Propagation modelling based on airborne particle release data from nanostructured materials for exposure estimation and prediction

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Abstract. The gap between release and exposure is limiting the current risk assessment of nanostructured materials. Both, release and exposure were connected to each other by transport and transformation processes and require therefore the description/specification of complex exposure scenarios. Within this study, propagation modelling based on experimentally determined airborne particle release data was used for exposure estimation and prediction in a defined model room. Therefore, 9 different exposure scenarios based on 3 release scenarios and 3 ventilation scenarios were analysed. Results for near field considerations have shown that the level of inhalation exposure is fundamentally defined by the present exposure scenario, that personal heat can cause particle availability in the breathing zone and that highest exposure levels arise immediate during material processing.

1. Introduction

Risk assessment on nanostructured materials requires data on both exposure and substance-specific hazard \cite{1}. Robust data for exposure estimation can be determined systematically by release analyses in laboratory \cite[e.g. 2, 3]{2}, which are currently became standardised \cite{4}. The state of dispersion (i.e. concentration, size) after release (condition at the particle source) can change significantly until exposure (condition at the entrance to the subject of protection) due to transport (e.g. dilution) and transformation (e.g. agglomeration) processes. Thus, one has to distinguish strictly between release and exposure data, because only in exceptional cases (i.e. accidents, misuse) release quantities can become exposure ones. Accordingly, exposure characterisation suffers usually on poorly reproducible, often cross-contaminated measurement data and requires in addition numerous contextual information \cite[e.g. on environment, ventilation conditions, particle source characteristics, sampling strategy]{5} for data interpretation \cite{5}. In this context, release characterisation aimed to provide information solely on the particle source, i.e. process-specific and preferably quantitative release data as the origin of exposure.

During the last years we have performed several experimental studies on the characterization of airborne particle release from nanostructured materials along their life-cycle, i.e. for the handling of powders \cite{6}, due to the spray application of liquid coatings \cite{7, 8} and during weak and moderate mechanical stress on solid composite materials (i.e. coatings, plastics) by abrasion \cite{9} and sanding.
[10-12]. Additionally, the impact of artificial aging and weathering on the release from solid composite materials due to wind erosion, dynamic friction and sanding was investigated [11, 12]. In order to provide quantitative data for further use, we renounced the use of measured particle concentration values and evaluated instead fractional numbers of released particles as described in [11] and which were related for the purpose of data-transfer (i.e. for scale-up/scale-down use) to process-specific values, like the stressed sample mass in the case of powder handling or the stressed surface area due to sanding [cf. 13, 14]. Note, that release rates (i.e. release quantities related to time), which are often requested in this context [e.g. 3, 5], are seen as derived semi-quantitative data of quantitative release data and thus are only valid for one case considerations.

Despite numerous release and exposure studies dealing with nanostructured materials [e.g. 2, 3, 15-17], there is still a gap concerning the use of release data for exposure estimation and thus for risk assessment [3]. To start with filling the gap, propagation modelling based on experimental determined release data was performed within the actual study for different exposure scenarios.

2. Details on propagation modelling

2.1. Computational details

2.1.1. Calculation modules. Propagation modelling was performed by coupling different calculation modules [e.g. 18] within a “parallel virtual machine” (PVM). The simulation of the indoor air flow is done by the computational fluid dynamic module ParallelNS [e.g. 19], which is based on a GALERKIN-Least-Squares finite element approach (GLS-FEM). This module uses the unsteady REYNOLDS-averaged NAVIER-STOKES equations (URANS) combined with various turbulence models, specific iterative wall functions and boundary layer approaches. To consider both fluid dynamics and thermodynamics within a geometric envelop, an enhanced version of a commercial thermal building simulation module called TRNSYS-TUD was coupled with ParallelNS.

2.1.2. Grid and time resolution. For the purpose of modelling, the grid of the chosen model room described in chapter 2.2 (cf. surfaces in Figure 1 b) was endowed with 800000 tetrahedron elements, whereof 350000 ones accrued around the person. Modelling was performed to observe the air quality over a time frame of 120 min. The first 30 min were solely used to receive stationary air-flow conditions before the actual release scenarios (see chapter 2.4) were launched.

2.1.3. Simplifications on release processes and airborne particles. The main appointed simplifications regarding release were that the release processes do not interact with their environment (i.e. particles are supplied interference-free without directional momentum in a source volume) and that the released airborne particles behave gas-like. The former one allows the embedding of any release quantity after completed propagation modelling. The latter one means that particle-particle interactions (e.g. agglomeration), particle-wall interactions (e.g. loss of airborne particles by deposition) and some other particle interactions (e.g. loss of airborne particles by settling) were at first disregarded. Interestingly, a subsequent verification of the simplifications regarding the behaviour of airborne particles after modelling, which will not be discussed in this paper, has shown that the particle interactions (e.g. agglomeration) cause a comparable minor impact on the level of exposure.

2.2. Model room specifications

2.2.1. Geometric specifications. Figure 1 (a) shows the chosen model room (5 m x 6 m x 3 m), which contains of a triple-part window (5 m x 1.5 m), a door, a heated floor, a workbench (1 m x 4 m x 0.95 m) and a person (1.8 m). Dark blue and red highlighted areas illustrate the positions for air inlet as well as for air outlet, which were used for the different ventilation scenarios described in chapter 2.3. Green highlighted areas show the particle source regions for the release scenarios (cf. chapter 2.4),
which were positioned in front of the person. Figure 2 (b) shows also the sensor location (red circle) in
the breathing zone (1.6 m) of the person.

2.2.2. Thermal specifications. Except for the north wall with the window and the floor, all other walls
as well as the ceiling are surrounded by other rooms. All walls fulfil the requirements of the German
Energy Saving Ordinance (EnEV 2009). The outdoor temperature was set to $\theta_{\text{outdoor}} = 5^\circ\text{C}$ that corres-
ponds to the mean European outdoor temperature in winter time. The underfloor heating provides a
mean room temperature of $\theta_{\text{room}} = 20^\circ\text{C}$, that lead to varying floor temperatures in the dependence of
the ventilation scenario (cf. chapter 2.3). Excepting head ($\theta_{\text{head}} = 35^\circ\text{C}$) and hands ($\theta_{\text{hands}} = 30^\circ\text{C}$), the
thermal-active person has a surface temperature of $\theta_{\text{clothes}} = 26^\circ\text{C}$ as typical for a clothed one at moder-
ate activity. All data were chosen according to DIN EN ISO 7730:2006 [20].

![Figure 1](image)

**Figure 1.** Model room envelope and interior (a) as well as positions of release sources and breathing
zone sensor (b); blue areas = air inlets, red areas = air outlets, green regions = particle release sources.

2.3. Ventilation scenarios

To consider both consumer protection and occupational safety, three different ventilation scenarios
were studied, i.e. natural ventilation by door-slit infiltration, natural ventilation by a pivot-hung
window and by an improved technical ventilation system. The main specifications of the ventilation
scenarios are summarised within Table 1.

| ventilation scenario | ID | air exchange rate [h$^{-1}$] | air inlet temperature [$^\circ\text{C}$] | comments on air inlet and outlet [-] |
|----------------------|----|-----------------------------|--------------------------------------|-----------------------------------|
| natural ventilation by door-slit infiltration | NVD | 0.5 | 20 | air inlet at door slit on east wall, air-outlet at ceiling on west wall |
| natural ventilation by pivot-hung window | NVW | 1.5 | 5 | air inlet and outlet at window on north wall |
| improved technical ventilation system | TVS | 8.0 | 20 | air inlet and outlet at ceiling of east and west wall, flow orientation on workbench |

2.4. Release scenarios

Three different near field release scenarios were chosen in this study, i.e. dry wiping of a coated work
piece (1 m x 0.5 m = 0.5 m²) for 10 s, belt sanding of a coated work piece (1 m x 0.5 m = 0.5 m²) for
60 s and spray can application of a liquid coating for 60 s. The main specifications of the release
scenarios are summarised in Table 2.
Table 2. Main specifications of the release scenarios.

| release scenario | ID ref. | original sample | area-spec. particle release number < 10 µm [#/m²] | particle release rate < 10µm [#/s] | processing time [s] | processed area [m²] | source volume [L] |
|------------------|---------|----------------|-----------------------------------------------|---------------------------------|-------------------|------------------|------------------|
| wiping           | WIP     | UV-ZnO         | 5.0E+05                                       | n.r.                            | 10                | 0.5              | 50               |
| sanding          | SAN     | UV*-ZnO        | 1.0E+11                                       | n.r.                            | 60                | 0.5              | 50               |
| spraying         | SPR     | PU-ZnO         | n.r.                                          | 7.5E+09                         | 60                | n.r.             | 8                |

* UV-curable parquet coating doped with ZnO nanoparticle additive (UV-ZnO)
* 2000 h artificially aged UV-curable parquet coating doped with ZnO nanoparticle additive (UV*-ZnO)
* two-pack polyurethane coating doped with a ZnO nanoparticle additive (PU-ZnO)
* not relevant

For the purpose of traceability, the measured number-weighted particle size distributions (\(q_0\)) of the chosen original samples were fitted at first to lognormal number-weighted density distributions (\(q_{0,LNVT}\)). This led to the case of sanding to a number-weighted median diameter of \(x_{50,0,SAN} = 240\) nm and a geometric standard deviation of \(GSD_{SAN} = 1.4\), for spraying to \(x_{50,0,SPR} = 120\) nm and \(GSD_{SPR} = 2.0\). Furthermore, the \(q_{0,LNVT}\) were converted according to ISO 9276-5:2005 [21] into volume/mass-weighted ones (\(q_{3,LNVT}\)) to provide volume/mass-weighted data. Note that the conversion of particle size distributions \(q_0\) between the different types of quantities can lead to huge errors, especially by operating lognormal fits [22]. However, \(q_{0,LNVT}\) and \(q_{3,LNVT}\) were combined with a gender and activity averaged modified ICRP 66 model for particle deposition in the human respiratory tract of adults as provided in [23] to determine the fractions of total deposition (\(\eta_{dep,tot,r}\)) as well as regional deposition for the head airways (\(\eta_{dep,HA,r}\)), the tracheobronchial region (\(\eta_{dep,TB,r}\)) and the alveolar region (\(\eta_{dep,AL,r}\)) based on the fraction of inhaled particles (\(\eta_{inh,r}\)). This results in the following set of empirical equations, wherein the parenthesized terms are the deposition efficiencies provided in [23].

\[
\begin{align*}
\eta_{inh,r} &= \frac{100 \mu m}{100 \mu m} \left[ 1 - 0.5 \left( 1 - \frac{1}{1 + 0.00076 \cdot x^2} \right) \right] q_r(x) dx \\
\eta_{dep,tot,r} &= \frac{100 \mu m}{100 \mu m} \left[ 1 - 0.5 \left( 1 - \frac{1}{1 + 0.00076 \cdot x^2} \right) \right] q_d(0.0587 + 0.911 \cdot 1 + \exp(0.508 - 2.50 \cdot \ln(x))) q_r(x) dx \\
\eta_{dep,HA,r} &= \frac{100 \mu m}{100 \mu m} \left[ 1 - 0.5 \left( 1 - \frac{1}{1 + 0.00076 \cdot x^2} \right) \right] q_d(0.0587 + 0.911 \cdot 1 + \exp(0.508 - 2.50 \cdot \ln(x))) q_r(x) dx \\
\eta_{dep,TB,r} &= \frac{100 \mu m}{100 \mu m} \left[ 1 - 0.5 \left( 1 - \frac{1}{1 + 0.00076 \cdot x^2} \right) \right] q_d(0.0587 + 0.911 \cdot 1 + \exp(0.508 - 2.50 \cdot \ln(x))) q_r(x) dx \\
\eta_{dep,AL,r} &= \frac{100 \mu m}{100 \mu m} \left[ 1 - 0.5 \left( 1 - \frac{1}{1 + 0.00076 \cdot x^2} \right) \right] q_d(0.0587 + 0.911 \cdot 1 + \exp(0.508 - 2.50 \cdot \ln(x))) q_r(x) dx \\
\end{align*}
\]

A summary of the determined number- and mass-weighted fractions for total and regional deposition in the human respiratory tract is provided in Table 3. Note that in [9] no particle size distribution could be determined based on the low numbers of released particles.

Table 3. Number- and mass-weighted fractions for regional deposition in the human respiratory tract based on the gender and activity averaged modified ICRP 66 model for adults [23].

| release scenario | ID ref. | original sample | parameter of \(q_{0,LNVT}\) | number-weighted fractions for total and regional deposition | mass-weighted fractions for total and regional deposition |
|------------------|---------|----------------|-------------------------------|----------------------------------------------------------|---------------------------------------------------------|
|                  |         |                | \(x_{50,0}\) | GSD | \(\eta_{dep,HA,0}\) | \(\eta_{dep,TB,0}\) | \(\eta_{dep,AL,0}\) | \(\eta_{dep,HA,3}\) | \(\eta_{dep,TB,3}\) | \(\eta_{dep,AL,3}\) |
| wiping           | WIP     |                | 50.0 | 1.4 | 11.30 | 3.80 | 0.80 | 6.70 | 14.10 | 6.50 | 0.70 | 6.90 |
| sanding          | SAN     | UV*-ZnO        | 240  | 2.0 | 21.52 | 3.37 | 3.04 | 15.12 | 26.21 | 15.67 | 1.56 | 8.98 |
| spraying         | SPR     | PU-ZnO         | 120  | 2.0 | 21.52 | 3.37 | 3.04 | 15.12 | 26.21 | 15.67 | 1.56 | 8.98 |
3. Results

3.1. Ventilation scenarios

To assess the quality of air exchange in steady state flow conditions, the ventilation scenarios were compared using the local air exchange index $\varepsilon$, which is defined as the ratio of the mean air age at the exit $\tau_{\text{mean,out}}$ (i.e. reciprocal of air exchange rate $n_{\text{AER}}$) to the local air age $\tau_{\text{local}}$ in the room [e.g. 18, 24]:

$$\varepsilon = \frac{\tau_{\text{mean,out}}}{\tau_{\text{local}}} = \frac{1}{n_{\text{AER}} \cdot \tau_{\text{local}}}$$ (2)

Local air exchange indices of $\varepsilon < 1$ indicate regions of poor air exchange, while for $\varepsilon > 1$ regions with effective air exchange can be identified. Figure 2 provides beside the local air exchange index, the velocity field in the room as well as the mean velocity in the sectional plane through the working area for the three simulated ventilation scenarios in stationary state.

![Graphs showing local air exchange index and flow velocity field in the model room and mean flow velocity in sectional plane (through working area) for different ventilation scenarios.](image)

**Figure 2.** Quality of air exchange and mean velocity in the sectional plane at stationary state for the different ventilation scenarios.
Figure 2 reveals that in the case of NVD an effective air exchange can only be found on the floor behind the person, while in case of NVW regions of effective air exchange are limited to the window and the floor. The best spatial distributed regions of effective air exchange arose for TVS. Regardless the kind of ventilation, a local air exchange index of about 1 can be observed at the breathing zone, i.e. the local air age correlates with the air exchange rate. As it can be deduced from the mean velocity illustration, both NVD and NVW suffer from a poor flow through the working area in contrast to TVS. Furthermore, comparable high flow velocities on the person caused by personal heat can be observed.

3.2. Propagation scenarios and exposure scenarios
When reaching steady state ventilation conditions after 30 min, the release scenarios (cf. chapter 2.4) were launched for \( \leq 1 \) min. A visualization of the particle cloud propagation at 100 s after release initiation for sanding and spraying based on the three ventilation scenarios is provided in Figure 3.

![Visualisation of the particle cloud propagation at 100 s after release initiation based on the illustration of three different iso-surfaces for the relative gas exchange.](image-url)

**Figure 3.** Visualisation of the particle cloud propagation at 100 s after release initiation based on the illustration of three different iso-surfaces for the relative gas exchange.
As it can be deduced from Figure 3 for all propagation scenarios, the flow velocities of around 0.2 m/s on the person caused by personal heat (cf. Figure 2) lead to an up-flow and thus to an aerosol propagation in direction to the ceiling via the breathing zone. In contrast to NVD and NVW, the TVS led to a faster dilution of the released airborne particles that is indicated by considerable higher spatial aerosol propagation.

Based on the recorded data of the relative gas exchanges at the sensor and the experimentally determined release data, the temporal courses of the particle number concentration in the breathing zone (i.e. exposure) was determined as exemplarily shown in Figure 4 (a) for spraying. The temporal courses of the particle number concentration for wiping and sanding show a similar shape, but differ significantly in the concentration levels.

Figure 4. Particle number concentration in the breathing zone over the first 30 min after launch of release (a) and cumulative number of inhaled particles over the whole modelling time (b) for the three ventilation scenarios on the example of spray can application.

Figure 4 (a) reveals that the highest exposure levels arise immediate during or rather short after release with a slight time delay. After the release, the particle number concentration in the breathing zone decreases at first rapidly. Afterward the concentration increases slightly for a short period of time before a gradually decrease over time can be observed. Both, the magnitude of the rapid decrease in the first phase and the strength of the slope in the third phase depend clearly on the ventilation scenario.

Based on a gender and activity averaged breathing rate of 383 cm³/s, cumulative numbers of inhaled particles were determined. The values of fractions for total and regional particle deposition in the human respiratory tract (cf. Table 3) and the assumption of unit density (i.e. 1000 kg/m³) were used for the calculation of cumulative numbers and masses of inhaled and deposited particles. These data are shown in Figure 5, while the corresponding values are provided in Table 4.
Figure 5. Cumulative numbers of inhaled/deposited particles (a) and cumulative masses of inhaled/deposited particles (b) of the exposure scenarios.

Figure 5 and Table 4 reveal that the exposure levels due to wiping are negligible (i.e. $n_{\text{inh}, \text{WIP}} < 1 \times 10^2$), while the spray can application led to the highest exposure levels (i.e. $n_{\text{inh}, \text{SPR}} = 2.6 \times 10^8 - 1.2 \times 10^9$; $m_{\text{inh}, \text{SPR}} = 2.0 \mu g - 8.8 \mu g$), especially due to poor ventilation by door slit infiltration. The exposure levels due to sanding (i.e. $n_{\text{inh}, \text{SAN}} = 1.6 \times 10^4 - 8.3 \times 10^4$; $m_{\text{inh}, \text{SAN}} = 0.2 \text{ ng} - 1.2 \text{ ng}$) were found to be around 4 magnitudes of orders lower than the ones for spraying, but 6 magnitudes of orders higher in comparison to wiping.

**Table 4.** Calculated scenario-specific cumulative numbers/masses of inhaled and regional deposited particles in the human airways based on averaged values for gender (adult breathing rate of 383 cm$^3$/s), activity (i.e. moderate activity) and fractional deposition (modified ICRP 66 deposition model according to [23]).

| release scenario | ventilation scenario | $n_{\text{inh}}$ | $n_{\text{dep}}$ | $n_{\text{dep,HA}}$ | $n_{\text{dep,TB}}$ | $n_{\text{dep,AL}}$ | $m_{\text{inh}}$ | $m_{\text{dep}}$ | $m_{\text{dep,HA}}$ | $m_{\text{dep,TB}}$ | $m_{\text{dep,AL}}$ |
|------------------|----------------------|------------------|------------------|---------------------|---------------------|---------------------|------------------|------------------|---------------------|---------------------|---------------------|
| wiping           | NVD                  | 8.5E-2           | n/a              | n/a                 | n/a                 | n/a                 | n/a              | n/a              | n/a                 | n/a                 | n/a                 |
|                  | NVW                  | 6.5E-2           | n/a              | n/a                 | n/a                 | n/a                 | n/a              | n/a              | n/a                 | n/a                 | n/a                 |
|                  | TVS                  | 1.6E-2           | n/a              | n/a                 | n/a                 | n/a                 | n/a              | n/a              | n/a                 | n/a                 | n/a                 |
| sanding          | NVD                  | 8.3E+4           | 9.4E+3           | 3.2E+3              | 6.6E+2              | 5.6E+3              | 1.0E-3           | 1.4E-4           | 6.6E-5              | 7.1E-6              | 7.0E-5              |
|                  | NVW                  | 6.3E+4           | 7.1E+3           | 2.4E+3              | 5.0E+2              | 4.2E+3              | 7.7E-4           | 1.1E-4           | 5.0E-5              | 5.4E-6              | 5.3E-5              |
|                  | TVS                  | 1.6E+1           | 1.8E+3           | 6.0E+2              | 1.3E+2              | 1.1E+3              | 1.9E-4           | 2.7E-5           | 1.3E-5              | 1.4E-6              | 1.3E-5              |
| spraying         | NVD                  | 1.1E+9           | 2.4E+8           | 3.7E+7              | 3.3E+7              | 1.7E+8              | 8.8E+0           | 2.3E+0           | 1.4E+0              | 1.4E-1              | 7.9E-1              |
|                  | NVW                  | 9.2E+8           | 2.0E+8           | 3.1E+7              | 2.8E+7              | 1.4E+8              | 7.4E+0           | 1.9E+0           | 1.2E+0              | 1.2E-1              | 6.6E-1              |
|                  | TVS                  | 2.6E+8           | 5.5E+7           | 8.6E+6              | 7.7E+6              | 3.9E+07             | 2.0E+0           | 5.4E-1           | 3.2E-1              | 3.2E-2              | 1.8E-1              |

In order to quantify the magnitude of dilution for each exposure scenario, ratios between the numbers of released particles to the numbers of inhaled particles (designated as RIR = release-inhalation-ratio) were determined (cf. Table 5). Across all the analysed exposure scenarios, the RIR varied between $4 \times 10^2$ up to $1.5 \times 10^7$, because of the different local positions of the release sources in the flow field. Considering separately the change of RIR within the exposure scenarios for each release scenario, the dilution efficiency due to the different ventilation scenarios can be examined. Thus, the NVW lead to a
1.2 – 1.3 times higher dilution or respectively lower exposure level than the NVD, while the dilution efficiency increases by a factor of 4.3 - 5.2 due to switching from NVD to TVS. Data on the RIR change between the ventilation scenarios show furthermore, that with decreasing distance to the source the dilution efficiency decreases.

**Table 5.** Magnitude of dilution from release to exposure based on the ratio between released and inhaled particles (RIR) for each exposure scenario and comparison between the different ventilation scenarios.

| release scenario | distance from sensor to source [cm] | release duration [s] | ratio between released and inhaled particles (RIR) | change of RIR between the ventilation scenarios |
|------------------|------------------------------------|----------------------|-----------------------------------------------|-----------------------------------------------|
|                  |                                    |                      | NVD [-] NVW [-] TVS [-]                         | NVW/NVD [-] TVS/NVW [-] TVS/NVD [-]           |
| wiping           | 65.0                               | 10                   | 2.9E+6 3.8E+6 1.5E+7                          | 1.3 4.0 5.2                                  |
| sanding          | 65.0                               | 60                   | 6.0E+5 8.0E+5 3.2E+6                          | 1.3 4.0 5.2                                  |
| spraying         | 52.5                               | 60                   | 4.1E+2 4.9E+2 1.8E+3                          | 1.2 3.6 4.3                                  |

**4. Summary and conclusion**

Propagation modelling based on experimentally determined airborne particle release data was performed for exposure estimation and prediction. Overall 9 different exposure scenarios based on 3 near-field (< 1 m distance from source to breathing zone) release scenarios (i.e. wiping, sanding, spraying) and 3 ventilation scenarios (i.e. technical ventilation, natural ventilation by door-slit infiltration and by natural pivot-hung-window ventilation) were analysed within a 90 m³ model room. For the purpose of exposure estimation, the air condition in the breathing zone was observed for a time frame of 120 min, whereof the first 30 min served solely for reaching almost steady state ventilation conditions before the actual release scenarios were launched for ≤ 1 min. On the basis of modelled data for the relative gas exchange, particle number and mass concentration over time as well as cumulative numbers and masses of inhaled and deposited particles in the human respiratory tract were determined.

Despite a lot of assumptions and specifications for propagation modelling, the chosen exposure scenarios show impressive that the level of exposure is affected fundamentally by the release scenario, the ventilation scenario and the positioning of the subject of protection (i.e. consumer/worker). The latter one comprises beside the distance from source to breathing zone also the localisation within the flow field. Within this study, the ratio between the number of released particles to the number of inhaled particles, which can be seen as a kind of dilution factor, varied between 4·10² up to 1.5·10⁷ for the analysed exposure scenarios. The highest levels of exposure revealed for the modelled spray scenario, where around one billion particles with a mass of ca. 9 µg were inhaled during and after 60 s spray can application in a room at poor ventilation conditions. Additionally, it could be observed for all exposure scenarios that convective flow structures due to person-caused heat can lead to particle availability in the breathing zone and that highest exposure levels arise immediate during material processing.

Accordingly, it could be illustrated how measured particle release data have to be added into well-considered surrounding scenarios to get consumer-relevant or occupational exposure data. This underlines the requirement on a sufficient set of contextual information [e.g. 3, 5], which are necessary for the sampling strategy regarding exposure measurement, the interpretation of measured exposure data or for the prediction/assessment of exposure based on experimentally determined release data.

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