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Hand-disinfectant alcoholic vapors in incubators

THESE

préparée sous la direction du Docteur Bernard Laubscher, PD

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Synthèse

La désinfection des mains avant d'effectuer des soins est un acte indispensable en médecine clinique pour limiter le risque de transmission de germes. Après utilisation des produits désinfectants mis à disposition dans les services de soins, il se dégage une odeur alcoolique forte et désagréable, liée directement aux alcools antimicrobiens des solutions. Une étude a montré qu'une exposition aiguë et brève aux vapeurs d'éthanol et isopropanol chez des enfants prématurés pouvait être mise en relation avec des changements hémodynamiques au niveau de la zone olfactive orbito-frontale [1]. Aucune norme réglementant les concentrations de vapeurs d'éthanol ou isopropanol auxquelles les nouveau-nés peuvent être exposés n'existe.
Cette thèse avait pour but d'étudier l'exposition des nouveaux nés soignés dans des incubateurs à des vapeurs d'alcool (éthanol et isopropanol). Elle était composée de 2 parties qui ont été publiées dans 2 articles différents et qui représentent le travail de doctorat [2-3].

La 1ère partie était une étude observationnelle d'une série de cas [2]. Des mesures des concentrations des vapeurs d'alcool ont été effectuées auprès de 9 nouveau-nés soignés dans des incubateurs de même modèle au sein de l'unité de néonatologie du Centre Hospitalier Universitaire Vaudois à Lausanne. Sur 4 heures, les concentrations instantanées et moyennes ont été mesurées par deux techniques (photoionisation et respectivement chromatographie après absorption sur charbon actif).

Onze analyses ont été effectuées en 2004-2005. Elles ont révélé des taux très variables d'éthanol et d'isopropanol dans les incubateurs (avec des valeurs maximales de 1982 ppm pour l'isopropanol et 906 ppm pour l'éthanol) correspondant aux introduction de mains fraichement désinfectées dans les isolettes. Les concentrations moyennes variaient entre 9.8 ppm et plus de 61 ppm pour l'éthanol et < 0.01 ppm et 119 ppm pour l'isopropanol.

La 2e partie a été réalisée en collaboration avec le PD Dr D. Vernez de l'Institut Universitaire Romand de Santé au Travail [3]. Un modèle théorique prédictif des concentrations alcooliques dans des incubateurs pour nouveau-nés a été développé. Des séries de mesures standardisées des variations des concentrations alcooliques dans un incubateur sans patient ont été effectuées en changeant trois variables: 1) le renouvellement de l'air dans l'incubateur en variant le nombre de portes ouvertes, 2) la quantité de solution alcoolique versée sur les mains avant de les introduire dans l'incubateur 3) le temps de séchage des mains après désinfection et avant de les introduire dans l'incubateur. La modélisation a permis de décrire la cinétique des concentrations d'alcool dans les incubateurs et d'évaluer les pistes potentielles pour diminuer les risques d'exposition des nouveau-nés à ces vapeurs dans leurs incubateurs.

En conclusion, la 1ère partie a mis en évidence, pour la première fois, que des nouveau-nés soignés en incubateurs peuvent être exposés à des vapeurs d'alcool. Comme il n y a aucune norme d'exposition pour cette population et que les seules limites d'exposition

existantes sont destinées à des travailleurs adultes, aucune conclusion précise ne peut être avancée sur les risques toxicologiques. L'exposition à des vapeurs polluantes d'un nouveau-né à terme ou prématuré, en plein développement neuro-sensoriel, devrait toutefois, à priori, être évitée.

La 2ème partie permet de proposer des pistes pratiques pour diminuer les concentrations des vapeurs d'alcool dans les incubateurs: respecter le temps de séchage des mains après leur désinfection et avant de les introduire dans les isolettes et/ou préférer un désinfectant alcoolique à faible temps d'évaporation.

Ces travaux ont été les premiers à mettre en évidence une problématique potentiellement importante. Alors que la sensorialité des nouveau-nés est de plus en plus discutée, à ce jour seuls les sens auditifs, visuels et tactiles ont été abordés dans la littérature néonatale. La Dresse A. Borghini (SUPEA, CHUV), en collaboration avec les Prof B. Schaal, de l'Institut des Sciences Biologiques (Centre Européen des Sciences du Goût, Université de Dijon) et A. Moessinger (DMCP, CHUV), va d'ailleurs poursuivre la réflexion sur la mémoire à long terme d'une expérience olfactive chez des enfants prématurés dans le cadre d'un projet d'une étude longitudinale soutenue par le FNS. L'odeur cible sera un désinfectant alcoolique composé d'isopropanol dont l'odeur est associée aux soins donnés à l'enfant.

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Hand-disinfectant alcoholic vapors in incubators

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Abstract. *Objective*: To analyze the atmosphere inside incubators regarding alcoholic solvent such as isopropanol or ethanol which are commonly used in hand disinfecting solutions.

Design: Observational.

Setting: The third level neonatal unit of the Centre Hospitalier Universitaire Vaudois, Lausanne, Switzerland.

Patients: Nine neonates with median (range) gestational age of 29 4/7 (25 5/7–39 0/7) weeks and birth weight of 960 (550–3050) grams. All neonates were inside incubators.

Interventions: Alcoholic vapors inside incubators were directly and cumulatively measured by photoionisation and gas chromatography respectively after absorption on a charcoal sampling tube.

Results: Eleven studies (mean study time: 230 ± 19 minutes) were performed. Highly variable isopropanol/ethanol concentrations profiles were found inside incubators. Peak value for isopropanol was 1982 part per million and for ethanol was 906 part per million.

Conclusions: Incubators' inner atmosphere can be highly polluted by alcohol vapors. To reduce them staff should respect long evaporation time between hands disinfection and manipulations inside incubators. The use of an ethanol-based disinfecting solution, because of its short evaporation time, could be favored. As alcohol vapor toxicity for neonate remains largely unknown, further studies could be welcome.

Keywords: Neonate, isopropanol, ethanol, incubator

1. Introduction

Current best practices for hand hygiene in neonatal units include hand rubbing with an alcoholic solution whose main compounds are isopropanol and ethanol. Alcohol solutions are currently favored since they have a broad spectrum antimicrobial activity, develop their full antiseptic activity within 15 to 30 seconds, have been shown to significantly improve compliance with hand hygiene and are well tolerated by health care workers' skin [1].

However, introduction of alcoholic vapors inside incubators after routine hand cleansing can occur if insufficient time for complete evaporation is not respected before introduction of the hand inside the incubator.

Current neonatal unit practices seek to optimize the physical environment of neonates by minimizing potentially noxious stimuli such as aggressive

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light, noise, and scents [2]. Evaporating alcohol from freshly disinfected hands can be very "smelly" and thus represent a potentially deleterious stimulus to neonates in incubators. Only one study analyzed the effect of an acute, brief, intense inhalation of an ethanol/isopropanol solution in preterm newborns: it showed cortical hemodynamic modifications whose consequences however are unknown [3]. There are no published environmental exposure limits for alcoholic solvents in neonates or even children. Furthermore, no data exist on the potential hazards of a chronic exposure to such vapors at a crucial stage of neurological development such as the neonatal period.

The aim of this preliminary study was to determine if ethanol or isopropanol vapors were found around neonates inside their incubators after routine hand cleansing by professional staff (nurses and doctors) and parents.

2. Material and method

The measurements were performed in the neonatal unit of the Centre Hospitalier Universitaire Vaudois (CHUV). Alcoholic solutions in use were Sterillium® (isopropanol based) and Sterillium Virugard® (ethanol based) (Bode, Beiersdorf AG, Münchenstein, Switzerland).

The study was based on a convenience sample. It was descriptive in nature and initiated as a quality improvement initiative.

The overall clinical workload determined when the primary author could perform bed-site measurements. No systematic criteria were chosen to select which infant was to be studied. A study duration of approximately 4 hours was arbitrarily chosen as it was the longest period to fit easily in the first author's work schedule.

Only Dräger IC 8000 incubators with an internal volume of 157 liters (Carbamed, Liebefeld, Bern, Switzerland) were used.

To determine the average concentration of both isopropanol and ethanol over each study period, cumulative measurement was performed on a charcoal absorption tube (Anasorb CSC 226-01, SKC inc., Eighty Four, PA, USA), air being sampled at a 100 ml/min flow with a pump (SKC pocket pump, Blanc-Labo, Tolochenaz, Switzerland) located outside the incubator. Charcoal sampling tubes were desorbed with CS_2 and analyzed through gas chromatography (Capillary column CPSIL 8B 60Pm, Chrompack, Middelburg, Germany) with a detection limit of 1 microgram/tube (NIOSH/400 alcohols 1). Direct isopropanol and ethanol measurements were performed during the study period every 4th second using a pocket photoionisation detector (Toxi Rae®, Rae Systems Inc., Sunnyvale, California, USA) with a detection limit of 3 ppm. All air sampling were realized close to the infant's head where both probes were introduced at study time = 0.

Sterillium® producer recommends to "rub your dry hands with at least 3 ml alcoholic solutions for 30 seconds". No specific recommendations were given to staff members or parents about the accurate amount of disinfecting solution to be used or the duration of hands rubbing. All interventions (defined as incubator doors opening with hand introduction inside it) were recorded concomitantly to the vapors measurements. Average time between each intervention as well as hand disinfecting ratio (proportion of interventions with disinfected hands) were thus computed.

To prevent any change in hand disinfection practices, staff and parents of a neonate inside a studied incubator were informed orally and with a short written protocol that "the air quality" inside the incubator was to be analyzed. No formal informed written parental consent was required as the study was considered as a quality control (personal communication, M. Burnier, head of the CHUV Ethics Commission).

3. Results

Nine neonates (median (range) gestational age/birth weight of 29 4/7 weeks (25 5/7–39 0/7), respectively 960 grams (550–3050)) were evaluated. Eleven studies were realized (mean study time 230 ± 19 minutes). Only nurses introduced their hands in the incubators during all recordings. The table shows average alcohol concentrations and peak values measured inside incubators. Wide range of exposure concentrations were seen within the same unit or with the same type of disinfecting solution. Peak concentrations could reach high values (case 4, 1982 ppm). The highest average concentration over 4 hours was 119 ppm (case 7). A typical exposure profile is shown in Fig. 1 (Table 1-case 7). Each peak represents alcohol introduction in the incubator, as solvent residues on nurse's hands or

on disinfection swabs. Numbered arrows are given for some examples.

High exposure concentrations could be observed during short periods. In case 4, isopropanol concentration overshot 400 ppm during 5 minutes. In case 7, ethanol concentrations were greater than 200 ppm during two 20 minutes periods.

Studies 7 and 11 revealed the presence of both ethanol and isopropanol although only ethanol containing Sterillium Virugard® was in use at that time. The former was due to nurses hand disinfection. The latter to the infant's skin disinfection with an isopropanol solution.

Although all measurements were performed in the same department, the concentration profiles exhibited considerable discrepancies. While the neonatal special care unit (NSCU) profiles showed a score of well identifiable peaks followed by an exponential decrease, frequent increases and irregular decreases were observed on the neonatal intensive care unit (NICU) profiles.

The average time between two interventions in the NSCU and in the NICU were 21.9 min ($n=56$, SD = 23.1), respectively 9.9 min ($n=63$, SD = 10.3). Hands were disinfected prior to interventions in 70% of cases in the NSCU and in 38% of cases in the NICU.

4. Discussion

The purpose of this brief communication is to illustrate, using reliable measurement tools, the concentration of alcoholic vapors within an inhabited neonatal incubator over time. This work, for the first time, presents actual measurements of alcoholic vapor concentration inside incubators and should therefore be taken into consideration as illustrations of recognized potentially deleterious practices [2].

The concentration profiles observed inside incubators were highly variable. This variability was partly due to the lack of uniform patient selection criteria. The variability is also explained by the small incubator's volume as well as other factors: 1) the amount of solvent (and thus the maximal concentration) introduced at each manipulation is strongly influenced by the quantity of used hand disinfectant, the drying time before hands introduction and the manipulation duration. 2) The measuring site can determine the concentration kinetics since a direct contact or a very close proximity between the probe and the disinfected hands can influence the peak concentrations. 3) Air renewal conditions during and after each manipulation can affect the pollutant kinetics. For instance, rapid concentration decreases were observed during manipulations requiring the opening of several incubator's apertures or wide arms' movements inside the incubators. 4) The intervention frequency can affect the overall concentration profiles (peak concentration frequency) and can heavily weigh on average exposure concentrations. 5) Various alcohol containing products can influence solvent vapors levels in incubators: hand cleansing solution, disinfecting swabs or any alcoholic products to clean incubators inner walls.

Cohen et al. analyzed staff and visitors' interventions close to and within NICU incubators. Their interventions definition differed slightly from ours but, using their data, average time interval between their interventions within an incubator was computed to be 2.7 min (922 interventions over 41.6 hours), a much shorter interval than the 9.9 min. we found in our NICU. They also found that 38% of their interventions were preceded by correct hand hygiene practice, a similar ratio to what we observed in our NICU, using different hand hygiene practice though [4].

Intervention frequency can affect alcohol introduction inside incubators; the more interventions, the higher risks of exposure to alcohol. Neonates needing frequent manipulation (like Cohen et al.'s patients) could be exposed to even higher alcohol vapors than the NICU patients we studied.

Our study has a few limitations. First, it was based on a convenience sample and cannot thus be generalised to all neonatal patients or similar neonatal units. Second, although recorded prospectively, nurse hand disinfection before intervention inside an incubators could have gone unnoticed, especially during high workload periods with unstable sick neonates. We were effectively surprised and disappointed by the low 38% hand disinfection ratio in our NICU especially since we use the currently recommended best practices for hand hygiene which have been shown to significantly improve compliance with hand disinfection [1]. Third, little is known on the health hazards of neonatal exposure to isopropanol or ethanol vapors; literature reveals only a few acute intoxication case reports [5–9] but no data on their potential chronic/repetitive influences on the neonatal well being or developing olfaction,

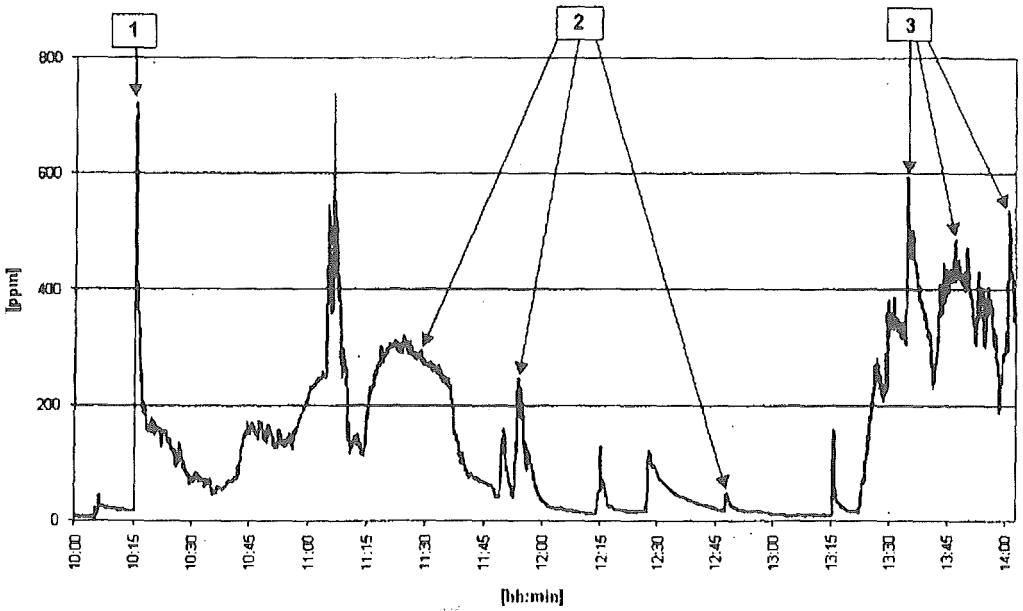

Fig. 1. Ethanol concentration over time in an incubator with a 1 day old neonate (gestational age 38 weeks 3/7, birth weight 3050 g) in the NICU. x-axis: time in minutes; y-axis: concentration in part per million (ppm). Arrow 1: ethanol rise in the incubator when introducing the solvent detector with dry but freshly disinfected hands. Arrows 2: multiple ethanol peaks during various procedures (umbilical artery catheter insertion, X-ray, blood sampling). Arrows 3: close to the study end, plateau elevation of ethanol at about 300 ppm for 50 minutes because of multiple manipulations with disinfected hands and introduction of disinfection swabs.

brain and other organs. Olfaction seems to be of high significance in the environment of both healthy and high-risk infants and the use of special odors could have long-term consequences on neural and behavioral development [10, 11]. Reference values for exposition to alcohol vapors exist only in the field of adult occupational health. Briefly, occupational exposure limits (OEL) have been defined for short (15 minutes (OEL_S)) and long (8-hours time-weighted average (OEL_L)) term exposures. In Switzerland, OEL_S and OEL_L for isopropyl alcohol and ethanol have been set at 400 ppm respectively 200 and 1000 ppm respectively 500 ppm [12]. It must be pointed out that OEL are established for healthy adults in chronic exposure conditions (workers). Therefore, they are not appropriate for neonates in incubators. We thus cannot evalu-

Table 1
Average solvent concentrations and peak values obtained inside incubators

	Time of analysis [min]	Disinfectant	Average concentration		Peak value [ppm]	Unit
			Isoropanol [ppm]	Ethanol [ppm]		
1	238	S	66.8	–	388	NICU
2	200	S	23.8	–	669	NSCU
3	246	S	13.8	–	545	NSCU
4	225	S	71.4	–	1982	NSCU
5	240	SV	1.3	26.3	273	NSCU
6	246	SV	<0.01	20.1	599	NSCU
7*	241	SV	119	>61**	906	NICU
8	193	SV	1.5	9.8	265	NICU
9	239	SV	0.13	15.5	n.r.	NSCU
10	245	SV	0.03	26.6	504	NSCU
11	218	SV	69.5	>33**	546	NICU

S = Sterillium®, SV = Sterillium Virugard®, NICU = neonatal intensive care unit, NSCU = neonatal special care unit, *see figure, **absorption tube saturated, n.r.: not reported.

ate our patients' risks on that basis although some were exposed to high concentrations for short periods (case 4).

We conclude that sick neonates in incubators can be exposed to alcohol vapors whose potential risks are largely unknown. Further study is encouraged. In the meantime, hand disinfection procedures at the incubators'side have to be analyzed: 1) sufficient time for complete alcohol evaporation has to be respected and 2) the use of an ethanol-based disinfecting solution, because of its shorter evaporation time, could be favored.

Financial disclosure

Authors declare no financial interest.

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Solvent vapours in incubators: a source of exposure among neonates?

D. Vernez, C. Paccaud, M. Berode, N. Hopf, N. Charrière, B. Laubscher

Abstract Hygiene practices in neonatal units require the use of disinfecting solutions containing ethanol or isopropanol. Newly disinfected hands or soaked swabs introduced inside the incubators may emit vapours leading to alcohol exposures to the neonates. Alcohol emissions from hands and other occasional sources (e.g. soaked disinfecting swabs) lead to measurable levels of vapours inside incubators. Average isopropanol and ethanol concentrations ranging from 33.1 to 171.4 mg/m³ (13.8 to 71.4 ppm) and from 23.5 to more than 146 mg/m³ (9.8 to > 6 ppm) respectively were measured inside occupied incubators (n = 11, measurement time about 230 min) in a neonatal unit of the Centre Hospitalier Universitaire Vaudois in Lausanne during regular activity. Exposure concentrations in a wide range of possible situations were then investigated by modeling using the one-box dispersion model. Theoretical modeling suggested typical isopropanol peaks and average concentrations ranging between 10^2 and 10^3 mg/m³ ($4 \cdot 10^1$ to $4 \cdot 10^2$ ppm), and 10^1 to 10^2 mg/m³ (4 to $4 \cdot 10^1$ ppm), respectively. Based on our results we suggest several preventive measures to reduce the neonates' exposures to solvent vapours.

Lösungsmitteldämpfe in Inkubatoren: Eine Belastungsquelle für Neugeborene?

Zusammenfassung Hygienemaßnahmen in Frühgeburtenabteilungen erfordern den Gebrauch von Desinfektionsmitteln, die Ethanol oder Isopropanol enthalten. Frisch desinfizierte Hände und andere Quellen (z. B. Tupfer) können in Inkubatoren messbare Dämpfe freisetzen, die zu Alkoholbelastung bei Neugeborenen führen. In besetzten Inkubatoren (n = 11) einer Frühgeburtenabteilung des Universitätskrankenhauses in Lausanne reichen die durchschnittlichen Isopropanol- und Ethanolkonzentrationen während eines normalen Arbeitstages von 33,1 bis 171,4 mg/m³ (13,8 bis 71,4 ppm) beziehungsweise von 25,5 bis zu mehr als 146 mg/m³ (9,8 zu > 61 ppm). Expositionskonzentrationen vieler möglicher Situationen wurden mit einem „One-box dispersion model" modelliert. Die Resultate legen typische Isopropanol-Höchst- und Durchschnittswerte nahe, die zwischen 10^2 und 10^3 mg/m³ ($4 \cdot 10^1$ bis $4 \cdot 10^2$ ppm), bzw. 10^1 und 10^2 mg/m³ (4 bis $4 \cdot 10^1$ ppm) variieren. Aufgrund unserer Ergebnisse schlagen wir einige Präventivmaßnahmen vor, um bei Frühgeborenen die Belastung mit Lösungsmitteldämpfen zu verringern.

1 Introduction

Incubators are widely used in neonatology to maintain suitable environmental conditions for neonates. The incubator is a small volume chamber enclosed by a bottom shell and a transparent top casing. The ventilation system for this chamber regulates the air flow and is equipped with a humidifier. To maintain constant humidity, air flow and temperature, the nurses/doctors introduce only his/her hands and forearms inside the incubator, using small apertures in the top casing (see **Figure 1**).

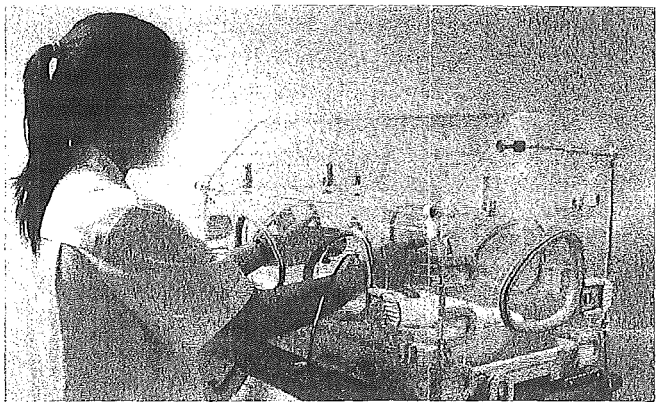

Figure 1. Incubator used in neonatology (front doors open and forearms inside).

Part of the hygiene practice used by the workers in neonatal units requires disinfecting the hands by rubbing them with alcoholic solutions either based on ethanol or isopropanol [1; 2]. The user is recommended to wait (about one minute) for complete alcohol evaporation before introducing his/her hands into the incubators. In practice, the workers happen to insert their hands into the incubators probably before complete evaporation due to a high workload or to the neonates' urgent needs. This practice could lead to an increase in organic solvent vapours inside the incubators.

Available data on neonates' exposure to alcoholic vapours is scarce. Until now no study has investigated the neonates' exposure while in incubators. Cortical hemodynamic modifications in the olfactory region of the brains of preterm infants have been found after exposure to odorous substances routinely used in the neonatal intensive care [3]. An accidental death of a neonate (1,500 g, 37 week gestation), following an acute exposure, due to isopropanol exposures has also been reported [4].

The aim of our study was to assess neonates' exposures to ethanol and isopropanol concentrations inside the incubators using both field measurements and theoretical modeling. The results were expected to refine current recommendations regarding the use of hand disinfectants by neonatal nurses/doctors/parents.

2 Material and methods

2.1 Study population

This study was performed at the Neonatal Unit at the Centre Hospitalier Universitaire Vaudois. Hand disinfectants in clinical use at the time of the study were Sterillium® (45%

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2-propanol and 30% 1-propanol) and Sterillium Virugard® (95% ethanol) (Bode, Beiersdorf AG, Münchenstein, Switzerland). The manufacturer recommends to *"rub your dry hands with at least 3 ml alcoholic solutions for 30 sec"*.

2.2 Field measurements

Eleven field measurements were performed in both neonatal intensive and special care units (NICU resp. NSCU). Convenience sampling was used because of restricted access and possible interferences with intensive or continuous care activities in the neonatal units. Isopropanol and ethanol concentrations were measured inside incubators using a direct-reading instrument; a photoionisation detector (Toxi Rae®, Rae Systems Inc., Sunnyvale, California, USA), and cumulative air concentration (230 ± 19 min) using charcoal absorption tubes (Anasorb CSC 226–01, SKC inc., Eighty Four, PA, USA) and pocket pumps (100 ml/min, SKC pocket pump, Blanc-Labo, Tolochenaz, Switzerland). The photoionisation detector was calibrated with 2-propanol (for Sterillium®) or ethanol (Sterillium Virugard®) before each measurement. Ambient air concentrations outside the incubators were measured using the same method as described for air concentrations inside the incubators.

Staff's hands disinfection as well as the opening and closing of the incubator's apertures are referred to as interventions. Hands disinfections, incubator manipulations (e.g. opening/closing apertures), and introduction of hands in the incubators were recorded by a pediatric resident concomitantly to the measurements.

The charcoal tubes were analyzed by desorption with CS_2, and quantified using a gas chromatography (Capillary column CPSIL 8B, 60m, Chrompack, Middelburg, Germany) with a FID detector. The detection limit was of 1 µg/tube (NIOSH 1,400 alcohols 1).

2.3 Exposure modeling

The alcohol air concentrations inside the incubators are influenced by numerous parameters. It is therefore not practical to investigate the range of possible situations in an experimental way. Due to the convenience sampling used ($n = 11$), the number of field measurements available was not representative and an alternative to experimental measurements was necessary. Exposure modeling was therefore used to estimate isopropanol exposures in a wide range of input parameters and to investigate parameters' influence on exposure. Results obtained from simulation can easily be extrapolated to similar exposure situations (e.g. different chemicals).

The one box model, also called Well-Mixed Box (WMB) Model, has been used in this paper [5]. The key hypothesis of the model is that an ideal mixing occurs in the room (or the volume considered). In practice, ideal mixing is seldom achieved, particularly in large or complex volumes because of dead-spaces or short-circuits. In our study, the volume considered is small (157 l) and hence, this limitation of the model would be low. Moreover, experimental measurements indicated that the isopropanol decrease inside the incubator followed an exponential kinetic (linear decrease of the pollutant concentration logarithm over time), as expected from an ideal-mixing. In the WMB model, sinking (adsorption) is neglected, and the relationships between the pollutant concentration C_i in mg/m³, the ventilation flow Q in m³/s, the emission rate E in mg/s, and the compartment volume V in m³ are expressed by a differential mass balance over time:

$$V \cdot \frac{dC_i}{dt} = E(t) - Q \cdot \left(C_i(t) - C_{i0}\right) \quad (1)$$

Introducing air renewal R in time^{-1} ($R = Q/V$), and assuming a clean incoming air ($C_{i0} = 0$) gives:

$$V \cdot \frac{dC_i}{dt} = E(t) - R \cdot V \cdot C_i(t) \quad (2)$$

Where $E(t)$ is a constant, this equation can be integrated and has an analytical solution. In our case however, emission varies over time as it occurs when newly disinfected hands are introduced inside the incubators. $E(t)$ can be expressed as a function of the following parameters: the time lag (TL) between two interventions (the time duration between two interventions inside the incubator), the disinfection ratio (DR) (the average number of interventions preceded by hand disinfection divided by the total number of intervention) and the amount of alcohol emitted during a specific intervention e (i being the total number of interventions during the simulated period)

$$E(t) = f(DR, TL, e_1 \ldots e_i) \quad (3)$$

The amount of alcohol emitted (e) inside the incubator during a specific intervention depends on the amount of disinfectant solution used (Md) and the time lapse (referred in this paper as "waiting time after use of disinfectant" or WT) between the disinfection of the hands and their introduction into the incubator. Only Md and WT parameters were included in our study. Additional parameters that may affect evaporation such as hand surface, skin temperature, and local ventilation conditions during disinfection were not explicitly considered.

$$e = f(WT, M_d) \quad (4)$$

The one box theoretical model (2) was implemented using simulation software (Ithink, version 7.0, isee systems inc., Lebanon, New Hampshire, USA). Numeric simulations were conducted for a wide range of input parameters in order to generate typical concentration profiles and to assess the influence of some exposure determinants.

2.3.1 Assessing model parameters

All the incubators included in this study were of the same model (Dräger IC 8000, Draeger Medical AG & Co. KG, Lübeck, Germany). Their inner air volume (V) was 157 l. R (air renewal) was obtained experimentally using an empty incubator set at 32.5 °C and 50% humidity. Isopropanol (100 ml) was injected inside the incubator through a front aperture with a syringe. The concentration decrease after injection was measured by photoionisation and used to assess air renewal according to the one box model analytical solution [5].

Three air renewal situations were considered:

(1) all apertures closed, which is expected when no work was required; (2) two front apertures open, which is expected shortly before and after interventions; and (3) forearms and hands inside incubators (through the open apertures), which is expected during intervention. Each experiment was repeated three times. The repeat averages were

used in the model. *TL* (time lag) and *DR* (disinfection ratio) were obtained by observation while performing the measurements. *TL* and *DR* were 21.9 min (n = 56, SD = 23.1; SD = standard deviation) and 70%, respectively, in the continuous care unit, and 9.9 min (n = 63, SD = 10.3) and 38%, respectively, in the intensive care unit. The latter reflected higher workloads and time constraints. It should be noted that the disinfection ratios were within the range of hand hygiene compliance levels observed in previous studies [6].

Md was assessed experimentally. Hand disinfections were performed repeatedly by the same pediatric resident who was asked to use "smaller than usual" (n = 9; 0.322 g, SD = 0.035), "usual" (n = 9; 0.668 g, SD = 0.063), and "larger than usual" (n = 10; 1.368 g, SD = 0.194) amounts of Sterillium®. The bottle of disinfectant was weighed before and after each use, using a Mettler P163 balance (Mettler Inc AG, Zürich, Switzerland).

Three *WT* durations were considered: regular hand cleaning practice (1 min), an unintentional underestimate of the *WT* (30 s), and a situation requiring immediate attention (10 s), where the regular hand cleaning practice was not respected.

Three alcohol emission (*Ej*) scenarios were considered using the *Md* and *WT* values previously obtained: a "small" (smaller than usual Md, WT 30 s), "fair" (usual *Md*, *WT* 30 s), and "large" emission scenario (larger than usual *Md*, *WT* 10 seconds). All three scenarios were performed by the pediatric resident. Isopropanol concentrations inside the incubator were measured concomitantly by direct-reading. Each experiment was repeated three times. *Ej* was then calculated using the mass-balance relationship (2) and the isopropanol concentrations (corresponding to Ci in the model).

3 Results

3.1 Field measurements

Our field results indicate that neonates in incubators were exposed to measurable ethanol and isopropanol concentrations from disinfectants, especially peak exposures. Average isopropanol and ethanol concentrations found inside the incubators through sampling were, respectively 83.6 mg/m³ *SD* 103.3 mg/m³ and 45.7 mg/m³ *SD* 27.5 mg/m³ (air renewal range was 7.1 to 19.6 h⁻¹). Lower levels of isopropanol and ethanol, 12.6 and 4.4 mg/m³, respectively, were detected in the ambient air (outside the incubators).

Typical exposure profiles measured inside incubators are shown in **Figure 2**. High exposure concentrations up to 3 g/m³ were observed during short time periods.

Although all measurements were performed in the same unit the concentrations profiles were of different shape. The neonatal special care unit (NSCU) profiles obtained through direct reading measurements (Figure 2a) showed several well-identifiable peaks followed by an exponential decrease while irregular increases and decreases were observed on the NICU profiles (Figure 2b). This difference reflected the more complex tasks required in intensive care (longer interventions, successive opening/closing, more handling inside incubator) compared to special care.

3. 2 Exposure modeling

Air renewal rates with apertures closed, two front apertures open, and forearms and hands inside incubators were found to be 7.1, 10.8, and 19.6 h⁻¹, respectively. A constant supply of fresh air is maintained, even in closed-aperture conditions,

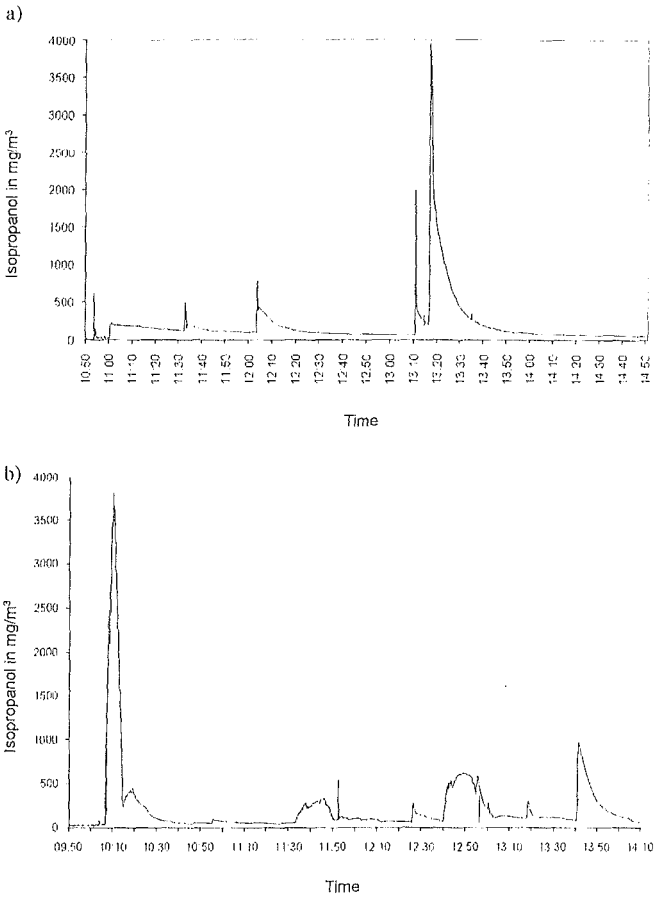

Figure 2. Temporal profile of isopropanol concentrations as measured in NICU (a) and NSCU (b) incubators.

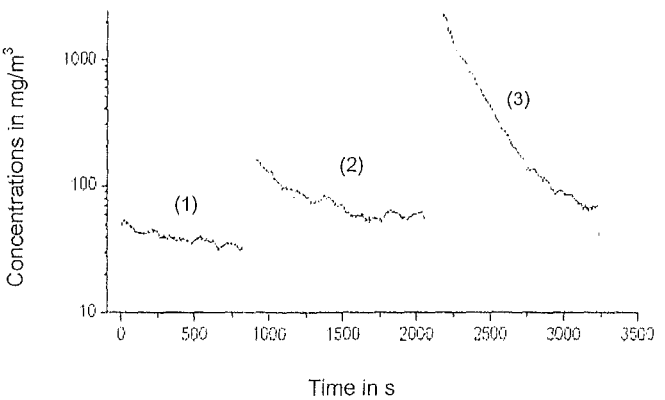

Figure 3. Measured isopropanol concentrations following the introduction of hands according to: (a) the "small" emisson scenario, (b) the "fair" emission scenario and (c) the "large" emission scenario.

in order to maintain adequate hygrometric and temperature conditions within the incubator. The "clearance" of the solvent vapours in closed-aperture conditions is nevertheless lower than in open-apertures condition due to the lower air renewal.

Isopropanol concentrations inside the incubators following hands introduction for the three considered scenarios are presented in **Figure 3**. The maximum isopropanol concentration (above 1,000 mg/m³) was obtained for the "large" emission scenario. The corresponding isopropanol amounts emitted inside incubator for "small", "fair", and "large" emission scenarios were 8.9, 16.3, and 230 mg, respectively.

An example of a typical modeled exposure profile, in "fair"

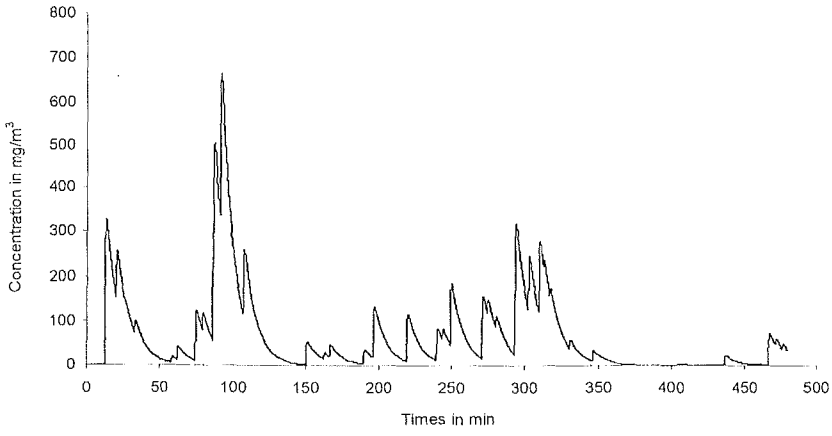

Figure 4. Example of a computerized exposure profile.

tion was higher than what was reached with a single peak emission.

We compared the simulation results obtained from various exposure conditions, assuming constant time lags in each run. The simulation parameters used are summarized in the **Table**. Although theoretical, this approach allows assessing the influence of simulation parameters on potential exposure. The mean concentrations obtained for various time lags, emission scenarios, and air renewal scenarios (apertures open or closed) are shown in **Figure 5**.

Generally, the mean isopropanol concentration was strongly affected by simulation parameters values and three orders of magnitudes

Simulation parameters used to compare scenarios.

Scenario	Air renewal, R in h^{-1}	Amount emitted per intervention, e_i in mg	Waiting time, WT in s	Time Lag, TL in min
a (large emission, apertures closed)	7.1	230	10	3 to 60
b (large emission, apertures open)	19.6	230	10	3 to 60
c (fair emission, apertures closed)	7.1	16.3	30	3 to 60
d (small emission, apertures closed)	7.1	8.9	30[1]	3 to 60
e (fair emission, apertures open)	19.6	16.3	30	3 to 60
f (small emission apertures open)	19.6	8.9	30[1]	3 to 60

[1] A WT of 1 min did not produce measurable amounts of alcohol inside the incubators and was thus not considered. A WT of the 30 s rather than 1 min was therefore considered in this scenario

emission conditions (usual disinfectant amount, *WT* 30 s), in a NICU obtained through simulation is presented in **Figure 4**. In order to reflect the variability of the work, lognormal distributions were used for time lag (*TL*) and amount emitted per intervention (e_i). Peak concentrations reached 600 mg/m³ and lead to mean concentrations of 64.8 mg/m³ in this simulation profile. Interestingly, the highest concentrations reached were when the time lag between two "peaks" was short, typically below ten minutes. If an additional pollutant was introduced into the incubator while the previous "peak" had not cleared, the resulting cumulative concentrations were found between the lowest (3 mg/m³, scenario a, *TL* = 3 min) and highest (4,000 mg/m³, scenario f, *TL* = 60 min) predicted values. When other simulation parameters remain unchanged, the air renewal conditions affect average isopropanol concentrations similarly and isopropanol concentrations obtained for closed apertures were 2.7 times higher than for open apertures. The "large" emission scenarios (scenario a and b) lead to average concentrations ranging between 70 and 3,900 mg/m³. These values are 14 times higher than the results obtained for "fair" emissions under similar conditions (scenarios c and e). The situation is similar for the time lag parameter for which a dramatic increase in average alcohol concentration can be observed below 10 min.

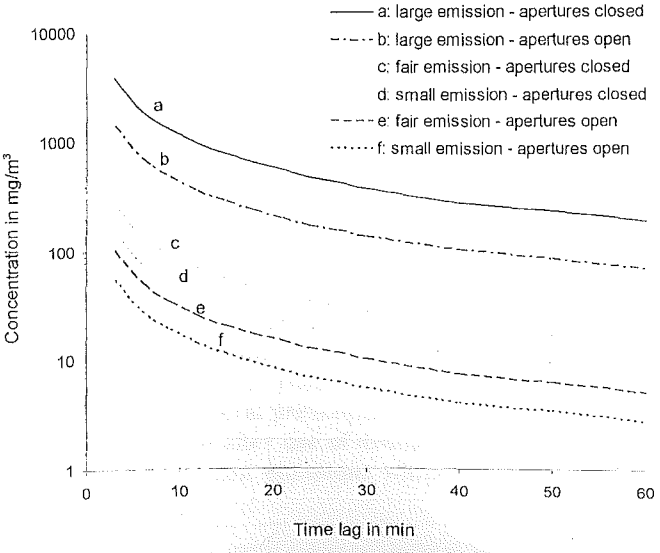

Figure 5. Sensitivity analysis: mean isopropanol concentrations for various emission scenarios, time lags and air renewal conditions.

Disinfecting solutions based on ethanol or isopropanol will lead to different simulation results in terms of absolute concentration levels; however, the pollutant dynamic behaviour (kinetics) and its sensitivity to the simulation parameter (e.g. air renewal rate) were independent of the chemical considered. Similar behaviour may therefore be found for other disinfectant used in neonatal care units.

4 Discussion

Vapours from alcoholic disinfecting solutions (ethanol and isopropanol) were found in measurable concentrations in neonatal incubators. Considering that lower levels of ethanol and isopropanol concentrations were found in ambient air, the alcohol concentrations measured inside the incubators can be attributed to the introduction of vapour-emitting disinfectant within the incubator. Newly disinfected hands were the most common source of peak exposures observed.

Disinfecting swabs, soaked with isopropanol, may also be unintentionally forgotten after a procedure, leading to a longer-lasting elevated level of alcoholic vapours. Once for instance, the photoionisation detector reacted strongly to the presence of a mother's perfumed scarf, which was lovingly left next to her baby's head. There is no way to know whether the perfume vapours were detrimental or unpleasant to the baby. Solvent emitting objects should nevertheless be avoided in a general sense due to the limited volume of incubators. In addition, various anatomical, clinical and even near infrared spectroscopy studies have shown that the olfactory system is indeed functional by 28 weeks of gestation [7], and perfume or other vapour emitting materials may affect the baby's well-being or development. Reducing the emission of alcoholic vapours inside incubators may contribute to the well-being of newborns in neonatal units.

Little is known with regard to possible health effects in neonates from exposures to isopropanol or ethanol vapours. For inhalation, only one neonatal case of accidental alcohol inhalation has been reported [4]. Preterm neonate have an immature skin and a high body surface to weight ratio making them prone to skin absorption. In a rabbit model, *Martinez* et al. have shown that transdermal isopropanol absorption can be significant [8]. However, no data on neonatal human skin absorptive properties exist. Percutaneous systemic ethanol and isopropanol intoxications in preterm and term neonates have been described but were always due to intense direct contact between skin and liquid ethanol or isopropyl alcohol [9 to 12]. For neonates supported by assisted ventilation, exposure to alcohol vapours inside incubators could be less than expected. A percutaneous absorption of alcohol vapours seems improbable although both ethanol and isopropanol are known to be absorbed by the neonatal skin when in direct contact with the liquid form.

Exposure prediction through modeling indicated that time-related parameters (waiting time after use of disinfectant and time lag between two interventions) were key factors for exposure concentration levels. Peaks of exposure, either due to emissions from the hands or to the cumulative effects of repetitive interventions, were important sources of increase in the predicted average exposure.

Direct-reading measurements indicated that isopropanol „peak" exposures up to several thousand mg/m³ may occur in incubators. The simulation of a wide range of possible situations through modeling produced concomitant results and also suggested that, in adverse conditions, average exposure concentrations of several hundred mg/m³ may occur. Considering that there is no published environmental exposure limits for isopropanol in neonates or even children[1], it would be prudent to implement preventive measures to decrease neonates' exposures to solvent vapours.

Acting on air renewal conditions (e.g. favouring bigger incubators, keeping apertures open after interventions) will contribute to reducing the overall exposures but may impair the environmental control function of the incubator. The most effective prevention is to reduce emissions from the hands. We recommend several prevention measures:

- A 1-minute waiting time after use of disinfectant appears sufficient to avoid significant emissions within incubators and should therefore be respected. A shorter waiting time after use of disinfectant, which may be sufficient for most hand-rubbing situations, appears inappropriate when performing duties on neonates in incubators. Measurable levels of alcoholic solvents have been found for waiting times less than or equal to 30 seconds. Organizational measures, such as increasing awareness of alcohol vapour exposures to neonates when using disinfectants, should be implemented.
- In general, a disinfecting solution container limiting the amount of product used (e.g. containers with push buttons) is favoured. This measure would prevent the inadvertent use of excessive amounts of solution (requiring longer evaporation times). It is interesting to note that, in the specific case of Sterillium®, the 3 ml amount recommended by the producer is higher than the "larger than usual" amount of product considered in this study.
- Currently, the best hand disinfection solutions are still based on alcohol [3]. There are thus no good alternatives to be considered for the care of neonates in incubators. A disinfecting alcohol with a very short evaporation time (e.g. ethanol) could decrease potential exposure of neonates to solvents.
- The use of electrical hand-dryers to reduce the evaporation time after hand rubbing should be investigated. Fast hand-drying may be of particular interest when situations requiring immediate attention occur regularly (e.g. intensive care units).

This paper highlights exposure situations resulting from hand disinfection practices in neonatal units. The small inner volume of the incubators facilitates temperature and humidity control, but it may also lead to concentration levels in pollutant higher than in ambient air when emission sources are present. Preventive measures should be implemented to avoid unnecessary exposures in these micro-environments, while maintaining a high-level of hygiene. Care must be taken when implementing preventive measures in order to preserve both incubator air quality requirements and hand hygiene requirement.

[1] Only Occupational Exposure Limits (OELs) defined for healthy working adults are known to the authors (500 mg/m³ for a 8 hrs-average exposure in Switzerland).

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Technik und Recht

TRGS 800 „Brandschutzmaßnahmen"

Die TRGS 800 gilt für Tätigkeiten mit brennbaren oder oxidierenden Gefahrstoffen, bei denen Brandgefährdungen entstehen können. Sie enthält Hinweise zur Ermittlung, Beurteilung und Festlegung von Maßnahmen.

Im Rahmen der Gefährdungsbeurteilung müssen alle für die Entstehung, Ausbreitung und Auswirkung eines Brandes relevanten Faktoren berücksichtigt werden. Insbesondere zu beachten sind Gefährdungen durch Rauch, andere (toxische) Brandfolgeprodukte, Wärme sowie das Versagen von Bauteilen.

Zur Beurteilung der Brandgefährdung muss ermittelt werden, an welchen Orten, in welchen Mengen und in welchem Zustand brennbare oder oxidierende Gefahrstoffe vorhanden sind oder entstehen können. Dabei sind insbesondere zu berücksichtigen:

1. vorhandene Gefahrstoffe und deren gefährliche Eigenschaften, die Brandausbreitung in der Anfangsphase, die auftretenden Brandfolgeprodukte, z. B. Partikel, Rauchgase sowie Brandrückstände,
2. eingesetzte Arbeitsmittel einschließlich Anlagen,
3. Betriebsweise von Anlagen,
4. Arbeitsverfahren mit offener Flamme oder hohen Temperaturen,
5. bauliche, örtliche und betriebliche Gegebenheiten,
6. Arbeitsbedingungen, -organisation und -umgebung und
7. mögliche Wechselwirkungen.

Bei der Beurteilung sind die verschiedenen Betriebszustände zu berücksichtigen. Betriebszustände wie beispielsweise Instandhaltung (Wartung, Inspektion, Instandsetzung, Verbesserung) sowie die In- und Außerbetriebnahme von Sicherheitseinrichtungen, die gesonderte Maßnahmen erforderlich machen, sind stets gesondert zu beurteilen.

Ferner sind Informationen über die relevanten physikalisch-chemischen Eigenschaften der vorhandenen brennbaren oder oxidierenden Gefahrstoffe und deren Beurteilung hinsichtlich der Brandgefährdung zu beschaffen sowie die relevanten Zündquellen (Einwirkung von Wärmeenergie, elektrischer, mechanischer und chemischer Energie) zu ermitteln.

Die durchzuführenden Maßnahmen sind davon abhängig, in welche der folgenden Gefährdungskategorien der Arbeitsbereich aufgrund der Gefährdungsbeurteilung eingeordnet wird:

- Normale Brandgefährdung

Diese liegt vor, wenn eingestufte brennbare oder oxidierende Gefahrstoffe in nur geringer Menge vorhanden sind, die Wahrscheinlichkeit einer Brandentstehung, die Geschwindigkeit der Brandausbreitung und die damit verbundene Gefährdung von Beschäftigten und anderen Personen durch Rauch oder Wärme vergleichbar gering sind, wie z. B. bei einer Büronutzung.

- Erhöhte Brandgefährdung

Diese liegt dann vor, wenn ein Kriterium der normalen Brandgefährdung nicht erfüllt ist oder nicht alle Kriterien für die hohe Brandgefährdung erfüllt sind.

- Hohe Brandgefährdung

Diese liegt vor, wenn die Menge der brennbaren oder oxidierenden Gefahrstoffe die „geringe Menge" der Gefährdungskategorie „normale Brandgefährdung" überschreitet, mit hoher Wahrscheinlichkeit mit einer Brandentstehung zu rechnen ist und eine schnelle und unkontrollierbare Brandausbreitung oder eine große Rauch- oder Wärmefreisetzung zu erwarten ist. Eine beispielhafte Liste von entsprechenden Arbeitsbereichen wird in der TRGS 800 genannt.

Beispiele für zu treffende Schutzmaßnahmen werden unterteilt in die drei Gefährdungskategorien in der Tabelle 1 der Technischen Regel genannt. Die Anlage 3 zur TRGS 800 enthält eine Checkliste für die Überprüfung der Schutzmaßnahmen. Die Fragen dienen einer strukturierten Überprüfung auf Plausibilität von Schutzmaßnahmen bei einer erhöhten oder hohen Brandgefährdung.

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