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Original Article

Chemical Risk Assessment Screening Tool of a Global Chemical Company

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ABSTRACT

Background: This paper describes a simple-to-use and reliable screening tool called Critical Task Exposure Screening (CTES), developed by a chemical company. The tool assesses if the exposure to a chemical for a task is likely to be within acceptable levels.
Methods: CTES is a Microsoft Excel tool, where the inhalation risk score is calculated by relating the exposure estimate to the corresponding occupational exposure limit (OEL) or occupational exposure band (OEB). The inhalation exposure is estimated for tasks by preassigned ART1.5 activity classes and modifying factors.
Results: CTES requires few inputs. The toxicological data, including OELs, OEBs, and vapor pressure are read from a database. Once the substance is selected, the user specifies its concentration and then chooses the task description and its duration. CTES has three outputs that may trigger follow-up: (1) inhalation risk score; (2) identification of the skin hazard with the skin warnings for local and systemic adverse effects; and (3) status for carcinogenic, mutagenic, or reprotoxic effects.
Conclusion: The tool provides an effective way to rapidly screen low-concern tasks, and quickly identifies certain tasks involving substances that will need further review with, nevertheless, the appropriate conservatism. This tool shows that the higher-tier ART1.5 inhalation exposure assessment model can be included effectively in a screening tool. After 2 years of worldwide extensive use within the company, CTES is well perceived by the users, including the shop floor management, and it fulfills its target of screening tool.

1. Introduction

There is a continuous need to improve the risk assessment process to efficiently track the potential risks needing attention, perform more detailed assessments, or prioritize preventive actions. Efficient and easy to use screening tools are essential in chemical risk management systems. The Solvay Industrial Hygiene Team developed a risk-screening tool (Critical Task Exposure Screening; CTES), with a dedicated exposure assessment part, based on a broadly accepted exposure assessment model. Moreover, the hazard database of the company is considered more useful in combination with exposure assessment for risk screening. The idea behind the tool is that shop floor management may be easily involved in the review of exposure to chemicals at their own workplace. It uses nonexpert and simple criteria of assessments, and should confirm which are the activities needing either exposure reduction measures or more detailed assessments by a health, safety, environment (HSE)/industrial hygiene (IH) specialist. Within the CTES procedures, interuser variability is minimized by training, describing tasks in an understandable language and minimizing the parameters to choose from.

There is a number of commonly used worker exposure assessment models (Stoffenmanager® [1], EMKG-EXPO-TOOL [2], ART1.5 [3], ChemSTEER [4] ECETOC-TRA V3 [5], and Emission Scenario Documents [6]), but, as described in a recent evaluation of Tier 1 exposure assessment tools [7], there is large variability in outcome

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by user, which is clearly a disadvantage when used at shop floor level over a wide range of geographical areas. Substantial variability has also been shown between individual assessors' estimates [8] when using ART1.5 [3] for exposure assessment. Screening tools like Control of Substances Hazardous to Health Essentials [9] and ChemSTEER version 3.0 [4], which respectively meet the needs of small- and medium-sized enterprises and workplace release and exposure estimation for new chemicals submitted for review by the United States (US) Environmental Protection Agency, are less suitable for the chemicals management needs of a global chemical company.

This study aimed to show the effectiveness and added value of a company-wide systematic screening tool for risk management of hazardous substances. The company has a global policy approach for hazard and exposure assessment to chemicals, which is implemented at all operational sites handling chemicals in the company. Additional requirements might apply depending on national legislation.

CTES was set up and designed with the following focuses: easy to use for the shop floor management, calibrated on a published advanced higher-tier exposure assessment model (ART1.5 [3]) and providing assurance of compliance with occupational exposure limits (OELs), or assurance of acceptable residual risk regarding Solvay Occupational Exposure Band (S-OEB [10]). The principle of hierarchy of OELs used is described elsewhere [11].

CTES is designed to screen the risk for airborne chemicals (vapors, solids, and solids in liquids) and identify dermal hazards. In CTES a screening score is calculated by comparing the exposure estimate for a task with the relevant substance hazard information from a hazard database (internal hazard database built preliminarily). For the exposure assessment, a database was created, in which, for each task, a specific set of ART1.5 conditions, as a use scenario, were defined. The exposure for a task is calculated and based on the ART1.5 mechanistic model by the characteristics of the substance combined with the preassigned conditions. Comparing with Tier 1 exposure assessment models, ART1.5 accounts for more specific input parameters, such as ventilation rate, room size, orientation of spray operations, and secondary sources of exposure [3,12,13], but because the task database in CTES has preassigned ART conditions, CTES is restrictive and therefore considered a screening tool.

In the present paper, the added value of the CTES screening approach is described, where the inhalation exposure assessment is performed with a list of tasks with simple wording describing the actual activity and working station. It covers substances with and without OELs thanks to the hazard banding tool (S-OEB).

2. Materials and methods

2.1. CTES description

CTES is a basic and quick chemical risk assessment tool with a limited number of entries, generating a clear and simple screening score for exposure by inhalation and a dermal warning. CTES, a standalone Microsoft® Excel (2010) spreadsheet (< 1.5 Mb) working under Excel 2010, was developed in 2014 and 2015. In this paper, Version 3.4 is described, which is available in eight languages.

CTES combines the hazard of a substance with the assessment for inhalation exposure, which is based on the exposure potential generated by the task description, physical state, solid in solution, fugacity (vapor pressure band or dustiness), concentration, and duration.

The inhalation exposure relative to the OEL or the S-OEB determines the risk screening class. For dermal exposure, the risk screening is based on hazard properties only. If CTES determines that the inhalation or dermal hazard poses a risk, or that the substance is carcinogenic, mutagenic, or reprotoxic [CMR Category 1a (known to have CMR potential for humans, based largely on human evidence) or 1b (presumed to have CMR potential for humans, based largely on experimental animal data)], appropriate actions have to be taken. The workflow of CTES is illustrated in Fig. 1.

The CTES Excel file comprises six spreadsheets. The user performs the assessment in Sheet 2. Sheet 1 can be filled before the screening takes place. The result sheets, Sheets 3 and 4, contain the action plan and the report, which is generated automatically after Sheet 2 is filled. In Sheet 5 statistics are presented and Sheet 6 contains the task list database, for reference only.

Sheet 1. Products sheet containing all the relevant substance/product information. This sheet is populated either manually or automatically by selecting substances from the hazard database.

Sheet 2. Screening sheet in which the similar exposure group name is added to a scenario, the substance/product is selected from the previous spreadsheet, and the handling conditions are defined through the tasks selection. The tasks selection determines the handling conditions for the exposure assessment. A screening score covering risk by inhalation is generated, and a dermal warning when applicable and specific information regarding the CMR1a or 1b status is presented.

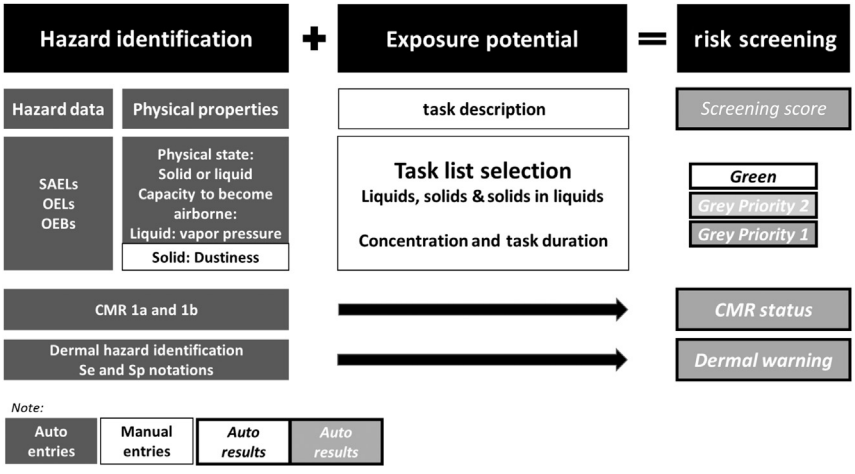


Fig. 1. Workflow of Critical Task Exposure Screening. OEB, occupational exposure band; OEL, occupational exposure limit; SAEL, Solvay Acceptable Exposure Limits.

Sheet 3. Action plan sheet containing the main entries, the screening scores, and the associated actions.

Sheet 4. Report sheet containing a printable format with all entries, scores, and actions after selection of a scenario.

Sheet 5. Statistics sheet giving an overview of the numbers of scenarios/assessments, numbers of CMRs, and distribution of scores.

Sheet 6. Task list sheet to help the user to browse and select the correct task for solids and liquids or solids in solution.

2.2. CTES users and training

CTES was developed and tested among a panel of HSE and operational teams in the four main geographical zones where the company operates: US, Europe, Asia, and Latin America. An actual and relevant description of tasks/working station is mandatory to get a CTES score. It cannot be used without proper knowledge of the circumstances. If a site has difficulty in finding the correct task, pictures can be requested from the companies IH experts. An HSE/IH correspondent has all latitude and is encouraged to involve shop floor representatives in the CTES process. Unit managers ensure that risks assessments are being performed and validate results. Users of CTES are trained during half a day. The training includes topics from the company HSE policy, the understanding and use of CTES and how to implement results from the action plan.

2.3. Hazards

The substance data (hazard assessment, OELs, S-OEBs, and physicochemical properties) is read from a substance database (SAP® software solutions (Walldorf, Germany)). The chemical hazard for the inhalation risk screening is based on two types of information; namely, the exposure limits or the S-OEB and weighted by the physical state (liquid or solid), and the capacity to become airborne. Official OELVs like Solvay Acceptable Exposure Limits (SAELs), the American Conference of Governmental Industrial Hygienists - Threshold Limit Values® (ACGIH TLV®s), and local OELs, take precedence over OEBs in the CTES model.

The substance data also contains information on the dermal hazards and CMR1a or 1b status. In the hazard banding system (S-OEB), there are five bands, A–E; A being the least hazardous substance and E the most hazardous substance (Table 1). Each band generates a preliminary range of acceptable airborne concentrations at workplace. This enables us to compare the exposure estimates with this range of airborne concentrations. The substance database covers ~8,000 substances inside the assets of the company, of which 70 have SAELs, mainly for the commercial products of the company; ~800 have an OEL; and for ~7,000, the S-OEB is applicable.

2.4. Inhalation exposure

The algorithms of the Tier 2 ART model, version 1.5 [3,12] are used for the inhalation exposure assessment. Each task group/task description is considered as a separate exposure scenario with preassigned ART modifying factors. An inventory of the most common exposing tasks to chemicals covering company activities was created, generating 96 tasks with explicit wording from a shop floor point of view (Table 2). The ART model is based on a source receptor model to evaluate inhalation exposures from dusts, vapors, and mists [12,13]. It describes stepwise the transport of a contaminant from the source to the receptor and defines independent principal modifying factors (MFs). Each set of these MFs has a set of underlying parameters and inputs of the parameters that are used to calculate an exposure estimate. It incorporates various MFs into the two-zone near field/far field model [14,15]. The ART framework defines the principal MFs and provides a methodology for clustering occupational activities into activity classes. The clustering of activities into activity classes is based on two main components: (1) the type of emission generation mechanism; and (2) the physical state of the product handled during an activity (solid or liquid). Emission rates and exposure levels within an activity class can be different, but the influence of the activities on emissions within one class can be described by a unique set of determinants. Examples of MFs are: activity emission potential, substance emission potential, localized control, and surface contamination. Examples of activity classes are: activities with open liquid surfaces and open reservoirs, spreading of liquid products, handling of contaminated solid objects or paste, and transfer of powders, granules, or pelletized material.

The ART model was not modified, but used in a simplified and more restrictive way. The exposure potential is based on the task description, which is determined at shop floor level (operators working in the evaluated unit, shop floor managers and HSE/IH correspondents), by selecting the appropriate task from a predefined list of tasks. A task is a set of actions required to complete a specific work assignment. Task groups are proposed and from each group, choices can be made from a list of tasks. There are two sets of groups: one for solids and one for liquids. If a solid substance is handled in solution, the option “solid in solution” is manually selected and CTES automatically gives the task group for liquids.

The selection and description of tasks is a company exercise, involving consensus between industrial hygienists and shop floor management. There are nine groups of tasks: material handling, transfers, sampling, cleaning, maintenance, packaging, laboratory, production, and other activities. For each group, a task list is proposed. This task list is different for liquid or solid substances as the conditions and equipment are different. The preassigned MFs are applicable to situations in the company and are determined with a lengthy consensus route by a team of four industrial hygienists, experienced in ART1.5 assessments.

The only determinants that can be chosen in CTES for calculation of the emission potential are the task, physical state, fugacity, dilution/concentration, and duration of the task. For liquids, the molar fraction of the chemical substance in the product is linearly related to the emission of the chemical (i.e., a 10% content of the chemical substance in the product gives a 10 times lower emission than the pure substance). For solids, the weight fraction is used.

When the laboratory group is selected, additional selections (type of extraction, task duration, and quantities) are required to make the screening score more relevant.

In contradiction to ART1.5, CTES does not allow for consideration of multiple activities within an 8-hour shift. Only one activity is considered per task assessment.

CTES calculates the 95th percentile and 90th percentile of exposure and the interquartile confidence intervals for these levels. These outcomes are not presented, but related to the exposure limit values or hazard bands. The 95th percentile of exposure and confidence intervals are recognized sufficiently conservative and in

Table 1
Acceptable concentration ranges of S-OEB for liquids (vapor/gas) and solids (dust)

S-OEB band	Concentration range for liquid (ppm)	Concentration range for solid (mg/m^3)
A	50–500	10–100
B	5–50	1–10
C	0.5–5	0.1–1.0
D	0.05–0.5	0.01–0.1
E	0.005–0.05	0.001–0.01

S-OEB, Solvay Occupational Exposure Band.

Table 2
Task groups and task, in understandable language, which are the basis of the CTES tool*

Activities with liquids Task group/task description	Activities with solids Task group/task description
Raw material handling	
Decoupling of Quickconnect (loading/unloading of railway/road tank, IBC)	Bulk unloading from road/railway tank (decoupling)
Decoupling of DryConnect (loading/unloading of railway/road tank, IBC)	Flow bin with LEV or closed system
Carboys/drums/IBC charging booth with LEV	Bags/filling hopper, no LEV (including small quantities)
Carboys/drums/IBC charging station with LEV	Bags/charging booth with LEV or laminar flow (including small quantities)
Carboys/drums/IBC charging station with no LEV	Big bags/segregated charging unit
Pouring liquids with LEV	Big bags/manual charging unit
Pouring with no LEV	Manual handling of contaminated empty bags or big bags
Charge of small quantities $<$ 10 L into vessels (No LEV)	Charge of small quantities $<$ 10 kg into vessels (No LEV)
Transfer	
Weighing booth with local extraction	Weighing station/booth with local extraction
Weighing station with local extraction	Weighing station with no local extraction, manual transfer by scooping
Weighing station with no local extraction	Weighing station with mobile LEV Scooping of damp filter cake Removing waste from dust extraction unit Conveyor transfer Conveyor transfer, covered system
Sampling	
Enclosed sampling device: screwed bottle, syringe	Manual sampling, scooping
Ventilated sampling point Open sampling point (simple valve) Manual sampling on top of an IBC, tanker, vessel	
Cleaning	
Handling of contaminated objects (absorbent pads/pillow), cleaning activities	Cleaning of contaminated surfaces: manual cleaning
Use of liquid product (spreading)	Cleaning of contaminated surfaces: vacuum cleaner
Activity generating aerosols (high pressure cleaner)	Removing waste from dust collection unit
	Sweeping with damp clothe
Maintenance	
Activities with cleaned production equipment	Activities with cleaned production equipment
Activities with noncleaned production equipment	Activities with noncleaned production equipment: blockage clearance, change of filter cloth/bag
Gluing, greasing, lubricating	Gluing, greasing
	Use of paste with powdered material
Packaging	
Carboy/drum/IBC filling station with no LEV	Manual packaging of bag/kegs: filling, transfer & bag closing/all operations with LEV
Carboy/drum/IBC filling booth or station with LEV	Manual packaging of bag/kegs: filling &/or transfer of open bags &/or bag closure with no LEV
Manual closing carboys/drums/IBC	Big bag filling/weighing station
Bulk loading/decoupling or closing manway	Bulk loading
Laboratory	
Transfer of liquids (pouring)	Transfer of solids
Weighing	Weighing
Sampling	Sampling
Sample preparation for analysis	Filtration (damp cake)
Activity with burette, dispenser, or pipette (titration, transfer)	Drying
Filtration (mother & wash liquors)	Manual recovery by scraping with spatula
Handling damp cake after filtration/drying	Manual grinding (mortar & pestle)
Flash chromatography (fraction collector)	Milling generating dust
Glassware/equipment cleaning	Sieving
Cleaning with dipping bath	Glassware/equipment cleaning
Waste elimination	Sample testing (extrusion, injection, calendering)
Reconditioning	Reconditioning
Solution preparation	Activity in sealed or closed systems
Sample testing (extrusion, injection, calendering)	Activity with open container
Activity generating aerosols (spraying, application of paint, reagent, cleaning agent)	Sample preparation for analysis
Activity with open container	
Activity in sealed or closed systems	
Activities under fume cupboard with large quantities (sieving, mixing)	
Production	

(*continued on next page*)

Table 2 (*continued*)

Activities with liquids Task group/task description	Activities with solids Task group/task description
Scooping of damp filter cake	Activity in sealed or closed systems
Activity in sealed or closed systems	Production activities: other process activities with possible exposures, i.e., drying, grinding, sieving, screening
Other open process activities with possible exposures	Handling of contaminated objects: scrapping, partial equipment dismantling
Activity generating aerosols	Visible dusty workplace (general &/or partial)
Other activities	
Other activities	Other activities

CTES, Critical Task Exposure Screening; IBC, Intermediate Bulk Container; LEV, Local Exhaust Ventilation.
* For each task, an ART1.5 activity class and modifying factors are pre-assigned in CTES.

agreement with recommendations at EU level, in case the substance has an OEL. The 90th percentile of exposure and confidence intervals are recognized sufficiently conservative in case the exposure is related to a hazard band, because the S-OEB assignment is intrinsically more conservative than an OEL assignment. Indeed, this relaxed percentile for S-OEB (90th percentile instead of 95th percentile), balances the more conservative S-OEB process.

The CTES model is constructed in a way to easily update task scenarios at advancing insights or the MFs, in case the ART model is updated.

2.5. Vapor pressure and dustiness derived class

For liquid substances, the exposure potential in the ART1.5 model is determined by the potential to become airborne or by aerosol formation. The evaporation rate of a substance depends on the physicochemical properties of the liquid (such as volatility), the dimensions of the source (surface area), and the environmental conditions, such as air temperature, air velocity, direction, and turbulence.

In CTES, the vapor pressure (Vp) of the substance under normal conditions (room temperature) is considered. The fugacity of the substance, that is, its capacity to become airborne, is expressed as a four-level band. Vp limits are set to determine the band and a reference Vp is used for the calculation: very low for Vp $\leq$ 10 Pa/reference Vp = 50 Pa; low for Vp $\leq$ 500 Pa/reference Vp = 500 Pa; medium for Vp $\leq$ 10,000 Pa/reference Vp = 5,000 Pa; and high for Vp $>$ 10,000 Pa/reference Vp = 50,000 Pa.

CTES uses classes for Vp instead of the linear approach as the ART model uses. The ART lower intrinsic emission factor of 10 Pa has been chosen for the very low fugacity limit in CTES. In ART1.5, the exposure assessment is based on aerosol release for liquids with Vp $<$ 10 Pa [10]. As the ART MFs for aerosol exposure weights are lower than or equal the vapor exposure weights, CTES calculates the worst-case emission estimate of liquids with a very low fugacity with triggering the very low fugacity at 10 Pa.

For solids, the fugacity is determined by the dustiness. Dustiness class can be assigned by the CTES user. The five solid fugacity bands from ART [3] are reduced to three CTES bands (Fig. 2): high, medium, and low. The two finest ART groups are the high band and the two coarsest are the low band. The dustiness of a solid is determined by: the physical aspect of the product; the working place conditions as they may reveal the handling of dusty material or not; and feedback from the operator.

2.6. Applicability domain

The inhalation exposure assessment part of CTES is applicable to liquids (nonvolatile and volatile) and solids (powders, granules, and pelletized material). Gas (Vp $>$ 100,000 Pa), fibrous material, nanoparticles, and molten metal are outside the applicability domain.

For liquids, the Vp of the substance under normal conditions (room temperature) is taken into account for the CTES calculation. To cover the cases where the task is performed at temperature $>$ 80°C, an option is proposed triggering an adjustment of the exposure estimate and the associated CTES score.

The screening scores do not take the use of personal protective equipment (PPE) into account.

The outcome of the assessments also give input for the European Unions chemicals legislation, REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) related assessments, because all task groups/task descriptions are matched to REACH use descriptors (process categories) and ECETOC TRA V3 [5] determinants, except use of PPE.

2.7. Risk assessment for inhalation exposure

Once the task is selected, CTES automatically generates a screening score for inhalation exposure for all chemicals involved in the task. CTES compares the output of the ART1.5 calculations with the associated OELs or the acceptable concentrations range of the associated S-OEB of these chemicals (Fig. 3).

CTES calculates the risk score as follows: (1) Green: The OEL and upper limit of S-OEB interval are below the lower interquartile confidence interval of the 95th or 90th percentile exposure levels respectively; (2) Grey Priority 2: the exposure estimate confidence interval covers the OEL or the S-OEB acceptable concentration range; and (3) Grey Priority 1: the OEL and the lower limit of the S-OEB interval are higher than the upper interquartile confidence interval of the 95th or 90th percentile exposure level, respectively.

When the screening score is Green, the residual risk is considered acceptable. For both Priority 1 and 2, a more detailed risk assessment and/or control measures required. The two levels Priority 2 and Priority 1 express that the exposure estimates are within or above the tolerance intervals, respectively. These are useful to prioritize the actions associated with these scores, with Priority 1 being potentially more prone to generate overexposure.

When a more detailed assessment is needed, exposure assessment models, such as ART1.5 can be used, or exposure data can be generated via a validated air-sampling program.

2.8. Risk assessment in case of STEL

If the substance has a Short Term Exposure Limit (STEL) (15 minutes), the exposure estimate calculated by default of a full shift (8 hours) is reprocessed to calculate the exposure over the duration of the task with a maximum of 15 minutes. So, if the task duration is $<$ 15 minutes, the 8-hour estimate (P95 estimate) is multiplied by a factor of 32 to obtain a short-term exposure estimate. If the task duration is $>$ 15 minutes, the factor is lowered by 15/task duration.

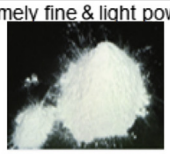
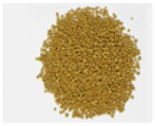
Type of solid	Description	CTES solid fugacity
Extremely fine & light powder 	A powdered product containing very fine, free flowing, light particles. This category may also contain products with a mixture of very fine particles & large particles or granules. Handling the product in its dry form results in a dust cloud that remains airborne for a long time.	High
Fine dust 	A powdered product containing fine particles. This category may also contain products with a mixture of fine particles & large particles or granules. Handling the product in its dry form results in a dust cloud that is clearly visible for some time	
Coarse dust 	A powdered product containing coarse particles. Handling the product in its dry form results in a dust cloud that settles quickly due to gravity	Medium
Granules, flakes, or pellets 	Granules or flakes may fall apart & crumble, resulting in only a very limited amount of fine particles. Handling the product does not result in a visible dust cloud	Low
Firm granules, flakes, or pellets 	Product does not result in dust emission without intentional breakage of products	

Fig. 2. ART1.5 dustiness categories and descriptions and related Critical Task Exposure Screening solid fugacity category.

If the task based exposure value, based on the P95 8-hour estimate, is higher than the STEL value, a Priority 1 is given for short-term exposure.

2.9. Risk assessment for CMR substances

If a substance is a CMR1a or 1b, this is indicated with a shaded color. Even if the score is Green for inhalation exposure, the scenario has to be reviewed by an industrial hygiene specialist, for exposure minimization, detailed assessment, or looking for substitution.

2.10. Identification of skin hazard with skin warning

It is critical to assess the potential risk via the dermal route, as in many cases the skin is the main route of exposure, for both local and systemic effects. CTES generates dermal warnings, to implement appropriate skin exposure controls. A warning alert notation is given to chemicals when their hazard classification highlights a possible effect by skin contact.

Chemicals that may cause systemic adverse effect due to a skin exposure are assigned an "Sp" notation for skin penetration. Possible sources of information for the Sp notation are: ACGIH (US), national HSE agencies such as the Health and Safety Executive in the United Kingdom, the Ministère du Travail (France), the Permanent Senate Commission for the Investigation of health Hazards of Chemical Compounds in the Work Area (MAK commission) (Germany), Occupational Safety and Health Administration (US), internal toxicological studies on the substance, and the substance safety data sheet. In addition, all substances with a specific set of H Phrases in United Nations Globally Harmonized System of Classification and Labeling of Chemicals are to be flagged (Table 3). Chemicals that may cause local adverse effects due to skin exposure are assigned an "Se" notation for skin effect, with a specific set of H phrases covering possible effects by skin contact and local effect, namely, the corrosive products.

In addition, notations can be assigned by company experts when specific toxicological information is available on the chemical notwithstanding its classification. Both the Se and Sp notations are distinguished in two subclasses depending on the severity of the potential health effect: Se1: substances that may cause mild local

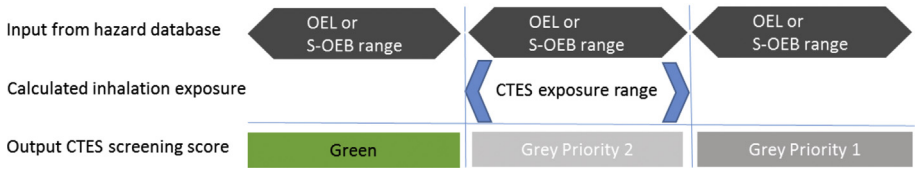


Fig. 3. CTES screening scores for inhalation exposure for substances with an OEL or S-OEB. CTES, Critical Task Exposure Screening; OEL, occupational exposure limit; SAEL, Solvay Acceptable Exposure Limits; S-OEB, Solvay Occupational Exposure Band.

Table 3
Skin warning notations assigned for the GHS statements

GHS statement	Statement description	Notation
H316	Causes mild skin irritation	Se1
H315	Causes skin irritation	Se1
EUH066	Repeated exposure may cause skin dryness or cracking	Se1
H370 (only if the skin route is specifically mentioned)	Causes damage to organs	Sp2
H371 (only if the skin route is specifically mentioned)	May cause damage to organs	Sp1
H314 (all cat.)	Causes severe burns & eye damage	Se2
H313	May be harmful in contact with skin	Sp1
H312	Harmful in contact with skin	Sp1
H311	Toxic in contact with skin	Sp1
H317	May cause an allergic skin reaction	Sp2
H310	Fatal in contact with skin	Sp2
H372 (only if the skin route is specifically mentioned)	Causes damage to organs through prolonged or repeated exposure	Sp2
H373 (only if the skin route is specifically mentioned)	May cause damage to organs through prolonged or repeated exposure	Sp1

GHS, Globally Harmonized System of Classification and Labeling of Chemicals; Se1, substances that may cause mild local adverse effects; Se2, substances that may cause serious local adverse effects; Sp1, substances that may cause mild systemic adverse effects; Sp2, substances that may cause serious systemic adverse effects.

adverse effects; Se2: substances that may cause serious local adverse effects; Sp1: substances that may cause mild systemic adverse effects; and Sp2: substances that may cause serious systemic adverse effects. Depending on the outcome, different control measures apply: an internal guidance, presented as a matrix of control, covers various aspects of skin exposure control, such as segregation, cleanliness, PPE, or monitoring, for each one of these four skin warning levels.

2.11. Quality assurance

For quality assurance, all MFs for all task groups in the Excel worksheet were reviewed by the first author against the MFs in the TNO report V9009 [3]. For comparison of the CTES and original ART1.5 outcomes, calculations were made for a few example scenarios for substances with OELs with the internet version of the ART1.5 model (https://www.advancedreachtool.com), using the same MFs as CTES. The predicted 95th percentile exposure level and associated confidence intervals were calculated with ART1.5.

3. Results

3.1. Actual result of CTES for examples fully described

For trimethylamine, paramethoxy phenol, and isopropanol, CTES examples (Fig. 4) were made. In addition, the inhalation exposure was calculated with the internet version of the ART1.5 model (Table 4).

For trimethylamine, the inhalation exposure during a sampling task was screened for three different levels of localized controls (3 task groups). The CTES Priority 1 outcome for the open sampling point (first scenario) was indeed identical when the internet version of ART1.5 was used: the range of the estimated exposure was 3.6–7.9 mg/m^3. As the OEL TWA (Time Weighted Average) was 2.07 mg/m^3, the CTES score was Priority 1 with this sampling scenario. With increasing the control levels, that is, the enclosed sampling device and screwed bottle, the range became 0.036–0.079 mg/m^3, triggering the Green score as it was below the OEL TWA of 2.07 mg/m^3. These exposure estimates in CTES were not visible to the user, but are given for the reader's perusal. The substance had a skin warning (Se2 and Sp2), but not a CMR status.

For paramethoxy phenol, the inhalation exposure during up to 4 hours of packaging is was determined and related to the inhalation exposure limit (time-weighted average over 8 hours). The CTES Green score outcome for this packaging unit is was indeed identical when the internet version of ART1.5 is was used: the range of the estimated exposure is was 0.64–1.4 mg/m^3. As the OEL TWA was 5.0 mg/m^3, the CTES score was Green with this packaging task. The screening results with CTES and with internet ART1.5 gave no priority settings. CTES, however, indicated skin warnings (Se1 and Sp2) for this substance.

For isopropanol, the inhalation exposure during raw material handling (decoupling of QuickConnect) was screened. The screening result showed no risk for inhalation overexposure for either full-shift or short-term exposure. The ART1.5 assessment showed that both the full-shift and short-term exposure were lower than the OEL and STEL value.

3.2. CTES deployment

Since the beginning of 2014, more than 100 HSE/IH correspondents have been trained to use CTES. The feedback from the early CTES users suggested that the tool was well received. Feedback was positive concerning the relevance of the tool for risk management and ease of use.

3.3. Level of discrimination provided by this screening tool

At the end of the fourth quarter of 2016, 85 of 135 sites were using CTES worldwide and reported their results. Seventy-six percent of the risk assessments were Green, covering more than 2,500 substances. A more focused detailed risk assessment is planned, with the assurance that the IH assessment expertise resources can definitively be focused on the 24% remaining scenarios. For the situations that are not Green after a more detailed and dedicated exposure and risk assessment, risk management can focus on control of those risks.

4. Discussion

CTES helps to set priorities and to focus on the most critical scenarios. It gives three outputs: inhalation risk score, identification of the skin hazard with the skin warning Se and Sp, and CMR status triggering a more detailed analysis. On the hazard identification, the fugacity needs to be identified only for solids. On the exposure potential, only three entries (duration, concentration, and task description) need to be recorded, and two extra for laboratory activities.

Inhalation exposure is assessed with the MFs from the Tier 2 exposure assessment tool (ART1.5). The MFs, however, are preassigned and users are trained. It is expected that between-user variability is minimized this way, even though the tool is used by

Substance name	Triethylamine		
CAS	121-44-8	Physical state	Liquid
Dilution / concentration	>25%	Fugacity	medium

TWA	STEL	Ceiling	OEB
2.07 mg/m³	4.14mg/m³	None	D

CMR?	Skin warning	
NA	Se2	Sp2

Task > 80°C ?	No	Duration	5 – 15 min

		Screening results		
Task group	Sampling	TWA	STEL	Ceiling
Task description	Open sampling point (simple valve)	Priority 1	Priority 1	NA
Task description	Ventilated sampling point	Green	Priority 1	NA
Task description	Enclosed sampling device: screwed bottle, se	Green	Green	NA

Substance name	PMP		
CAS	150-76-5	Physical state	Solid
Dilution / concentration	>25%	Fugacity	medium

TWA	STEL	Ceiling	OEB
2.07 mg/m³	5.00 mg/m³	None	C

CMR?	Skin warning	
NA	Se1	Sp2

Task > 80°C ?	NA	Duration	1–4 h

		Screening results		
Task group	Packaging	TWA	STEL	Ceiling
Task description	Manual packaging of bag/kegs: filling, bag closing /all operations with LEV	Green	NA	NA

Substance name	Sopropanol / IPA		
CAS	150-76-5	Physical state	Solid
Dilution / concentration	>25%	Fugacity	Medium

TWA	STEL	Ceiling	OEB
2.07 mg/m³	490 mg/m³	980 mg/m³	B

CMR?	Skin warning	
NA	NA	Sp1

Task > 80°C ?	NA	Duration	5–15 min

		Screening results		
Task group	Raw_Material_Handling	TWA	STEL	Ceiling
Task description	Decoupling of Quickconnect (loading/unloading of railway/road tank, IBC,	Green	Green	NA

Fig. 4. Example of CTES input and output for sampling of triethylamine, for packaging of PMP and for IPA during decoupling of Quickconnect. CAS, Chemical Abstracts Service; CMR, carcinogenic, mutagenic or reprotoxic; CTES, Critical Task Exposure Screening; IBC, Intermediate Bulk Container; IPA, isopropanol; NA, not applicable; OEB, occupational exposure band; PMP, paramethoxy phenol; STEL, Short Term Exposure Limit; TWA, Time Weighted Average.

Table 4
Examples for five scenarios (3 substances) Tier 2 exposure assessment by the internet version of ART1.5

CTES task description	ART1.5 modifiers		Exposure estimates range: 95th percentile – upper interquartile CI	
	Substance & activity emission potential	Primary LC	Shift concentration / TWA (8 h)	Average concentration/ STEL (15 min)
Substance: triethylamine /task: sampling (3 types of contaminant); 15 min			OEL TWA = 2.07 mg/m^3	OEL STEL = 4.14 mg/m^3
Open sampling point (simple valve)	Product type/ process temperature/ vapor pressure/liquid mole fraction: liquid/process 20°C/7963 Pa/100% Activity class/activity subclass/type of handling: transfer of liquid products/falling liquids/transfer of liquid flow: 0.1 −1 l/min Dispersion: indoors/300 m^3/good general ventilation	Open process/submerged loading/no local controls	TWA (8 h) 3.6–7.9 mg/m^3 Priority 1	STEL (15mn) 115–250 mg/m^3 Priority 1
Ventilated sampling point		Open process/submerged loading/LEV/ fixed capturing hood/no secondary LC	TWA (8 h) 0.36–0.79 mg/m^3 GREEN	STEL (15 min) 12–25 mg/m^3 Priority 1
Enclosed sampling device: screwed bottle, syringe		Open process/submerged loading/ medium containment/ no secondary LC	TWA (8 h) 0.036–0.079 mg/m^3 GREEN	STEL (15 min) 1.2–2.5 mg/m^3 GREEN
Substance: paramethoxy phenol/packaging activities; 4 h			OEL TWA = 5 mg/m^3	
Manual packaging of bag/kegs: filling, transfer & bag closing/all operations with LEV	Product type/dustiness/moisture content/powder weight fraction: coarse dust/ dry product/100% Activity class/activity subclass/falling of powders, granules or pelletized material/type of handling/ drop height: transfer of powders, granules, or pelletized material falling of powder/transferring rate: 1–10 kg/min/drop height < 0.5 m/routine dispersion: indoors/300 m^3/good general ventilation	Open process/fixed capturing hood/no secondary LC	TWA (8 h) 0.64–1.40 mg/m^3 GREEN	NA
Substance: isopropanol IPA /bulk unloading; 15 min			OEL TWA = 490 mg/m^3	OEL STEL = 980 mg/m^3
Decoupling of Quickconnect (loading/ unloading of railway/road tank, IBC)	Product type/process temperature/vapor pressure/liquid mole fraction: liquid/process 20°C/6020 Pa/100% Activity class/activity subclass/type of handling: transfer of liquid products/ falling liquids/transfer of liquid flow: 0.1 −1 L/min Dispersion: Outdoors/far from buildings	Handling that reduces contact between product & adjacent air/submerged loading/no LCs	TWA (8 h) 0.24–0.65 mg/m^3 GREEN	STEL (15 min) 6.7–21 mg/m^3 GREEN

CI, Confidence Interval; CTES, Critical Task Exposure Screening; IBC, Intermediate Bulk Container; LC, localized control; LEV, Local Exhaust Ventilation; NA, not applicable; OEL, Occupational Exposure Limit; STEL, Short Term Exposure Limit; TWA, Time Weighted Average.

nonexperts. Experienced ART users (industrial hygienists) were involved in assigning the MFs to the CTES tasks, which was done based on consensus.

A strong point of CTES is that shop floor stakeholders at the level where the risks arise are involved in the risk assessment. This way, it is more likely that awareness will grow and that workers by intrinsic motivation will cooperate with implementation of the necessary risk control measures at workstation level to reduce exposure to hazardous chemicals.

Departments/subsidiaries can learn from each other where the same substance, or group of substances, has a better control level. Because the same tool is used, it can be easily identified and communicated where the differences are, to take appropriate actions. This therefore stimulates a best practice approach.

When comparing the results on a higher level, it also gives indications where priorities of improvement are within the company. CTES seems to effectively and selectively prioritize risk but also to ensure compliance (OEL and SAEL) or acceptable risk relative to S-OEBs. The 73% of situations that were Green after screening and not needing priority attention form industrial hygienists are considered a benefit for allocation of expertise resources. The margin of safety of a screening tool is considered sufficient for prioritization.

The ART1.5 model was chosen as the engine for the exposure assessment, because in comparison with other models, ART1.5 seems to assess the exposure most accuratly [16]. It is also considered sufficiently conservative. An evaluation in 2011 [17] showed that ART could estimate with 90% confidence geometric mean exposure levels within a factor between two and six of the measured geometric mean exposure levels for levels for dusts, mists, and vapors. Two validation studies using independent measurement series indicated that ART estimates were within the uncertainty ranges found in the calibration [18,19].

The inhalation exposure assessments by CTES are considered conservative, as for comparison with OELs and OEBs, interquartile confidence interval of the 95th percentile and 90th percentile of exposure, respectively, is used as outcome. Nevertheless, this choice for different percentiles, which may appear more based on professional judgment than science should be developed in further studies.

The extrapolation from long-term to short-term exposure estimates for comparison with the STEL value is even more conservative, as the already high percentile for the full-shift exposure is multiplied. The STEL refers to a concentration in the right tail of the lognormal exposure distribution, which is exceeded only infrequently. A more realistic 95th percentile of the short-term exposure level can be derived [20,21].

The main problem experienced when using the CTES, is that fibers, gases, and nanoparticles cannot be screened with this tool. Therefore substances like ethylene oxide, butadiene, ammonia, and hydrogen fluoride acid cannot be screened with CTES. Inventory, monitoring and control of fugitive emissions, are, for such substances, to be managed according to IH, environment, and process safety issues.

In conclusion, CTES is a screening tool that enables efficient prioritization for substances versus tasks that need more attention in terms of preventive measures or higher tier approaches, requiring few inputs, as the substance-related data are already uploaded in the tool. Behind the relatively simple input parameters, there is a powerful Tier 2 exposure assessment tool (ART1.5), which may provide assurance of compliance with OEL for scenarios with acceptable residual risk. The concept may also be applicable for other industries and sectors. However, each should assign activity classes and MFs for their specific situation and circumstances, starting from the inventory of the tasks handling chemicals in their own industrial processes.

Conflict of interest

The authors declare that they have no competing interests that might be perceived to influence this paper.

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