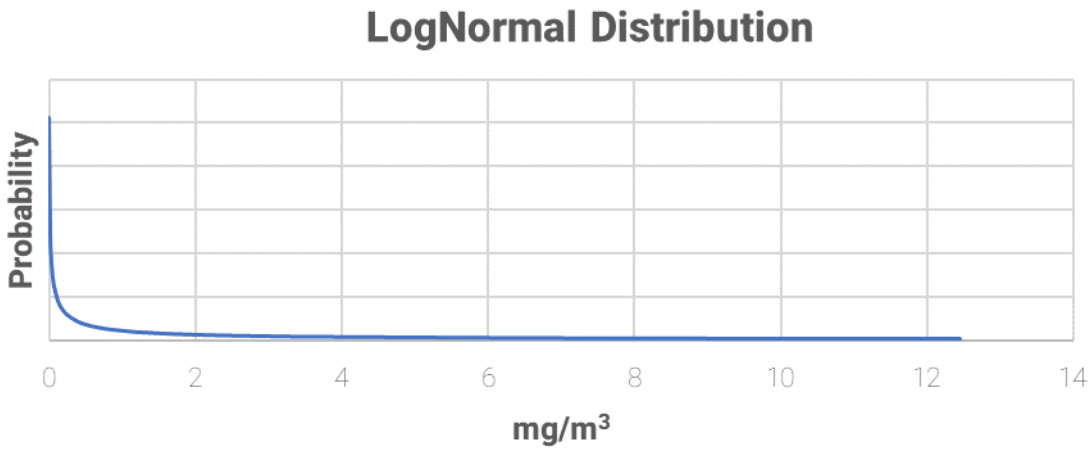


Figure 22: Dosing – Data distribution – (n=31)

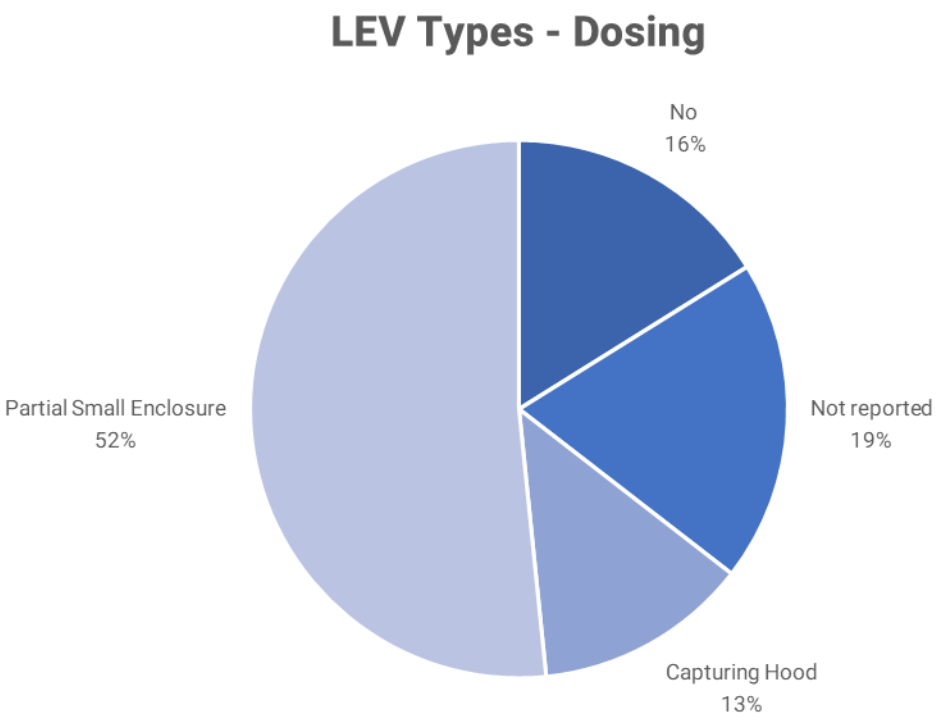


Figure 23: Local Exhaust Ventilation Types – Dosing

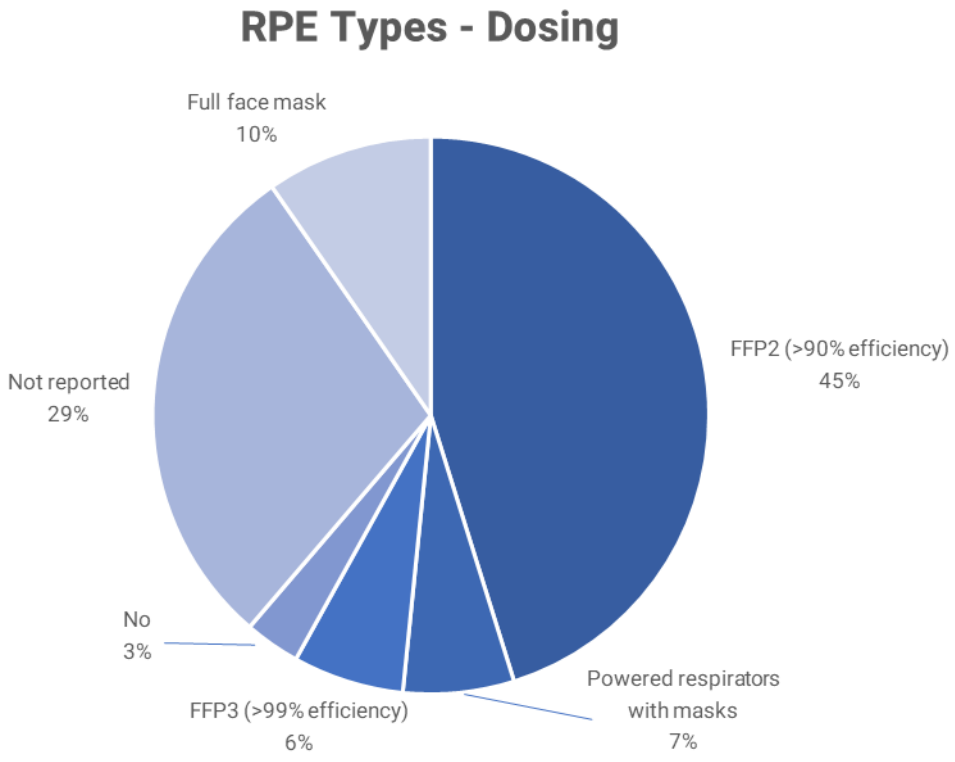


Figure 24: Respiratory Protective Equipment – Dosing

Bulk Transfers

20 entries describe PROC 8b activities involving on-site bulk transport and handling, including transfers from silo to trucks, forklift handling of Big-Bags, opening of the Big-Bag on the unloading equipment from the bottom, transfer of empty Big-Bags to waste container, unloading truck, transport from storage areas.

Partial large enclosures are used to control dusts and aerosols augmented in all cases by RPE, and with gloves and overalls for skin protection. Exposure is typically below 2 mg/m^3, however 3 out of 20 values exceed the EU OEL of 2 mg/m^3. The 70% UCL is 1.5 mg/m^3.

Table 10: Calculated percentiles of Air Exposure measurements (mg/m^3)
Bulk Transfers (all 20 data)

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	<LoQ
25th Percentile (Quartile 1)	0.03
50th Percentile (Median)	0.5
75th Percentile (Quartile 3)	1.1
90th Percentile	2.7
95th Percentile	5.8
Maximum	8.15
Arithmetic Mean (Average)	1.2
Standard Deviation	2.1
Geometric Mean	0.13
Geometric Standard Deviation	22.3
70% Confidence Level (95th Percentile)	0.3
70% Upper Confidence Limit (UCL)	1.5

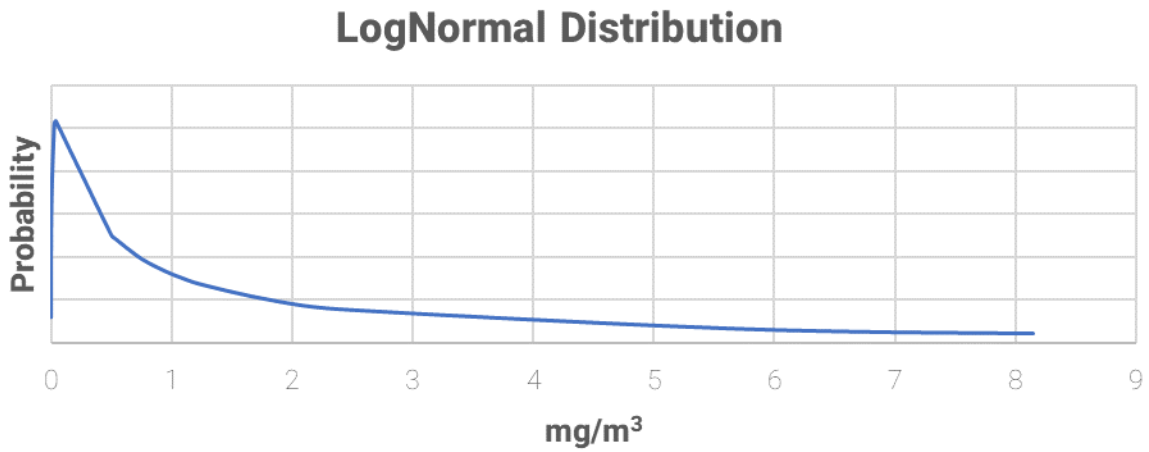


Figure 25: Bulk Transfers - Data distribution (n=20)

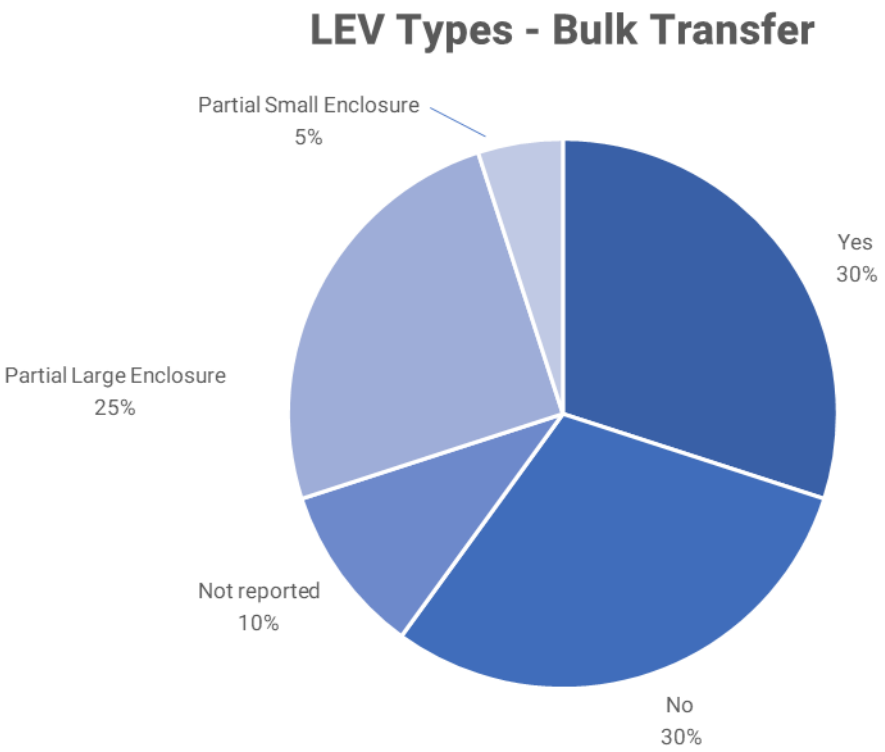


Figure 26: Local Exhaust Ventilation Types – Bulk Transfer

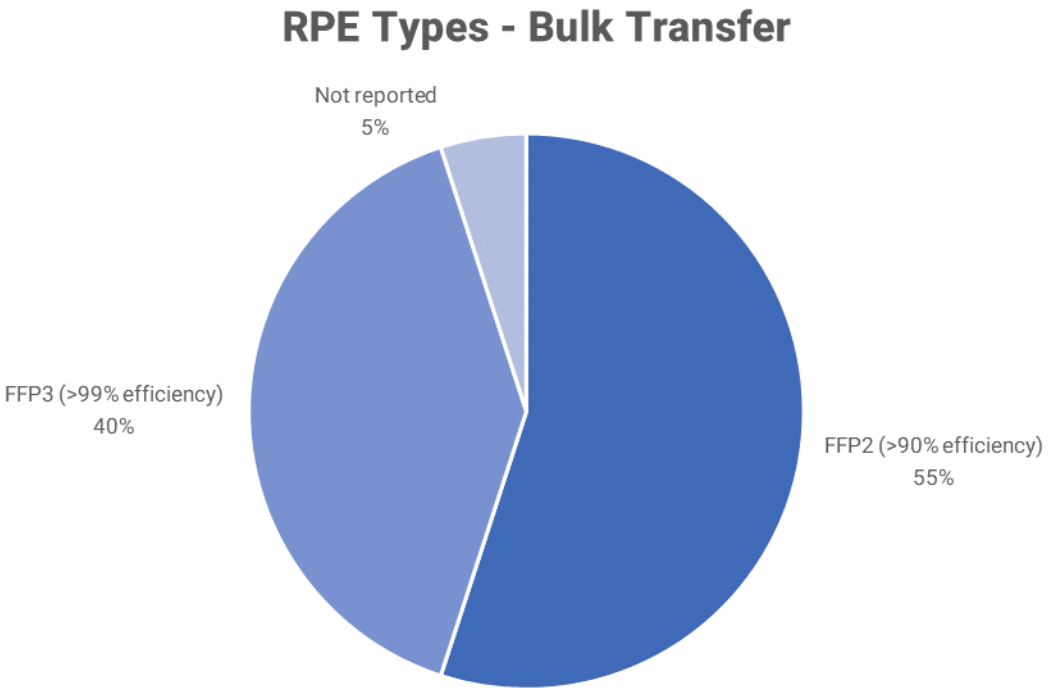


Figure 27: Respiratory Protective Equipment – Bulk Transfer

Big-Bag filling

21 air measurements are provided for activities involving granulation of BPA and filling to Big-Bags, exchange pelletizer (BPA pellets), and transfer from silos to Big-Bags in open dedicated facilities. Management of exposure levels is generally achieved by the employment of partial enclosures and additionally supplemented by RPE and skin protection.

2 of 21 air values exceeded the EU OEL of 2 mg/m^3. The 70% UCL is 0.99 mg/m^3.

Table 11: Calculated percentiles of Air Exposure Measurements (mg/m^3) – Big-Bag Filling (all 21 data)

Descriptor	Value [mg/m^3]
Minimum	0.02
10th Percentile	0.04
25th Percentile (Quartile 1)	0.19
50th Percentile (Median)	0.35
75th Percentile (Quartile 3)	0.66
90th Percentile	1.6
95th Percentile	2.5
Maximum	8.2
Arithmetic Mean (Average)	0.9
Standard Deviation	1.8
Geometric Mean	0.35
Geometric Standard Deviation	3.9
70% Confidence Level (95th Percentile)	0.1
70% Upper Confidence Limit (UCL)	0.99

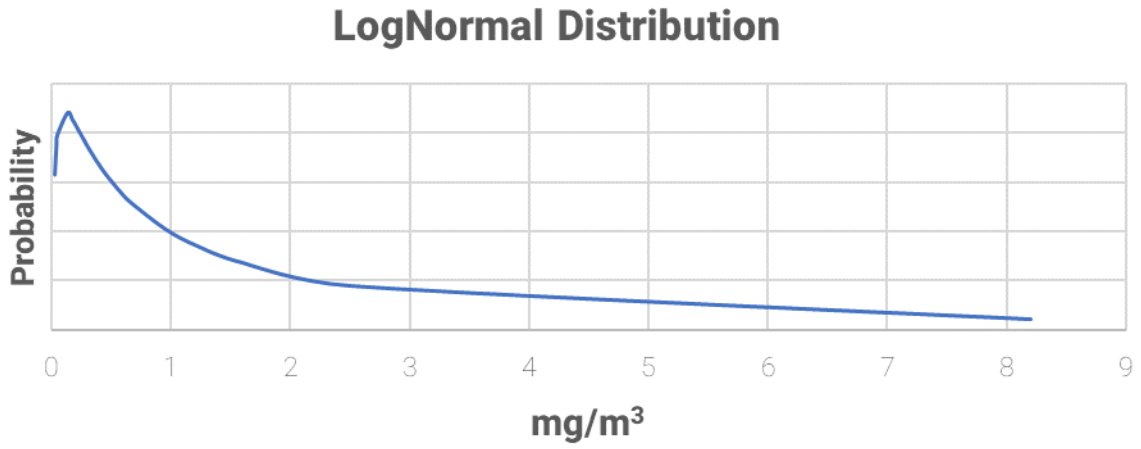


Figure 28: Big-Bag Filling - Data distribution (n=21)

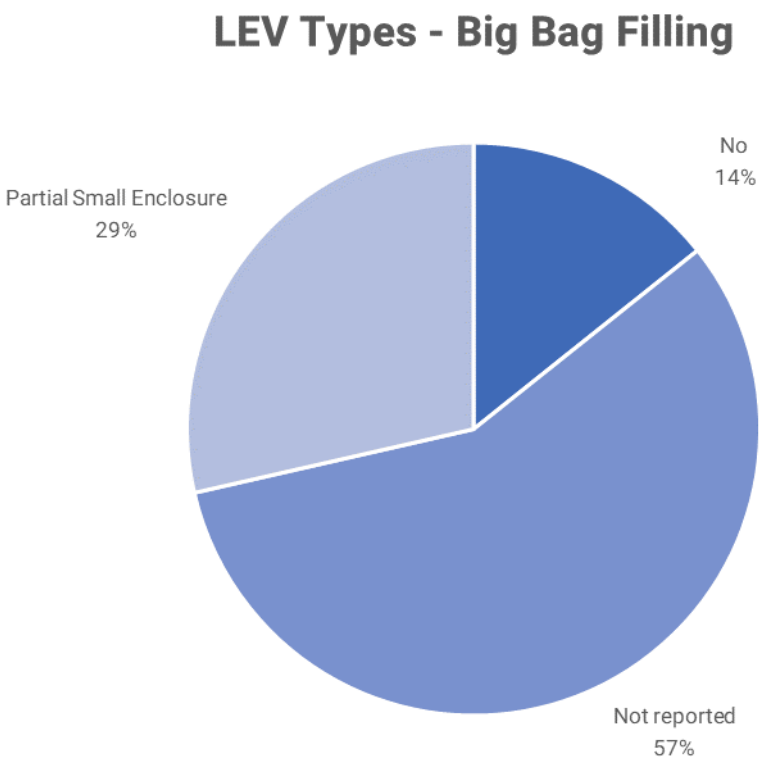


Figure 29: Local Exhaust Ventilation Types – Big-Bag Filling

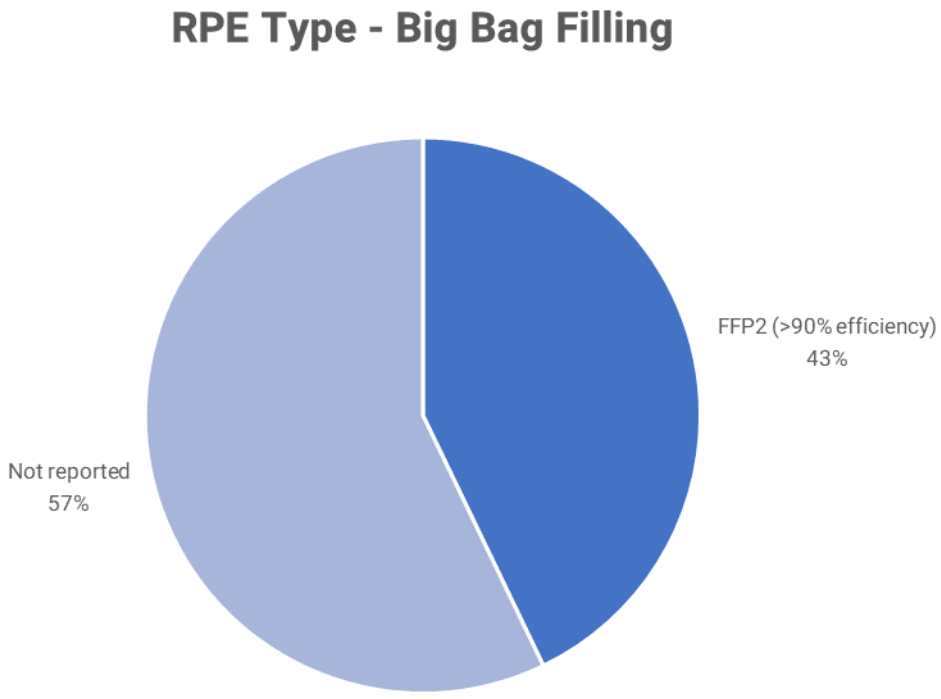


Figure 30: Respiratory Protective Equipment – Big-Bag Filling

Solid BPA Handling – other

The highest number of data points (n=80) are provided for solid BPA handling activities, involving BPA packing, bagging of small samples, filling totes, closed automated feed lines, manual lifting of bags to weigh station and loading pallets.

With a considerable number of outliers, this activity shows a wide range of air exposure values for dusts and aerosols which are typically not correlated with LEV type. Nevertheless, exposure seems to be well controlled below the EU OEL and there is a reliance placed on operator RPE use – mostly FFP2 (>90% efficiency) – and skin protection.

Table 12: Calculated percentiles of Air Exposure Measurements (mg/m^3) – Bagging – other (all 80 data)

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	<LoQ
25th Percentile (Quartile 1)	<LoQ
50th Percentile (Median)	0.05
75th Percentile (Quartile 3)	0.2
90th Percentile	1.4
95th Percentile	3.1
Maximum	7.3
Arithmetic Mean (Average)	0.5
Standard Deviation	1.3
Geometric Mean	0.03
Geometric Standard Deviation	18.9
70% Confidence Level (95th Percentile)	0.06
70% Upper Confidence Limit (UCL)	0.58

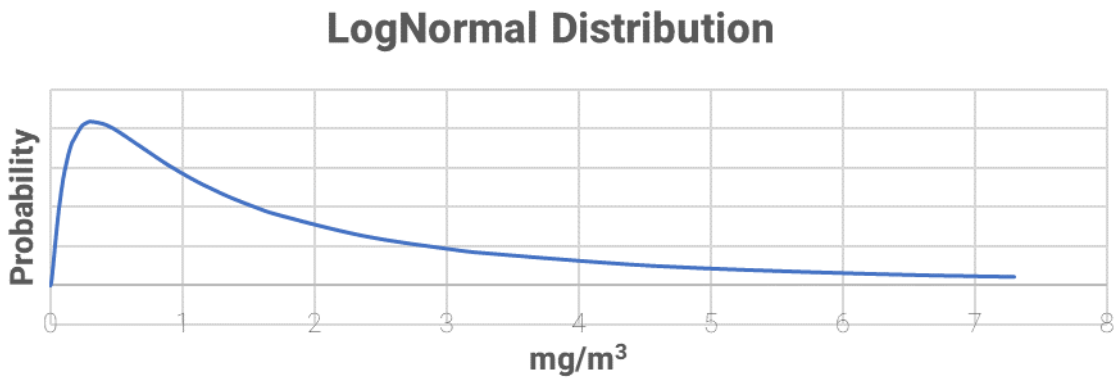


Figure 31: Solid BPA Handling - other – Data distribution (n=80)

6 of 80 values exceeded the EU OEL of 2 mg/m^3. The 70% UCL is 0.58 mg/m^3.

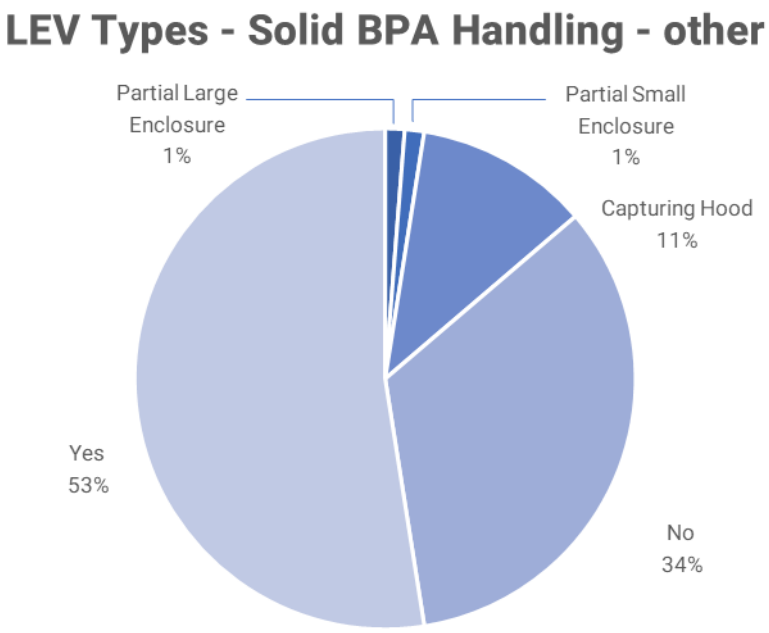


Figure 32: Local Exhaust Ventilation Types – Solid BPA Handling – other

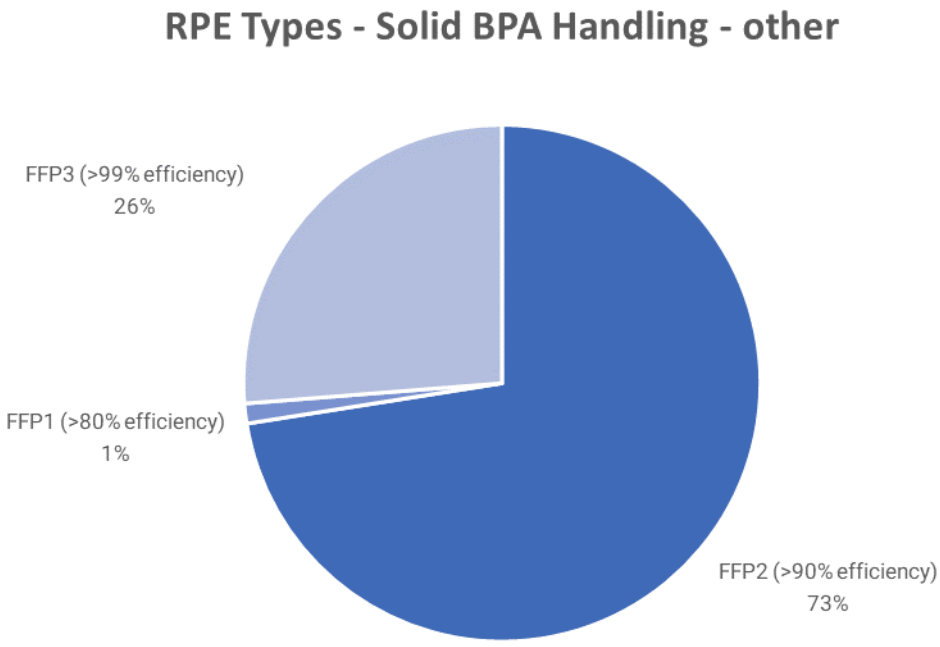


Figure 33: Respiratory Protective Equipment – Solid BPA Handling - other

Laboratory Use

18 available air measurements for dusts / aerosols confirm that PROC 15 laboratory / analytical work is conducted under well controlled exposure conditions.

Table 13: Calculated percentiles of Air Exposure Measurements (mg/m^3)
Laboratory Use (all 18 data)

Descriptor	Value [mg/m^3]
Minimum	<LoQ
10th Percentile	<LoQ
25th Percentile (Quartile 1)	<LoQ
50th Percentile (Median)	0.0015
75th Percentile (Quartile 3)	0.013
90th Percentile	0.076
95th Percentile	0.21
Maximum	0.46
Arithmetic Mean (Average)	0.04
Standard Deviation	0.1
Geometric Mean	0.003
Geometric Standard Deviation	11
70% Confidence Level (95th Percentile)	0.01
70% Upper Confidence Limit (UCL)	0.05

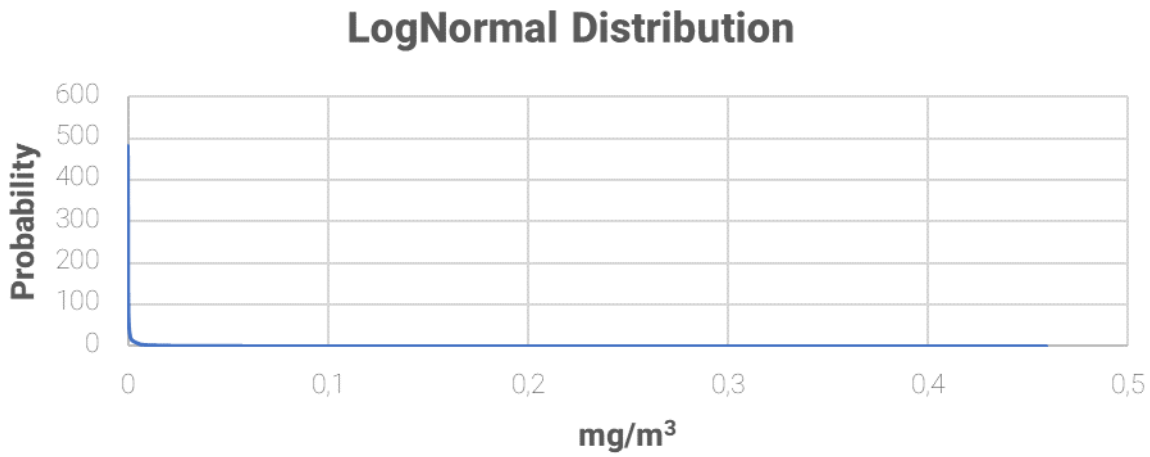


Figure 34: Laboratory Use – Data distribution (n=18)

All measured values fall well below the EU OEL of 2 mg/m^3. The 70% UCL is 0.05 mg/m^3.

Discussion and Conclusions

The purpose of this report is to provide an overview on available data of workplace exposure to BPA during its production and subsequent transformation to Polycarbonate or Epoxy systems.

The data gathered in this report originated from the majority of all European plants for BPA manufacturing and its conversion into Polycarbonate and base Epoxy resins. These conversions account for 98 % of all uses of BPA. Downstream uses of Polycarbonate and Epoxy Resins are not covered in this report. There is no handling of BPA during downstream process steps of Polycarbonate, i.e. the manufacturing of articles. Polycarbonate only comprises traces of residual BPA.
For Epoxy uses, there are additional downstream actors in the value chain handling BPA. These additional downstream uses have not been included in the data collection.

Exposure from BPA uses other than Polycarbonate and Epoxy resin manufacturing (2%) have not been assessed in this study.

The provided air measurement data show a degree of variability, coming from multiple sources employing different sampling methodologies and analytical techniques. For example, dusts may be collected and subjected to HPLC analysis, however some measurements reported total dusts, which may provide an overestimate of exposure in some cases.

Nevertheless, when viewed in its totality across all activities, the data demonstrate that exposure to BPA dusts/vapours and aerosols is well controlled at these facilities.

Except for a small number of measured values, exposures are typically well below the current EU OEL value (OEL) of 2 mg/m^3.

Activities can broadly be grouped into two categories according to exposure potential.

1) Lower exposures (geometric mean $\leq$ 0.01 mg/m^3) are observed during controlled activities involving closed systems (PROC 1 and PROC 2). The related activities are demonstrably safe. Where appropriate, these activities are supplemented by enhanced Respiratory Protective Equipment.

2) Higher exposures (geometric mean 0.02 to 0.4 mg/m^3) are observed during activities where dusts may be generated and that require manual handling, such as bagging, dosing, bulk transfer, filling and emptying of bags/hoppers (corresponding to PROC 4, PROC 8b and
PROC 9). It is notable that these activities show more dependence on the use of

respiratory protection against dusts, with common use of FFP2 and FFP3 particle masks.

Using a statistical test from the EN 689 standard indicates that exposure from most activities is anticipated to remain below the current EU OEL. There is one exception - dosing - which shows the highest mean exposures and where the 70% Upper Confidence Limit (UCL) slightly exceeds the current EU OEL. However, these dosing activities are typically performed using Respiratory Protective Equipment (RPE).

When mapped according to year of measurement, the data suggest an overall slight reduction in exposures across all activities, however the findings are not statistically robust enough to allow a firm conclusion on the overall trend of exposure reduction over time.

In conclusion, the available workplace exposure data from activities in the manufacturing of BPA and its conversion to Polycarbonate and Epoxy resins generally demonstrate good ability to comply with historical and current Occupational Exposure Limits (OELs). Activities where handling of solid BPA leads to highest potential for exposure, measurement data mostly showed air concentrations below the current EU binding OEL of 2 mg/m³. Worker protection is facilitated by the use of closed systems and Local Exhaust Ventilation (LEV) during manual handling activities. Protection is further enhanced by the common use of Respiratory Protective Equipment (RPE).

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Thank you

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