Validation of an EDP assisted model for assessing inhalation exposure and dermal exposure during spraying processes

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baua:
Bundesanstalt für Arbeitsschutz
und Arbeitsmedizin

Research
Project F 2137

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Dortmund/Berlin/Dresden 2012

This publication is the final report of the project ‘Validation of an EDP assisted model for assessing inhalation exposure and dermal exposure during spraying processes’ – Project F 2137 – on behalf of the Federal Institute for Occupational Safety and Health. The responsibility for the contents of this publication lies with the authors.

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Abstract

Software tools are increasingly used to assess the exposure of workers to hazardous substances. The absorbed dose is estimated on the basis of diverse models. For inhalation exposure and dermal exposure to non-evaporating substances applied by means of spraying processes, the deterministic model SprayExpo was revised, thoroughly tested, and compared to the existing models ConsExpo and BG-Spray in this research work. To this end, SprayExpo was validated with measurement results from real workplaces in the fields of antifouling and stored product protection.

An improved droplet impaction module for calculating the overspray during spraying onto a surface was incorporated into the SprayExpo model. Furthermore, it is no longer necessary to directly enter primary droplet distributions. Instead, for common spraying techniques these are stored in a database from which they can be retrieved by specifying the spraying technique and simple process parameters such as the spraying pressure. The sensitivity analysis revealed that besides the active substance release rate, the droplet spectrum is the decisive process parameter for the exposure. In contrast, the vapor pressure of the solvent only plays a secondary role for the exposure concentration of the active ingredient within the relevant range of values. To validate the SprayExpo model, exposure concentrations of the active substances used were determined at workplaces in the area of antifouling treatment and in several scenarios in stored product protection by personal sampling and subsequent chemical analysis. For both room spraying and spraying onto walls, comparisons between the model and experiments revealed that spray applications can generally be reproduced with an uncertainty factor of less than 4. As regards the dermal exposure, the model can only take into account the sedimentation flow of the airborne droplets, but not accidentally occurring splashes. Therefore, the dermal exposure at the workplace is underestimated by SprayExpo in the majority of cases. However, the dermal exposure is represented quite well in the case of room spraying. Based on the measured scenarios, three standard exposure scenarios were defined and documented in corresponding ‘fact sheets’.

All in all, SprayExpo is an appropriate system for assessing exposure during indoor spraying processes. However, the fact that all models have their advantages and disadvantages should be taken into consideration. Therefore, the models have to be used reasonably and with the required expert knowledge.

Key words:

spraying, antifouling, stored product protection, inhalation and dermal exposures, model calculations

Validierung eines DV-gestützten Modells zur Abschätzung der inhalativen und dermalen Exposition bei Sprayprozessen

Kurzreferat

Für die Bewertung der Exposition von Arbeitnehmern gegenüber gesundheitsgefährdenden Arbeitsstoffen werden in zunehmendem Maße Software-Tools verwendet. Die Abschätzung der aufgenommenen Dosis erfolgt dabei auf der Basis von unterschiedlichsten Modellen. Für die inhalative und dermale Exposition gegenüber nicht-verdampfbaren Wirkstoffen, die mittels Sprühprozessen ausgebracht werden, wurde in dieser Arbeit das deterministische Modell SprayExpo überarbeitet, eingehend untersucht und mit den existierenden Modellen ConsExpo und BG-Spray verglichen. Dazu wurde SprayExpo mit Messergebnissen an realen Arbeitsplätzen in den Bereichen Antifouling und Vorratsschutz validiert.
In das Modell SprayExpo wurde ein verbessertes Tropfenimpaktionsmodul für die Berechnung des Oversprays bei der Oberflächenbesprühung eingearbeitet. Des Weiteren müssen Primärtropfenverteilungen nicht mehr direkt eingegeben werden, sondern sind für gängige Sprühtechniken in einer Datenbank hinterlegt, auf die über die Eingabe der Sprühtechniken und einfacher Prozessparameter wie z. B. Sprühdruck zurückgegriffen werden kann. In der Sensitivitätsanalyse zeigte sich, dass neben der Wirkstofffreisetzungsrate das Tropfenspektrum der expositionsbestimmende Prozessparameter ist. Dagegen hat der Dampfdruck des Lösemittels im Rahmen des relevanten Wertebereichs für die Expositionskonzentration des Wirkstoffs nur eine untergeordnete Bedeutung. Zur Validierung des Modells SprayExpo wurden an Arbeitsplätzen im Antifoulingbereich und an Szenarien im Bereich des Vorratsschutzes durch personenbezogene Probenahme und anschließende chemische Analytik die Expositionskonzentrationen der verwendeten Wirkstoffe bestimmt. Bei dem Vergleich zwischen Modell und Experiment sowohl für Raum- als auch für Wandbesprühung zeigte sich, dass Sprühapplikationen mit einer Unsicherheit von in der Regel kleiner Faktor 4 abgebildet werden können. Für die dermale Exposition kann das Modell lediglich den Sedimentationsfluss der luftgetragenen Tropfen berücksichtigen und nicht zufällig auftretende Spritzer. Dadurch wird die dermale Exposition am Arbeitsplatz vom Modell SprayExpo meist unterschätzt. Allerdings wird die dermale Exposition im Falle der Raumbesprühung recht gut wiedergegeben. Aus den gemessenen Szenarien wurden insgesamt drei Standardexpositionsszenarien erstellt und in dazugehörigen „Factsheets“ dokumentiert.
Insgesamt ist SprayExpo für eine Expositionsabschätzung bei Sprühprozessen in Innenräumen geeignet. Es sollte aber darauf geachtet werden, dass alle Expositionsmodelle ihre Vor- und Nachteile haben und diese sinnvoll und mit dem nötigen Sachverstand angewendet werden müssen.

Schlagwörter:

Sprühen, Antifouling, Vorratsschutz, inhalative und dermale Exposition, Modellberechnungen

Validation d'un modèle informatique pour l'évaluation de l’exposition respiratoire et dermique dans les procédés de pulvérisation

Résumé

Les outils logiciels sont de plus en plus utilisés pour l'évaluation de l'exposition des salariés à l’ègard des substances dangereuses pour la santé. L'estimation de la dose absorbée s’effectue à la base des modèles les plus différents. Sur le thème de l’exposition respiratoire et dermique face à des substances non volatiles libérées par des processus de pulvérisation, le modèle déterministe SprayExpo a été révisé, vérifié en détail et comparé aux modèles existants ConsExpo et BG-Spray dans le cadre du travail présent. SprayExpo a été validé avec des résultats de mesures effectués aux des postes de travail réels dans les domaines de l'antifouling et de la protection des denrées stockées.
Un module amélioré d’impaction de gouttelettes destiné à évaluer la surpulvérisation dans le cadre de la pulvérisation de surface a été intégré dans le modèle SprayExpo. En outre les répartitions de gouttelettes primaires n’ont plus besoin d’être saisies directement mais sont enregistrées dans une base de données pour les techniques de pulvérisation courantes qui peut être consultée en entrant des techniques de pulvérisation et des paramètres simples tels que la pression de la pulvérisation par exemple. L’analyse de sensitivité a montré qu’à côté du taux de libération des substances actives, le spectre des gouttelettes représente le paramètre de processus déterminant de l’exposition. En revanche, la pression de vaporisation du solvant dans le cadre de la plage des valeurs pertinentes ne joue qu’un rôle mineur dans la concentration d’exposition de la substance active. Pour valider le modèle SprayExpo, les concentrations d’exposition des substances actives utilisées ont été déterminées par des postes de travail dans le domaine de l’antifouling et des scénarios dans le cadre de protection de denrées stockées avec prélèvements sur les personnes puis analyse chimique. La comparaison entre le modèle et l'expérience, en ce qui concerne la pulvérisation de locaux et de murs, a montrée que les applications de pulvérisation peuvent être représentées avec une incertitude généralement inférieure au facteur 4. En ce qui concerne l'exposition dermique, le modèle ne peut considérer que le flux de sédimentation des gouttelettes en suspension et ne pas les projections survenant au hasard. L’exposition dermique du poste de travail se reférante au modèle SprayExpo est par conséquent sous-estimée la plupart du temps. L'exposition dermique est en éffet bien représentée dans le cas de la pulvérisation à l’intérieur d’un local. Parmi les scénarios analysés, trois scénarios d’exposition standard au total ont été réalisés et documentés sous forme de « fiches techniques ».
Dans l’ensemble, SprayExpo est adapté à une évaluation d’exposition dans le cadre de procédés de pulvérisation à l’intérieur de locaux. Il faut toutefois considérer que tous les modèles d'exposition présentent des avantages et des inconvénients et qu’ils doivent être appliquées raisonnablement et avec le savoir faire qui s’impose.

Mots clés:

pulvériser/vaporiser, antifouling, protection des denrées stockées, exposition respiratoire et dermique, modèles mathématiques

1 Introduction

1.1 History

During the years 2001-2004, a mechanistic EDP-assisted model (SprayExpo) for predicting aerosol exposure during spray application of (biocidal) active substances (KOCH et al., 2004; KOCH, 2004; BERGER-PREIß et al., 2005) was developed in two BAuA-funded research projects (F 1702, F 2022). This model can be applied to spraying processes in enclosed rooms and refers to the aerosol exposure during the spraying process. In this regard, the model is comparable to the 'Exposure to spray' model in the software tool ConsExpo. What distinguishes this model is in particular the fact that it explicitly takes into account the evaporation kinetics of the droplets. As part of an enhancement of the model, a module for calculating the exposure-relevant overspray generated during spraying onto a surface was added.

In the past, the results predicted by this model had been verified by means of a few well-controlled application experiments under rather simple conditions (room spraying). The prediction quality of the model under real workplace conditions, however, had never been evaluated.

Analyses performed so far with this model and existing results of measurements at workplaces have demonstrated that the droplet spectrum of the spraying method used has a paramount impact on the exposure concentration. A user of the SprayExpo model, however, cannot be expected to have sufficiently precise information about the size distribution of spray droplets. Therefore, there is a need to improve the model in the sense of linking droplet spectra to easily determinable parameters of the spraying technique or spraying solution. During our past use of the model, further deficiencies concerning the range of values of model parameters and the droplet impaction module had been identified.

1.2 Aims of this project

The aims of this project can be summarized as follows:

In order to improve the SprayExpo model, the model part for calculating the overspray should be redesigned and the range of parameters to cover workplace scenarios should be enhanced. Furthermore, the possibilities for entering droplet size distributions should be enhanced and simplified.

To validate the model, SprayExpo should be compared with other selected deterministic calculation models such as ConsExpo and with measurements from workplaces and different scenarios. These comparisons should make use of indoor workplaces that are well defined with regard to the process conditions such as volume of the room, ventilation, and application technique. The aim is not to assess the individual workplaces, but to work out the uncertainties the model involves. In addition, sensitivity analyses should be performed in order to identify the most important factors influencing the exposure.

In the course of this project, the defined aims were enhanced. So-called ‘pick lists’ for the SprayExpo model were to be worked out, which should enable determination of the exposure-relevant droplet size distribution simply by specifying the application technique.

2 Survey of published literature

Our survey of published literature aimed to find existing models for assessing inhalation and dermal exposures during indoor spraying processes, to allow for similarities and differences between these models and SprayExpo to be determined.

We first searched freely accessible regulatory documents (TGD, TNsG) and two reports/publications (GUO, 2002; BOEHNKE, 2000) for comparable models suitable for our purpose. However, we could not find any other pertinent literature than that which we had already taken into account during the development of SprayExpo.

We subsequently searched the databases PubMed, ScienceDirect, and SpringerLink using the search terms ‘Spray’, ‘Application’, ‘Model’, ‘Validation’, and ‘Exposure’ (dates of publication ≥ 2000). The key words of our search were used in different combinations and were also combined with other search terms from the field of exposure assessment (see Tab. 2.1).

Tab. 2.1 Results of database searches

Database	Search terms	Limitations	Results
PubMed	Spray application	Title/Abstract	82
	Spray application model	Title/Abstract	0
	Spray model	Title/Abstract	2
	Spray model AND Application	Title/Abstract	0
	Spray application	Title	16
	Spray application (Title/ Abstract) AND Spray model	Title/Abstract	9
	Spray exposure	Title/Abstract	13
	Spray exposure	Title	4
	Spraying model	Title	0
	Spraying exposure	Title	0
	Indoor spraying exposure	Title/Abstract	0
	Indoor spraying model	Title/Abstract	0
	Spray validation	Title/Abstract	0
	Exposure validation	Title/Abstract	0
SpringerLink	Spray model	Title	13
	Exposure inhalation (general) AND Spray (Title)	Title/ Abstract	7
	Exposure AND Spray application (Title)	Title/ Abstract	10
	Spray application	Title	51
	Inhalation exposure AND Spray application (Title)	Title/ Abstract	1
	Indoor spraying	Title	0
	Indoor spray	Title	0
	Spray validation	Title	3
	Exposure validation	Title	8
ScienceDirect	Exposure spray biocide	Title/Abstract/Key	2
	Spray model	Title	67
	Spray exposure	Title	26
	Spray application	Title	80
	Indoor model spray	Title/Abstract/Key	2

Database	Search terms	Limitations	Results
	Indoor spraying exposure	Title/Abstract/Key	5
	Spray validation	Title	14
	Exposure validation	Title	29

Tab. 2.2 Results obtained for the different subject areas

Monitoring of spraying processes for plant protection (flow trends of droplets)	20 %
Industrial applications	10 %
Medical applications	10 %
Spray applications in combustion processes	8 %
Spray applications in analytics	5 %
Other (water spray systems, food industry, dermal exposure during spraying processes, heat exchange and mass transport models etc.)	47 %

It was nice to see that this research repeatedly identified the publication BERGER-PREIß et al. (2005), which was written during the development phase of the SprayExpo model. In addition, the publications identified by this search frequently mentioned or referred to models of spraying processes, however, in most cases these were publications about the monitoring of spraying processes aimed at plant protection, about spray applications in combustion processes, or medical or industrial spray applications, which cannot simply be translated to indoor scenarios (see Tab. 2.2).

Consequently, we did not find in the three databases any novel, clearly relevant literature that would have been of use for the validation of SprayExpo.

As no comparable models could be identified by using the above described searching techniques, we then used the search engine ‘Google’ to look for appropriate literature by means of search terms such as ‘Exposure, Model, Workers, Consumers, Spray, Validation’. We thereby managed to find three interesting publications (PARK et al., 2006; EICKMANN et al., 2007a and b).

In the paper by PARK et al. (2006), a variety of available tools and models for predicting consumer exposure were compared to the possibilities offered by ConsExpo.

EICKMANN et al. (2007a) described the exposure model BG-Spray, developed for the German professional association for health service and welfare care (BGW). This model consists of a system of equations defining a rule for calculating the concentration course in a room over time. The paper by EICKMANN et al. (2007b) compares the results obtained with the BG-Spray model to results yielded by ConsExpo (4.0 and 4.1) and SprayExpo. It became evident that the different modeling approaches each have their specific benefits and drawbacks, and that measurement results are reflected by the programs only to a limited degree, so that the models need to be improved and validated by means of measurement data.

As part of the validation study described in this report, the Internet addresses of institutions that are known to develop and refine exposure models and of the assessment authorities were furthermore checked for comparable ‘models’:

For ConsExpo, version 5 is meanwhile available as beta version in the Internet (as of January 2010). In contrast to version 4, this version 5 enables exposure calculations for different populations, with the possibility to now sum up the exposures to several products in several scenarios (e.g. mixing & loading phase, use phase). To this end, the functionality for probabilistic computations and the corresponding display options were refined. For the comparison with SprayExpo, it is interesting to note that in the ‘spray model’ a ‘first-tier approach’ has been introduced which assumes a direct release of aerosols. This corresponds to the approach employed in the ‘vapor model’ which was already included in version 4, thus representing only a simplification of the model that was already available in version 4, while the actual model obviously was not modified. Therefore, version 4 is sufficient for the comparison with SprayExpo.

The ‘Reach Guidance’, which replaces the TGD for industrial chemicals, mentions ECETOC TRA, EMKG-EXPO-TOOL, Stoffenmanager, ART, and RiskOfDerm for workplace exposures. For consumer exposure, the appendix lists the US models WPEM, CEM, and MCCEM in addition to ECETOC TRA and ConsExpo. CEM is furthermore integrated into the program E-Fast. To estimate the exposure during spraying processes, ECETOC TRA, RiskOfDerm, Stoffenmanager, ART, CEM, MCCEM, and ConsExpo are principally suitable.

ECETOC TRA is used as a tier-1 tool and is based on simplified algorithms (consumer) or on an adapted EASE version, a so-called analogy model (workplace). RiskOfDerm estimates the exposure based on measurements.

Stoffenmanager is based on the conceptual exposure model from the source through to the ‘recipient’ (CHERRIE & SCHNEIDER, 1999). The initial exposure depends on substance-specific properties (vapor pressure or dustiness). Other factors influencing the exposure, such as the type of application, room size, and risk management measures are taken into account for the exposure assessment in a categorized manner (Stoffenmanager scores). The model equations were/are validated by means of statistical analyses of real exposure measurements and adjusted if need be.

ART, like Stoffenmanager, is based on a mechanistic model, but offers more detailed input parameters, e.g. the spraying direction during spraying. Real measurement values here are integrated into the exposure assessment by means of Bayesian statistics. Validation data were not yet available.

The US models CEM and MCCEM are based on very simple assumptions with regard to spraying processes. CEM, for example, relies on the following: ‘For a product sprayed on a surface, such as a fabric protector or an aerosol paint, a portion of the applied chemical mass (default of 1 percent) is assumed to be aerosolized and is therefore immediately available for uptake by inhalation’; and similarly MCCEM: ‘…not include complex source models such as those for aerosols (e.g., to treat coagulation of particles in the air and subsequent size-dependent particle deposition rates)’.

The rules for exposure assessment under the Biocidal Products Directive 98/8/EC have been laid down in the TNsG on Human Exposure. For biocides, the use of BEAT, among others, is favored. BEAT is based on a database of measurement data regarding the exposure during the use of biocides and chemicals. This database also includes, among others, measurement data obtained during spraying processes for antifouling treatment. A lot of the measurement data have been adopted from the RiskOfDerm project and from other HSE projects. By means of search algorithms, BEAT allows exposure levels to be derived from all ‘appropriate’ spraying processes and their uncertainties to be computed by using a MonteCarlo analysis. The result directly depends on the measurement data (spraying processes) that are taken into account for the computation. If they differ strongly from the process under consideration, the results will be prone to high error which cannot even be compensated by the MonteCarlo analysis. Important parameters such as the droplet size distribution of the aerosols are not taken into consideration for the exposure assessment. Therefore, verifying the accuracy of the SprayExpo prediction by comparing it with the results from BEAT will hardly provide any scientifically relevant information.

Finally, an indoor air model (http://www.bama.co.uk/regulatory/) is available from the British Aerosol Manufacturers’ Association (BAMA). It consists in an Excel sheet which enables prediction of the exposure to aerosols after single or multiple releases. The exposure concentration is calculated directly from the released amount, the room size, and the ventilation rate; no other parameters are taken into account.

Other comparable deterministic models for spray applications are currently not available in the literature. All in all, it therefore seems to be the most reasonable approach to compare the results obtained with SprayExpo with those obtained by using ConsExpo and the BG-Spray model, as they are based on similar model approaches. For validation, the model results should be compared with measurement data.

3 Theoretical analysis of the models

3.1 Description of the models

ConsExpo

ConsExpo is a software tool developed by the Dutch institute RIVM to compute the exposure to chemicals in consumer products. The models can also be used to compute occupational exposure, if the default values are adjusted accordingly. Version 5 is meanwhile available as beta version via the Internet (see above). As, however, the ‘spray model’ obviously does not differ from the previous version, we used version 4.1 for the comparison with SprayExpo.

ConsExpo allows the inhalation exposure to be computed both for purely gaseous release (‘vapor model’) and for the release of non-volatile components into the indoor air (‘spray model’). Given that the present validation aimed to compare only the generation of a spray of non-evaporating components between the different models, we will refer in the following only to this part of the software tool.

In contrast to SprayExpo, which includes options for different release patterns with detailed information about the target of the spraying process and the sprayer’s position (wall line, wall area, ceiling, floor, or room), ConsExpo offers only two release patterns (‘spraying towards exposed person’ or not).

In the latter case, an instantaneous distribution of the spray in the room is assumed, so that the concentration will be the same everywhere in the room. To determine the decrease in concentration, the air exchange rate and particle sedimentation to the ground are taken into account. Deposition on the walls through diffusion is neglected. This strong simplification regarding the dispersion of the spray cloud by instantaneous diffusion dramatically differs from the actual physical dispersion behavior, in particular in high or very large rooms. In these settings, a concentrated particle cloud is initially created close to the source, spreading only very gradually through the whole room. In addition, special conditions such as overhead spraying or the spraying onto walls or floor surfaces, which involves immediate deposition of part of the particles, can be taken into account only to a limited degree with this model.

In contrast, in the first case (spraying towards exposed person) it is assumed that the product is released within one second in a cloud of a size to be defined (e.g., of 1 m^3), whose volume increases linearly during the spraying process, maximum up to room volume. The spray user in this case is always at the center of the spray cloud, unlike the typical situation during room spraying, where the cloud is released above or laterally above the spraying person.

The following input parameters to describe the room and the spraying conditions can be edited in the ‘spray model’: the spraying duration, the duration of inhalation, room height and volume, ventilation rate, the amount of product released, the airborne fraction, and the size distribution of the generated particles. Furthermore, for large particles a ‘cutoff’ value for respirability can be defined. What cannot be specified – as one of the major differences from SprayExpo – is the vapor pressure of the solvent to describe the evaporation kinetics of the droplets and the spraying distance from the wall or floor.

The results provided are: the mean value of the inhalable concentration during the time of inhalation, the total amount of inhaled product per kilogram of body weight, the internal dose, the external dermal exposure, and the oral exposure.

BG-Spray

The model BG-Spray is a system of balance equations (one-zone model and two-zone model) which allow the concentration course in a room over time to be calculated (see EICKMANN et al., 2007). Having been custom-developed for the German professional association for health service and welfare care, this model was not at our disposition. To enable comparison of the models, we programmed the one-zone model in Excel. Programming of the two-zone model is not feasible in Excel, as this requires a more than two-dimensional (particle size, time, and space) calculation matrix, which cannot be realized in an Excel sheet. It would also be conceivable to program the multi-zone model like in SprayExpo, but this would be quite a laborious task.

The model specifications include a rule for calculating the concentration course in a room over time. It serves to compute the concentration in a room as well as the dose or other derived values, which can then be compared with the corresponding values provided by SprayExpo and ConsExpo.

In this model, the dispersion of the particle cloud in a room under physical aspects is dealt with in a similar way as in ConsExpo (instantaneous homogeneous dispersion), resulting in highly similar concentration courses, as we will see in the examples given below. Differences seem to result only from numerical inaccuracies, such as the definition of time increments in particular.

SprayExpo

This model serves the purpose of calculating the exposure of the worker (recipient) during application of biocidal products by means of spraying or fogging techniques in enclosed rooms. The applied product here is a solution or suspension of an evaporating solvent and a non-volatile active substance. The aim is to compute the concentration of the non-evaporating active substance. To this end, a cuboid with the edge lengths A, B, and H is defined in a Cartesian coordinate system (x, y, z). The current source point (i.e. the point of release of the spray) is referred to as PS, the recipient point (the point of aerosol inhalation or aerosol deposition) as PR. A typical application process consists in moving a sprayhead along a certain path $\vec{R}_S(t)$ simultaneously releasing a spray of droplets at a rate Q(t) (see Fig. 3.1). The release rate Q specifies the amount of droplets released per time unit. Its dimension is ml/s.

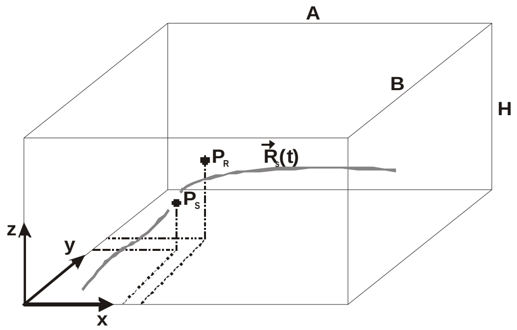


Fig. 3.1 Geometric definitions of the simulation model

The coordinates of the source point and the recipient point normally will not differ a lot, as the exposed person and the person applying the biocide are identical. For the spraying scenarios, constant distances between the recipient and the source can therefore be defined. For the vertical coordinate, the difference between the height of the source and the height of the recipient is more important because of the relevance of droplet sedimentation for the dispersion process and is therefore also taken into consideration.

Based on the process data, the exposure concentration is computed by means of a droplet simulation model. This model takes into account, among other factors, the turbulent mixing of the spray with the indoor air, the gravitational sedimentation of droplets, and droplet evaporation. To this end, corresponding balance equations are set up and solved numerically (KOCH, 2004).

The global model parameters, such as the room dimensions and ventilation data, physico-chemical product data, and technical data of the spraying process are entered via an input mask on the first program level (Fig. 3.2). In addition, the application pattern has to be specified. The model generally distinguishes between the spraying onto surfaces (walls, floor, ceiling) and room disinfection.

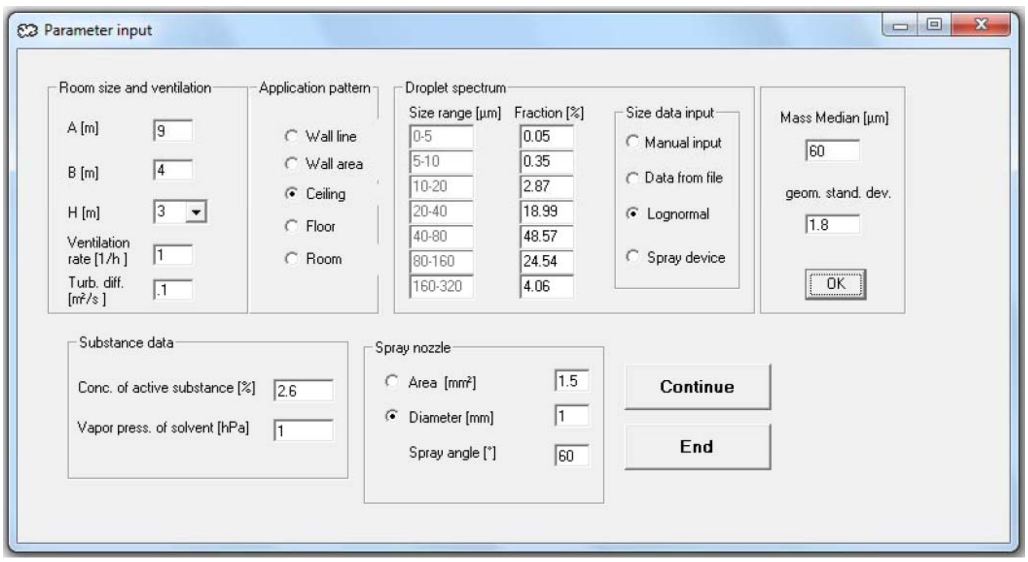


Fig. 3.2 Input mask 1 of the SprayExpo model

On the second program level, the time course of the selected spraying process has to be specified (Fig. 3.3). This includes in the first place the specification of the release path and the mass flow released. The results of the computation are also given on the second program level. The inhalation concentration and inhalation dose are given for a selected particle size fraction. The dermal exposure includes the deposition of active substance on body surfaces by aerosol settling.

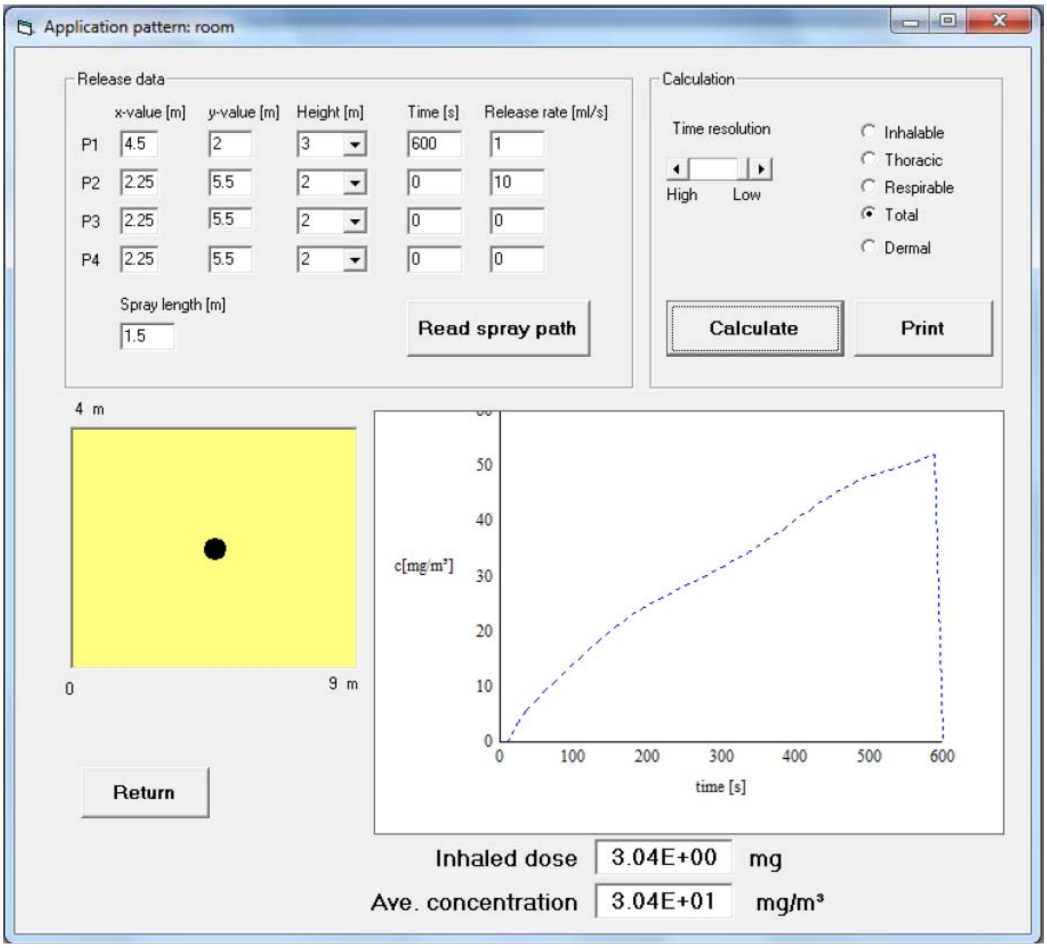


Fig. 3.3 Input mask 2 of the SprayExpo model

3.2 Description of SprayExpo model enhancements

Enhancement of the parameter range:

The computations performed by SprayExpo make use of files stored in the program folder and containing values which were numerically computed beforehand. The parameter range of the dimensionless parameters used for the numerical computations has been enhanced. This was done specifically by enhancing the parameter range of the characteristic length

$L_N = (Kt_R)^{1/2}$ (see report by KOCH (2004)) **(3.1)**

from [L_N = 2.45; L_N = 32.86] to [L_N = 1.35; L_N = 49.03]. This enables simulation of both longer and shorter exposure durations than before. The parameter L_N describes the size of an aerosol cloud released from a single point which this cloud has reached by turbulent diffusion (diffusion coefficient K) after the time interval t_R .

Redesign of the droplet impaction module:

For the surface spraying scenarios, the model calculates the overspray, i.e. the fraction of droplets that are not deposited onto the surface. The initial model approach for calculation of the overspray used a droplet trajectory model for still air. The improved model now takes into account the entrainment of air into the spray jet according to Bernoulli's principle. This leads to a decrease in the droplet deceleration that is due to air friction, resulting in an increased operating distance of the spray compared to injection of the droplets into still air. For the calculation of the deposition probability as a function of droplet size, droplet velocity, and distance from the wall, the algorithms described in FLYNN et al. (1999) and SAZHIN et al. (2001) were used.

Accordingly, the air velocity, v_L, in the spray cone (cone angle θ) at a distance x from the nozzle (nozzle diameter d) can be computed using the following equation:

$$v_L = \frac{2v_W^0}{\sqrt{1+16\ (\rho_L/\rho_W)\tan^2(\theta/2)(x/d)}} \qquad \textbf{(3.2)}$$

with
v_W^0 being the fluid velocity in the spraying nozzle,
ρ_L and ρ_W being the air density and water density, respectively.

The deposition of droplets takes place by impaction via a virtual impactor shown in Fig. 3.4.

The diameter of the dispatching nozzle of this virtual impactor can be computed using the following equation:

$$D_I = \frac{z_t D_{sp}}{D_{sp} + z_t} \qquad \textbf{(3.3)}$$

Particle velocity equals the air velocity v_L. Based on the nozzle diameter D_I, the particle velocity at z_I, and the particle relaxation time $\tau_{dr} = \frac{\rho_p {d_{dr}}^2}{18\mu}$ (ρ_{dr} being the material density of the droplets, μ the air viscosity), the Stokes number $Stk = v_L \tau_p / D_I$ can be computed. The parameter β is assigned a value of 1 for a round nozzle and a value of 1.5 for a flat fan nozzle. If the Stokes number exceeds the critical value of 0.22, the droplets will be deposited, otherwise they will be released into the air as overspray. The time that the droplets take to travel from the nozzle to the wall is normally so short and the local water concentration so high that droplet evaporation does not have to be taken into account for the deposition calculations. The program performs the calculations for each size range. The start conditions depend on the nozzle parameters and the liquid mass flow of the spraying nozzle.

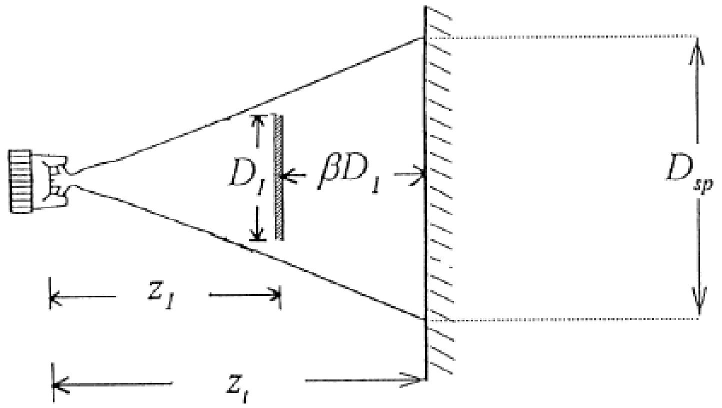


Fig. 3.4 Virtual impactor (according to FLYNN et al., 1999)

A third model improvement concerns the input modes for the droplet spectrum of the spraying device. The program subdivides the droplet spectrum into the discrete size ranges 0-5, 5-10, 10-20, 20-40, 40-80, 80-160, and 160-320 µm. There are now four different possibilities available to enter the data (Fig. 3.2):

1. Manual input of the percentages of droplet mass in the 7 size ranges.

2. Use of a file of measurement values, generated by the laser diffraction spectrometer HELOS of the company Sympatec in Clausthal-Zellerfeld, Germany. For some spraying techniques, this analytical instrument can be used to directly measure the droplet size distribution.

3. Input of the parameters median value of the droplet diameter of the mass size distribution and geometric standard deviation. A lognormal distribution of the droplet mass over the droplet diameter is assumed.

4. Selection of a common application technique used for biocidal treatment of surfaces and rooms. Eight techniques are at present implemented (Fig. 3.5). The first two of these assume the use of pressure-driven single-substance flat fan and hollow cone nozzles. When any of these is selected, the operating pressure and corresponding liquid throughput have to be specified in addition. The following three devices are cold foggers, followed by two thermal foggers. At the end of the list, a propellant-based spray formulation is offered. The cold and thermal foggers as well as the pressurized spray can have fixed droplet distributions independent of the operating parameters. The corresponding droplet distributions have been determined in model experiments (see chapter 4.3).

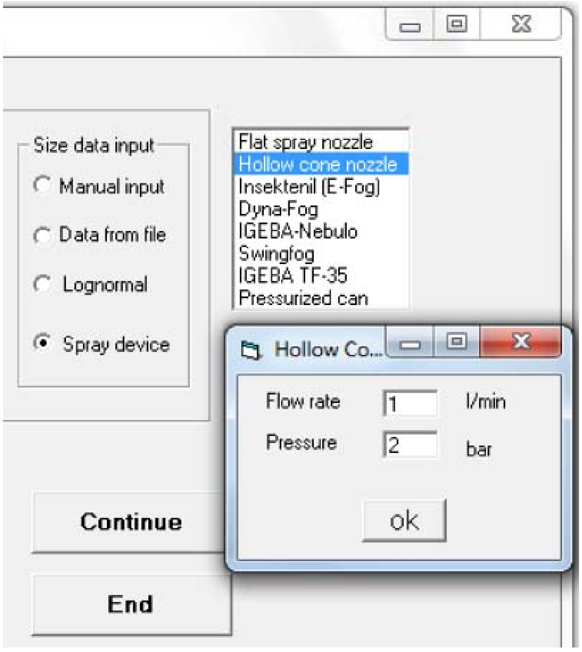


Fig. 3.5 Definition of the droplet size distribution by selection of the spraying method

3.3 Sensitivity analysis

The selected deterministic models can be used exclusively for indoor situations with defined room volumes. Another precondition is that the ventilation scheme be a turbulent mixing ventilation system. Locally introduced pollutants will be homogeneously dispersed in the room after a certain time. This is characterized by a typical mixing time of the introduced pollutants. Mass losses, due to the air exchange, are determined by the air exchange rate and also by particle sedimentation onto horizontal surfaces in the room.

The below described sensitivity analyses for the selected models were to be based on a relevant application example, namely biocidal treatment for stored product protection. Large silo cells for storing grains are treated with biocidal agents before storing the grains. This includes both room spraying and the spraying onto walls. The room dimensions for these real-life applications were 9 x 22 x 7.50 m (width x length x height), the air exchange rate was assumed to be 1 h^{-1} and the turbulent diffusion constant K = 0.1 m^2/s. These are standard values, which were used for the below described sensitivity analyses unless otherwise specified. The diffusion constant K primarily depends on the temperature gradient in the room (possible heat sources) and increases with increasing room size. Furthermore, movements of workers or machines will increase the air exchange. The selected value of K = 0.1 m^2/s (BAUGHMANN et al., 1994) should be valid for room heights from 3 m to 10 m, as long as there exist no other extraordinary influences such as heat sources etc.

The following influencing factors have been investigated: droplet spectrum, vapor pressure, spraying distance, room parameters, and ventilation parameters.

3.3.1 The SprayExpo model

The evaluation was based both on room fogging and on surface spraying scenarios in the storage rooms.

Room spraying

The following fixed parameters were used for the room spraying scenario: active substance concentration 2.6 %, liquid release rate 1 ml/s, release duration 11 min. Parameters subject to variation were the median droplet diameter (in the range from 10 to 580 µm) and the vapor pressure of the solvent (in the range from 0.00023 to 23 hPa). The geometric standard deviation was fixed to 1.8. This value was determined by analyzing size distributions of single-substance nozzles given in datasheets and from our own measurements (see chapter 4.3). The geometric standard deviation of the droplet distribution therefore was not considered to be a parameter that is subject to variation. The mean concentration of the thoracic fraction of the active substance is shown numerically in Tab. 3.1.

Tab. 3.1 Mean exposure concentration depending on droplet diameter and vapor pressure

		Vapor pressure [hPa]					
		0.00023	**0.0023**	**0.023**	**0.23**	**2.3**	**23**
Droplet size [µm]	10	7.1	10.1	11.8	12	12	12
	15	4.17	7.38	10.3	11	11	11
	23	1.92	3.98	7.73	8.9	8.9	9
	34	0.76	1.67	5	6.3	6.5	6.6
	51	0.25	0.56	2.45	3.47	3.71	3.8
	76	0.077	0.18	0.94	1.55	1.74	1.84
	114	0.022	0.05	0.31	0.57	0.67	0.72
	171	0.007	0.016	0.093	0.18	0.22	0.24
	256	0.00124	0.0034	0.026	0.05	0.06	0.07
	384	0.000399	0.0011	0.0075	0.015	0.02	0.02
	577	0.000016	0.0000389	0.0016	0.0039	0.005	0.005

The results provided by the model clearly suggest the median value of the droplet diameter to be the parameter which decisively impacts the exposure. The influence of the vapor pressure on the exposure concentration is noteworthy only at very low values (almost non-evaporable liquids) (see Fig. 3.6).

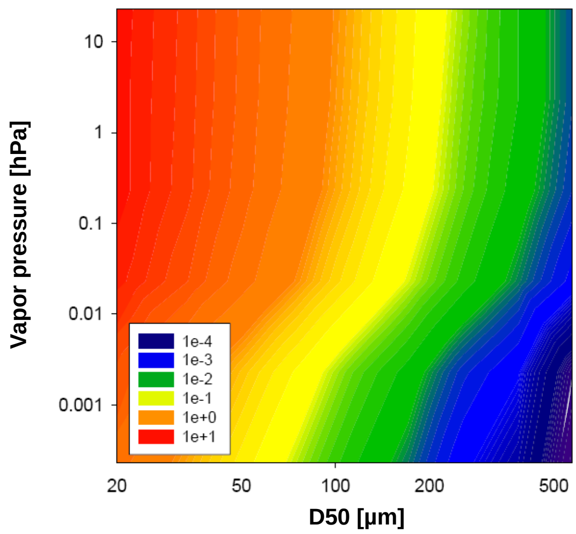


Fig. 3.6 Time-averaged exposure concentration of the thoracic fraction in relative units during biocidal treatment with a cold fogger. Varying parameters: median diameter of the droplet distribution and vapor pressure of the solvent

Spraying onto wall surfaces

Further analyses were performed for the scenario of spraying onto a wall. In this case, the vapor pressure of the solvent (water), the nozzle size, and the liquid flow rate were constant, while the droplet size and the distance of the nozzle from the wall were subject to variations (Fig. 3.7, Fig. 3.8). A circular nozzle shape with a diameter of 1 mm was assumed. The liquid flow rate is 8 ml/s, corresponding to a water discharge velocity of 10.2 m/s.

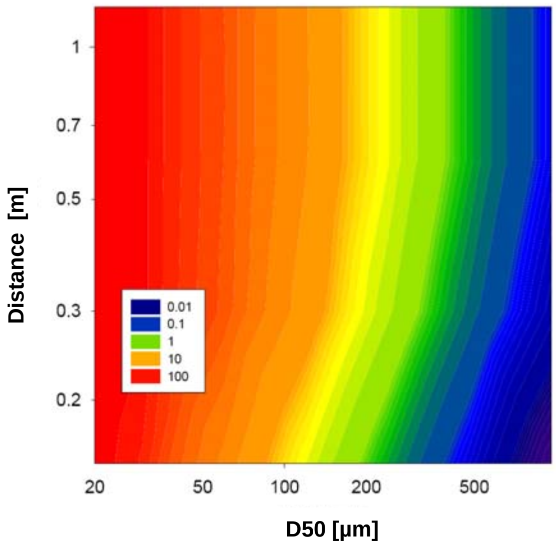


Fig. 3.7 Time-averaged exposure concentration of the inhalable fraction in relative units during biocidal treatment by spraying onto a wall using a single-substance nozzle. Varying parameters: median diameter of the droplet distribution and distance of the nozzle from the wall

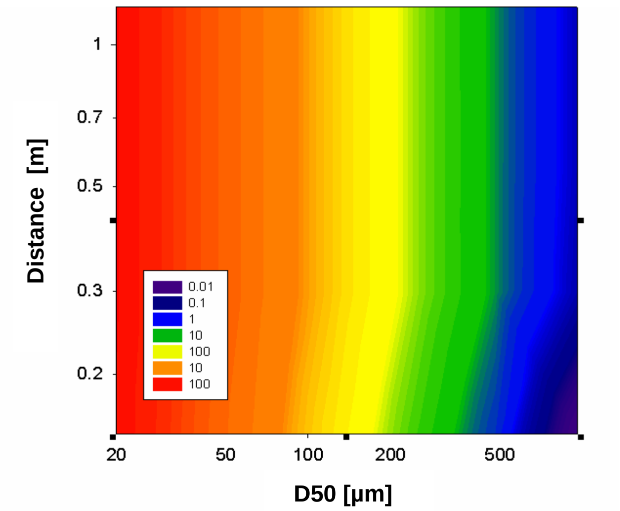


Fig. 3.8 Time-averaged exposure concentration of the thoracic fraction in relative units during biocidal treatment by spraying onto a wall using a single-substance nozzle. Varying parameters: median diameter of the droplet distribution and distance of the nozzle from the wall

When the median diameter is small, the whole spray becomes exposure-relevant as overspray. Due to their low inertia, the droplets are not deposited on the wall. In this example, a noteworthy deposition can be observed only for median diameter values above 80 µm. This becomes obvious if a vertical line is drawn in Figs. 3.7 and 3.8 for a constant median diameter: only above 80 µm a dependence of the exposure concentration on the distance of the spraying nozzle from the wall can be recognized in the form of a pronounced change in color. This dependence on the distance is more pronounced for the inhalable fraction than for the thoracic fraction (see also Fig.

3.9). For the thoracic fraction, taking into account the overspray fraction leads to a maximum reduction by a factor of 2 for spraying nozzles.

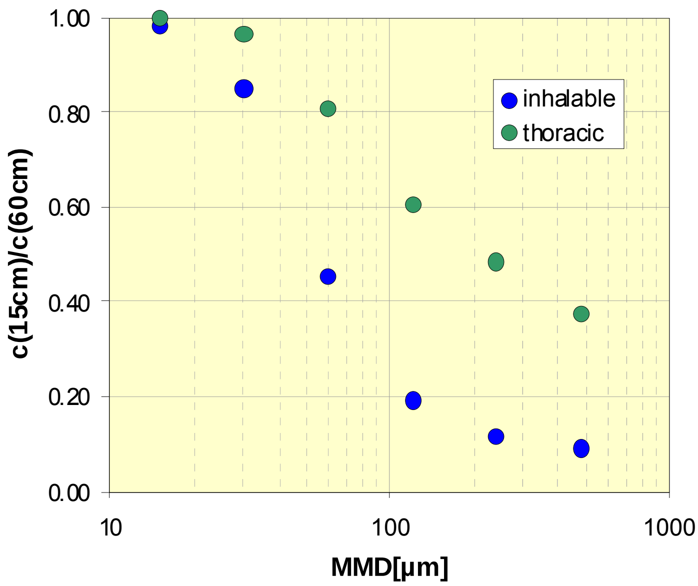


Fig. 3.9 Dependence of the exposure concentration on the distance as a function of the median droplet diameter

3.3.2 The ConsExpo and BG-Spray models

For ConsExpo and BG-Spray, sensitivity analyses regarding vapor pressure and distance from the wall are not possible, because these are no model parameters.

Consequently, for the models ConsExpo and BG-Spray we will investigate how the parameters surface area of the room, room height, and particle size affect the calculated mean concentration (arithmetic mean). For ConsExpo, we investigated the model version which assumes instantaneous dispersion of the spray through the entire room, since a comparison with measurement values, which will be evaluated below in more detail (see chapter 5.1), showed better agreement of this version than of the version 'spraying towards exposed person'. The basic conditions in both these models are: room width 8.5 m; spray release at a height of 2.5 m in the middle of the room; concentration of active substance in the released spray 2.6 %; geometric standard deviation of the size distribution in the spray 1.8; dosage 1 ml/s; duration of application and inhalation for the worker 10 min; air ventilation rate in the room once per hour.

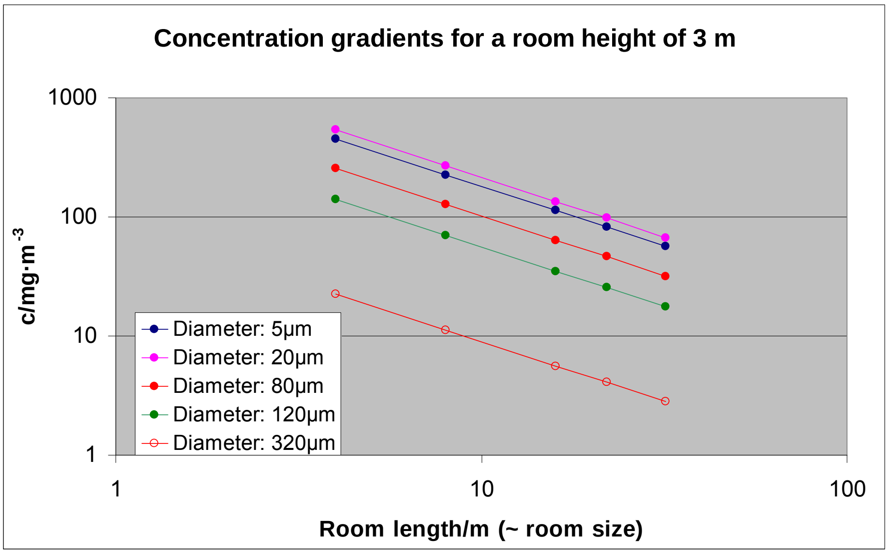


Fig. 3.10 Mean concentration depending on the room length as calculated with ConsExpo or BG-Spray

As was to be expected in view of the similarity regarding the physical simplifications in both models (see chapter 3.1), the two models differ only minimally and these differences are only due to numerical inaccuracies. The dependences in Fig. 3.10 and Fig. 3.11 therefore are shown only once for both models. In Fig. 3.10, dependence of the calculated mean aerosol concentration is shown in relation to the room length (in case of fixed height and fixed width, the length is proportional to the volume). We chose the double logarithmic representation to enable better identification of trends and patterns. All points of a size range are located on a straight line with a slope of minus one. This means that in case of constant height the concentration is inversely proportional to the room size, and the particle deposition rate does not change depending on the ground area of the room. This corresponds to the physical simplification in both models (instantaneous dispersion of the spray through the whole room).

Fig. 3.11 shows the dependence of the mean concentration on the height of the room having a ground area of 22 x 8.5 m^2. A diameter of the generated spray of 20 µm (5.9 µm aerosol diameter after evaporation of the solvent) is associated with the highest mean concentration or, putting it the other way round, the lowest particle deposition rate. From a spray diameter of 5 µm the concentration decreases again, i.e. the deposition rate increases. This deposition behavior in the model calculation of ConsExpo cannot be explained by sedimentation alone, since sedimentation must be lowest for the smallest particles. This result would be plausible if – in contrast to the ConsExpo model description – additional deposition by diffusion was taken into account, which would take effect in case of small particles. It can be seen for the higher deposition rates that the points of the same size range are no longer located on a straight line. This is due to the fact that the lower the room height, the higher the deposition rate.

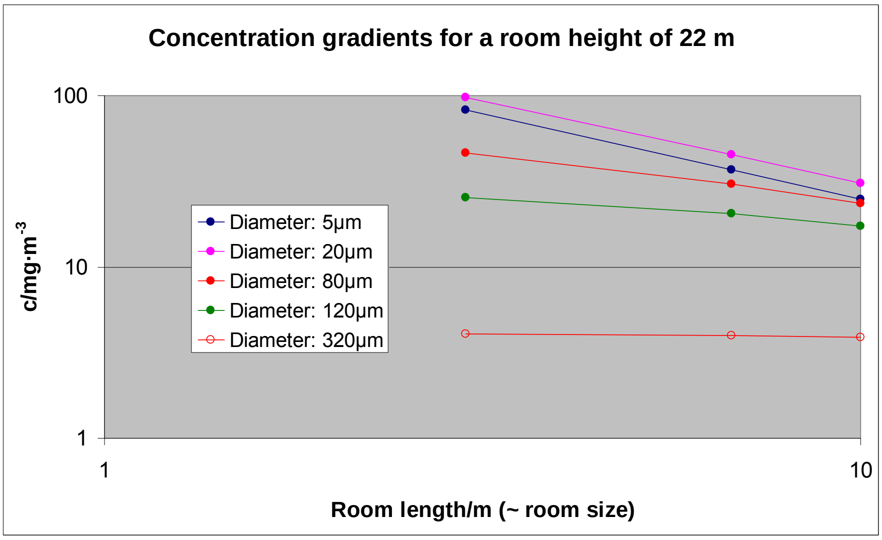


Fig. 3.11 Mean concentration depending on the room height as calculated with ConsExpo or BG-Spray

3.3.3 Comparison of SprayExpo with ConsExpo and BG-Spray

Room spraying

In the following, the inhalable mean concentrations calculated with the three models for a room spraying scenario will be directly compared. Seen that – as explained above – ConsExpo and BG-Spray yield identical results, only the concentration gradients provided by SprayExpo and ConsExpo will be shown in the figures.

The basic conditions in SprayExpo are: room width 8.5 m; spray release at a height of 2.5 m in the middle of the room; concentration of the active substance in the released spray 2.6 %; geometric standard deviation 1.8; release rate 1 ml/s; duration of application and inhalation for the worker 10 min; air exchange rate in the room once per hour. Parameters subject to variation are the length (4; 8; 16; 22; 32 m) and height (3; 6.75; 10 m) of the room and the MMD of the particle size in the released spray.
In ConsExpo/BG-Spray, instead of the length and width only the ground area of the room can be specified (differences therefore are to be expected for long, narrow rooms).

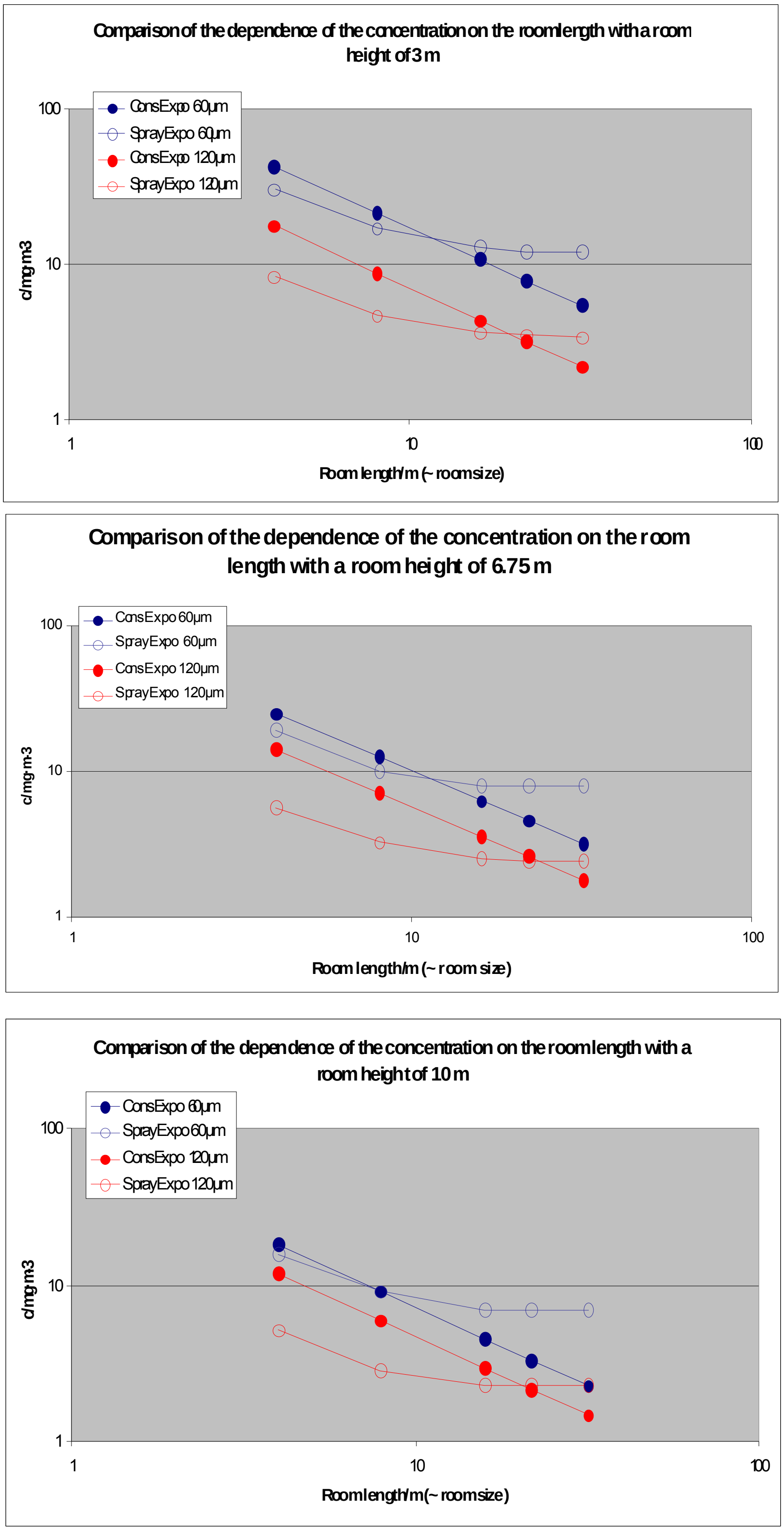


Fig. 3.12 Comparison of inhalable aerosol concentrations during room spraying

Tab. 3.2 Comparison of the mean inhalable aerosol concentration during room spraying

Height/m	MMD/µm	Length/m	$c_{SprayExpo}$/mg*m^{-3}	$c_{ConsExpo}$/mg*m^{-3}
3	60	4	30.0	43.2
3	60	8	17.0	21.6
3	60	16	13.0	10.8
3	60	22	12.0	7.9
3	60	32	12.0	5.4
3	120	4	8.3	17.5
3	120	8	4.7	8.8
3	120	16	3.6	4.4
3	120	22	3.5	3.2
3	120	32	3.4	2.2
6.75	60	4	19.0	25.0
6.75	60	8	10.0	12.5
6.75	60	16	8.0	6.2
6.75	60	22	8.0	4.5
6.75	60	32	8.0	3.1
6.75	120	4	5.6	14.1
6.75	120	8	3.2	7.1
6.75	120	16	2.5	3.5
6.75	120	22	2.4	2.6
6.75	120	32	2.4	1.8
10	60	4	16.0	18.2
10	60	8	9.0	9.1
10	60	16	7.0	4.6
10	60	22	7.0	3.3
10	60	32	7.0	2.3
10	120	4	5.1	11.9
10	120	8	2.9	5.9
10	120	16	2.3	3.0
10	120	22	2.3	2.2
10	120	32	2.3	1.5

Another decisive difference between the two models in how they deal with the dispersion of the spray in the room under physical aspects is that ConsExpo/BG-Spray assume the total aerosol to be dispersed immediately throughout the whole room, whereas in SprayExpo the dispersion takes place in a time-dependent manner (which makes sense under physical aspects). In some situations this leads to extremely different results: with ConsExpo/BG-Spray the concentration decreases linearly with a slope of -1 in the double logarithmic representation (Fig. 3.12). This means that the concentration is inversely proportional to the room size, i.e. it approaches zero in case of very large rooms. With SprayExpo the aerosol is dispersed within a limited space. Naturally, this space directly surrounds the worker applying the spray, so that for large rooms the computed concentrations of inhalable aerosol are higher than those yielded by ConsExpo/BG-Spray. For small rooms and small particles there is only a small difference. For large particles in small rooms, however, ConsExpo computes considerably higher values than SprayExpo. This is again due to the assumed instantaneous uniform dispersion in the room, here in particular with respect to the height. In real life, however, and also in SprayExpo large particles do not reach the upper areas in high rooms, i.e. they are deposited faster by sedimentation. In ConsExpo these particles have to travel a longer way until they reach the floor, thus increasing the mean concentration over time.

As can be seen in Fig. 3.12, the degree to which the inhalable aerosol is underestimated depends not only on the length of the room, but also on its height and the size of the aerosol. In the model example, the largest difference was found for a room length of 32 m, a room height of 10 m, and a size of released spray of 60 µm (see also Tab. 3.2, 6th line from the bottom). Under these conditions (bottom picture in Fig. 3.12), the difference, expressed as common logarithm, is 0.5, i.e.: ConsExpo/BG-Spray underestimate the actual concentration by a factor of 3. In this case, the concentration is 4.7 mg/m^3 lower and – seen the good agreement between the experimental results and SprayExpo (see Fig. 5.1) – the values are thus underrated.

Spraying onto wall surfaces

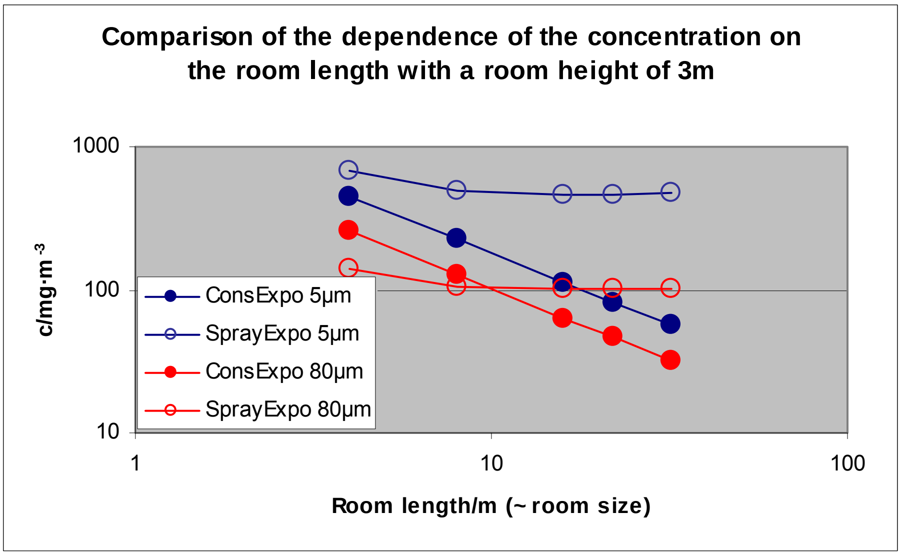
To compare the sensitivity of the models for spraying onto wall surfaces, the same basic conditions as described in the previous section were used. The amount of released spray, however, with 8 ml/s was by a factor of 8 higher. For this analysis, MMD of the generated spray of 5, 20, 80, 240, and 320 µm were taken into account.

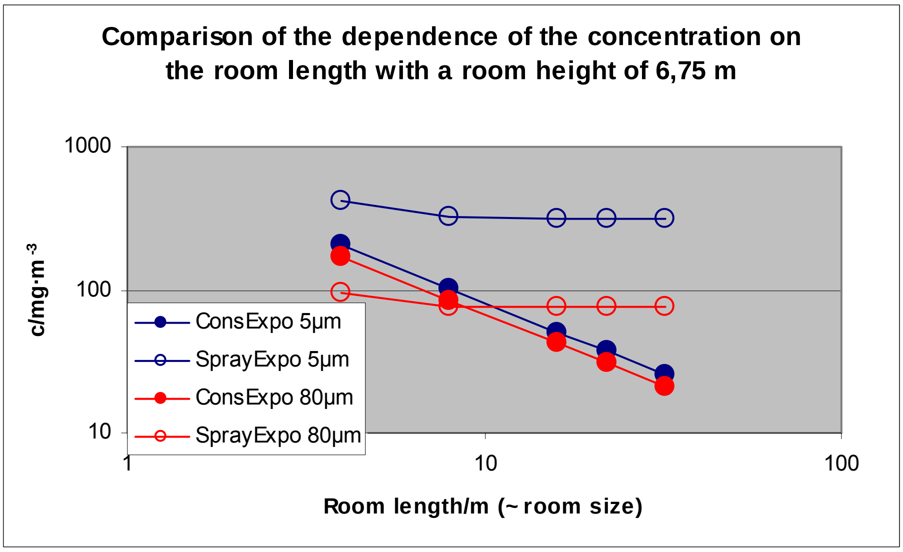
ConsExpo/BG-Spray do not compute the share of droplets that are not deposited on the wall. It is possible though to define an ‘airborne fraction’ in ConsExpo, to allow for the share that is deposited on the wall to be neglected for the airborne concentration. This share, however, strongly depends on the spraying conditions such as the sprayer’s distance from the wall. If this ‘airborne fraction’ is assumed to be 100 %, the computed values correspond exactly to the values that would be obtained for room spraying under otherwise identical conditions. In contrast, SprayExpo takes into account the specific conditions of this scenario (deposition on the wall depending on the selected nozzle properties, spraying onto the wall at a height between 0 m and 1 m, distance between sprayhead and wall 0.3 m). Fig. 3.13 shows a comparison of the concentrations computed with the different models in double logarithmic representation. In accordance with the modified approach, the results computed with SprayExpo in this case show significantly different results than in the previous section dealing with room spraying. Changes in the room size here result in considerably smaller changes than before. This holds true both for changes in the room height and in the room length. From a physical point of view this is quite understandable, as the wall now limits the dispersion of the spray cloud a lot more than when spraying in the middle of the room.

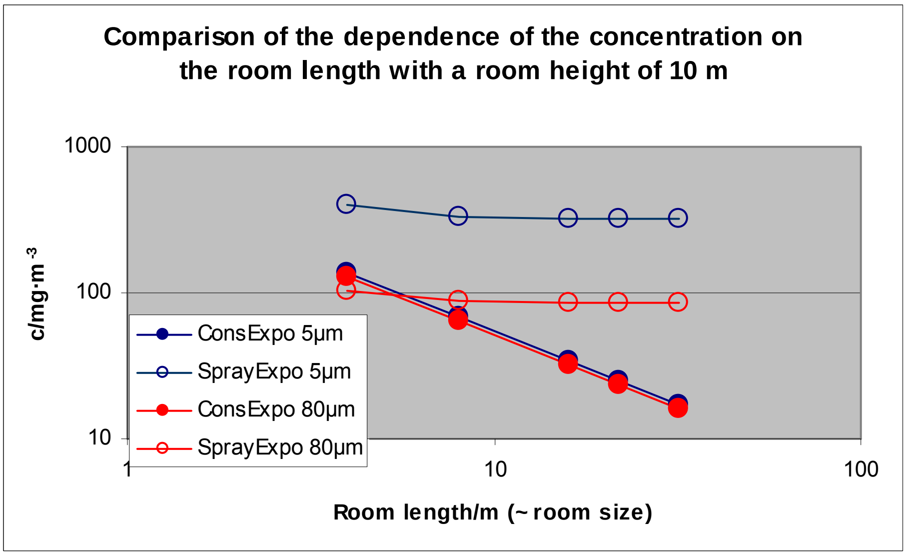
Tab. 3.3 Comparison of the mean inhalable aerosol concentration during spraying onto a wall

Height/m	MMD/µm	Length/m	$c_{SprayExpo}$/mg*m^{-3}	$c_{ConsExpo}$/mg*m^{-3}
3	5	4	675	453.2
3	5	8	490	226.6
3	5	16	466	113.3
3	5	22	468	82.4
3	5	32	470	56.7
3	20	4	583	536.8
3	20	8	428	268.4
3	20	16	408	134.2
3	20	22	410	97.6
3	20	32	411	67.1
3	80	4	138	254.8
3	80	8	106	127.4
3	80	16	103	63.7
3	80	22	103	46.3
3	80	32	103	31.8
3	240	4	7.7	39.6
3	240	8	6.09	19.8
3	240	16	5.9	9.9
3	240	22	5.91	7.2
3	240	32	5.93	4.9
3	320	4	3.2	22.4
3	320	8	2.5	11.2
3	320	16	2.45	5.6
3	320	22	2.45	4.1
3	320	32	2.46	2.8
6.75	5	4	416	203.3
6.75	5	8	326	101.6
6.75	5	16	315	50.8
6.75	5	22	316	37.0
6.75	5	32	316	25.4
6.75	20	4	366	248.6
6.75	20	8	288	124.3
6.75	20	16	279	62.2
6.75	20	22	279	45.2
6.75	20	32	280	31.1
6.75	80	4	94	168.5
6.75	80	8	77	84.3
6.75	80	16	75	42.1
6.75	80	22	75	30.6
6.75	80	32	76	21.1
6.75	240	4	5.44	37.6
6.75	240	8	4.51	18.8
6.75	240	16	4.41	9.4
6.75	240	22	4.42	6.8
6.75	240	32	4.43	4.7
6.75	320	4	2.26	21.8
6.75	320	8	1.9	10.9
6.75	320	16	1.8	5.5

Height/m	MMD/µm	Length/m	$c_{SprayExpo}$/mg*m^{-3}	$c_{ConsExpo}$/mg*m^{-3}
6.75	320	22	1.8	4.0
6.75	320	32	1.8	2.7
10	5	4	405	137.3
10	5	8	330	68.6
10	5	16	322	34.3
10	5	22	323	25.0
10	5	32	324	17.2
10	20	4	363	169.4
10	20	8	297	84.7
10	20	16	290	42.4
10	20	22	291	30.8
10	20	32	291	21.2
10	80	4	102	128.9
10	80	8	87	64.5
10	80	16	85	32.2
10	80	22	86	23.4
10	80	32	86	16.1
10	240	4	6.03	35.9
10	240	8	5.18	18.0
10	240	16	5.1	9.0
10	240	22	5.11	6.5
10	240	32	5.11	4.5
10	320	4	2.51	21.3
10	320	8	2.16	10.6
10	320	16	2.12	5.3
10	320	22	2.13	3.9
10	320	32	2.13	2.7


Comparison of the dependence of the concentration on the room length with a room height of 3m
1000
100
10
c/mg·m-3
1
10
100
Room length/m (~ room size)
ConsExpo 5µm
SprayExpo 5µm
ConsExpo 80µm
SprayExpo 80µm


Comparison of the dependence of the concentration on the room length with a room height of 6,75 m
1000
100
10
c/mg·m-3
1
10
100
Room length/m (~ room size)
ConsExpo 5µm
SprayExpo 5µm
ConsExpo 80µm
SprayExpo 80µm


Comparison of the dependence of the concentration on the room length with a room height of 10 m
1000
100
10
c/mg·m-3
1
10
100
Room length/m (~ room size)
ConsExpo 5µm
SprayExpo 5µm
ConsExpo 80µm
SprayExpo 80µm

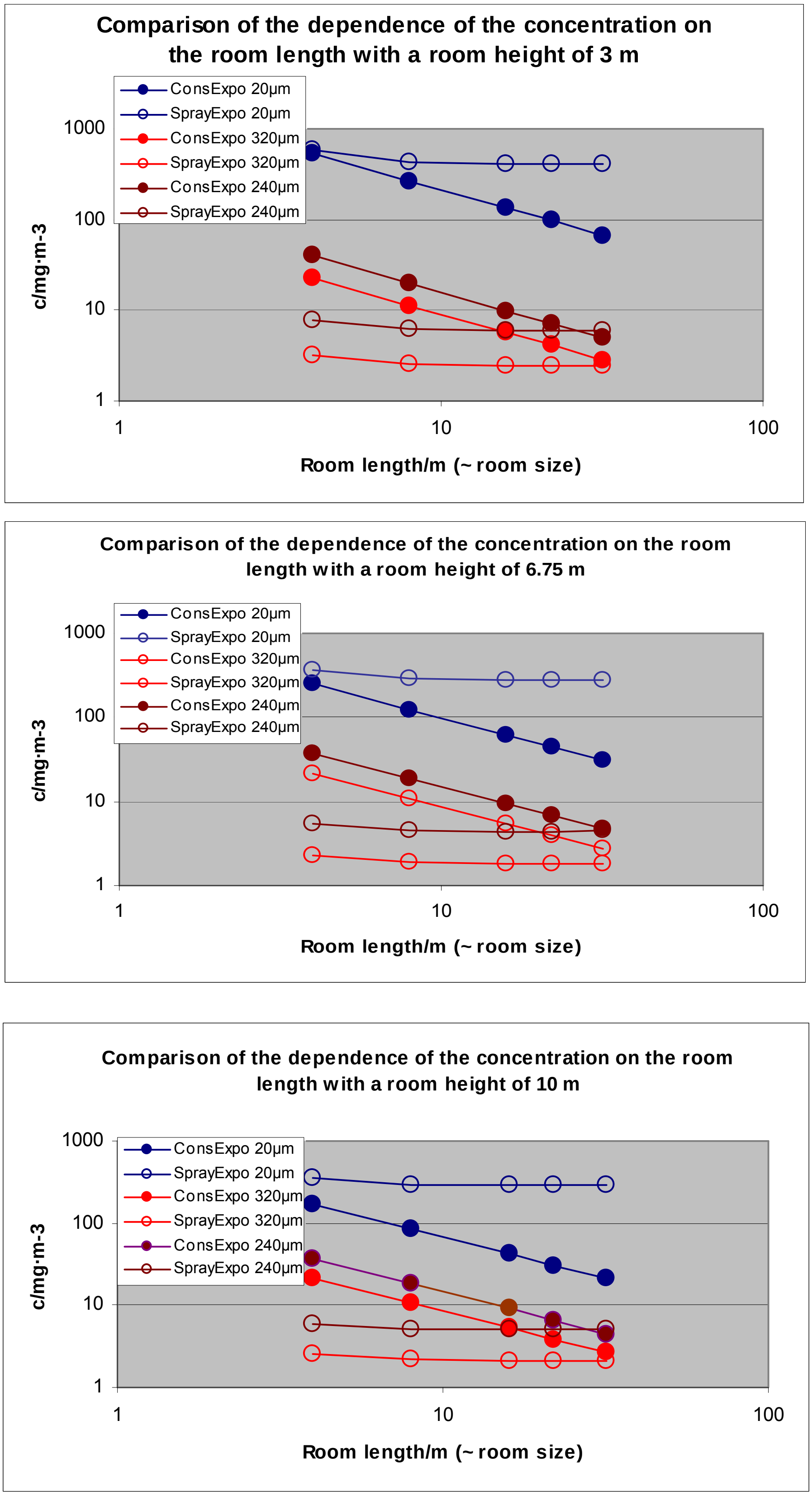


Fig. 3.13 Comparison of inhalable aerosol concentrations during spraying onto a wall

Since ConsExpo/BG-Spray assume a uniform dispersion of the spray cloud throughout the room also during spraying onto a wall, the results here of course deviate even more strongly from SprayExpo than for the room spraying scenario. For a diameter of 80 µm and the maximum room dimensions possible, ConsExpo/BG-Spray compute a concentration which is by a factor of more than 5 lower than that computed by SprayExpo (see Tab. 3.3). The smaller the mean size of the aerosol, the larger the difference in large rooms. For an MMD of 5 µm and a room height of 10 m, ConsExpo/BG-Spray underestimates the mean concentration by a factor of 19 for a room length of 32 m and by a factor of 3 for a room length of 4 m.

It is true that in case of large diameters the underestimation is compensated depending on the room size, in fact, it is sometimes even highly overcompensated (for an MMD of 320 µm, a room length of 4 m, and a height of 10 m, the result computed by ConsExpo/BG-Spray is by a factor of 9 or 19 mg/m^3 higher than that obtained with SprayExpo). This overcompensation is due to the simplification used in ConsExpo/BG-Spray, according to which all particles generated will first be dispersed in the entire room and will only thereafter slowly sink to the floor. This is, however, strictly impossible when generating large particles at a height below 1 m in a room with a height of ≥ 3 m. SprayExpo takes this into consideration.

A possible solution to eliminate this weakness of ConsExpo/BG-Spray may seem to be the idea of permitting only a maximum size of the space where the particles may be dispersed. As the size of this space, however, varies (the respective intersection points of the lines of best fit of the same color in the figures) depending on the particle size and the type of spraying (here spraying onto a wall or room spraying), this is not practicable.

Another solution might be to adjust the ‘airborne fraction’. However, only to a limited degree would this take into account the non-homogeneous dispersion of heavy droplets sprayed in the direction of the floor.

4 Exposure measurements

4.1 Method

4.1.1 Inhalation exposure

To characterize the exposure scenarios and determine the inhalation exposure measurements were performed using the aerosol monitoring and measurement system Respicon (Fig. 4.1), which was developed at the Fraunhofer ITEM (KOCH et al., 1999). This device includes three fiberglass filters that trap different particle size fractions (see below) and scattered-light photometers for on-line measurement. The data provided by the scattered-light photometers (voltages) are recorded by a portable data logger.

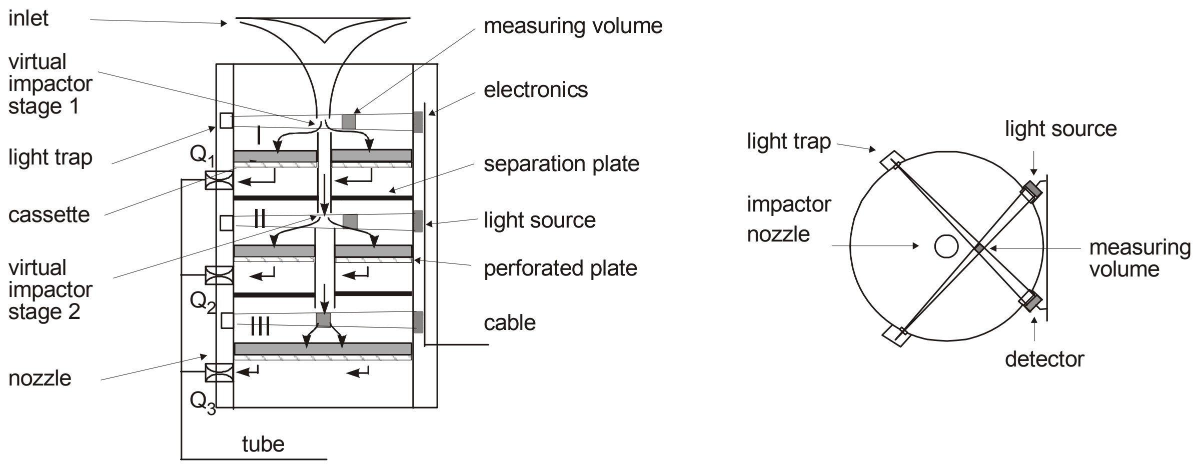


Fig. 4.1 Schematic representation of the Respicon

For inhalation exposure to an aerosol, the health-relevant particle size fractions defined in CEN 481 (CEN, 1993) are distinguished. These are the inhalable, the thoracic, and the respirable fractions of the total airborne active substance aerosol (see Fig. 4.2).

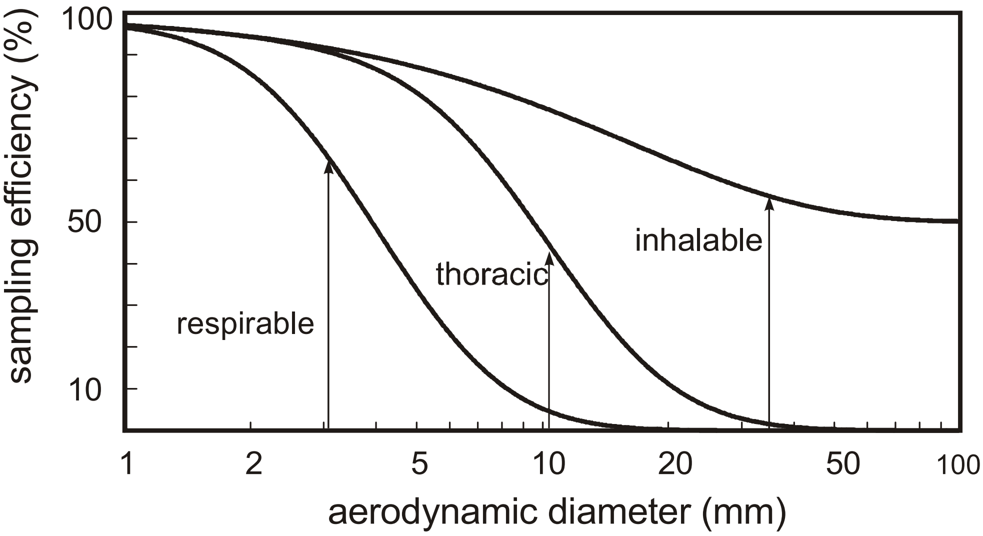


Fig. 4.2 Definition curves for the health-relevant aerosol size fractions according to CEN 481 (CEN, 1993)

The Respicon allows a person's exposure situation to be determined including its fluctuations in space and time. The measurement technology explicitly takes into account that inhalability and particle deposition in the human respiratory tract depend on particle size. The device enables simultaneous sampling of the respirable, thoracic, and inhalable fractions.

The inhalable fraction includes all particles that are breathed in via the mouth and nose (< 100 µm); the thoracic fraction includes the particles that pass the larynx and penetrate into the bronchi (< 10 µm); the respirable fraction are those particles that pass through the upper airways and the bronchi and penetrate into the unciliated airways, i.e. the alveoli (< 4.5 µm). Based on these fractions, further fractions can be defined: the extrathoracic fraction, i.e. those particles that remain in the area of the nasopharynx and the larynx, and the tracheobronchial fraction, i.e. particles which pass the larynx but do not get as far as the unciliated airways (see Tab. 4.1).

Tab. 4.1 Definition of particle size fractions

Fraction	
Inhalable fraction (C_{TH} + C_{NRK})	C_G
Thoracic fraction (C_F + C_{Tb})	C_{TH}
Respirable fraction	C_F
Tracheobronchial fraction (C_{Th} + C_F)	C_{Tb}
Extrathoracic fraction	C_{NRK}

The exposure concentrations (see Tab. 4.5, Tab. 4.7, and Appendix 3) were calculated based on single or summed-up filter deposits (masses of active substances and, if applicable, of the synergist piperonyl butoxide, which is used in biocidal products to enhance the insecticidal effect of pyrethroids and pyrethrins), taking into account the total volumetric flows of the device and the exposure time.

4.1.2 Dermal exposure

In addition, the potential dermal exposure of the spray user was monitored. To determine the dermal exposure (US EPA, 1987; OECD, 1997), 11 exposure pads (size 10 x 10 cm) made of filter paper were placed on defined body parts (see Fig. 4.3). The reverse side of the pads was protected with aluminum foil to avoid contamination. After completion of each spraying process, the pads were removed and the concentrations of active substances (active ingredient and synergist) determined (see Tab. 4.3).

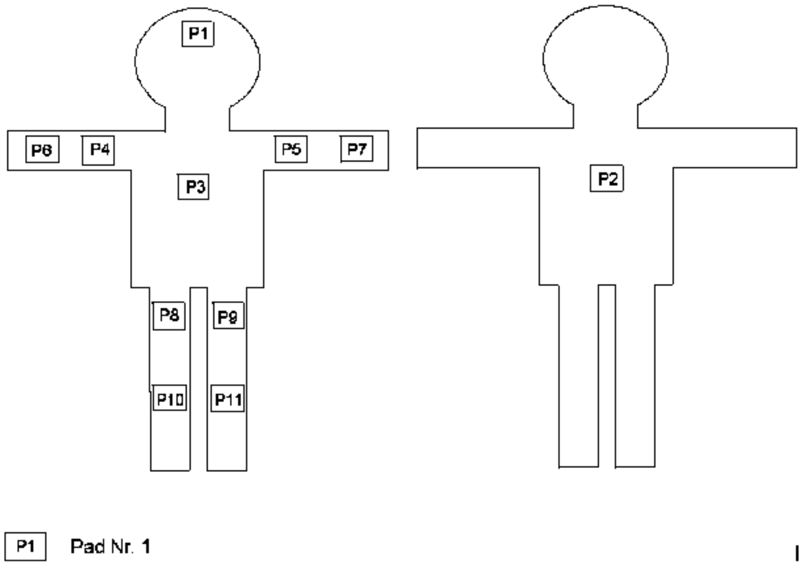


Fig. 4.3 Positioning of the pads

Tab. 4.2 Surface areas of different body parts (male adult, 80th percentile). Note: the given data include both arms and legs (OECD, 1997)

Body part	Surface (cm^2)
Head and face	1300
Back	3550
Chest	3550
Upper arms (left and right)	2910
Forearms (left and right)	1210
Thighs (left and right)	3820
Lower legs (left and right)	2380

To determine the potential dermal exposure of individual body parts (see Appendix 4), the masses of active ingredients (and of synergist, if applicable) found on the corresponding pad surface were multiplied by a factor resulting from the ratio of the surface area of the body part (see Tab. 4.2) to the surface area of the analyzed pad (100 cm^2).

To determine the exposure of the total body surface area (see Tab. 4.5 and Tab. 4.7), the masses of active ingredients (and of synergist) determined on the pads were summed up and multiplied by a factor resulting from the ratio of 1.9 m^2 total body surface area for an adult (BREMMER, 2006) to the total pad surface area.

Exposure of the hands was not determined separately, as this is influenced not so much by the actual spraying process, but rather by other actions (such as mixing of substances and handling of devices). For the validation of the SprayExpo model, this parameter therefore was not relevant.

4.1.3 Analytical methods to determine concentrations of active ingredients or tracers

To determine concentrations of the active ingredient and the synergist or tracer, the sampling media (filters, pads) were shredded and subject to extraction or hydrolysis (as indicated in Tab. 4.3) and subsequently measured.

Tab. 4.3 Analytical determination of active ingredients, synergists, and tracer substances

Substance	**Extraction method**	**Analytical method**
Pyrethrins	n-Hexane	Gas chromatography with electron capture detector
Permethrin	Ethyl acetate	Gas chromatography with mass-selective detector
Esbiothrin	Ethyl acetate	Gas chromatography with mass-selective detector
Piperonyl butoxide	Ethyl acetate	Gas chromatography with mass-selective detector
Cuprous oxide/cupric oxide	Acid hydrolysis	Atomic absorption spectroscopy (AAS)
Dysprosium acetate	Water	Inductively coupled plasma mass spectrometry (ICP-MS)

4.2 Field measurements

The following aspects were taken into consideration to select scenarios for the workplace measurements: application of biocides, product (agent) containing a non-evaporating substance (active ingredient/synergist), typical application technique, application in enclosed rooms, possibility to systematically vary relevant process parameters.

With these requirements in mind, workplaces in the area of antifouling treatment and scenarios in the area of stored product protection were selected for field measurements. Prior to the measurement campaigns, the facilities were visited, information about the relevance of the scenarios was obtained, and possibilities to vary typical process parameters were checked. Based on this knowledge, the field measurements were then planned in detail. For each measurement campaign an accompanying questionnaire was filled in, all of which have been included in Appendices 1 and 2.

Detailed information about typical spraying and fogging devices used in the above mentioned application areas can be found in the literature (KOCH et al., 2004).

4.2.1 Antifouling

Seven scenarios were characterized in the area of antifouling treatment. The investigations were performed during antifouling treatment with an Airless Sprayer in the blasting and coating workshops of a shipyard. Two products were employed which are commonly used for antifouling treatment (products (A) and (B)). A brief description of the scenarios is given in Tab. 4.4. For detailed information, please refer to the corresponding questionnaires in Appendix 1.

Tab. 4.4 Brief description of the investigated antifouling scenarios. The product ingredients are listed in the questionnaires

Scenario	Product	Device	Nozzles Pressure (operating pressure)*	Description of the application process
A1	(A)	Airless Sprayer	Graco (0.021``, 0.53 mm) 438 bar (248 bar)	Bow area of the ship/sprayer on a hoisting platform/spraying in horizontal or slightly downward direction
A2	(A)	Airless Sprayer	Graco (0.021``, 0.53 mm) 438 bar (248 bar)	Side part of the ship/sprayer below the part/spraying forward and upward, above the sprayer's head
A3-1	(A)	Airless Sprayer	Graco (0.021``, 0.53 mm) 438 bar (248 bar)	Side part of the ship, second coating/ sprayer below the part/spraying forward and upward, above the sprayer's head/ ventilation system off
A3-2	(A)	Airless Sprayer	Graco (0.021``, 0.53 mm) 438 bar (248 bar)	Side part of the ship, second coating/ sprayer below the part/spraying forward and upward, above the sprayer's head/ ventilation system off/immediately after application of the first coating in the same workshop
A4-1	(B)	Airless Sprayer	Graco (0.021``, 0.53 mm) 438 bar (248 bar)	Part of the double bottom, outer surface (facing ventilation outlets)/sprayer below the part/spraying forward and upward, above the sprayer's head and to side
A4-2	(B)	Airless Sprayer	Graco (0.021``, 0.53 mm) 438 bar (248 bar)	Part of the double bottom, middle section/ sprayer below the part/spraying forward and upward, above the sprayer's head
A4-3	(B)	Airless Sprayer	Graco (0.021``, 0.53 mm) 438 bar (248 bar)	Part of the double bottom, outer surface (away from ventilation outlets)/sprayer below the part/spraying forward and up-ward, above the sprayer's head

* Pressure = pressure inside the device; operating pressure = maximum effective pressure at the nozzle

Tab. 4.5 shows the results for the inhalation exposure (mean copper concentrations over time). All measurements with the Respicon were taken at the sprayer's breathing height. The lowest exposure concentrations to the copper-containing ingredients of the antifouling product (ca. 900 µg/m^3) were observed in Scenario A1 (hoisting platform, spraying in horizontal or slightly downward direction). Substantially higher exposure concentrations (3,700-7,800 µg/m^3) occurred during overhead spraying onto a side part of the ship (A2, A3). The highest concentrations were observed during antifouling treatment of a part of the double bottom, a rather large surface and thus a time-consuming process which involves overhead spraying (A4, 17,000-36,000 µg/m^3). During treatment of the side parts, the mean height of spray release was considerably higher than during spraying onto the bottom surfaces.

The results for the potential dermal exposure are shown in Tab. 4.5 (exposure of the total body surface, mass of copper per task) and in Appendix 4 (exposure of individual body parts per task). Like the inhalation exposure, the dermal exposure was lowest during spraying (in horizontal or downward direction) from the hoisting platform (A1). During overhead spraying with the Airless Sprayer (A2-A4) dermal exposure of the total body surface was by a factor of up to 125 higher (5,000-10,000 mg/task).

Tab. 4.5 Results of the measurements (inhalation and dermal exposures) during antifouling treatment

Scenario	**Application**			**Inhalation* µg/m³**			**Dermal *** mg/task**
	Device (product)	**Vol. (L)**	**t (min)****	C_G **(1)**	C_{Th} **(2)**	C_F **(3)**	
A1	Airless Sprayer (A)	45-50	30	930	90	10	78.6
A2	Airless Sprayer (A)	40	25	7840	1120	460	6142
A3-1	Airless Sprayer (A)	30	18	3730	490	270	6462
A3-2	Airless Sprayer (A)	30	15	7160	1230	570	9853
A4-1	Airless Sprayer (B)	70	52	n. s.	n. s.	n. s.	7996
A4-2	Airless Sprayer (B)	70	57	17120	2230	1200	7814
A4-3	Airless Sprayer (B)	60	38	35530	5860	3000	5142

n. s. Not specified
* Mean copper concentrations over time
** Duration of the spraying process or duration of measurement
*** Total body surface area
(1) Total inhalable fraction according to VDI 2265
(2) Thoracic fraction
(3) Respirable fraction

BEAT also provides measurement data from antifouling operations. The inhalation exposure to the applied product here is stated to be between 0 and 39.7 µl/m³ with a 75th percentile of 8.04 µl/m³ (HSE) and between 0.989 and 5.23 µl/m³ with a 75th percentile of 4.21 µl/m³ (HUGHSON & AITKEN). The potential dermal exposure of the body is stated to be 0.8-517 µl/min (HSE) and 9.21-165 µl/min (HUGHSON & AITKEN).

In our experiments, solutions containing 25-50 % cuprous oxide were used (= 22-45 % copper). The measurement results given in Tab. 4.5 are thus roughly in the same order of magnitude as the results given in BEAT (e.g. A2, C_G = 7840 µg/m³ approximately corresponds to 17-36 mg/m³ (≈ 17-36 µl/m³) referenced to the solution).

However, direct comparison is actually not possible, as decisive parameters are missing in the BEAT database. In the scenarios A2-A4 spraying was performed overhead, but little information about the underlying spraying process is available for the values given in BEAT. Depending on where and how the spraying is performed (e.g. downward or overhead spraying, spraying onto a side part or a part of the double bottom), exposure concentrations can differ by several orders of magnitude.

4.2.2 Stored product protection

Eleven scenarios were characterized in the area of stored product protection. The investigations were performed during the spraying/fogging of biocidal products using a high-performance spraying device (pressurized sprayer), an electric nebulizer, a thermal fogger, and spraying cans in silo cells and in a rice mill. Three different products were used, which in the following are referred to as products (C), (D), and (E). A brief description of the scenarios is given in Tab. 4.6. For detailed information, please refer to the corresponding questionnaires in Appendix 2.

Tab. 4.6 Brief description of the investigated stored product protection scenarios. The product ingredients are listed in the questionnaires in Appendix 2.

Scenario	Product	Device	Nozzles Pressure or setting	Description of the application process
M0	(C)	High-performance spraying device	Hollow cone (1 mm) 1.5-2 bar	Silo cell Close to the floor – along a line on the wall/downward spraying
M2	(C)	High-performance spraying device	Hollow cone (1 mm) 2-3 bar	Silo cell Close to the floor – along a line on the wall/downward spraying
M3	(C)	High-performance spraying device	Hollow cone (1 mm) 2-3 bar	Silo cell Vertical wall surface/horizontal spraying
M5	(C)	High-performance spraying device	Hollow cone (1 mm) 2-3 bar	Silo cell Floor surface/ downward spraying
M1	(C)	Electric nebulizer, cold fogger	n. s. medium	Silo cell Room fogging/meandering spraying in upward direction
M4	(D)	Spray can	n. s.	Silo cell Spraying at discrete spots in the room/ upward spraying direction
RM2	(E)	Thermal fogger	n. s.	Room fogging/horizontal forward spraying, with brief interruptions
RM3	(E)	Thermal fogger	n. s.	Room fogging/horizontal forward spraying
HS A	(D)	Spray can	Spray heads for continued spraying	Silo cell Room spraying/local release from 9 spray cans
HS B	(C)	Cold fogger	3 nozzles high	Silo cell Room fogging/local release, upwards at an angle
HS C	(C)	Thermal fogger	n. s. (1.2 mm)	Silo cell Room fogging/horizontal forward spraying and upwards at an angle

n.s. = not specified

The results for the inhalation exposure during pest control measures for stored product protection have been summarized in Tab. 4.7 (summed-up mean concentrations of active ingredients and synergist) and Appendix 3 (mean concentrations of active ingredients and synergist). The lowest exposure concentrations (170-630 µg/m^3) were observed during downward spraying with a high-performance spraying device (M0, M2, and M5). During spraying onto wall surfaces (M3), the concentration was about twice as high as during spraying onto the floor (M5). Use of the electric nebulizer (M1) for room fogging produced considerably higher concentrations (11,000-19,000 µg/m^3). The exposure concentration during the use of a spray can was similar, although in this case a substantially smaller amount of biocidal product was released in the room within the same time (M4). This is due to the considerably finer droplet distribution of a spray can, which is approximately 30 µm compared to 130 µm with the electric nebulizer. When using an electric nebulizer, a major part of the nebulized liquid is deposited on the silo floor. During use of the thermal fogger, the exposure concentrations of the non-evaporating ingredients were in the same range as during use of the electric nebulizer; the percentage of non-evaporating ingredients in product (E), however, was slightly lower than in product (C). With the thermal fogger, the complete airborne active substance aerosol belonged to the respirable fraction.

In the scenarios HS A to HS C, measurements were made over a prolonged period of time (independent of the duration of application of the biocidal product), as one of the aims here was to study the fading behavior of the non-evaporating ingredients in the room. Mean concentrations of the synergist piperonyl butoxide were between 14,000 and 15,000 µg/m^3 (measurement two hours) when using spray cans (HS A) or the cold fogger (HS B), with the respirable fraction being substantially higher when using spray cans. Use of the thermal fogger (HS C) resulted in a slightly lower concentration (ca. 5,500 µg/m^3), but with a very high respirable fraction (> 80 %).

The results for the potential dermal exposure are shown in Tab. 4.7 (exposure of the total body surface per task, summed-up masses of active ingredients and the synergist) and in Appendix 4 (exposure of individual body parts to the active ingredients and the synergist). The potential dermal exposure of the total body surface per task was lowest (0.5-5.5 mg/task) during spraying operations with the high-performance spraying device. Taking into account the small amount of substance applied, use of the spray can (M4) resulted in the highest dermal exposure (ca. 30 mg/task), which is in agreement with the relatively high inhalable concentrations. Use of the electric nebulizer (M1) equally caused a relatively high exposure; however, the amount of substance applied was substantially larger in this case.

Use of the thermal fogger (RM2, RM3) resulted in lower potential dermal exposures than use of a spray can or of the electric nebulizer. The high exposure value in scenario RM2 resulted from a strong contamination of the user’s lower leg, which was not so much due to sedimented overspray, but rather to a local contamination with the biocidal product.

Tab. 4.7 Results of the measurements (inhalation and dermal exposures) during pest control measures for stored product protection

Scenario	**Application**			**Inhalation* µg/m³**			**Dermal*** mg/task**
	Device (product)	**Vol. (L)**	**t (min)****	C_G (1)	C_{Th} (2)	C_F (3)	
M0	High-performance spraying device (C)	2.21	4.0	170	45	4	n. s.
M2	High-performance spraying device (C)	4.00	8.0	629	321	66	0.52
M2+	High-performance spraying device (C)	4.00	8.0	458	242	52	n. s.
M3	High-performance spraying device (C)	2.15	4.5	1446	667	142	3.31
M5	High-performance spraying device (C)	2.00	4.0	509	358	156	5.48
M1	Electric nebulizer (C)	6.00	12.0	19101	5069	1140	80.6
M1+	Electric nebulizer (C)	6.00	12.0	11310	2758	755	n. s.
M4	Spray can (D)	0.75	11.5	14542	6968	2249	31.2
RM2	Thermal fogger (E)	13.0	37.0++	10179	9859	10118	31.4
RM3	Thermal fogger (E)	6.00	8.0	11330	10999	11615	4.32
HS A	Spray can (D)	4.50	14 / 130(4)	22000 / 14888(5)	20000 / 13410(5)	10208(6)	n. s.
HS B	Cold fogger (C)	8.40	40 / 120(4)	25000 / 14246(5)	14000 / 9611(5)	5984(6)	n. s.
HS C	Thermal fogger (C)	7.00	35 / 145(4)	4000 / 5492(5)	4000 / 4903(5)	4641(6)	n. s.

M0-M5 Insektenil devices
* Summed-up mean concentrations of non-evaporating substances (active ingredients, synergist)
** Duration of the application
*** Total body surface area
\+ Accompanying person
++ With interruptions
(1) Total inhalable fraction according to VDI 2265
(2) Thoracic fraction
(3) Respirable fraction
(4) Duration of the spraying application/duration of measurement
(5) Mean concentration during the spraying application derived from the Respicon values/mean concentration during the whole duration of measurement
(6) Mean concentration during the whole duration of measurement
n. s. Not specified

4.3 Measurements in a model room to indirectly determine droplet size distributions for different application techniques

4.3.1 Motivation and method

In the course of the different workplace measurements and our comparative calculations by using the selected models, the predominant influence of the size distribution of spray droplets on the inhalation exposure became very obvious. At the same time, however, the difficulty of measuring this parameter directly for the different devices became apparent. Because of the dispersion and the discharge momentum of the spray jet, the laser diffraction spectrometer available at the Fraunhofer ITEM turned out to be unsuitable for measuring the droplet distribution of most of the devices used. For this reason and because manufacturers of spraying devices often do not provide any information about the droplet size distribution, this parameter normally cannot be assumed to be known by the users of the models.

Aiming to increase practicability in the use of the model, we will describe in the following the procedure of optimizing the model parameter droplet size distribution.

In the simulation program SprayExpo, the droplet size distribution should not be imported in the form of a file or entered directly in the form of the parameters of a lognormal distribution, but it should rather be stored as a dataset of the distribution parameters (MMD and σ_g). This dataset is parameterized according to the application technique and, if applicable, variable operating parameters etc., as shown for a specific example in Fig. 4.4.

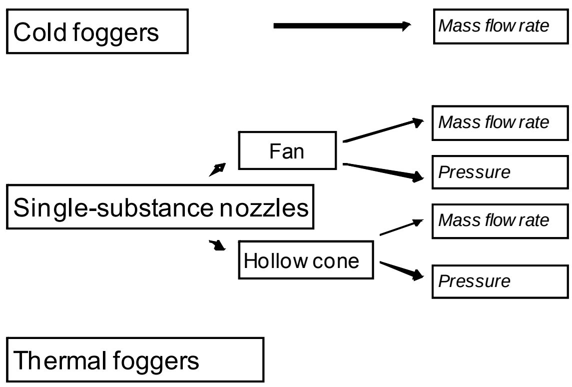


Fig. 4.4 Possible parametrization scheme for the application technique

To this end, spraying experiments with a broad range of devices were carried out under very well controlled conditions that were easy to model, with time-resolved and particle size-resolved measurement of the exposure concentrations. These processes were also simulated with the SprayExpo model, adjusting the droplet size distribution by means of the distribution parameters median diameter and geometric standard deviation such that the best possible agreement between model and experiment was reached. The distribution parameters determined were then stored in the models.

4.3.2 Execution of the measurements

In an empty storage room at the Fraunhofer ITEM, a total of 26 spraying experiments (Fig. 4.5) were performed with different spraying techniques (Tab. 4.8). In all these experiments, an aqueous formulation consisting of 0.2 % dysprosium acetate and 1 % sodium chloride was applied. The application was performed such that it could be simulated exactly with the program part 'room spray' in SprayExpo.

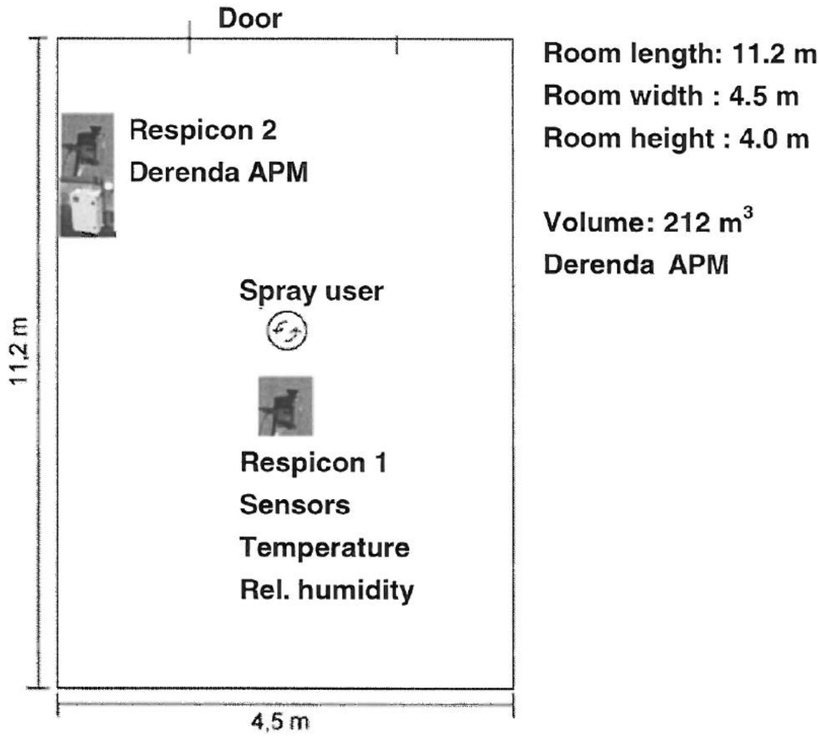


Fig. 4.5 Testing conditions during the controlled spraying experiments

The data recorded by Respicon 1 were used for the analyses, as this device describes the situation of the spray user. The spray droplets were released directly into the room without interference of limiting surfaces.

All experiments were performed according to the same time scheme:

- 5 minutes measurements prior to spraying
- 7 minutes spraying (4 x 1 minute spraying with 1 minute interruption in between)
- 30 minutes follow-up measurements

After termination of the experiment, the filters of the Respicon were analyzed for the amount of trapped dysprosium (see Tab. 4.3) and this value was then extrapolated to calculate the total mass concentration of the non-evaporating ingredients.

4.3.3 Results

Typical measurement results are shown in Fig. 4.6. The respirable fraction is always very small when using single-substance nozzles. The size distribution therefore was adjusted by means of the thoracic and inhalable fractions from the Respicon measurements.

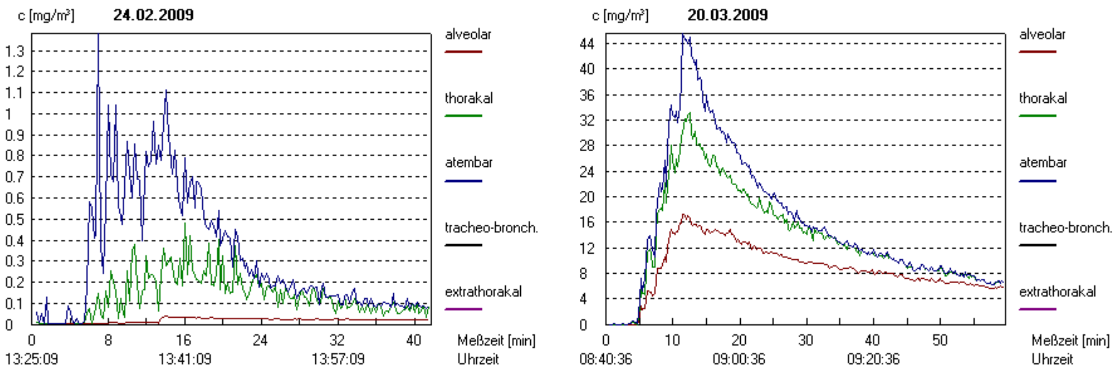


Fig. 4.6 Concentration gradients for a single-substance flat fan nozzle (coarse droplets) and for a thermal fogger (fine droplets) during controlled application in a test room

A summary of all results is given in Tab. 4.8. For all distributions a geometric standard deviation of 1.8 was used. These are typical values that were determined from measurements taken during experiments with hand-held spraying devices as part of another project conducted on behalf of the German professional association for health service and welfare care.

Single-substance pressure nozzles (flat fan nozzle, hollow cone nozzle) tend to generate rather coarse droplets. The median droplet diameter increases with decreasing operating pressure. For single-substance nozzles, we tested an empirical parametrization of the droplet size, d_{50}, in relation to the operating parameters pressure, p, and typical dispersion, l, of the nozzle according to the following equation:

$$d_{50} = A\, l^{\nu} / p^{\mu} \tag{4.1}$$

The typical dispersion, l, was calculated using the discharge velocity, V, as calculated by means of the equation $\Delta p = 1/2 \rho\, V^2$, and the surface that results from the corresponding throughput. For hollow cone and flat fan nozzles, different parameter sets A,ν,μ were adjusted to the experimentally determined datasets for hollow cone and flat fan nozzles (see Tab. 4.9). The quality of the correlations is demonstrated in Fig. 4.7. The type of the correlation reflects the expected trends, i.e. an increase in droplet size with increasing nozzle diameter and decreasing spraying pressure.

Tab. 4.8 Summary of the results of indirect determination of the droplet size distribution

Experi-ment	Spraying device/ nebulizer	Type of nozzle or nebulizer	Manufac-turer/nozzle name	Primary pressure [bar]/ setting	Through-put	MMD, d_{50}, experiment
					[ml/s]	[µm]
V1	Gloria high-performance spraying device	Flat fan nozzle	Frowein 6503	4.5	19.6	400
V2	Gloria high-performance spraying device	Flat fan nozzle	Frowein 6503	3.0	15.4	470
V3	Gloria high-performance spraying device	Flat fan nozzle	Frowein 6503	1.5	10.0	600
V4	Gloria high-performance spraying device	Flat fan nozzle	Frowein 650067	4.5	5.0	250
V5	Gloria high-performance spraying device	Flat fan nozzle	Frowein 650067	3.0	4.2	400
V6	Gloria high-performance spraying device	Flat fan nozzle	Frowein 650067	1.5	2.7	500
V7	Gloria high-performance spraying device	Flat fan nozzle	Frowein 50015	4.5	10.4	340
V8	Gloria high-performance spraying device	Flat fan nozzle	Frowein 50015	3.0	8.3	380
V9	Gloria high-performance spraying device	Flat fan nozzle	Frowein 50015	1.5	5.4	420
V10	Gloria high-performance spraying device	Hollow cone nozzle	Gloria	4.5	14.2	280
V11	Gloria high-performance spraying device	Hollow cone nozzle	Gloria	3.0	11.3	300
V12	Gloria high-performance spraying device	Hollow cone nozzle	Gloria	1.5	6.0	290
V13	Insektenil high-performance spraying device	Hollow cone nozzle	Hentschke + Sawatzki G-H-49-55	4.5	9.8	230
V14	Insektenil high-performance spraying device	Hollow cone nozzle	Hentschke + Sawatzki G-H-49-55	3.0	8.1	270
V15	Insektenil high-performance spraying device	Hollow cone nozzle	Hentschke + Sawatzki G-H-49-55	1.5	5.8	340
V16	Insektenil electric nebulizer	Cold fogger	Hentschke + Sawatzki	Low	5.4	130
V17	Insektenil electric nebulizer	Cold fogger	Hentschke + Sawatzki	High	13.3	140

Experi-ment	Spraying device/ nebulizer	Type of nozzle or nebulizer	Manufac-turer/nozzle name	Primary pressure [bar]/ setting	Through-put [ml/s]	MMD, d_{50}, experiment [µm]
V18	Insektenil electric nebulizer	Cold fogger	Hentschke + Sawatzki	Medium	7.9	110
V19	Swingfog SN50	Thermal fogger	Swingtec 1,2	--	7.3	50
V20	Dyna-Fog Hurricane	Cold fogger	Curtis Dyna-Fog	Medium	2.7	100
V21	Dyna-Fog Hurricane	Cold fogger	Curtis Dyna-Fog	High	5.6	130
V22	Nebulo	Cold fogger	IGEBA	Low	3.0	80
V23	Nebulo	Cold fogger	IGEBA	High	4.7	100
V24	TF 35	Thermal fogger	IGEBA 1,2	--	6.7	70
V25	TF 35	Thermal fogger	IGEBA 0,8	--	4.3	65
V26	TF 35	Thermal fogger	IGEBA 1,0	--	4.2	55

Tab. 4.9 Parameters for correlation of the median value d_{50}/µm of the diameter of droplet size distribution (l in cm, p in bar in equation 4.1)

Type of nozzle	A	ν	µ
Hollow cone nozzle	5270	1.00	0.25
Flat fan nozzle	3310	0.65	0.30

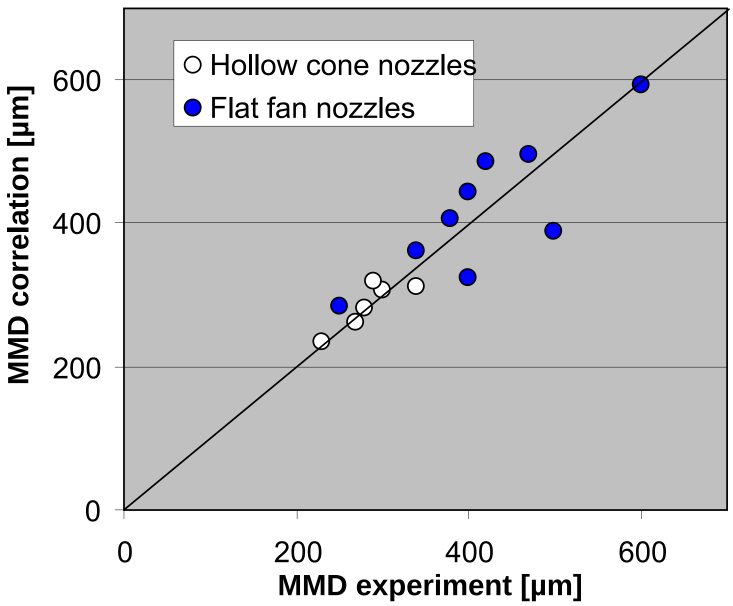


Fig. 4.7 Comparison of the mean droplet diameter values determined in the experiment and derived from the correlation (equation 4.1)

5 Comparison of model and experiments

5.1 ITEM model room

As described above, 26 spraying experiments were performed in the ITEM model room using different spraying techniques. These measurements on the one hand served the purpose of characterizing the exposure-relevant droplet spectrum of the common spraying techniques applied, but they can also be used for model validation (ConsExpo and BG-Spray). Tab. 5.1 shows a comparison between the measurement values obtained with the Respicon in the ITEM model room and the modeled values yielded by SprayExpo, ConsExpo, and BG-Spray.
Particle concentrations in the room after instantaneous diffusion are shown in the last two columns of the table for ConsExpo and BG-Spray. Due to the fact that ConsExpo and BG-Spray are based on the same physical approaches (total diffusion), similar values were to be expected, as has already been mentioned several times. As can be seen in the last two columns of the table, this has actually become true with only minor deviations.

Tab. 5.1 Comparison between Respicon and the different models

Experiment For parameters (device, pressure, MMD etc.) see Tab. 4.8	**Respicon**	**SprayExpo**	**ConsExpo 'spraying towards exposed person'**	**ConsExpo 'not spraying towards exposed person'**	**BG-Spray**
	Inhalable [mg/m³]				
V1	0.32	0.27	3.39	1.70	1.68
V2	0.3	0.13	2.05	0.96	0.95
V3	0.03	0.03	0.90	0.38	0.38
V4	0.3	0.29	1.77	1.09	1.08
V5	0.13	0.06	0.71	0.36	0.35
V6	0.04	0.02	0.33	0.15	0.15
V7	0.34	0.24	2.30	1.23	1.22
V8	0.16	0.14	1.55	0.79	0.76
V9	0.06	0.07	0.86	0.42	0.42
V10	0.71	0.61	4.21	2.48	2.44
V11	0.45	0.39	2.97	1.69	1.66
V12	0.26	0.23	1.70	0.99	0.97
V13	0.72	0.77	3.93	2.53	2.48
V14	0.4	0.39	2.55	1.52	1.50
V15	0.16	0.14	1.29	0.69	0.68
V16	1.87	2.32	5.31	4.28	4.21
V17	3.39	4.69	11.54	9.07	8.94
V18	4.41	5.12	10.13	8.58	8.44
V19	15.7	17.1	29.16	27.57	27.57
V20	1.93	2.35	2.77	2.16	2.10
V21	2.08	2.59	4.02	2.82	2.79
V22	3.93	4.12	4.34	3.63	3.58
V23	3.12	4.02	4.81	3.77	3.66
V24	9.88	11.8	11.86	10.26	10.23
V25	7.7	8.59	8.50	7.49	7.46
V26	10.19	10.8	10.45	9.51	9.40

More interesting is a comparison of the inhalable fraction between SprayExpo, ConsExpo, and the measurement values obtained by means of the Respicon. These are the data given in columns 2 to 5 of the table. Looking at the deviations between the model values and the measurement values of the Respicon, both models are sometimes in good agreement and sometimes wide off the mark. For SprayExpo, strong relative deviations are found only at low concentrations below 0.5 mg/m^3. This becomes particularly clear when plotting the results of the model calculations against the measurement results (Fig. 5.1). This shows excellent agreement for SprayExpo with the measurement results, with a slight overestimation in the case of larger values. In contrast, ConsExpo for some experiments deviates considerably from the measurement results. Comparison between 'spraying towards exposed person' (initial cloud size: 1 m^3) and a instantaneous diffusion in the room (columns 3 and 4), which is normally used in ConsExpo, shows the strong impact of the ‘room size’ when dealing with large particles (e.g. ITEM 1 to 3). In contrast, for small particles (e.g. ITEM 24 to 26) the differences between the two results are only small. These small difference are due to the fact that the spraying duration in this series of experiments was relatively short in relation to the total time of the person’s staying in the room. Because of the long duration, there is enough time for the cloud to be uniformly dispersed in the whole room, and for the mean concentration of small particles this leads to similar values as with instantaneous particle dispersion. The model version 'spraying towards exposed person', however, generally leads to a poorer agreement with the measurement values obtained with the Respicon.

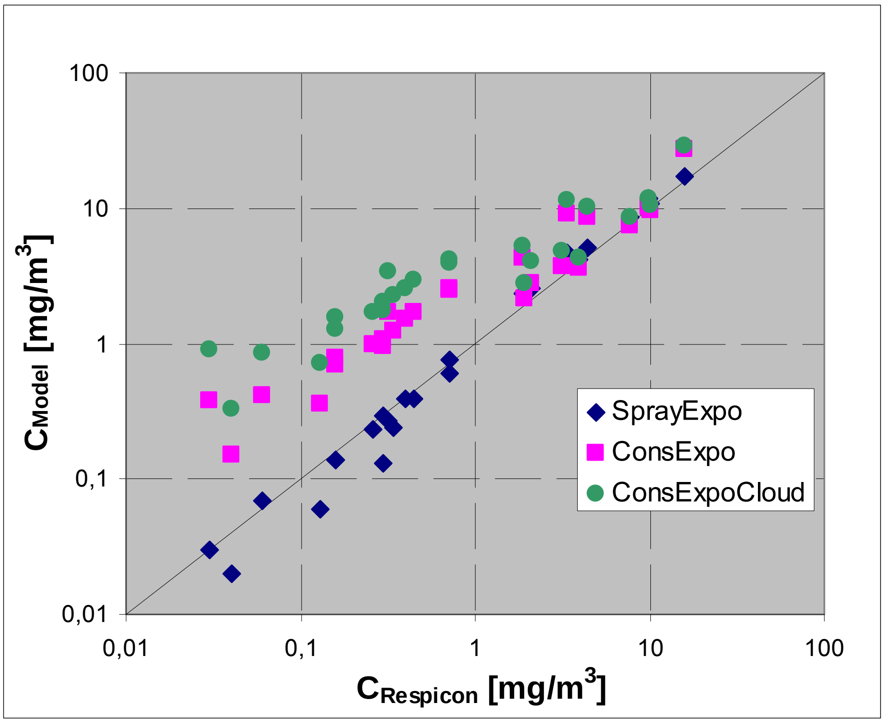


Fig. 5.1 Display of the calculated mean concentrations in relation to the measurement values

5.2 Antifouling (shipyard)

For the antifouling scenario, only the experiments A2 to A4 were simulated. The scenario A1 could not be mapped in SprayExpo, as it does not include this application pattern. A1 involves a moving hoisting platform and curved surfaces onto which spray is being applied in horizontal, slightly downward direction. SprayExpo does not offer spraying onto a wall with free space underneath. For the simulation of A2 to A4, a very large ground area of 30 x 30 m² was selected. The parts of the ship's hull was jacked up in this workshop and was being sprayed from underneath. The height was approximately 2.50 m. In the simulation, we therefore selected the scenario of spraying towards the ceiling in a model room with the dimensions 30 x 30 x 3 m³. Only a part of the surface was sprayed during the measurements. In addition, a value of 250 µm was assumed as median droplet size value for the spraying nozzle used (information provided by the spray user; we had no possibility to do our own measurements of droplet size distribution with this antifouling product). Fig. 5.2 shows a spraying scenario as an example and the corresponding simulation result. A summary of the comparison between measurements and SprayExpo calculations is shown in Fig. 5.3. The result is independent of the size of the workshop where the ship part is being treated. Despite the difficulty of defining the overall basic conditions, the prediction quality of the SprayExpo model is quite good.

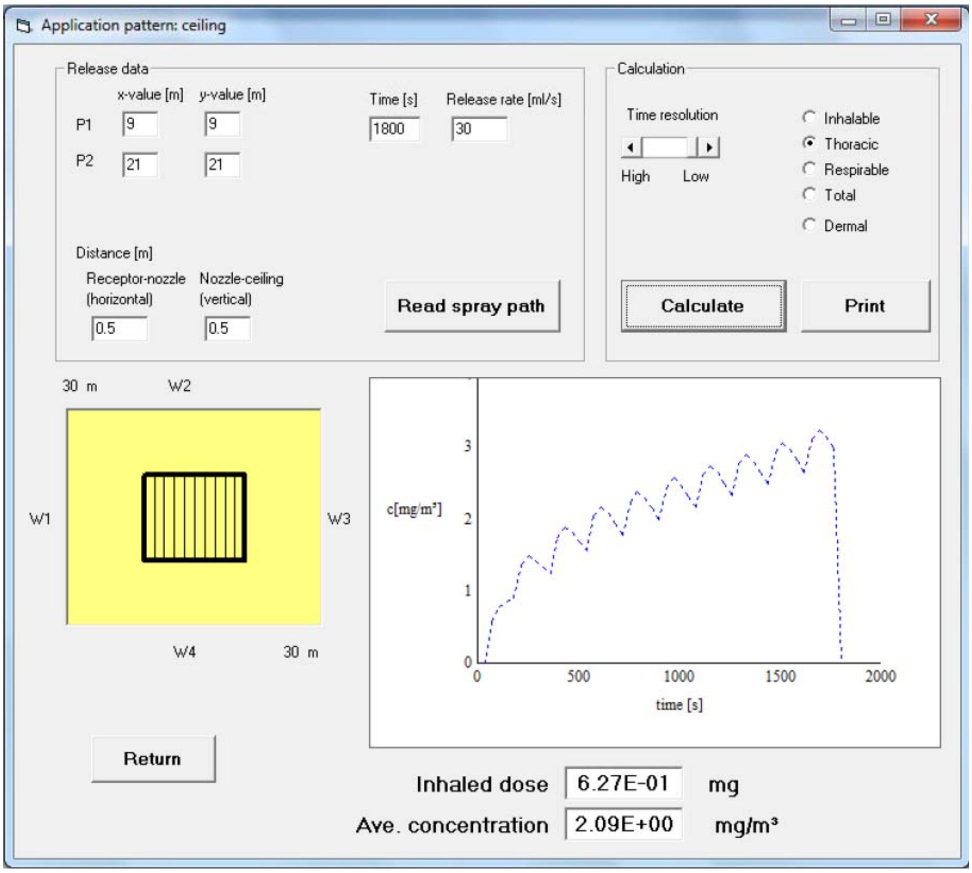


Fig. 5.2 Scenario used for simulating the process of overhead spraying the parts of the ship's hull

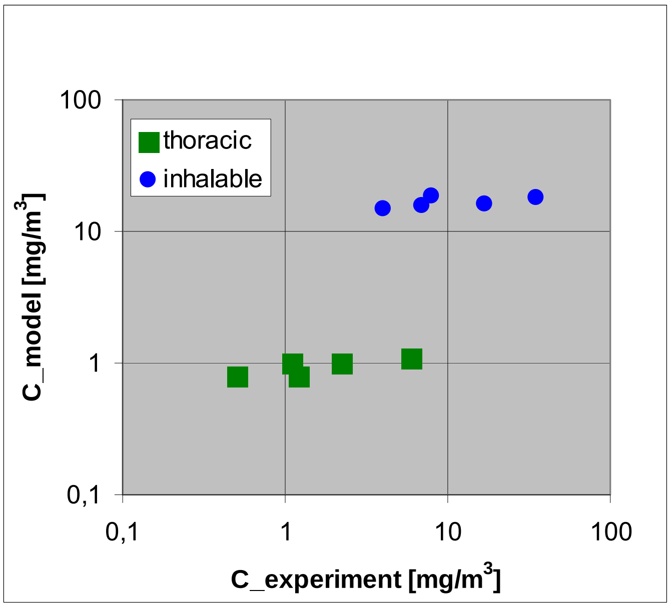


Fig. 5.3 Exposure concentration for the experiments of the *antifouling* measurement campaign (for modeling input parameters, please refer to Appendix 5)

5.3 Stored product protection (grain silo)

Based on the experiments performed in the area of stored product protection, all three models were evaluated. We first investigated to what extent the two exposure models ConsExpo and BG-Spray reflect the experimental courses in the five different settings (room spraying, wall line spraying (crack and crevice), spraying onto a wall area, and spraying onto a floor surface) described in the previous chapter. As explained already in chapter 3, the main difference between these two models and SprayExpo is that they assume the total amount of released spray to be instantaneously dispersed in the whole room under investigation and that the exact position of the sprayhead in the room cannot be defined. In accordance with their similar physical parameters, the results yielded by these two models are very similar, so that here only the calculations performed with ConsExpo will be displayed (Fig. 5.4).

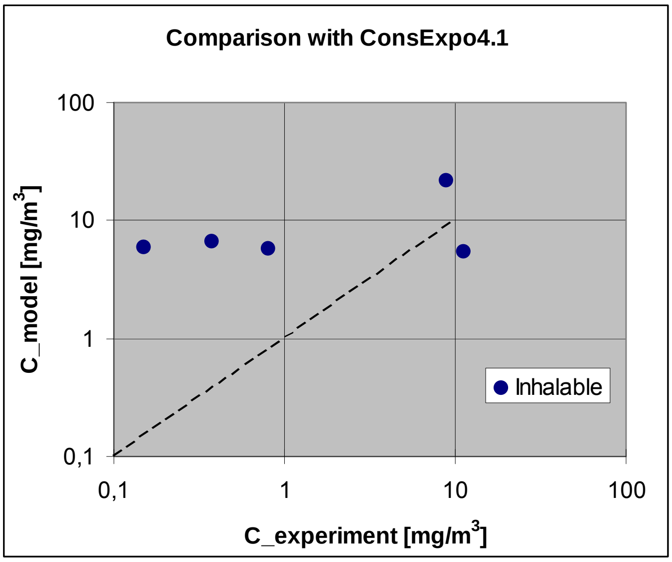


Fig. 5.4 Comparison of the exposure concentrations calculated with ConsExpo version 4.1 with the concentrations measured in the 5 experiments of the *stored product protection* measurement campaign

The scenarios coming closest to an instantaneous diffusion of the spray are the two room spraying scenarios (values at ca. 10 mg/m^3). As a result, the values computed by the model here are in rather good agreement with the measurement values. But already for the spraying onto a wall area (measuring point in the middle) ConsExpo overestimates the measuring point by a factor of 10. Modeling this scenario with SprayExpo, a constant distance of the nozzle from the wall of 50 cm was assumed. The differences are even larger for wall line spraying and spraying onto a floor surface (the two measuring points on the left). In these two cases in particular, sedimentation of the spray occurs very quickly because of the low spraying height and the spray thus cannot be dispersed in the room. Using the cloud model 'spraying towards exposed person' would result in even higher exposure values and thus in even more pronounced discrepancies. On the other hand, ConsExpo also enables definition of an overspray factor (= airborne fraction). This empirical factor has to be selected. For some applications, this factor has been stored in so-called 'fact sheets'. Using this factor the estimation results will be better.

The results of the SprayExpo computations are shown in Fig. 5.5, both for the inhalable and the thoracic fractions. For details on the calculations as compared with the time-resolved measurements, please refer to Appendix 5. Since SprayExpo takes into account the height of spray release, this model in almost all cases is in rather good agreement with the measured values. Especially for the spraying onto a wall area or floor surface, SprayExpo thus is to be preferred over the ConsExpo model.

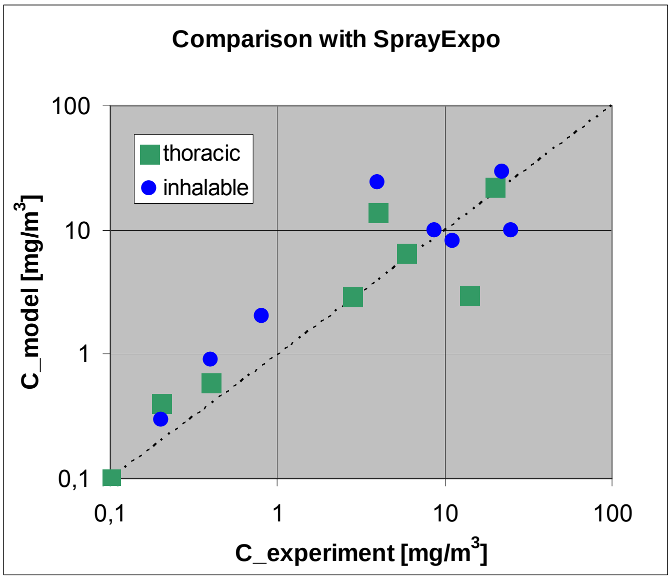


Fig. 5.5 Comparison of the exposure concentrations calculated with SprayExpo with the concentrations measured in the experiments of the *stored product protection* measurement campaign (for modeling input parameters, please refer to Appendix 5)

5.4 Quality of SprayExpo predictions

With regard to the SprayExpo model, a total of 13 comparisons between measured and computed values were made for spray application of biocidal products at workplaces (5 comparisons in the antifouling area, 8 in the area of stored product protection). The results shown in Tab. 5.2 were computed using the boundary values given in Appendix 5. The parameters with the greatest impact on the result of the calculations are mass flow rate, concentration of the active ingredient, MMD, application pattern, and application time (until a balance is reached). The size of the room has little impact on the calculated values for spraying onto a surface, but does have an impact in case of room spraying. The diffusion constant and the air exchange rate only have a minor impact.

The respirable fractions have not been included in Tab. 5.2, as the very low values involve higher measurement uncertainty. Based on the ratio of prediction and measurement (M./E.) the geometric mean and the geometric standard deviation were computed and added at the bottom of the table. On average, the exposure concentrations are slightly overestimated by the model. The geometric standard deviations of 2.3 (assuming lognormal distribution) mean that in about 70 % of cases the model is in agreement with the measurements within a factor of 4-5. However, the actual concentrations at work places are also highly variable although the process parameters are expected to be similar. When the droplet size distribution and all the other boundary parameters are exactly known the predictive power of the model is much better. The experiments in the model room have shown a geometric mean of 0.94 and a geometric standard deviation of 1.3 in the ratio reflecting the uncertainty of the measurements and the model prediction.

The dermal exposure during antifouling treatment on average is considerably underestimated by the model. This is due primarily to the fact that during use of the Airless Sprayer the potential dermal exposure results above all from splashes that hit the pads incidentally and cannot be correlated with the actual spraying process. The model can only take into account the deposition of the active substance on the body surface by aerosol settling. For room spraying (M1, M4) the potential dermal exposure is reflected quite well by the model.

Tab. 5.2 Measured (Respicon) and computed (SprayExpo) exposure concentrations (in mg/m^3) and potential dermal exposures (in mg/task) at workplaces and corresponding conditions

		Thoracic			**Inhalable**			**Dermal**		
		Exp.	**Mod.**	**M./E.**	**Exp.**	**Mod.**	**M./E.**	**Exp.**	**Mod.**	**M./E.**
Stored product protection	M1	2.8	2.9	1.0	8.8	9.9	1.1	80.6	92.0	1.1
	M2	0.2	0.4	1.8	0.4	0.9	2.5	0.5	4.4	8.5
	M3	0.4	0.6	1.6	0.8	2.0	2.5	3.31	5.9	1.8
	M4	5.9	6.6	1.1	11.2	8.1	0.7	31.2	17.8	0.6
	M5	0.1	0.1	0.9	0.2	0.3	1.8	5.48	0.8	0.1
	HS A	20.0	22.0	1.1	22.0	29.0	1.3			
	HS B	14.0	3.0	0.2	25.0	10.0	0.4			
	HS C	4.0	14.0	3.5	4.0	24.0	6.0			
Summary	Geom. mean			**1.1**			**1.5**			**1.0**
	Geom. Std. dev.			**2.3**			**2.3**			**5.5**
Antifouling	A2	1.1	1.0	0.9	8.0	18.5	2.3	6142	1225	0.20
	A3-1	0.5	0.8	1.6	4.0	14.7	3.7	6400	585	0.09
	A3-2	1.2	0.8	0.7	7.0	15.7	2.2	9800	520	0.05
	A4-2	2.2	1.0	0.5	17.0	16.2	1.0	7814	2000	0.26
	A4-3	5.9	1.1	0.2	35.0	18.0	0.5	5142	1475	0.29
Summary	Geom. mean			**0.9**			**1.5**			**0.4**
	Geom. Std. dev.			**2.3**			**2.2**			**4.6**

Based on these measured and modeled scenarios, three standard exposure scenarios were selected – one from the area of antifouling treatment and two from the area of stored product protection – and default values for these scenarios were derived (see Appendix 7). These standard exposure scenarios can be used to determine the exposure for registration of biocidal active substances (reasonable worst-case estimates). It should be kept in mind, however, that the default values are partially based only on individual observations, such as the dimensions of the coating workshop in the shipyard. Should better data be available, the default values should be adjusted accordingly.

All in all, it can be stated that the quality of the model predictions decisively depends on whether or not the droplet size distribution is known. As a rule, this information will not be available to the model user. This is why a ‘pick list’ has been implemented in the model SprayExpo, offering typical spraying devices for selection. The program will then automatically use the corresponding droplet size distribution. Geometric parameters such as the room size are less critical, in particular when the spraying duration is so short that the atomized spray does not get dispersed in the whole room during the spraying process.

In most practical cases the vapor pressure of the solvent is not relevant for the modeling result obtained. It is normally sufficient to distinguish between non-evaporating – this has to be indicated on the cover page by entering the fraction of non-evaporating substance in % – and evaporating. 1 hPa can be entered as vapor pressure for the solvent (evaporating fraction) as a default value.

In general, the model can be used only for indoor environments where the air exchange is based on turbulent diffusion. Convective (directed) mass transport is not taken into account in the physical approach of the model. In addition, it should be noted that the mass loss of applied active substance due to sedimentation is underestimated by the model, because only a single horizontal surface – the floor – is taken into consideration. In reality, sedimentation of released droplets and aerosols occurs, of course, on all horizontal surfaces in the room.

6 Summary and outlook

Software tools are increasingly used to assess the exposure of workers to hazardous substances. The absorbed dose is estimated on the basis of a large variety of models. Under the Biocidal Products Directive 98/8/EC, the method for calculating exposures has been described in the 'TNsG on Human Exposure'. In addition to ConsExpo and BEAT, this document also makes reference to the SprayExpo tool. It is assumed there, however, that SprayExpo has not been validated, in particular for applications involving dermal exposure and applications with droplet impaction.

This is why in the course of this research work, the deterministic model SprayExpo (F 1702, F 2022) has been revised, thoroughly investigated, and compared to the existing models ConsExpo and BG-Spray with regard to inhalation and dermal exposures to non-evaporating active ingredients applied by spraying processes. For this purpose, the models were validated with measurement results gained at workplaces and in scenarios of antifouling treatment and stored product protection.

An improved droplet impaction model for overspray calculation in scenarios involving spraying onto a surface has been implemented. Furthermore, it is no longer necessary to directly enter primary droplet distributions. Instead, for common spraying techniques these have been stored in a database from which they can be retrieved by specifying the spraying technique and simple process parameters such as the spraying pressure.

The sensitivity analysis revealed that besides the substance release rate, the droplet spectrum is the process parameter that has a decisive impact on the exposure level. In contrast, the vapor pressure of the solvent only plays a secondary role for the exposure concentration of the active ingredient within the relevant range of values.

To validate the SprayExpo model, the exposure concentrations of the applied active ingredients were determined at workplaces in the area of antifouling treatment by personal sampling and subsequent chemical analysis. Depending on the application scenarios, inhalable copper concentrations were between 900 and 36,000 µg/m^3, and the potential dermal exposures during overhead spraying were 5,000-10,000 mg/task. In addition, several scenarios in the area of stored product protection were investigated. Depending on the spraying technique, inhalation exposure to the active ingredients (+ synergist) under the investigated conditions (room size, concentration of the active ingredient etc.) was 170-19,000 µg/m^3 and potential dermal exposure was 0.5-80 mg/task.

Furthermore, 26 spraying experiments were performed in the ITEM model room by using different spraying techniques. In all these experiments, an aqueous formulation containing 0.2 % dysprosium acetate and 1 % sodium chloride was applied. The application was performed such that it could be exactly simulated with the program part 'room spray' in SprayExpo. These measurements on the one hand served the purpose of characterizing the exposure-relevant droplet spectrum of the common spraying techniques applied, but could also be used for model validation (ConsExpo and BG-Spray).

The concentrations calculated with the three models – SprayExpo on the one hand and ConsExpo and BG-Spray on the other hand – in some instances differ considerably. This is due to the substantial physical simplifications made in the models ConsExpo and BG-Spray as compared to the SprayExpo model. These simplifications are the instantaneous evaporation of the solvent, the instantaneous uniform dispersion of the spray throughout the whole room immediately upon its release (for the program version 'not spraying towards exposed person' in ConsExpo and for BG-Spray) – independent of the actual dispersion conditions – and the undifferentiated local definition of the sprayhead and spraying direction – e.g. onto the wall or floor surface. While the vapor pressure of the solvent has only little influence (at least as long as it is within the range of the typical solvents used, > 0.1 hPa), the other simplifications are of substantial impact.

The calculation of concentration values in ConsExpo or BG-Spray requires the droplet size distribution of the aerosols to be specified. Since on the one hand the user in general does not possess the required information regarding the droplet spectrum and on the other hand – as shown by our analyses – the size distribution of the emitted droplet spectrum is decisive for the inhalable aerosol concentration, this may present an essential limitation to the sensible and error-free use of the models. The solution implemented in SprayExpo of replacing the droplet spectrum by parameters of the spraying technique, therefore, should not only be an approach that is easy to handle, but also decisively improves the trustworthiness of the calculated results.

Our comparison of the model results with measurement results has shown that calculation of the aerosol concentration in ConsExpo and BG-Spray tends to overestimate the measured concentration for room spraying, but within one order of magnitude. For the spraying onto a wall or floor surface, however, ConsExpo and BG-Spray overestimate the actual concentration partly by a factor of 10. As we were able to show by means of SprayExpo, the actual concentration depends to a high degree on the spraying distance from the wall and on the droplet size. These parameters are subject to strong physical variation. For an estimation that should be as accurate as possible, therefore, it would not make sense to simply substitute this missing physical module in ConsExpo by an arbitrary specification of the percentage of aerosol mass that is actually released into the air (parameter 'airborne fraction').

In contrast to this, the present validation data show that SprayExpo allows the inhalation exposure during spraying applications in the areas of antifouling treatment and stored product protection to be mapped with an uncertainty that is normally below a factor of 4. Certain application scenarios, however, such as the downward spraying from a hoisting platform in antifouling treatment, at present cannot even be simulated in SprayExpo; but these scenarios also cannot or only to a limited extent be mapped in the other deterministic models. In particular for the spraying onto a wall or floor surface SprayExpo is much better capable of making accurate predictions. SprayExpo generally bears the advantage of calculating the exposure independent of the room size. For dermal exposures the model can only take into account the deposition of the active substance on the body surface by aerosol settling, but not accidentally occurring splashes. As a result, the dermal exposure at the workplace is in most cases underestimated by the SprayExpo model. For room spraying scenarios, however, the dermal exposure is reflected quite well in SprayExpo.

Based on the measured scenarios, three standard exposure scenarios for spray application were defined and documented in corresponding ‘fact sheets’. These can be used to obtain a reasonable worst-case estimate for the corresponding application situation (antifouling paint, surface and room spraying within stored product protection).

As an alternative to the deterministic models SprayExpo, ConsExpo, and BG-Spray, another option could be the use of BEAT. In particular for scenarios corresponding only vaguely to the stored database, however, there is no evidence in how far BEAT leads to realistic (valid) results or rather to an unrealistic over- or underestimation. The results of the measurements used for the SprayExpo validation, therefore, should be integrated into BEAT in order to improve the available data records. Important parameters that have an influence on spraying processes (e.g. for antifouling treatment or stored product protection) include, besides the nozzle, pressure, and droplet size distribution, also the spraying direction (room, wall, floor, overhead). It thus seems imperative to add the missing parameters to BEAT, to enable selection of the best suited scenarios for exposure assessment and MonteCarlo analysis. When using BEAT for exposure assessment, it is important to make sure that only ‘similar’ processes are used. Otherwise, errors or uncertainties in the result may reach several orders of magnitude, and this may lead significant under- or overestimation of the risk.

All in all, SprayExpo is a suitable model for assessing the exposure during indoor spraying processes, for example to biocidal products. It should be kept in mind, however, that all exposure models have their advantages and disadvantages and have to be used sensibly and with the necessary expert knowledge.

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Appendix 1 Description of exposure scenarios in antifouling treatment

Questionnaire for Project 2137 - Field Measurements

Process no.	A1
Date	Jan 28, 2008
Business	Shipyard

Scenario	*Airless spraying process* *Bow area of the ship*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(A)*	
Manufacturer		*n.s.*	
Package size		*20 L, bucket*	
Composition (concentrations)		*Cuprous oxide 25-50%, zinc oxide 12.5-15%, copper pyrithione 1-3%*	Xylene 10-12.5%, ethyl alcohol 5-10%, ethyl benzene 1-3%, 4-methyl-pentane-2-on 1-3%, paraffin 0.15-0.3%, mesitylene 0.1-0.15%
Safety data sheet		*Available*	
Labeling		*T, N*	
R-phrases		*R23, R22, R50/53*	
Product database record no.		*None*	
Application Area			
Description	*Shipyard, blasting and coating workshop 12 B*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	O natural* **X** technical**	*ca. 40 m x 35 m x 21.5 m*	18 °C/46%
Ventilation conditions	* Windows and doors O open **X** closed ** Suction **X** yes O no; air flow O yes O no; air flow rate m/s 0.1-0.2		
Additional remarks	*Central air suction system for the entire workshop, 2-3 m/s via 5 exhaust air sockets (each 0.75 m²), at both narrow sides of the workshop*		
Spray application conditions			
Description of the work process/work steps	*Antifouling coating by using the airless spraying technique, bow area of the ship, the spray user sprays from a hoisting platform, the hoisting platform is moved on after defined time intervals, during these movements the spraying process is interrupted*		
Process parameters	Start	End	Duration
	10:17 h	*10:47 h*	*30 minutes*
	Application volume	Processed surface area m²	Type of surface
	45-50 L	*ca. 70 m²*	*Metal*
	Surface shape/orientation	Number of processes	Other
	Curved, slope of 45 ° ◗	*1 with short interruptions*	
Additional remarks	*Applied volume: ca. 1 L/1.5 m²*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Airless Sprayer	*Graco*	*n.s.*
Nozzle	Type: *RAC 5 - 0.021``*	Manufacturer/no.	Diameter
	Nozzle 421, spraying angle 40°	*n.s.*	*0.021``, 0.53 mm*
Pressure conditions	Pressure: *1:73 (438 bar)*	Pressure generation	Throughput
	Max operating pressure 248 bar	*Generator, 6 bar*	*ca. 2 L/min*
Additional remarks	Direction: *towards the surface to be sprayed, horizontal direction or slightly downwards* Movement of the spray can and spray user: *Spray gun in the worker's right hand, target-oriented posture* *At defined time intervals the hoisting platform with the worker on it is moved on*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	2.5-3 m	*45-90°*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 1 m	*ca. 1 m*	
Additional remarks	*Worker and hoisting platform are periodically moved on, spraying is then interrupted* *Spraying is done in horizontal direction or with the nozzle pointing slightly downward*		
User			
General information	Qualification	Professional experience	Gender
	Painter	*15 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Safety data sheet	*Suction*	*Protective clothes, see below*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Single-use overall with hood	*Safety shoes*	*Full face mask*
	Goggles	Gloves	
	n/a	*Leather gloves*	
Exposure details			
Duration of spraying process	*30 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray, overspray	O < 30 cm O > 100 cm	*Deposited spray*
		X *30 - 100 cm*	
Frequency of the operation	During shift	During month	
	2 times	*Estimated 4 times*	
Other observations			

Additional remarks/notes
During the spraying process measurements with the Respicon on the spray user as well as measurements to determine the dermal exposure (full patch set) were performed. *Observations: strong smell of solvents in the workshop.* *No staining visible on the sprayer's protective overall.*

Questionnaire for Project 2137 - Field Measurements

Process no.	A2
Date	Feb 18, 2008
Business	Shipyard

Scenario	*Airless spraying process* *Side part of the ship*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(A)*	
Manufacturer		*n.s.*	
Package size		*20 L, bucket*	
Composition (concentrations)		*Cuprous oxide 25-50%, zinc oxide 12.5-15%, copper pyrithione 1-3%*	Xylene 10-12.5%, ethyl alcohol 5-10%, ethyl benzene 1-3%, 4-methyl-pentane-2-on 1-3%, paraffin 0.15-0.3%, mesitylene 0.1-0.15%
Safety data sheet		*Available*	
Labeling		*T, N*	
R-phrases		*R23, R22, R50/53*	
Product database record no.		*None*	
Application area			
Description	*Shipyard, blasting and coating workshop 12 A*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	O natural* **X** technical**	*ca. 40 m x 35 m x 21.5 m*	16-18 °C/41-44%
Ventilation conditions	* Windows and doors O open **X** closed ** Suction **X** yes O no; air flow O yes O no; air flow rate m/s 0.15		
Additional remarks	*Cubic volume (ca. 30100 m³), central air suction system for the entire workshop, 2-3 m/s via 5 exhaust air sockets (each 0.75 m²), at both narrow sides of the workshop*		
Spray application conditions			
Description of the work process/work steps	*Antifouling coating by using the airless spraying technique, side part of the ship, the spray user stands on the floor and sprays exclusively above his head, during spraying the sprayer slowly moves on, sometimes briefly interrupting the spraying*		
Process parameters	Start	End	Duration
	9:35 h	*10:00 h*	*25 minutes*
	Application volume	Processed surface area m²	Type of surface
	ca. 40 L (2 buckets)	*ca. 150 m²*	*Metal (ca. 7 m x 25 m)*
	Surface shape/orientation	Number of processes	Other
	Mostly horizontal	*1 with short interruptions*	
Additional remarks			
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Airless Sprayer	*Graco*	*n.s.*
Nozzle	Type: *RAC 5 - 0.021``*	Manufacturer/no.	Diameter
	Nozzle 421, spraying angle 40°	*n.s.*	*0.021``, 0.53 mm*
Pressure conditions	Pressure: *1:73 (438 bar)*	Pressure generation	Throughput
	Max operating pressure 248 bar	*Generator, 6 bar*	*ca. 2 L/min*
Additional remarks	Direction: *towards the horizontal surface to be sprayed above the sprayer's head* Movement of the spray can and spray user: *Spray gun in the worker's right hand, target-oriented posture forward and upward* *The spray user stands and walks below the ship component*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	ca. 2.50 m	*180°, vertically upwards*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 0.5 m	*ca. 0.3-0.5 m*	
Additional remarks	*During spraying the worker stands and walks on below the ship component* *Spraying is done overhead with the sprayer's arm extended*		
User			
General information	Qualification	Professional experience	Gender
	Painter	*Unknown*	*Male*
Protective measures	Organizational	Technical	Personal
	Safety data sheet	*Suction*	*Protective clothes, see below*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Single-use overall with hood	*Safety shoes*	*Full face mask*
	Goggles	Gloves	Other: *scarves on head and*
	n/a	*Leather gloves*	*forearm under the overall*
Exposure details			
Duration of spraying process	*25 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray, overspray	O < 30 cm O > 100 cm	*Deposited spray*
		X *30 - 100 cm*	
Frequency of the operation	During shift	During month	
	2 times	*Estimated 6 times*	
Other observations			

Additional remarks/notes
During the spraying process measurements with the Respicon on the spray user as well as measurements to determine the dermal exposure (full patch set) were performed. *Observations: strong smell of solvents in the workshop.* *Clearly visible staining of the upper part of the sprayer's protective overall.*

Questionnaire for Project 2137 - Field Measurements

Process no.	A3-1
Date	Feb 19, 2008
Business	Shipyard

Scenario	*Airless spraying process* *Side part of the ship (second antifouling coating after 24 hours)*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(A)*	
Manufacturer		*n.s.*	
Package size		*20 L, bucket*	
Composition (concentrations)		*Cuprous oxide 25-50%, zinc oxide 12.5-15%, copper pyrithione 1-3%*	Xylene 10-12.5%, ethyl alcohol 5-10%, ethyl benzene 1-3%, 4-methyl-pentane-2-on 1-3%, paraffin 0.15-0.3%, mesitylene 0.1-0.15%
Safety data sheet		*Available*	
Labeling		*T, N*	
R-phrases		*R23, R22, R50/53*	
Product database record no.		*None*	
Application area			
Description	*Shipyard, blasting and coating workshop 12 A*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	O natural* **X** technical**	*ca. 40 m x 35 m x 21.5 m*	13-15 °C/53%
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes **X** no; air flow O yes O no; air flow rate m/s		
Additional remarks	*Suction system not operating during the spraying process, cubic volume: 30100 m³*		
Spray application conditions			
Description of the work process/work steps	*Antifouling coating by using the airless spraying technique, side part of the ship (second coating), the spray user stands on the floor and sprays exclusively above his head, during spraying the sprayer slowly walks on, sometimes briefly interrupting the spraying*		
Process parameters	Start	End	Duration
	9:50 h	*10:08 h*	*18 minutes*
	Application volume	Processed surface area m²	Type of surface
	ca. 30 L (1.5 buckets)	*ca. 150 m²*	*Metal (ca. 7 m x 25 m)*
	Surface shape/orientation	Number of processes	Other
	Mostly horizontal	*1 with short interruptions*	
Additional remarks	*During the antifouling coating process, a surface of the second ship component in the workshop was being spray coated with green varnish*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Airless Sprayer	*Graco*	*n.s.*
Nozzle	Type: *RAC 5 - 0.021``*	Manufacturer/no.	Diameter
	Nozzle 421, spraying angle 40°	*n.s.*	*0.021``, 0.53 mm*
Pressure conditions	Pressure: *1:73 (438 bar)*	Pressure generation	Throughput
	Max operating pressure 248 bar	*Generator, 6 bar*	*ca. 2 L/min*
Additional remarks	Direction*: towards the horizontal surface to be sprayed above the sprayer's head* Movement of the spray can and spray user: *Spray gun in the worker's right hand, target-oriented posture forward and upward* *The spray user stands and walks below the ship component*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	ca. 2.50 m	*180°, vertically upwards*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 0.5 m	*ca. 0.3-0.5 m*	
Additional remarks	*During spraying the worker stands and walks on below the ship component* *Spraying is done overhead with the sprayer's arm extended*		
User			
General information	Qualification	Professional experience	Gender
	Painter	*Unknown*	*Male*
Protective measures	Organizational	Technical	Personal
	Safety data sheet	*Not operating*	*Protective clothes, see below*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Single-use overall with hood	*Safety shoes*	*Full face mask*
	Goggles	Gloves	Other: *scarves on head and*
	n/a	*Leather gloves*	*forearm under the overall*
Exposure details			
Duration of spraying process	*18 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray, overspray	O < 30 cm O > 100 cm	*Deposited spray*
		X *30 - 100 cm*	
Frequency of the operation	During shift	During month	
	2 times	*Estimated 6 times*	
Other observations			

Additional remarks/notes
During the spraying process measurements with the Respicon on the spray user as well as measurements to determine the dermal exposure (full patch set) were performed. *Observations: strong smell of solvents in the workshop.* *Clearly visible staining of the upper part of the sprayer's protective overall.* *During the antifouling coating operation, a surface of the second ship component that was simultaneously present in the workshop was being spray coated with green varnish.* *The surrounding area was contaminated with green paint, the pads and filters also showed staining with green paint.* *The green paint was no antifouling product (two-component system).*

Questionnaire for Project 2137 - Field Measurements

Process no.	A3-2
Date	Feb 19, 2008
Business	Shipyard

Scenario	*Airless spraying process* *Side part of the ship (second antifouling coating after 24 hours)*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(A)*	
Manufacturer		*n.s.*	
Package size		*20 L, bucket*	
Composition (concentrations)		*Cuprous oxide 25-50%, zinc oxide 12.5-15%, copper pyrithione 1-3%*	Xylene 10-12.5%, ethyl alcohol 5-10%, ethyl benzene 1-3%, 4-methyl-pentane-2-on 1-3%, paraffin 0.15-0.3%, mesitylene 0.1-0.15%
Safety data sheet		*Available*	
Labeling		*T, N*	
R-phrases		*R23, R22, R50/53*	
Product database record no.		*None*	
Application area			
Description	*Shipyard, blasting and coating workshop 12 A*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	O natural* **X** technical**	*ca. 40 m x 35 m x 21.5 m*	13-15 °C/53%
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes **X** no; air flow O yes O no; air flow rate m/s		
Additional remarks	*Suction system not operating during the spraying process, cubic volume: 30100 m³*		
Spray application conditions			
Description of the work process/work steps	*Antifouling coating by using the airless spraying technique, side part of the ship (second coating of the second side part), the spray user stands on the floor and sprays exclusively above his head, during spraying the sprayer slowly walks on, sometimes briefly interrupting the spraying*		
Process parameters	Start	End	Duration
	10:10 h	*10:25 h*	*15 minutes*
	Application volume	Processed surface area m²	Type of surface
	ca. 30 L (1.5 buckets)	*ca. 150 m²*	*Metal (ca. 7 m x 25 m)*
	Surface shape/orientation	Number of processes	Other
	Mostly horizontal	*1 with short interruptions*	
Additional remarks	*During the antifouling coating process, an adjacent surface of this ship component was being spray coated with green varnish, the two work areas being separated by a plastic curtain*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Airless Sprayer	*Graco*	*n.s.*
Nozzle	Type: *RAC 5 - 0.021``*	Manufacturer/no.	Diameter
	Nozzle 421, spraying angle 40°	*n.s.*	*0.021``, 0.53 mm*
Pressure conditions	Pressure: *1:73 (438 bar)*	Pressure generation	Throughput
	Max operating pressure 248 bar	*Generator, 6 bar*	*ca. 2 L/min*
Additional remarks	Direction*: towards the horizontal surface to be sprayed above the sprayer's head* Movement of the spray can and spray user: *Spray gun in the worker's right hand, target-oriented posture forward and upward* *The spray user stands and walks below the ship component*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	ca. 2.50 m	*180°, vertically upwards*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 0.5 m	*ca. 0.3-0.5 m*	
Additional remarks	*During spraying the worker stands and walks on below the ship component* *Spraying is done overhead with the sprayer's arm extended*		
User			
General information	Qualification	Professional experience	Gender
	Painter	*Unknown*	*Male*
Protective measures	Organizational	Technical	Personal
	Safety data sheet	*Not operating*	*Protective clothes, see below*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Single-use overall with hood	*Safety shoes*	*Full face mask*
	Goggles	Gloves	Other: *scarves on head and*
	n/a	*Leather gloves*	*forearm under the overall*
Exposure details			
Duration of spraying process	*15 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray, overspray	O < 30 cm O > 100 cm	*Deposited spray*
		X *30 - 100 cm*	
Frequency of the operation	During shift	During month	
	2 times	*Estimated 6 times*	
Other observations			

Additional remarks/notes

During the spraying process measurements with the Respicon on the spray user as well as measurements to determine the dermal exposure (full patch set) were performed.

Observations: strong smell of solvents in the workshop.
Clearly visible staining of the upper part of the sprayer's protective overall.

During the antifouling coating operation, an adjacent surface of the second ship component was being spray coated with green varnish, a plastic curtain separating the two work areas.
The surrounding area was contaminated with green paint, the pads and filters also showed staining with green paint.
The green paint was no antifouling product (two-component system).

Questionnaire for Project 2137 - Field Measurements

Process no.	A4-1
Date	May 9, 2008
Business	Shipyard

Scenario	*Airless spraying process* *Part of the double bottom (first antifouling coating)* *Coating of the outer surface facing the ventilation outlets*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(B)*	
Manufacturer		*n.s.*	
Package size		*20 L, bucket*	
Composition (concentrations)		*Cuprous oxide 30-40%, zinc oxide 5-10%, zineb 3-5%, synth. mineral fibers 3-5%, 2-methylthio-4-tert-butylamino-6-cyclopropyl amino-s-triazine 0.5-1%*	Xylene 15-20%, ethyl benzene 3-5%, petroleum 1-3%, 4-methylpentan-2-one 1-3%, white spirit 0.15-0.2%
Safety data sheet		*Available*	
Labeling		*Xn, N*	
R-phrases		*R10, R20/21/22, R38, R43*	R50/53
Product database record no.		*n.s.*	
Application area			
Description	*Shipyard, coating workshop 12 C*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	O natural* **X** technical**	*ca. 57 m x 35 m x 17 m*	*19.1-20.1 °C/42.8-34.8%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction **X** yes O no; air flow O yes O no; air flow rate m/s 0.15-0.2		
Additional remarks	*The air suction system was operating during the spraying process, cubic volume: ca. 34000 m³, central ventilation system with exhaust outlets at one narrow side of the workshop, full power*		
Spray application conditions			
Description of the work process/work steps	*Antifouling coating by using the airless spraying technique, part of the double bottom (outer surface), the spray user stands on the floor and sprays above his head, at the edges upwards to the side (ca. 20%). During spraying the sprayer slowly moves on, sometimes briefly interrupting the spraying.*		
Process parameters	Start	End	Duration
	ca. 8:36 h	*9:28 h*	*52 minutes*
	Application volume	Processed surface area m²	Type of surface
	ca. 70 L (3.5 buckets)	*ca. 250 m²*	*Metal (ca. 9 m x 28 m)*
	Surface shape/orientation	Number of processes	Other
	Above, horizontal and lateral	*1 with short interruptions*	
Additional remarks	*Lacquer was simultaneously being applied to the interior of the ship component by using a roller and by spraying. An additional 4-8 persons were present in the workshop.*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Airless Sprayer	*Graco*	*n.s.*
Nozzle	Type: *RAC 5 - 0.021``*	Manufacturer/no.	Diameter
	Nozzle 421, spraying angle 40°	*n.s.*	*0.021``, 0.53 mm*
Pressure conditions	Pressure: *1:73 (438 bar)*	Pressure generation	Throughput
	Max operating press. 248 bar	*Generator, 6 bar*	*2L/min*
Additional remarks	Direction: *towards the horizontal surface to be sprayed above the sprayer's head and sidewards at the outer edge* Movement of the spray can and spray user: *Spray gun in the worker's right hand, target-oriented posture forward and upward or sideward, the spray user stands and walks on below the ship component*		
Operating technique			
Spraying parameters	Spraying height	Spraying angle	
	ca. 2.00 m	*180°, vertically upwards*	*120°, upwards to the side*
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 0.8 m	*ca. 0.3-0.5 m*	
Additional remarks	*During spraying the worker stands and walks on below the ship component* *Spraying is done overhead with sprayer's arm extended, at the edge upwards to the side*		
User			
General information	Qualification	Professional experience	Gender
	Painter	*2 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Safety data sheet	*Ventilation*	*Protective clothes, see below*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Single-use overall with hood	*Safety shoes*	*Full face mask*
	Goggles	Gloves	Other: *scarves on head and*
	n/a	*Leather gloves*	*forearm under the overall*
Exposure details			
Duration of spraying process	*52 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray, overspray	O < 30 cm O > 100 cm	*Deposited spray*
		X *30 - 100 cm*	
Frequency of the operation	During shift	During month	
		Estimated 3-4 times	
Other observations			

Additional remarks/notes
During the spraying process measurements with the Respicon on the spray user as well as measurements to determine the dermal exposure (full patch set) were performed. *During the spraying process, video recordings and measurements with a PIMEX device were made.* *Observations: slight smell of solvents in the workshop.* *Visible staining of the upper part of the sprayer's protective overall.*

Questionnaire for Project 2137 - Field Measurements

Process no.	A4-2
Date	May 9, 2008
Business	Shipyard

Scenario	*Airless spraying process* *Part of the double bottom (first antifouling coating)* *Coating of the middle section*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(B)*	
Manufacturer		*n.s.*	
Package size		*20 L, bucket*	
Composition (concentrations)		*Cuprous oxide 30-40%, zinc oxide 5-10%, zineb 3-5%, synth. mineral fibers 3-5%, 2-methylthio-4-tert-butylamino-6-cyclopropyl amino-s-triazine 0.5-1%*	Xylene 15-20%, ethyl benzene 3-5%, petroleum 1-3%, 4-methylpentan-2-one 1-3%, white spirit 0.15-0.2%
Safety data sheet		*Available*	
Labeling		*Xn, N*	
R-phrases		*R10, R20/21/22, R38, R43*	R50/53
Product database record no.		*n.s.*	
Application area			
Description	*Shipyard, coating workshop 12 C*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	O natural* **X** technical**	*ca. 57 m x 35 m x 17 m*	*19.1-20.1 °C/42.8-34.8 %*
Ventilation conditions	* Windows and doors O open **X** closed **		
	Suction **X** yes O no; air flow O yes O no; air flow rate m/s 0.15-0.2		
Additional remarks	*Air suction system was operating during spraying, cubic volume: ca. 34000 m³, central ventilation system with exhaust outlets at one narrow side of the workshop, full power*		
Spray application conditions			
Description of the work process/work steps	*Antifouling coating by using the airless spraying technique, part of the double bottom (outer surface), the spray user stands on the floor and sprays the middle part of the ship component above his head. During spraying the sprayer walks on, sometimes briefly interrupting the spraying.*		
Process parameters	Start	End	Duration
	ca. 10:10 h	*11:07 h*	*57 minutes*
	Application volume	Processed surface area m²	Type of surface
	ca. 70 L (3.5 buckets)	*ca. 250 m²*	*Metal (ca. 9 m x 28 m)*
	Surface shape/orientation	Number of processes	Other
	Above, horizontal	*1 with short interruptions*	
Additional remarks	*Lacquer was simultaneously being applied to the interior of the ship component by using a roller and by spraying. An additional 4-8 persons were present in the workshop.*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Airless Sprayer	*Graco*	*n.s.*
Nozzle	Type: *RAC 5 - 0.021``*	Manufacturer/no.	Diameter
	Nozzle 421, spraying angle 40°	*n.s.*	*0.021``, 0.53 mm*
Pressure conditions	Pressure: *1:73 (438 bar)*	Pressure generation	Throughput
	Max operating press. 248 bar	*Generator, 6 bar*	*2L/min*
Additional remarks	Direction: *towards the horizontal surface to be sprayed above the sprayer's head* Movement of the spray can and spray user: *Spray gun in the worker's right hand, target-oriented posture forward and upward, the spray user stands and walks on below the ship component*		
Operating technique			
Spraying parameters	Spraying height	Spraying angle	
	ca. 2.00 m	*180°, vertically upwards*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 0.8 m	*ca. 0.3-0.5 m*	
Additional remarks	*During spraying the worker stands and walks on below the ship component* *Spraying is done overhead with the sprayer's arm extended*		
User			
General information	Qualification	Professional experience	Gender
	Painter	*2 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Safety data sheet	*Ventilation*	*Protective clothes, see below*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Single-use overall with hood	*Safety shoes*	*Full face mask*
	Goggles	Gloves	Other: *scarves on head and*
	n/a	*Leather gloves*	*forearm under the overall*
Exposure details			
Duration of spraying process	*57 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray, overspray	O < 30 cm O > 100 cm	*Deposited spray*
		X *30 - 100 cm*	
Frequency of the operation	During shift	During month	
		Estimated 3-4 times	
Other observations			

Additional remarks/notes
During the spraying process measurements with the Respicon on the spray user as well as measurements to determine the dermal exposure (full patch set) were performed. *During the spraying process, video recordings and measurements with a PIMEX device were made.* *Observations: increasing smell of solvents in the workshop.* *Visible staining of the upper part of the sprayer's protective overall.*

Questionnaire for Project 2137 - Field Measurements

Process no.	A4-3
Date	May 9, 2008
Business	Shipyard

Scenario	*Airless spraying process* *Part of the double bottom (first antifouling coating)* *Coating of the outer surface facing away from the ventilation outlets*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(B)*	
Manufacturer		*n..s.*	
Package size		*20 L, bucket*	
Composition (concentrations)		*Cuprous oxide 30-40%, zinc oxide 5-10%, zineb 3-5%, synth. mineral fibers 3-5%, 2-methylthio-4-tert-butylamino-6-cyclopropyl amino-s-triazine 0.5-1%*	Xylene 15-20%, ethyl benzene 3-5%, petroleum 1-3%, 4-methylpentan-2-one 1-3%, white spirit 0.15-0.2%
Safety data sheet		*Available*	
Labeling		*Xn, N*	
R-phrases		*R10, R20/21/22, R38, R43*	R50/53
Product database record no.		*n.s.*	
Application area			
Description	*Shipyard, coating workshop 12 C*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	O natural* **X** technical**	*ca. 57 m x 35 m x 17 m*	*19.1-20.1 °C/42.8-34.8 %*
Ventilation conditions	* Windows and doors O open **X** closed Suction **X** yes O no; air flow O yes O no; air flow rate m/s 0.15-0.2		**
Additional remarks	*Air suction system was operating during spraying, cubic volume: ca. 34000 m³, central ventilation system with exhaust outlets at one narrow side of the workshop, full power*		
Spray application conditions			
Description of the work process/work steps	*Antifouling coating by using the airless spraying technique, part of the double bottom (outer surface), the spray user stands on the floor and sprays above his head. Spraying on the side facing away from the suction system. During spraying the sprayer slowly walks on, sometimes briefly interrupting the spraying.*		
Process parameters	Start	End	Duration
	ca. 11:20 h	*11:58 h*	*38 minutes*
	Application volume	Processed surface area m²	Type of surface
	ca. 60 L (3 buckets)	*ca. 210 m²*	*Metal (ca. 7.5 m x 28 m)*
	Surface shape/orientation	Number of processes	Other
	Above, horizontal	*1 with short interruptions*	
Additional remarks	*Lacquer was simultaneously being applied to the interior of the ship component by using a roller and by spraying. An additional 4-8 persons were present in the workshop.*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Airless Sprayer	*Graco*	*n.s.*
Nozzle	Type: *RAC 5 - 0.021``*	Manufacturer/no.	Diameter
	Nozzle 421, spraying angle 40°	*n..s.*	*0.021``, 0.53 mm*
Pressure conditions	Pressure: *1:73 (438 bar)*	Pressure generation	Throughput
	Max operating press. 248 bar	*Generator, 6 bar*	*2L/min*
Additional remarks	Direction: *towards the horizontal surface to be sprayed above the sprayer's head* Movement of the spray can and spray user: *Spray gun in the worker's right hand, target-oriented posture forward and upward, the spray user stands and walks below the ship component*		
Operating technique			
Spraying parameters	Spraying height	Spraying angle	
	ca. 2.00 m	*180°, vertically upwards*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 0.8 m	*ca. 0.3-0.5 m*	
Additional remarks	*During spraying the worker stands and walks on below the ship component* *Spraying is done overhead with the sprayer's arm extended*		
User			
General information	Qualification	Professional experience	Gender
	Painter	*2 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Safety data sheet	*Ventilation*	*Protective clothes, see below*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Single-use overall with hood	*Safety shoes*	*Full face mask*
	Goggles	Gloves	Other: *scarves on head and*
	n/a	*Leather gloves*	*forearm under the overall*
Exposure details			
Duration of spraying process	*38 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray, overspray	O < 30 cm O > 100 cm	*Deposited spray*
		X *30 - 100 cm*	
Frequency of the operation	During shift	During month	
		Estimated 3-4 times	
Other observations			

Additional remarks/notes

During the spraying process measurements with the Respicon on the spray user as well as measurements to determine the dermal exposure (full patch set) were performed.

Observations: increasing smell of solvents in the workshop.
Visible staining of the upper part of the sprayer's protective overall.

Appendix 2 Description of exposure scenarios in stored product protection

Questionnaire for Project 2137 - Field Measurements

Process no.	M0
Date	June 5, 2008
Business	Mill/schnapps distillery

Scenario	*Meandering spraying movements with a high-performance spraying device (backpack sprayer) along the marked spraying strip in a silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(C)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	*Isoparaffin mixture*
Safety data sheet			
Labeling		*Xn, N, F*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*n.s.*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Meandering spraying movements along the marked spraying strip by using the Insektenil high-performance spraying device to control crawling and flying storage pests in a silo cell.*		
Process parameters	Start	End	Duration
	17:21 h	*17:25 h*	*4 minutes*
	Application volume	Processed surface area m²	Type of surface
	2.21 L	*ca. 60 m²*	*Concrete*
	Surface shape/orientation	Number of processes	Other
	Wall: vertical, floor: horizontal	*1*	
Additional remarks	*Dimensions of the marked spraying strip: height: 0-50 cm on the wall, width: 0-50 cm on the floor*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Insektenil high-performance spraying device	*Hentschke + Sawatzki*	*2007*
Nozzle	Type	Manufacturer/no.	Diameter
	Hollow cone, type: G-H49-55	*n.s.*	*1 mm*
Pressure conditions	Pressure	Pressure generation	Throughput
	2 bar to 1.5 bar	*Manual*	*ca. 0.55 L/min*
Additional remarks	Direction: *downwards* Movement of the spraying nozzle and spray user: *Meandering movements along the marked spraying strip*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	0 - max. 50 cm	*0-45°*	
Spraying distance	Nozzle - person	Nozzle - object	
	1.3 m	*ca. 0.3 m*	
Additional remarks	*The spray user proceeds through the silo cell once at a small distance from the wall.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*None*
	Goggles	Gloves	
	n.s.	n.s.	
Exposure details			
Duration of spraying process	*4 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Very little	O < 30 cm **X** > 100 cm	*Little, legs*
		O 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the sprayer's breathing height were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	M1
Date	June 6, 2008
Business	Mill/schnapps distillery

Scenario	*Meandering nebulization by using the Insektenil electric nebulizer in the silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(C)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	*Isoparaffin mixture*
Safety data sheet			
Labeling		*Xn, N, F*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*21 °C/50%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Meandering nebulization in the silo cell by using the Insektenil electric nebulizer, type 26-AX, to control crawling and flying storage pests.*		
Process parameters	Start	End	Duration
	9:24 h	*9:36 h*	*12 minutes*
	Application volume	Processed surface area m^2	Type of surface
	6 L	*ca. 1400 m^3*	*None, indoor air treatment*
	Surface shape/orientation	Number of processes	Other
	n.s.	*1*	
Additional remarks	*Indoor air treatment of the silo cell*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Insektenil electric nebulizer, type 26-AX	*Hentschke + Sawatzki*	*2008*
Nozzle	Type	Manufacturer/no.	Diameter
	n.s.	*n.s.*	*2 mm*
Pressure conditions	Pressure	Pressure generation	Throughput
	Set to: Medium	-	*ca. 0.5 L/min*
Additional remarks	Direction: *upwards* Movement of the spraying nozzle and spray user: *Meandering movements of the nebulizer's hose with the nozzle during the nebulization process*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	ca. 5-6 m	*130°*	
Spraying distance	Nozzle - person	Nozzle - object	
	0.5 m	*ca. 5-6 m*	
Additional remarks	*The user proceeds in cross direction through the silo cell.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*Full face mask*
	Goggles	Gloves	
	n.s.	*Protective gloves*	
Exposure details			
Duration of spraying process	*12 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray	O < 30 cm O > 100 cm	*Deposited spray*
		X 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the user's and an accompanying person's breathing height as well as measurements to determine the dermal exposure (full patch set) were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	M2
Date	June 6, 2008
Business	Mill/schnapps distillery

Scenario	*Meandering spraying movements with a high-performance spraying device (backpack sprayer) along the marked spraying strip in a silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(C)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	*Isoparaffin mixture*
Safety data sheet			
Labeling		*Xn, N, F*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*21 °C/50%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Meandering spraying movements along the marked spraying strip by using the Insektenil high-performance spraying device to control crawling and flying storage pests in a silo cell.*		
Process parameters	Start	End	Duration
	10:33 h	*10:41 h*	*8 minutes*
	Application volume	Processed surface area m²	Type of surface
	4 L	*ca. 60 m²*	*Concrete*
	Surface shape/orientation	Number of processes	Other
	Wall: vertical, floor: horizontal	*1*	
Additional remarks	*Dimensions of the marked spraying strip: height: 0-50 cm on the wall, width: 0-50 cm on the floor*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Insektenil high-performance spraying device	*Hentschke + Sawatzki*	*2007*
Nozzle	Type	Manufacturer/no.	Diameter
	Hollow cone, type: G-H49-55	*n.s.*	*1 mm*
Pressure conditions	Pressure	Pressure generation	Throughput
	3 bar to 2 bar	*Manual*	*ca. 0.5 L/min*
Additional remarks	Direction: *downwards* Movement of the spraying nozzle and spray user: *Meandering movements along the marked spraying strip*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	0 - max. 50 cm	*0-45°*	
Spraying distance	Nozzle - person	Nozzle - object	
	1.3 m	*ca. 0.3 m*	
Additional remarks	*The spray user proceeds through the silo cell once at a small distance from the wall.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*None*
	Goggles	Gloves	
	n.s.	*n.s.*	
Exposure details			
Duration of spraying process	*8 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Very little	O < 30 cm **X** > 100 cm	*Little, legs*
		O 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the user's and an accompanying person's breathing height as well as measurements to determine the dermal exposure (full patch set) were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	M3
Date	June 6, 2008
Business	Mill/schnapps distillery

Scenario	*Meandering spraying movements with a high-performance spraying device (backpack sprayer) along one of the walls in a silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(C)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	*Isoparaffin mixture*
Safety data sheet			
Labeling		*Xn, N, F*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*21 °C/48%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Meandering spraying onto a wall surface by using the Insektenil high-performance spraying device to control crawling and flying storage pests in a silo cell.*		
Process parameters	Start	End	Duration
	11:39:30 h	*11:44 h*	*4.5 minutes*
	Application volume	Processed surface area m²	Type of surface
	2.15 L	*ca. 28.5 m²*	*Concrete*
	Surface shape/orientation	Number of processes	Other
	Vertical	1	
Additional remarks	*Spraying onto the vertical wall; dimensions: height 0-3 m, width 9.5 m*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Insektenil high-performance spraying device	*Hentschke + Sawatzki*	*2007*
Nozzle	Type	Manufacturer/no.	Diameter
	Hollow cone, type: G-H49-55	*n.s.*	*1 mm*
Pressure conditions	Pressure	Pressure generation	Throughput
	3 bar to 2 bar	*Manual*	*ca. 0.48 L/min*
Additional remarks	Direction: *upwards at an angle, horizontal, slightly downwards* Movement of the spraying nozzle and spray user: *Spraying with meandering movements onto a vertical wall surface*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	0-3 m	*10-130°*	
Spraying distance	Nozzle - person	Nozzle - object	
	1.3 m	*ca. 0.3 m*	
Additional remarks	*The spray user proceeds through the silo cell once at a small distance from the wall.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*None*
	Goggles	Gloves	
	n.s.	*n.s.*	
Exposure details			
Duration of spraying process	*4.5 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Little, overspray possible	O < 30 cm **X** > 100 cm	*Sedimented spray*
		O 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the user's breathing height as well as measurements to determine the dermal exposure (full patch set) were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	M4
Date	June 6, 2008
Business	Mill/schnapps distillery

Scenario	*Spray nebulization at discrete spots in a silo cell by using a can with propellant*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(D)*	
Manufacturer		*n.s.*	
Package size		*0.5 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	*1-methoxy-2-propanol, 1,1,1,2-tetrafluoroethane*
Safety data sheet			
Labeling		*N*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*22 °C/48%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Nebulization in a silo cell by using a can with propellant to control crawling and flying storage pests.*		
Process parameters	Start	End	Duration
	13:30 h	*13:41:30 h*	*11.5 minutes*
	Application volume	Processed area m³	Type of surface
	750 ml	*ca. 1400 m³*	*None, indoor air treatment*
	Surface shape/orientation	Number of processes	Other
	None (indoor space)	*1*	
Additional remarks	*Spray release at discrete spots, can 1: 2/3 of the cell, 8 spots, can 2: 1/3 of the cell, 2 spots*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Can with propellant	*Hentschke + Sawatzki*	*2008*
Nozzle	Type	Manufacturer/no.	Diameter
	n.s.	*n.s.*	*n.s.*
Pressure conditions	Pressure	Pressure generation	Throughput
	n.s.	*Propellant*	*n.s.*
Additional remarks	Direction: *upwards* Movement of the spraying nozzle and spray user: *Overhead spraying, spray release at discrete spots*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	3 m	*130°*	
Spraying distance	Nozzle - person	Nozzle - object	
	0.5 m	*n.s.*	
Additional remarks	*The user proceeds in cross direction through the silo cell. Overhead spraying, spray release at discrete spots.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the can	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*n.s.*
	Goggles	Gloves	
	n.s.	*None*	
Exposure details			
Duration of spraying process	*11.5 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray	O < 30 cm O > 100 cm	*Deposited spray*
		X 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the user's breathing height as well as measurements to determine the dermal exposure (full patch set) were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	M5
Date	June 6, 2008
Business	Mill/schnapps distillery

Scenario	*Meandering spraying movements with a high-performance spraying device (backpack sprayer) onto the floor in a silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(C)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	*Isoparaffin mixture*
Safety data sheet			
Labeling		*Xn, N, F*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*22 °C/48%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Meandering spraying onto the floor surface by using the Insektenil high-performance spraying device to control crawling and flying storage pests in a silo cell.*		
Process parameters	Start	End	Duration
	14:28 h	*14:32 h*	*4 minutes*
	Application volume	Processed surface area m²	Type of surface
	2 L	*ca. 30 m²*	*Concrete*
	Surface shape/orientation	Number of processes	Other
	Horizontal	1	
Additional remarks	*Downward spraying onto the floor surface; dimensions: length 12 m, width 2.5 m*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Insektenil high-performance spraying device	*Hentschke + Sawatzki*	*2007*
Nozzle	Type	Manufacturer/no.	Diameter
	Hollow cone, type: G-H49-55	*n.s.*	*1 mm*
Pressure conditions	Pressure	Pressure generation	Throughput
	3 bar to 2 bar	*Manual*	*ca. 0.5 L/min*
Additional remarks	Direction: *downwards at an angle* Movement of the spraying nozzle and spray user: *Meandering spraying movements downwards onto a floor surface.*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	0 m	*0-30°*	
Spraying distance	Nozzle - person	Nozzle - object	
	1.3 m	*ca. 0.3 m*	
Additional remarks	*The spray user proceeds in cross direction to the cell's longitudinal direction.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*None*
	Goggles	Gloves	
	n.s.	*n.s.*	
Exposure details			
Duration of spraying process	*4 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Very little	O < 30 cm **X** > 100 cm	*Little, legs*
		O 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the user's breathing height as well as measurements to determine the dermal exposure (full patch set) were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	RM2
Date	August 9, 2008
Business	Rice mill

Scenario	*Thermal fogging by using a pulsFOG K-10 in the different stories (workshops) of a rice mill to control the red flour beetle*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(E)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Permethrin 5 g/kg, piperonyl butoxide 10 g/kg esbiothrin 1.5 g/kg*	Dichloromethane
Safety data sheet		*Yes*	
Labeling		*Xn*	
R-phrases		*20/22-40-52/53*	
Product database record no.		*n.s.*	
Application area			
Description	*Rice mill (stone building) comprising several stories (workshops) that can be accessed via a separate staircase in the building. The different stories include a large variety of machinery and equipment.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*ca. 50 m x 16 m x 3.50 m**	*24-26 °C/41-42%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate *n.s.* m/s		
Additional remarks	*Ventilation openings were closed during the fogging process.* **Approximate size of stories 2-4; story 1: height ca. 8 m.*		
Application conditions			
Description of the work process/work steps	*Thermal fogging of the different stories of the building. The user proceeds in each story from the rear area to the door, carrying the fogger at waist level. Treatment starts in the upper story, then the user moves on to the next lower story via the separate staircase, down to the bottom storey.*		
Process parameters	Start	End	Duration
	11:55 h	*12:32 h*	*37 minutes*
	Application volume	Processed area m³	Type of surface
	13 L (4+9 L)	*ca. 15000*	*Indoor area, n.s.*
	Surface shape/orientation	Number of processes	Other
	Indoor area	*1*	
Additional remarks	The fogging process was briefly interrupted several times (to refill the fogger, change to the next story).		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	pulsFOG K-10	*Dr. Strahl + Sohn GmbH*	*n.s.*
Nozzle	Type	Manufacturer/no.	Diameter
	12er	*n.s.*	*n.s.*
Pressure conditions	Pressure buildup	Pressure generation	Throughput
	By combustion gases	*Fuel engine*	*10-35 L/h**
Additional remarks	*Portable thermal fogger* *Generation of ultrafine droplets by using thermopneumatic energy* ** depending on the dosing nozzle used; manufacturer's information*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	1.20 m	*90-120°*	
Spraying distance	Nozzle - person	Nozzle - object	
	1 m	*n.s.*	
Additional remarks	*The user carries the fogger at waist level and applies the active substance to the workshop with the fogging tube in forward direction.*		
User			
General information	Qualification	Professional experience	Gender
	Chemical equipment operator	*10 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*Accompanying person*	*Protective clothing*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Disposable protective coverall	*Work shoes*	*Filter A2B2-P3*
	Goggles	Gloves	
	n.s.	*Work glove*	
Exposure details			
Duration of spraying process	*37 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray	O < 30 cm O > 100 cm	*Deposited spray*
		X 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*2-3 times*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the user's breathing height as well as measurements to determine the potential dermal exposure (full patch set) were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	RM3
Date	August 9, 2008
Business	Rice mill

Scenario	*Thermal fogging by using a pulsFOG K-10 in the silo of a rice mill to control the red flour beetle*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(E)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Permethrin 5 g/kg, piperonyl butoxide 10 g/kg esbiothrin 1.5 g/kg*	Dichloromethane
Safety data sheet		*Yes*	
Labeling		*Xn*	
R-phrases		*20/22-40-52/53*	
Product database record no.		*n.s.*	
Application area			
Description	*Silo (stone building) of a rice mill. The bottom area hosts a large variety of machinery, equipment, and conveyer belts, as well as upward ducts.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*ca. 25 m x 5 m x ? m*	*20 °C/48%*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate *n.s.* m/s		
Additional remarks	*Ventilation openings were closed during the fogging process.*		
Application conditions			
Description of the work process/work steps	*Thermal fogging in the lower part of the silo. The user proceeds from the rear area of the silo towards the door, carrying the fogger at waist level.*		
Process parameters	Start	End	Duration
	13:00 h	*13:08 h*	*8 minutes*
	Application volume	Processed area m³	Type of surface
	ca. 6 L	*n.s.*	*Indoor area, n.s.*
	Surface shape/orientation	Number of processes	Other
	Indoor area	*1*	
Additional remarks			
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	pulsFOG K-10	*Dr. Strahl + Sohn GmbH*	*n.s.*
Nozzle	Type	Manufacturer/no.	Diameter
	12er	*n.s.*	*n.s.*
Pressure conditions	Pressure buildup	Pressure generation	Throughput
	By combustion gases	*Fuel engine*	*10-35 L/h**
Additional remarks	*Portable thermal fogger* *Generation of ultrafine droplets by using thermopneumatic energy* ** depending on the dosing nozzle used; manufacturer's information*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	1.20 m	*90-120°*	
Spraying distance	Nozzle - person	Nozzle - object	
	1 m	*n.s.*	
Additional remarks	*The user carries the fogger at waist level and applies the active substance with the fogging tube in forward direction.*		
User			
General information	Qualification	Professional experience	Gender
	Chemical equipment operator	*10 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*Accompanying person*	*Protective clothing*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Disposable protective coverall	*Work shoes*	*Filter A2B2-P3*
	Goggles	Gloves	
	n.s.	*Work glove*	
Exposure details			
Duration of spraying process	*8 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray	O < 30 cm O > 100 cm	*Deposited spray*
		X 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*2-3 times*	
Other observations			

Additional remarks/notes
Measurements with the Repicon at the user's breathing height as well as measurements to determine the potential dermal exposure (full patch set) were performed.

Questionnaire for Project 2137 - Field Measurements

Process no.	HS A
Date	May 6, 2010
Business	Mill/schnapps distillery

Scenario	*Room fogging by using cans with propellant (automated fogger) in a silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(D)*	
Manufacturer		*n.s.*	
Package size		*0.5 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	1-methoxy-2-propanol, 1,1,1,2-tetrafluoroethane
Safety data sheet			
Labeling		*N*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*14 °C*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Fogging of a silo cell by using 9 propellant cans equipped with spray heads for continued spraying to control crawling and flying storage pests.*		
Process parameters	Start	End	Duration
	10:00 h	*10:14 h*	*14 minutes*
	Application volume	Processed area m³	Type of surface
	4500 ml (9 x 500 ml)	*ca. 1400 m³*	*None, indoor air treatment*
	Surface shape/orientation	Number of processes	Other
	Indoor area	*1*	
Additional remarks	*Local release, 9 cans were placed (evenly distributed) on the floor of the silo cell. Activation of the cans began in the rear area of the cell.*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Cans with propellant	*Hentschke + Sawatzki*	*2010*
Nozzle	Type	Manufacturer/no.	Diameter
	n.s.	*n.s.*	*n.s.*
Pressure conditions	Pressure	Pressure generation	Throughput
	n.s.	*Propellant*	*n.s.*
Additional remarks	Direction: *upwards*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	4-5 m	*180°*	
Spraying distance	Nozzle - person	Nozzle - object	
	n.s.	*n.s.*	
Additional remarks	*The user proceeds from the rear to the front of the silo cell, activating the spray heads for continued spraying, then leaves the room.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the can	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*n.s.*
	Goggles	Gloves	
	n.s.	*none*	
Exposure details			
Duration of spraying process	*14 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray	O < 30 cm O > 100 cm	*Deposited spray*
		X 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Respicon were performed in the middle of the cell at the user's breathing height. *User dwell time 14 minutes max. Duration of the measurements 135 minutes (5 minutes prior to start of fogging).*

Questionnaire for Project 2137 - Field Measurements

Process no.	HS B
Date	May 6, 2010
Business	Mill/schnapps distillery

Scenario	*Cold fogging by using a Dyna-Fog Hurricane in a silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(C)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	Isoparaffin mixture
Safety data sheet			
Labeling		*Xn, N, F*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*14 °C*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Cold fogging in a silo cell to control crawling and flying storage pests.*		
Process parameters	Start	End	Duration
	13:11 h	*13:51 h*	*40 minutes*
	Application volume	Processed area m³	Type of surface
	8.4 L (4.0 L + 4.4 L)	*ca. 1400 m³*	*None, indoor air treatment*
	Surface shape/orientation	Number of processes	Other
	Indoor area	*1*	
Additional remarks	*Local release of fog (upwards at an angle) at two locations (first in the rear area, then in the front area of the cell). Refill with solution after 20 minutes (duration ca. 1 minute).*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Dyna-Fog Hurricane 2792	*Curtis, Dyna-fog*	*n.s.*
Nozzle	Type	Manufacturer/no.	Diameter
	3 nozzles	*n.s.*	*n.s.*
Pressure conditions	Pressure	Pressure generation	Throughput
	Setting: high	*see below*	*210 ml/min*
Additional remarks	*The air flow creates a negative pressure in the nozzle, thereby suctioning the solution to be fogged from the tank through the dosing valve to the nozzles. The user holds the fogger upwards at an angle.*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	Up to 6 m	*90-120°*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 1 m	*n.s.*	
Additional remarks	*The user carries the fogger in his hand, holding it upwards at an angle. The first part of the solution is fogged in the rear area, the second part in the front area of the cell.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*Full face mask*
	Goggles	Gloves	
	n.s.	*None*	
Exposure details			
Duration of spraying process	*40 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray	O < 30 cm O > 100 cm	*Deposited spray*
		X 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Respicon were performed in the middle of the cell at the user's breathing height. *User dwell time 40 minutes max. Duration of the measurements 125 minutes (5 minutes prior to start of fogging).*

Questionnaire for Project 2137 - Field Measurements

Process no.	HS C
Date	May 6, 2010
Business	Mill/schnapps distillery

Scenario	*Thermal fogging by using a Swingfog SN 50 in a silo cell*

Product details	Concentrate	Ready-to-use solution	Other
Product name		*(C)*	
Manufacturer		*n.s.*	
Package size		*10 L*	
Composition (concentrations)		*Pyrethrins 4g/L, piperonyl butoxide 22 g/L*	Isoparaffin mixture
Safety data sheet			
Labeling		*Xn, N, F*	
R-phrases			
Product database record no.		*n.s.*	
Application area			
Description	*Stone building which includes several adjacent silo cells in a row. Each silo cell can be entered from the bottom via a hatch. The cells are open at the top and connected by a catwalk.*		
Ambient conditions	Type of ventilation	Size L/W/H	Temperature/humidity
	X natural O technical**	*22 m x 8.50 m x 7.50 m*	*14 °C*
Ventilation conditions	* Windows and doors O open **X** closed ** Suction O yes O no; air flow O yes O no; air flow rate m/s		
Additional remarks	*No ventilation, dark*		
Application conditions			
Description of the work process/work steps	*Thermal fogging in a silo cell to control crawling and flying storage pests.*		
Process parameters	Start	End	Duration
	16:08 h	*16:43 h*	*35 minutes*
	Application volume	Processed area m³	Type of surface
	7 L	*ca. 1400 m³*	*None, indoor air treatment*
	Surface shape/orientation	Number of processes	Other
	Indoor area	*1*	
Additional remarks	*Release of fog (direction of the fogging tube from forward to upward at an angle). The user proceeds from the rear to the front of the silo cell.*		
Utensils			
Specification	Name/type	Manufacturer	Year of manufacture
	Swingfog SN50	*Swingtec*	*n.s.*
Nozzle	Type	Manufacturer/no.	Diameter
	Nozzle for active substances	*Swingtec*	*1.2 mm*
Pressure conditions	Pressure	Pressure generation	Throughput
		see below	*ca. 200 ml/min*
Additional remarks	*A fuel/air mixture is ignited in the combustion chamber, and the resulting deflagrations oscillate a column of gas in the resonator tube. The solution is injected into the high-speed hot air stream at the end of the fogging tube, dispersed into aerosol droplets, and distributed into a light, floating fog. The user holds the fogger with the fogging tube in forward direction or slightly upwards at an angle.*		
Operating technique			
Spraying parameters	Spraying height	Angle	
	ca. 5 m	*90-120°*	
Spraying distance	Nozzle - person	Nozzle - object	
	ca. 1.2 m	*n.s.*	
Additional remarks	*The user carries the fogger in his hand, holding it forward or upwards at an angle.*		
User			
General information	Qualification	Professional experience	Gender
	Licensed pest control applicator	*19 years*	*Male*
Protective measures	Organizational	Technical	Personal
	Instructions on the container	*None*	*Workwear*
Detailed information about personal protective measures	Clothes	Shoes	Mask
	Work coverall	*Work shoes*	*Full face mask*
	Goggles	Gloves	
	n.s.	*None*	
Exposure details			
Duration of spraying process	*35 minutes*		
Possible contact (theoretical)	Inhalation	Distance from source	Dermal/body part
	Atomized spray	O < 30 cm O > 100 cm	*Deposited spray*
		X 30 - 100 cm	
Frequency of the operation	During shift	During month	
	n.s.	*n.s.*	
Other observations			

Additional remarks/notes
Measurements with the Respicon were performed in the middle of the cell at the user's breathing height. *User dwell time 35 minutes max. Duration of the measurements ca. 150 minutes (5 minutes prior to start of fogging).*

Appendix 3 Supplementary experimental data on inhalation exposure

Field measurements in stored product protection

Scenario	Application			Inhalation* of pyrethrins/*esbiothrin**** (µg/m³)			Inhalation* of PBO/*permethrin**** (µg/m³)		
	Device (product)	**Vol. (L)**	**t (min)****	C_G (1)	C_{Th} (2)	C_F (3)	C_G (1)	C_{Th} (2)	C_F (3)
M0	High-performance sprayer (C)	2.21	4.0	n. d.	n. d.	n. d.	170	45	4
M2	High-performance sprayer (C)	4.00	8.0	n. d.	n. d.	n. d.	629	321	66
M2+	High-performance sprayer (C)	4.00	8.0	n. d.	n. d.	n. d.	458	242	52
M3	High-performance sprayer (C)	2.15	4.5	n. d.	n. d.	n. d.	1446	667	142
M5	High-performance sprayer (C)	2.00	4.0	n. d.	n. d.	n. d.	509	358	156
M1	Electric nebulizer (C)	6.00	12.0	2734	608	103	16367	4461	1037
M1+	Electric nebulizer (C)	6.00	12.0	1619	372	110	9691	2386	645
M4	Spray can (D)	0.75	11.5	2219	997	190	12323	5971	2059
RM2	Thermal fogger (E)	13.0	37.0++	*68.7*	*67.2*	*70.1*	*587.4*	*581.9*	*608.6*
							9523	9210	9439
RM3	Thermal fogger (E)	6.00	8.0	*178.6*	*165.0*	*167.8*	*1050*	*962.9*	*968.0*
							10101	9871	10479

* Mean concentration of active substances or synergist
** Duration of application or duration of measurement
*** Measurement values for esbiothrin and permethrin are printed in italics
\+ Accompanying person
++ With interruptions
(1) Total inhalable fraction according to VDI 2265
(2) Thoracic fraction
(3) Respirable fraction
n. d. Not detectable

Appendix 4 Supplementary experimental data on dermal exposure

Field measurements in antifouling treatment

Application processes using the Airless Sprayer

Dermal exposure (A 1)

Body part	Position	Deposition of copper mg/pad	Factor	Deposition of copper mg/body part/task
Head	1	0.6	13.0	8.1
Back	2	0.4	35.5	12.7
Chest	3	0.2	35.5	7.7
Upper arm, R	4	0.7	29.1/2	10.1
Upper arm, L	5	0.3	29.1/2	4.9
Forearm, R	6	0.8	12.1/2	4.5
Forearm, L	7	0.9	12.1/2	5.7
Thigh, R	8	0.1	38.2/2	1.1
Thigh, L	9	0.2	38.2/2	3.8
Lower leg, R	10	0.2	23.8/2	2.9
Lower leg, L	11	0.1	23.8/2	1.5

Dermal exposure (A 2)

Body part	Position	Deposition of copper mg/pad	Factor	Deposition of copper mg/body part/task
Head	1	92.5	13.0	1203
Back	2	8.6	35.5	306
Chest	3	27.1	35.5	961
Upper arm, R	4	54.6	29.1/2	795
Upper arm, L	5	3.5	29.1/2	51
Forearm, R	6	7.2	12.1/2	43
Forearm, L	7	84.5	12.1/2	511
Thigh, R	8	42.6	38.2/2	814
Thigh, L	9	Lost	38.2/2	n. s.
Lower leg, R	10	1.3	23.8/2	15
Lower leg, L	11	1.4	23.8/2	17

Dermal exposure (A 3-2)

Body part	Position	Deposition	Factor	Deposition
		of copper		of copper
		mg/pad		mg/body part/task
Head	1	106.5	13.0	1384
Back	2	44.5	35.5	1581
Chest	3	42.0	35.5	1490
Upper arm, R	4	63.7	29.1/2	926
Upper arm, L	5	32.7	29.1/2	476
Forearm, R	6	108.6	12.1/2	657
Forearm, L	7	93.3	12.1/2	565
Thigh, R	8	26.4	38.2/2	504
Thigh, L	9	32.4	38.2/2	618
Lower leg, R	10	12.1	23.8/2	144
Lower leg, L	11	8.3	23.8/2	99

Dermal exposure (A 4-1)

Body part	Position	Deposition	Factor	Deposition
		of copper		of copper
		mg/pad		mg/body part/task
Head	1	48.5	13.0	631
Back	2	Lost	35.5	n. s.
Chest	3	8.8	35.5	314
Upper arm, R	4	97.9	29.1/2	1425
Upper arm, L	5	57.1	29.1/2	831
Forearm, R	6	51.6	12.1/2	312
Forearm, L	7	2.8	12.1/2	17
Thigh, R	8	27.8	38.2/2	531
Thigh, L	9	Lost	38.2/2	n. s.
Lower leg, R	10	Lost	23.8/2	n. s.
Lower leg, L	11	Lost	23.8/2	n. s.

Dermal exposure (A 4-2)

Body part	Position	Deposition of copper mg/pad	Factor	Deposition of copper mg/body part/task
Head	1	85.9	13.0	1117
Back	2	11.6	35.5	412
Chest	3	54.3	35.5	1927
Upper arm, R	4	48.9	29.1/2	712
Upper arm, L	5	49.7	29.1/2	724
Forearm, R	6	65.0	12.1/2	393
Forearm, L	7	11.7	12.1/2	71
Thigh, R	8	Lost	38.2/2	n. s.
Thigh, L	9	Lost	38.2/2	n. s.
Lower leg, R	10	Lost	23.8/2	n. s.
Lower leg, L	11	1.8	23.8/2	21

Dermal exposure (A 4-3)

Body part	Position	Deposition of copper mg/pad	Factor	Deposition of copper mg/body part/task
Head	1	33.9	13.0	441
Back	2	42.4	35.5	1504
Chest	3	36.0	35.5	1279
Upper arm, R	4	50.0	29.1/2	728
Upper arm, L	5	53.7	29.1/2	781
Forearm, R	6	24.3	12.1/2	147
Forearm, L	7	14.3	12.1/2	87
Thigh, R	8	11.2	38.2/2	213
Thigh, L	9	Lost	38.2/2	n. s.
Lower leg, R	10	1.9	23.8/2	23
Lower leg, L	11	2.8	23.8/2	34

Field measurements in stored product protection

Application processes using the Insektenil high-performance spraying device

Dermal exposure (M2)

Body part	Position	Deposition	Deposition	Factor	Deposition	Deposition
		pyrethrins	PBO		pyrethrins	PBO
		µg/pad	µg/pad		µg/body part/task	µg/body part/task
Head	1	< LOQ	0.84	13.0	< LOQ	11
Back	2	< LOQ	3.40	35.5	< LOQ	121
Chest	3	< LOQ	2.77	35.5	< LOQ	98
Upper arm, R	4	< LOQ	2.23	29.1/2	< LOQ	32
Upper arm, L	5	< LOQ	5.40	29.1/2	< LOQ	79
Forearm, R	6	< LOQ	1.20	12.1/2	< LOQ	7
Forearm, L	7	Lost	Lost	12.1/2	n. s.	n. s.
Thigh, R	8	< LOQ	2.30	38.2/2	< LOQ	44
Thigh, L	9	< LOQ	1.80	38.2/2	< LOQ	34
Lower leg, R	10	< LOQ	3.00	23.8/2	< LOQ	36
Lower leg, L	11	< LOQ	4.20	23.8/2	< LOQ	50

Dermal exposure (M3)

Body part	Position	Deposition	Deposition	Factor	Deposition	Deposition
		pyrethrins	PBO		pyrethrins	PBO
		µg/pad	µg/pad		µg/body part/task	µg/body part/task
Head	1	3.50	16.60	13.0	46	216
Back	2	Lost	Lost	35.5	n. s.	n. s.
Chest	3	1.60	12.50	35.5	57	444
Upper arm, R	4	2.50	11.80	29.1/2	36	172
Upper arm, L	5	3.80	32.60	29.1/2	55	474
Forearm, R	6	Lost	Lost	12.1/2	n. s.	n. s.
Forearm, L	7	2.10	17.20	12.1/2	13	104
Thigh, R	8	2.20	10.00	38.2/2	42	191
Thigh, L	9	1.40	9.10	38.2/2	27	174
Lower leg, R	10	1.90	17.80	23.8/2	23	212
Lower leg, L	11	1.20	9.10	23.8/2	14	108

Dermal exposure (M5)

Body part	Position	Deposition	Deposition	Factor	Deposition	Deposition
		pyrethrins	PBO		pyrethrins	PBO
		µg/pad	µg/pad		µg/body part/task	µg/body part/task
Head	1	< LOQ	0.4	13.0	< LOQ	5
Back	2	< LOQ	5.9	35.5	< LOQ	209
Chest	3	< LOQ	1.4	35.5	< LOQ	50
Upper arm, R	4	< LOQ	3.2	29.1/2	< LOQ	47
Upper arm, L	5	< LOQ	9.5	29.1/2	< LOQ	138
Forearm, R	6	< LOQ	1.7	12.1/2	< LOQ	10
Forearm, L	7	< LOQ	7.4	12.1/2	< LOQ	45
Thigh, R	8	1.9	9.6	38.2/2	36	183
Thigh, L	9	37.4	192.5	38.2/2	714	3677
Lower leg, R	10	1.3	10.9	23.8/2	15	130
Lower leg, L	11	7.9	26.2	23.8/2	94	312

Application processes using the Insektenil electric nebulizer

Dermal exposure (M1)

Body part	Position	Deposition	Deposition	Factor	Deposition	Deposition
		pyrethrins	PBO		pyrethrins	PBO
		µg/pad	µg/pad		µg/body part/task	µg/body part/task
Head	1	144.0	715.0	13.0	1872	9295
Back	2	Lost	Lost	35.5	n. s.	n. s.
Chest	3	75.0	415.0	35.5	2663	14733
Upper arm, R	4	56.0	325.0	29.1/2	815	4729
Upper arm, L	5	Lost	Lost	29.1/2	n. s.	n. s.
Forearm, R	6	10.5	63.0	12.1/2	64	381
Forearm, L	7	74.5	341.0	12.1/2	451	2063
Thigh, R	8	98.0	454.0	38.2/2	1872	8671
Thigh, L	9	Lost	Lost	38.2/2	n. s.	n. s.
Lower leg, R	10	42.0	187.0	23.8/2	500	2225
Lower leg, L	11	83.0	309.0	23.8/2	988	3677

Application process using spray cans

Dermal exposure (M4)

Body part	Position	Deposition	Deposition	Factor	Deposition	Deposition
		pyrethrins	PBO		pyrethrins	PBO
		µg/pad	µg/pad		µg/body part/task	µg/body part/task
Head	1	122.5	595.0	13.0	1593	7735
Back	2	3.0	20.5	35.5	107	728
Chest	3	23.5	131.5	35.5	834	4668
Upper arm, R	4	35.5	185.5	29.1/2	517	2699
Upper arm, L	5	46.0	214.0	29.1/2	669	3114
Forearm, R	6	17.0	94.5	12.1/2	103	572
Forearm, L	7	44.0	212.5	12.1/2	266	1286
Thigh, R	8	3.0	13.0	38.2/2	57	248
Thigh, L	9	4.0	15.0	38.2/2	76	287
Lower leg, R	10	1.0	4.5	23.8/2	12	54
Lower leg, L	11	4.0	18.5	23.8/2	48	220

Application processes using a thermal fogger

Dermal exposure (RM2)

Body part	Pos.	Deposition			Factor	Deposition		
		Esbiothrin	PBO	Permethrin		Esbiothrin	PBO	Permethrin
		µg/pad				µg/body part/task		
Head	1	0.7	26.5	2.9	13.0	8	344	37
Back	2	0.6	10.1	1.7	35.5	21	357	60
Chest	3	0.8	16.6	3.2	35.5	28	588	114
Upper arm, R	4	0.7	18.7	2.8	29.1/2	10	271	40
Upper arm, L	5	0.7	16.7	2.2	29.1/2	9	242	32
Forearm, R	6	Lost			12.1/2	n. s.	n. s.	n. s.
Forearm, L	7	0.6	8.4	1.3	12.1/2	4	51	8
Thigh, R	8	Lost			38.2/2	n. s.	n. s.	n. s.
Thigh, L	9	Lost			38.2/2	n. s.	n. s.	n. s.
Lower leg, R	10	1.2	37.2	7.9	23.8/2	14	442	94
Lower leg, L	11	36.4	877.5	246.0	23.8/2	433	10442	2927

Dermal exposure (RM3)

Body part	Pos.	Deposition			Factor	Deposition		
		Esbiothrin	PBO	Permethrin		Esbiothrin	PBO	Permethrin
		µg/pad				µg/body part/task		
Head	1	< LOQ	18.6	4.5	13.0	< LOQ	241	59
Back	2	< LOQ	19.4	4.6	35.5	< LOQ	687	162
Chest	3	< LOQ	3.0	0.7	35.5	< LOQ	105	23
Upper arm, R	4	< LOQ	11.4	2.9	29.1/2	< LOQ	166	41
Upper arm, L	5	< LOQ	10.9	2.7	29.1/2	< LOQ	159	39
Forearm, R	6	< LOQ	9.4	2.0	12.1/2	< LOQ	57	12
Forearm, L	7	< LOQ	3.5	0.9	12.1/2	< LOQ	21	5
Thigh, R	8	< LOQ	18.7	3.8	38.2/2	< LOQ	356	73
Thigh, L	9	Lost			38.2/2	n. s.	n. s.	n. s.
Lower leg, R	10	< LOQ	20.2	4.4	23.8/2	< LOQ	240	52
Lower leg, L	11	2.0	67.2	19.2	23.8/2	23	800	228

Appendix 5 Modeling input parameters

Stored product protection (silo)

Experi-ment	Non-evaporating fraction /%	Vapor pressure /hPa	MMD /µm	Geom. std. dev.	Diameter /mm	Spray angle /°	Room size L*W*H /m^3	Release rate /ml s^{-1}	Time /min	Application
M1			120		Not necessary			8.33	12	Room, release height 3 m, spraying length 3 m, four release points at ca. 4, 8, 12 and 16 m at the centerline of the room, release time in each case 3 minutes
M2			240		1	55		8.33	8	Wall line, wall line in clockwise direction, distance sprayer (receptor) – wall 1.5 m, distance nozzle – wall 0.5 m, 160 s at the long wall sides, 80 s at the shorter sides
M3			240	1.8	1	55		8.0	4.5	Wall, distance sprayer (receptor) – wall 1.5 m, distance nozzle – wall 0.5 m, 270 s at one long wall, start 5 m, end 11 m, max. spraying height 4 m
M4	2.6 [1)]	2.3 [2)]	50		Not necessary		9*22*6.75	1.08	11.5	Room, release height 3 m, spraying length 0.5 m, four release points at ca. 4, 8, 12 and 16 m at the centerline of the room, release time in each case 2.9 minutes
M5			240		1	55		8.33	4	Floor, area 2.5 x 12 m^2 in the middle of the room
HS A			Spray can		Not necessary			14	5.36	Room, release height 3 m, spraying length 1 m, one release point in the middle of the room
HS B			Dyna-Fog		Not necessary			40	3.5	Room, release height 3 m, spraying length 1 m, two release points at the centerline of the room
HS C			Swingfog		Not necessary			35	3.33	Room, release height 3 m, spraying length 1 m, one release point in the middle of the room

1) = concentration of a. i. + synergist; 2) estimated for isoparaffin mixture or 1-methoxy-2-propanol and 1,1,1,2-tetrafluoroethane

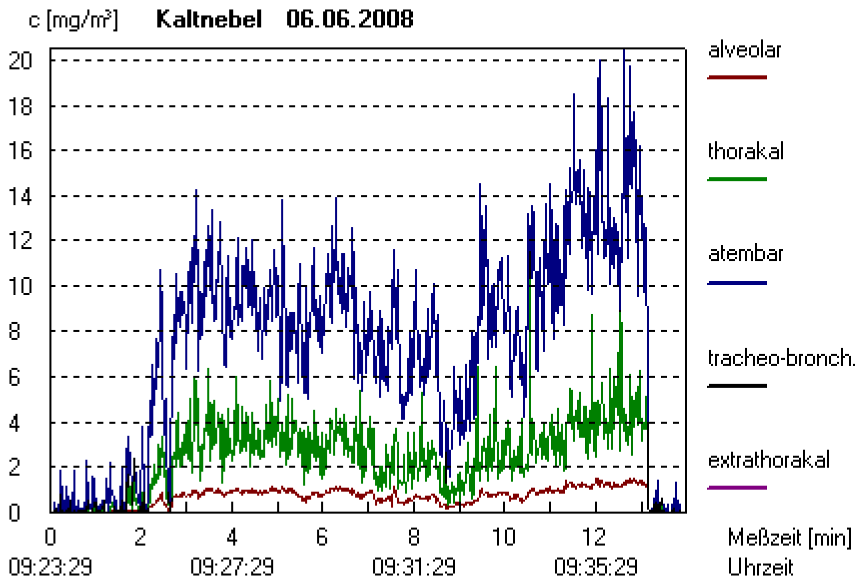
Antifouling

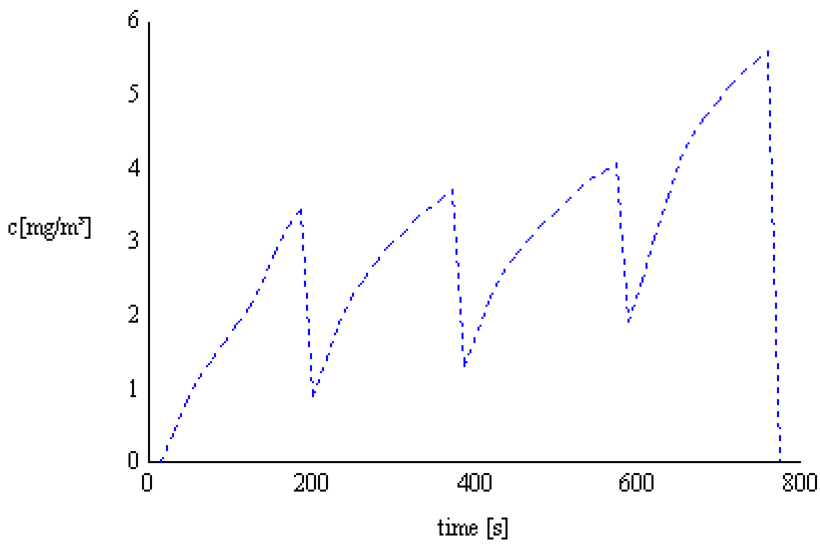
Experiment	Non-evaporating fraction /%	MMD /µm	Geom. std. dev.	Diameter /mm	Spray angle /°	Room size L*W*H /m³	Release rate /ml s⁻¹	Time /min	Application
A2	100 *	250	1.8	0.53	40	30*30*3	26.4	30	Ceiling, area of 7 x 25 = 175 m² in the middle of the room, meandering spraying vertically to the long side of the area, distance sprayer (receptor) – nozzle 1 m, distance nozzle – ceiling 0.5 m
A3-1							27.8	18	Ceiling, area of 7 x 25 = 175 m² in the middle of the room, meandering spraying vertically to the long side of the area, distance sprayer (receptor) – nozzle 1 m, distance nozzle – ceiling 0.5 m
A3-2							33.3	15	Ceiling, area of 7 x 25 = 175 m² in the middle of the room, meandering spraying vertically to the long side of the area, distance sprayer (receptor) – nozzle 1 m, distance nozzle – ceiling 0.5 m
A4-2							20.5	57	Ceiling, area of 9 x 28 = 252 m² in the middle of the room, meandering spraying vertically to the long side of the area, distance sprayer (receptor) – nozzle 1 m, distance nozzle – ceiling 0.5 m
A4-3							26.3	38	Ceiling, area of 7.5 x 28 = 210 m² in the middle of the room, meandering spraying vertically to the long side of the area, distance sprayer (receptor) – nozzle 1 m, distance nozzle – ceiling 0.5 m

- = for comparison with the experimental values the Cu concentrations had to be calculated from the results of the modeling; as the Cu(I) oxide concentration was between 25-50 % in all experiments and thus the precise Cu content was not known, the results were divided approximately by a factor of 2 for the comparison

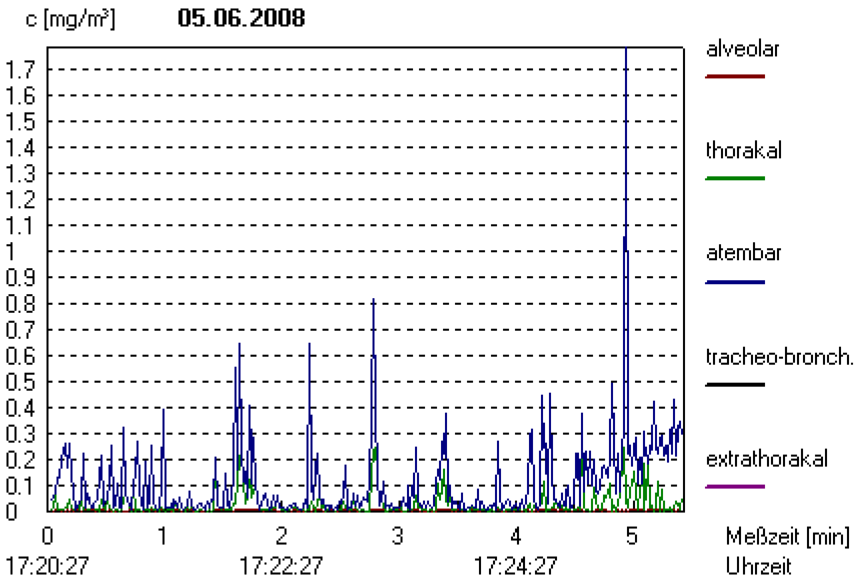
Appendix 6 Measured and simulated (thoracic fraction only) time courses of exposure concentrations during measurements in stored product protection

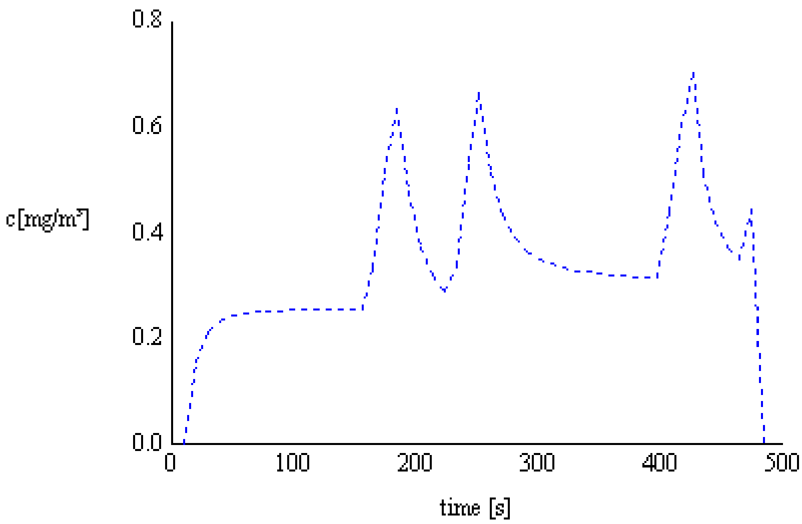
Experiment M1:



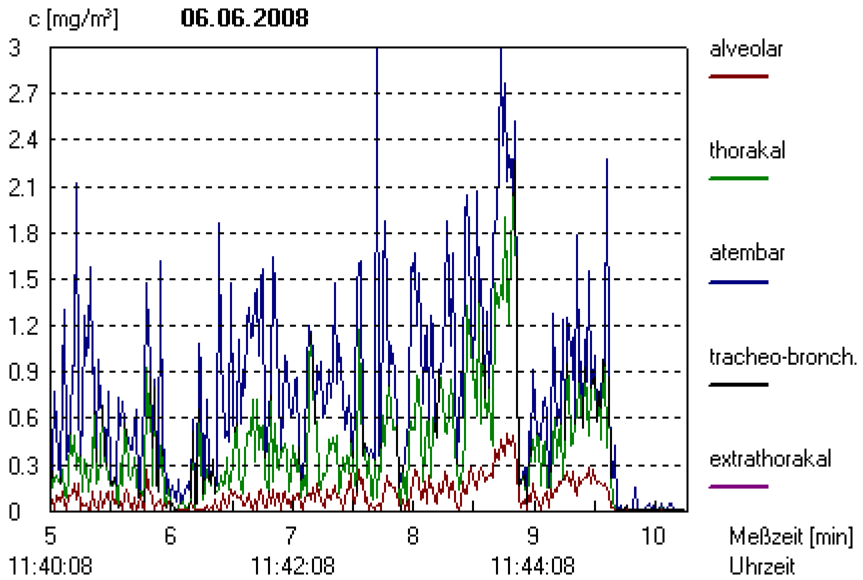


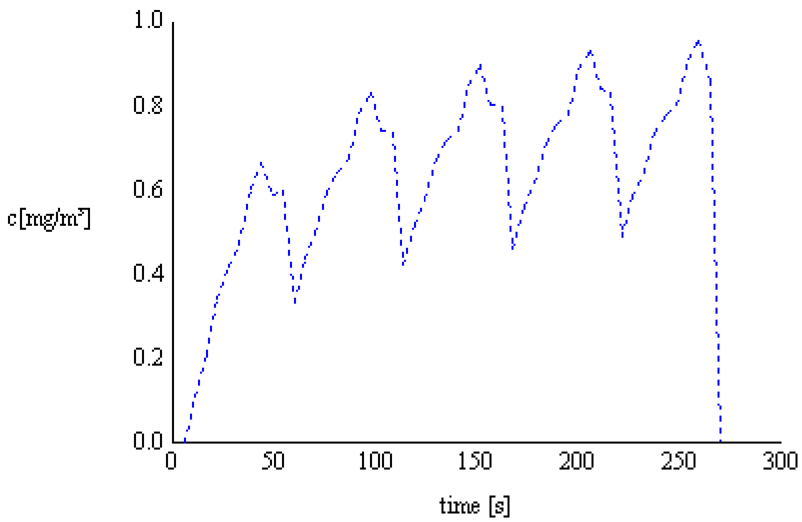
Experiment M2:



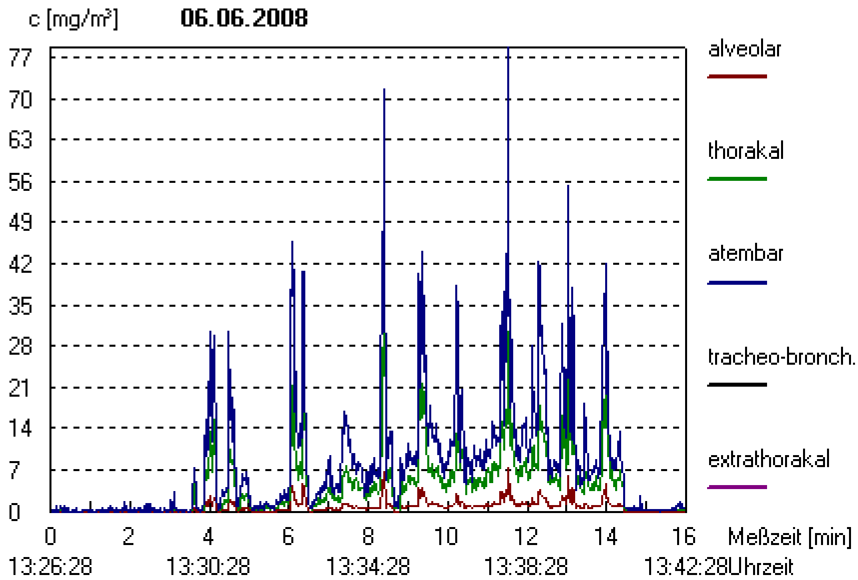


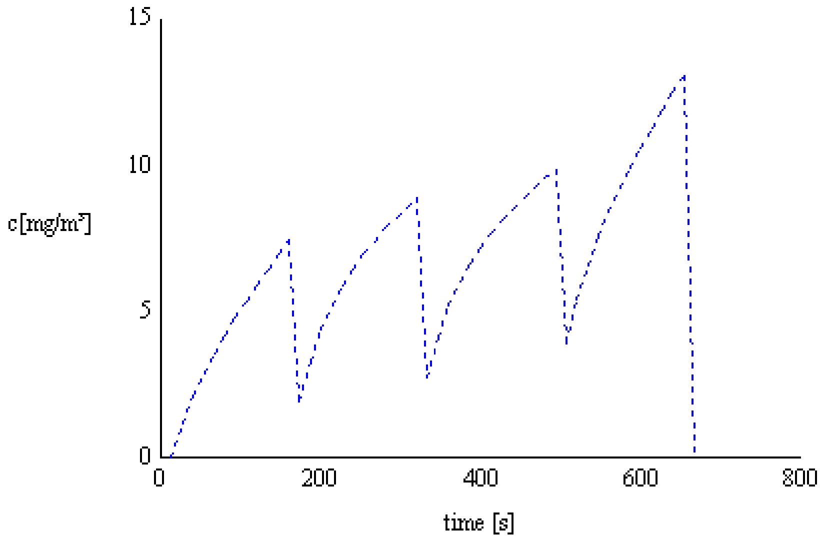
Experiment M3:



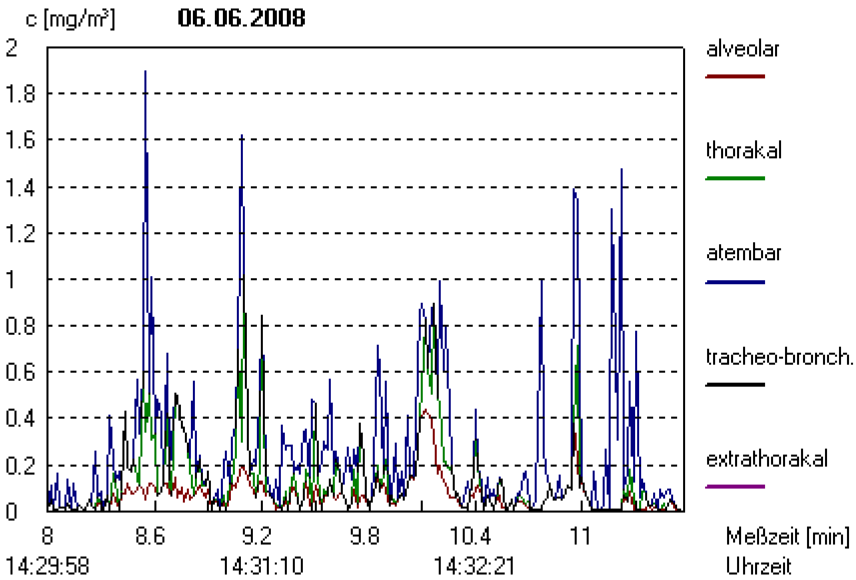


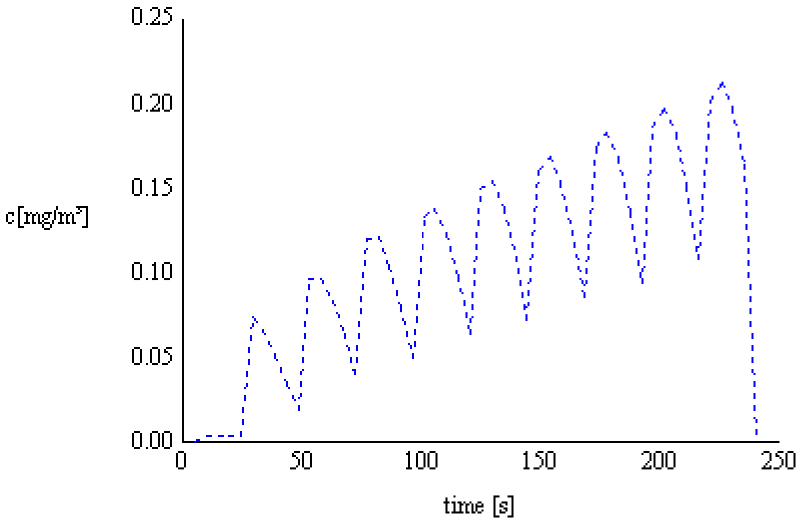
Experiment M4:



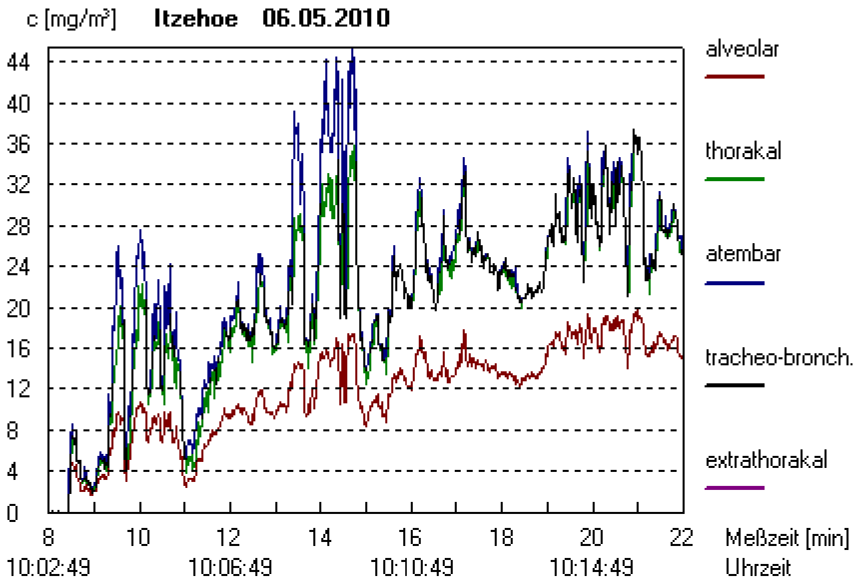


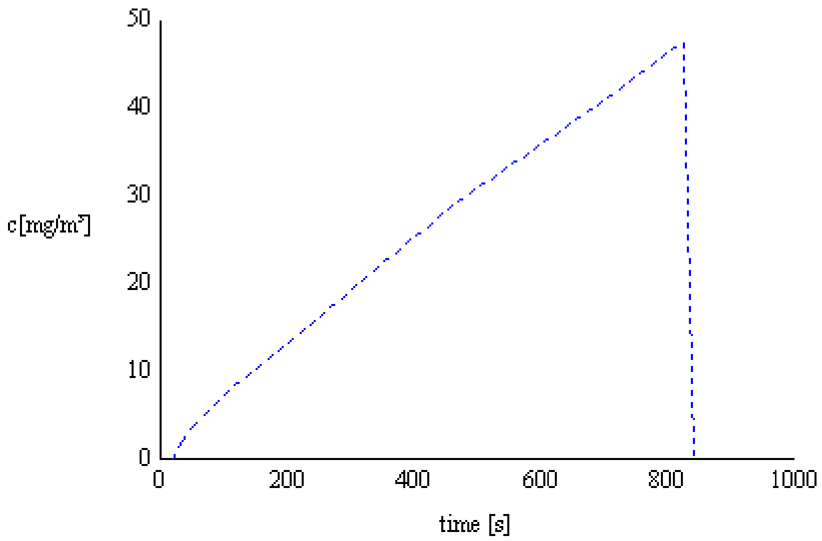
Experiment M5:



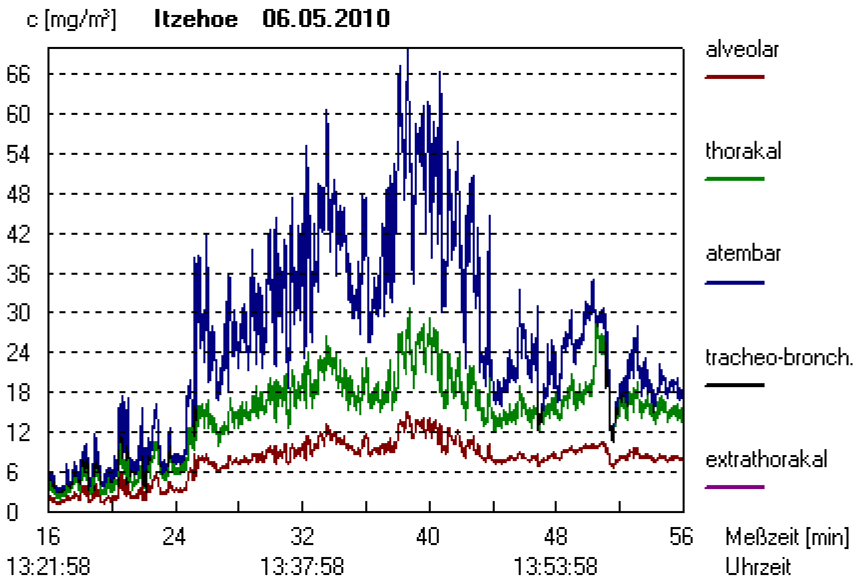


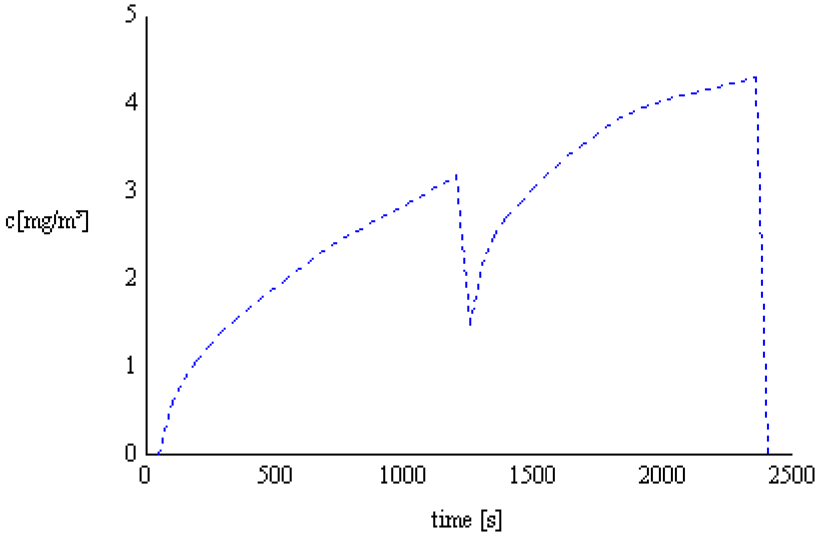
Experiment HS A:



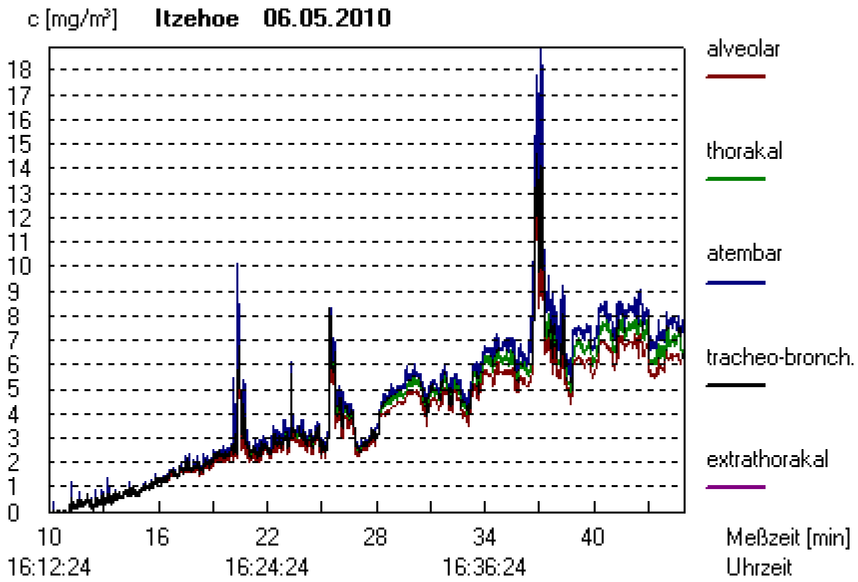


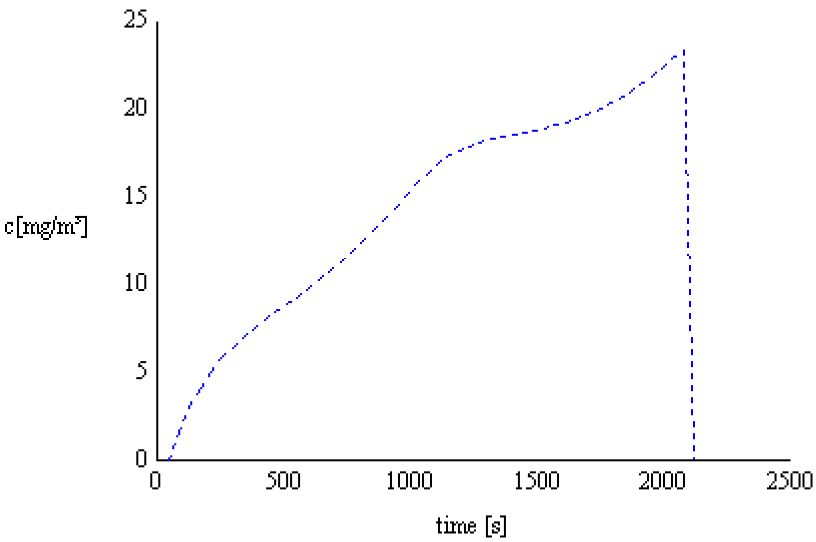
Experiment HS B:





Experiment HS C:





Appendix 7 Standard scenarios (fact sheets)

A7-1. General

SprayExpo can be used to estimate the exposure to chemical substances or products during spray applications in indoor environments. The model within SprayExpo is based on equations which characterize the dynamics of the spray cloud in the room of application. The model requires several input parameters.

These fact sheets present standard scenarios with default parameters which can be used in the exposure assessment of professional spraying applications in indoor environments when using SprayExpo. The fact sheets could be used in the evaluation of biocides for different product types (PT), for example PT 21 (Antifoulings), PT 3 (Veterinary hygiene biocidal products), or PT 18 (Insecticides).

This approach facilitates the extrapolation of exposure data available for certain products to other products and other scenarios for which specific data are not available. In addition, preliminary specified default values for the various model parameters ensure a high degree of consistency in the assessments.

A7-1.1. 'Reasonable worst-case' estimate

The estimation of default parameter values should result in a reasonable worst-case scenario which covers the frequent use of a certain product under less favorable circumstances. However, the default parameters should not result in an accumulation of worst-case assumptions that would represent unrealistic values.

Therefore, the default parameters have been chosen such that a relatively high but still realistic exposure and uptake are calculated. The result is a 'reasonable worst-case' estimate.

A7-1.2. Uncertainties and limitations

The exposure estimates from a model depend on the quality and reliability of the input data. Scenarios and their related parameters can have a major influence on the final exposure estimate. Therefore, default values should be chosen, determined, and improved with caution.

During validation of SprayExpo, the influence of several parameters was analyzed and discussed. The outcome was considered in the selection of default values. In addition, it should be noted that the models used in SprayExpo have been developed for spraying processes with products containing non-evaporating active substances in indoor environments only.

A more profound discussion on the default parameters could be elaborated in a next version of SprayExpo and/or in an update of these fact sheets based on more information to be collected. This will probably require an additional further adaptation of the exposure models, or even development of new models.

A7-1.3. Reliability of the data

Default values for all parameters are based on specifications of spraying applications (questionnaires) gathered during the validation studies for SprayExpo, as well as on literature sources. Generally, a value must be selected for each parameter; some values have only minor influence on the result, others are more complex.

The developer of ConsExpo[1] introduced a quality factor (Q-factor), which is a grading system for the value of the estimate of the exposure parameter. Low Q-factors indicate that the default value is based on insufficient (or no) data. If such a default is used in an exposure analysis, it should be carefully considered and, if possible, adapted. For example, if representative data are supplied (by producers, applicants, or authorities), these can be used to replace the default values. High Q-factors indicate that the defaults are based on sufficient (or more) data. These defaults generally require less attention. Nevertheless, it may happen that they need to be adapted to a particular exposure scenario. For example, an exposure estimate might be carried out for a room of a particular size; the well-established default room size should then be replaced by the actual value.

A Q-factor has been assigned to all parameter values in the standard scenarios, indicating the reliability of the estimate of the default value. The range of the quality factor from 1 to 4 has been adopted from ConsExpo. Table A7-1 shows the rationale for selecting the values of the quality factor.

Tab. A7-1 Values of the quality factor Q (adopted from ConsExpo)

Q	Value
4	Good quality, relevant data, reliable parameter value
3	Number and quality of the data satisfactory, parameter value usable as default value
2	Parameter value based on a single data source supplemented with personal judgment
1	Educated guess, no relevant data available, parameter value based only on personal judgment

[1] cf. http://www.rivm.nl/en/healthanddisease/productsafety/ConsExpo.jsp

A7-2. Standard scenarios

For the time being, standard scenarios have been predefined for the following biocide applications: spraying of antifouling paints (product type 21), and room and surface spraying during stored product protection (e.g. PT 3, PT 18) by professionals only. These standard scenarios are based on information gathered during the validation research project of SprayExpo (BAuA research project F 2137).

A7-2.1. Standard scenario for spraying of antifouling paints

Based on the typical application observed during the validation research project of SprayExpo (cf. questionnaires in Appendix 1 to the validation report), the following worst-case scenario could be derived.

Several spraying applications exist for antifouling paints, which can be differentiated mainly by their application pattern. The worst-case situation is overhead spraying underneath a (part of the) ship's hull.

General scenario description

The following reasonable worst-case scenario will be described and justified in detail below: spraying of antifouling paint by a worker from underneath a ship's hull or a part of a ship using a spray gun. The spraying device is an airless sprayer with a Graco nozzle. The spraying direction is overhead and the spraying duration is 30 minutes. The dimensions of the space below the hull are 30 m x 30 m x 3 m (see explanation below). The ventilation rate in this area is 1 h^{-1}. The scenario estimates the exposure of the sprayer but not of the pot-men, line-men, or bystanders during the spraying process.

Room size and ventilation

In the research project, the size of the dockyard was 40 m x 35 m x 21.5 m or 57 m x 35 m x 17 m. The worst-case application is underneath the hull, where the 'room' is limited to a sort of 'sub-room' with lower heights. Therefore, a default of 30 m x 30 m x 3 m has been selected. For the overhead spraying of antifouling paints, however, the room dimension has only limited influence, as the initial cloud is significantly smaller than the space underneath the hull.

According to TRGS 554[2], open halls have an air exchange rate (ventilation rate) of 10 h^{-1}, and closed halls with occasional transport activities have a rate of 1 h^{-1}. Although a dockyard has exhaust air ventilation and thus the ventilation rate in the whole dockyard is definitely higher, a ventilation rate of 1 h^{-1} should be used as default value to simulate a reasonable worst-case situation. This parameter, however, has only limited influence on the exposure values, since in this scenario the model is applied to short-term exposure (< 1 h, see below) only.

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[2] http://www.baua.de/de/Themen-von-A-Z/Gefahrstoffe/TRGS/TRGS-554.html cited in BIA report 3/2001 Berechnungsverfahren und Modellbildung in der Arbeitsbereichsanalyse (ISBN 3-88383-588-9)

For the turbulence diffusion, the default value is estimated to be 0.1 m^2s^{-1} (based on Baughmann et al.[3]).

Substance data

Generally, specific information on the non-evaporating fraction (including active substance or substance of interest) in the product is required. The products used in the validation research project contained maximally 50 % cuprous oxide. However, the non-evaporating fraction was nearly 100 %. Other products with other active substances require different concentrations which are given individually. Therefore, for the value 'non-evaporating fraction' product-specific information should be specified.

In addition, the sensitivity analysis showed that the vapor pressure of the solvent has a significant influence only at very low values. A value of 1 hPa could be used as reasonable worst case, as higher pressures will not increase exposure values significantly and lower values will decrease the exposure. However, if substance data are available in the product information, these data should be preferred. If the non-evaporating fraction is 100 %, the vapor pressure of the solvent does not need to be specified.

Application pattern

The worst-case situation is overhead spraying, thus the application pattern 'Ceiling' has been selected.

According to the questionnaires (one dockyard, tests A1-A4), this application was performed for 15-60 minutes (average 30 minutes), twice per working shift, and maximally six times per month (estimated). The time needed to treat a given surface area depends on the release rate. The task-based release rate was observed to be between 20.5 and 33.3 ml/s (90^{th} percentile 30 ml/s) using an airless sprayer with Graco nozzle, which will usually be used in a typical dockyard at an operating pressure of maximally 248 bar. During the on-site inspection the typical area sprayed within 15-60 minutes was 150-250 m^2. However, the area to be sprayed is of minor importance for the exposure in comparison to the time needed for this area.

Overall, all three parameters (surface area, release rate, and time) are interdependent. Based on several model calculations a reasonable worst-case situation will be represented by the combination: area = 144 m^2 (= 12 m x 12 m), release rate = 30 ml/s, and average time = 30 minutes. As a consequence, the default positions P1 and P2 for the sprayed surface as required by SprayExpo have been selected such that they are in the middle under the hull and represent 12 m x 12 m.

As observed in the dockyard, the distance between the worker and the nozzle was usually 0.5-0.8 m, and the distance between the nozzle and the ceiling was 0.3-0.5 m. The latter value will significantly influence the exposure value (overspray) as

[3] Baughmann, A.V., Gadgil, A., Nazaroff, W.W., Mixing of a Point Source Pollutant by Natural Convection Flow within a Room, Indoor Air, 1994, 4: 114-122

shown in the sensitivity analysis. Therefore, the distance sprayer to nozzle (horizontal) was set to 0.5 m, and the distance nozzle to ceiling (vertical) to 0.5 m, representing a worst-case estimate.

Spraying device/droplet spectrum/spraying nozzle

As highlighted in the sensitivity analysis, the droplet spectrum has the most significant influence on the exposure values. Therefore, act with particular caution when selecting these values.

An airless sprayer with a Graco nozzle was estimated to have lognormal droplet size distribution with a median of 250 µm; the geometric standard deviation is usually 1.8. These data are based on observations made when spraying the paint into a ventilated horizontal flow channel and estimating the settling velocity (i.e. the aerodynamic diameter) from the paint deposition pattern on the floor of the channel.

Tab. A7-2 Default values for spraying of antifouling paints

	Default value	**Q**
Room size and ventilation		
Length	30 m	2
Width	30 m	2
Height	3 m	2
Ventilation rate	1 h^{-1}	3
Turbulent diffusion	0.1 m^2s^{-1}	2
Substance data		
Non-evaporating fraction (incl. a.s.) in % w/w	Product-specific information	n. a.
Vapor pressure of solvent	1 hPa or product-specific information	3 or n. a.
Application pattern and data		
Application pattern	Ceiling	3
P1, P2	(9, 9); (21, 21)	2
Time	1800 s	2
Release rate	30 ml s^{-1}	2
Distance sprayer (receptor) – nozzle (horizontal)	0.5 m	2
Distance nozzle – ceiling (vertical)	0.5 m	2
Spraying device/droplet spectrum		
Size data input	Lognormal	1
Mass median (MMD)	250 µm	1
Geometric standard deviation	1.8	1
Spraying nozzle		
Diameter	0.53 mm	2
Angle	40 °	2

n. a. = not applicable

A7-2.2. Standard scenario for stored product protection (silo cell)

Spraying applications are usual within stored product protection for different biocidal applications (e.g. use of insecticides or disinfectants), for example in an elevator (silo cell). Applications can be differentiated mainly by their application pattern; both surface and room spraying by fogging/misting are used. Based on the typical applications observed during the validation research project of SprayExpo (cf. questionnaires in Appendix 2 to the validation report) as well as the investigations on droplet size distributions for different application techniques (V1-V17) in a model room at the Fraunhofer ITEM, the following worst-case scenario could be derived.

The on-site measurements included the different application patterns for surface spraying (Wall line, Wall area, and Floor) and for room spraying by pressurized cans or fogging/misting. The most reasonable case would be spraying along a wall line (crack and crevice) in combination with room spraying by fogging/misting. Spraying onto walls is assumed to be not very common. However, if specific information about a particular application pattern is available in the product information, this information should be preferred.

A7-2.2.1. Spraying along a line on the wall (silo cell)

Not all of the on-site measurements were relevant for spraying onto surfaces. Therefore, the scenarios Wall line (M2), Wall surface (M3), and Floor (M5) were used for deriving the default standard scenario.

General scenario description

The following reasonable worst-case scenario will be described and justified in detail below: spraying of a biocidal product, e.g. an insecticide, in a grain storage room (silo cell) with a size of 10 m x 20 m x 6.75 m. The worker uses a high-performance spraying device (backpack sprayer) with a handheld spray lance. The worker sprays along a line between the floor and the wall at a height of up to 0.5 m (wall line). The spraying direction is mainly downwards. Overall, a length of 60 m is being sprayed. The use of hollow cone nozzles with a flow rate of 0.6 l/min and a pressure of 3 bar maximum has been selected as default.

Room size and ventilation

The room size is assumed to be typical of large grain storage rooms in grain mills. On-site measurements (cf. questionnaires in Appendix 2 to the validation report) gave the dimensions 8.5 m x 22 m x 7.5 m. However, the room volume has only a minor influence on the exposure; more important is the area of spraying per time (cf. application pattern below). SprayExpo offers room heights of 3 m, 4 m, 6.75 m, and 10 m. A room of 10 m x 20 m x 6.75 m has been selected as default for this scenario.

According to TRGS 554[4], open halls have an air exchange rate (ventilation rate) of 10 h^{-1}, and closed halls with occasional transport activities have a rate of 1 h^{-1} Although storage rooms in grain mills are expected to be not fully closed, 1 h^{-1} has

[4] cf. footnote 2

been selected as default ventilation value to simulate a reasonable worst-case situation. This parameter, however, has only limited influence on the exposure values, since in this scenario the model is applied to short-term exposure (< 1 h, see below) only.

For the turbulence diffusion, the default value is estimated to be 0.1 m^2s^{-1} (based on Baughmann et al.[5]).

Substance data

Generally, specific information on the non-evaporating fraction (including active substance or substance of interest) in the product is required. The products used in the validation research project contained 4 g/L pyrethrins and 22 g/L piperonyl butoxide. However, other products with other active substances require different concentrations which are given individually. Therefore, for the value 'non-evaporating fraction' product-specific information should be specified.

In addition, the sensitivity analysis showed that the vapor pressure of the solvent has a significant influence only at very low values. A value of 1 hPa could be used as reasonable worst case, as higher pressures will not increase exposure values significantly and lower values will decrease the exposure. However, if substance data are available in the product information, these data should be preferred. If the non-evaporating fraction is 100 %, the vapor pressure of the solvent does not need to be specified.

Application pattern

As mentioned above, the most reasonable case would be spraying along a line on the wall (crack and crevice) in combination with room spraying by fogging/misting.

The application pattern Wall line simulates spraying along the border between floor and wall. Therefore, the four default position data W1-W4 have to be given as 2 x length and 2 x width; the height has to be set to 0.5 m. Overall, a distance of 60 m or an area of 60 m^2 (0.5 m height and 0.5 m on floor) is sprayed.

The release rate during all on-site measurements was 8.33 ml/s. Therefore, as a reasonable worst case this value has been rounded up to 10 ml/s.

The time required to spray this area depends on the release rate of the spraying device and the recommended dose rate of the product. In the on-site measurements, a total time of 8 minutes was necessary, and thus a time of 80 seconds per 10 meters. However, if substance data are available in the product information, these data should be preferred.

As observed during the on-site inspection, the distance between the sprayer (receptor) and the nozzle was typically 1.3 m, and the distance between the nozzle and the wall was 0.3 m. As shown in the sensitivity analysis, the distance between nozzle and wall will significantly influence the exposure concentration (overspray).

[5] cf. footnote 3

Therefore, the distance between the nozzle and the wall was set to 0.5 m and the distance between the sprayer and the wall to 1.5 m, representing a worst-case estimate.

Spraying device/droplet spectrum/spraying nozzle

As highlighted in the sensitivity analysis, the droplet spectrum has the most significant influence on the exposure values. Therefore, act with particular caution when selecting these values.

For spraying onto a surface, flat fan or hollow cone nozzles with a flow rate of 0.6 l/min and a pressure of 3 bar maximum will usually be used. As the hollow cone nozzle represents the worst case, it was selected as default. However, if specific information is available in the product information, these data are to be preferred. The diameter of the nozzle is typically 1 mm and the cone angle 55°.

Tab. A7-3 Default values for stored product protection – spraying along a line on a wall (crack and crevice) in a silo cell

	Default value	**Q**
Room size and ventilation		
Length	10 m	2
Width	20 m	2
Height	6.75 m	2
Ventilation rate	1 h^{-1}	3
Turbulent diffusion	0.1 m^2s^{-1}	2
Substance data		
Non-evaporating fraction (incl. a.s.) in % w/w	Product-specific information	n. a.
Vapor pressure of solvent	1 hPa or product-specific information	3 or n. a.
Application pattern and data		
Recommended dose rate in ml m^{-2}	Product-specific information	n.a.
Application pattern	Wall line	3
W1, W2, W3, W4	(0, 20); (0, 10); (0, 20); (0, 10)	2
Release height	0.5 m	2
Release rate	10 ml s^{-1}	2
Time	Product-specific information ((2*L+2*B)*1 m) x rec. dose rate/release rate)	n. a.
Distance sprayer (receptor) – wall (horizontal)	1.5 m	2
Distance nozzle – wall (vertical)	0.5 m	2
Spraying device/droplet spectrum		
Size data input	Spraying device	
Sprayer type/nozzle	Hollow cone	2
Flow rate	Release rate*1000/60 = 0.6 l min^{-1}	2
Pressure	3 bar	2
Spraying nozzle		
Diameter	1 mm	2
Angle	55 °	2

n. a. = not applicable

A7-2.2.2. Room spraying by fogging/misting (silo cell)

The only relevant scenarios of the on-site measurements for a reasonable worst-case estimate for room spraying were the scenarios M1, HS B, and HS C. The scenarios with pressurized cans (M4 and HS A) are regarded as not appropriate for a standard scenario for room disinfection in stored product protection, as they are not common among professionals.

General scenario description

The following reasonable worst-case scenario will be described and justified in detail below: spraying of a biocidal product, e.g. an insecticide, in a grain storage room (silo cell) with a size of 10 m x 20 m x 6.75 m. The worker uses a handheld fogger (electric cold fogger or thermal fogger) generating a droplet size mass median diameter (MMD) of 50 µm (geometric standard deviation 1.8) as worst case (see explanation below). The worker moves to four positions, with equal distances between each other and from the wall; at these positions the worker rotates once. The release is performed diagonally upwards (release height 3 m, spraying length 3 m).

Room size and ventilation

The room size is assumed to be typical of large grain storage rooms in grain mills. On-site measurements (cf. questionnaires in Appendix 2 to the validation report) gave the dimensions 8.5 m x 22 m x 7.5 m. However, the room volume has only a minor influence on the exposure; more important is the area of spraying per time (cf. application pattern below). SprayExpo offers room heights of 3 m, 4 m, 6.75 m, and 10 m. A room of 10 m x 20 m x 6.75 m has been selected as default for this scenario.

According to TRGS 554[6], open halls have an air exchange rate (ventilation rate) of 10 h^{-1}, and closed halls with occasional transport activities have a rate of 1 h^{-1} Although storage rooms in grain mills are expected to be not fully closed, 1 h^{-1} has been selected as default ventilation value to simulate a reasonable worst-case situation. This parameter, however, has only limited influence on the exposure values, since in this scenario the model is applied to short-term exposure (< 1 h, see below) only.

For the turbulence diffusion, the default value is estimated to be 0.1 m^2s^{-1} (based on Baughmann et al.[7]).

Substance data

Generally, specific information on the non-evaporating fraction (including active substance or substance of interest) in the product is required. The products used in the validation research project contained 4 g/L pyrethrins and 22 g/L piperonyl butoxide. However, other products with other active substances require different

[6] cf. footnote 2
[7] cf. footnote 3

concentrations which are given individually. Therefore, for the value 'non-evaporating fraction' product-specific information should be specified.

In addition, the sensitivity analysis showed that the vapor pressure of the solvent has a significant influence only at very low values. A value of 1 hPa could be used as reasonable worst case, as higher pressures will not increase exposure values significantly and lower values will decrease the exposure. However, if substance data are available in the product information, these data should be preferred. If the non-evaporating fraction is 100 %, the vapor pressure of the solvent does not need to be specified.

Application pattern

The application pattern Room simulates spraying in a room at different positions. SprayExpo requires up to four positions P1-P4. As a default, four positions are selected, with equal distances between each other and from the wall.

As observed during the on-site inspection, the spray release (nozzle) was typically above the worker. Therefore, the height was set to a default of 3 m (SprayExpo offers the options 0.5 m, 1 m, 2 m, 3 m etc). The spraying height is given to be 6 m, and thus the default for the spraying length has been set to 3 m.

The release rate in the relevant on-site measurements was 200-500 ml/min. As more time is necessary with a lower release rate, the reasonable worst-case value was set to 3.5 ml/s.

The time required to spray a particular room volume depends on the release rate of the spraying device and the recommended dose rate of the product. In the on-site measurements, a total time of 12-40 minutes was necessary. However, if substance data are available in the product information, these data should be preferred.

Spraying device/droplet spectrum/spraying nozzle

As highlighted in the sensitivity analysis, the droplet spectrum has the most significant influence on the exposure values. Therefore, act with particular caution when selecting these values.

The spray nozzle parameters do not need to be specified in the model of room spraying by fogging, as no overspray occurs; only the type of spraying device or the mass median diameter (MMD) has to be specified. As smaller droplets result in higher exposure values, a mass median diameter (MMD) of 50 µm with a geometric standard deviation of 1.8 has been selected as reasonable worst case for hot and cold fogging/misting.

Tab. A7-4 Default values for stored product protection – room spraying by fogging/misting (hot and cold) in a silo cell

	Default value	**Q**
Room size and ventilation		
Length	10 m	2
Width	20 m	2
Height	6.75 m	2
Ventilation rate	1 h^{-1}	3
Turbulent diffusion	0.1 m^2s^{-1}	2
Substance data		
Non-evaporating fraction (incl. a.s.) in % w/w	Product-specific information	n. a.
Vapor pressure of solvent	1 hPa or product-specific information	3/S
Application pattern and data		
Recommended dose rate in ml m^{-3}	Product-specific information	n. a.
Application pattern	Room	3
P1, P2, P3, P4	(5, 4); (5, 8); (5, 12); (5, 16)	2
Release height	3 m	2
Spraying length	3 m	2
Release rate	3.5 ml s^{-1} (depends on sprayer type)	2
Time	Product-specific information ((L*B*H) x rec. dose rate/release rate)	n. a.
Spraying device/droplet spectrum		
Size data input	Lognormal	1
Mass median (MMD)	50 µm	1
Geometric standard deviation	1.8	1

n. a. = not applicable