Report

SC13: REACH restriction support – Lead in fishing tackle and ammunition (Part 6)

Version:	Final
Prepared by:	**Triskelion** Reactorweg 47-a 3542 AD Utrecht The Netherlands
Date:	31th of August 2021
Reference:	P30161-1

DUCARES B.V. | trading as TRISKELION • Reactorweg 47-A, 3542 AD Utrecht • P.O. Box 40237, 3504 AA Utrecht • The Netherlands • +31 88 382 2737
www.triskelion.nl • info@triskelion.nl • IBAN NL10INGB0654470189 • BIC/SWIFT INGBNL2A • VAT NL818503324B01 • Chamber of Commerce 30230493

TRISKELION

Contents

1 Summary

The purpose of this report is to create an understanding of the extent of exposure to lead during home-casting, using information obtained from literature and modelling data. In this assessment two home-casting scenarios were assessed. The first includes casting by an individual for own hobby use, covering a typical 4 casts per year (ranging from 1 to 10 times) using a typical 8 kg of lead per year (ranging from 1 to 100 kg). The frequency and amount of casting will be relatively low, and thereby the experience of the individual involved. The second scenario includes casting by an individual in a non-industrial setting for selling the products to other people, covering a typical 40 casts per year (range 30 to 50 times) using a typical of 200 kg (range 30 to 500 kg).

Home-casting is performed in a non-industrial setting, using equipment readily available from the internet. These activities, are often carried out in ‘garage’-type settings, in backrooms of shops or outdoors, without the supervision of the usual national OSH, and industrial emission supervisions and regulations. The raw material for home-casting can be lead ingots, lead pieces (including ‘old’ lead fishing tackle) which are available at home, or from fishing tackle shops, small metal recycling workshops, scrap sellers or directly from the internet. The lead is melted in day-to-day kitchenware or melting pots, often with some skimming with a simple hand-held tool, and then poured into moulds to manufacture lead sinkers/lures and bullets of any size.

Melting and pouring of lead leads to some evaporation and possibly some emission via metal droplets, resulting in fumes. Estimating the actual exposure is challenging. Limited information on home-casting activities, e.g. related to duration, amounts, temperatures or conditions, are available and no truly appropriate models exist for estimating the relevant exposures for these uses. In addition, most literature also do not truly represent the scenarios assessed. Still, it could be concluded from the available literature that melting and casting activities result in serious levels of exposure. Especially using bad melting practices, such as rapid heating or overheating to temperatures much higher than the melting point by using gas torches, that heat parts of the material very quickly with high energy, and poor general hygiene, result in significantly higher exposure levels. Careful heating keeps the temperature not too far above the melting point. Overheating may lead to temperatures (of part of the material) of around 800 °C or even higher, which is in the area where the vapour pressure of lead starts to increase very fast with increasing temperature.

Modelling of exposure was performed by using several well-known exposure models. The input parameters were derived based on expert judgement after getting acquainted with the used procedures in home-casting as explained on forums and shown in video tutorials.
By using the exposure models MEASE and ART and results from measurements for similar small-scale activities with molten lead reported in literature, **exposure via inhalation** is estimated at below 0.001 to 1 mg/m^3 (8-hour average), where the lower value would be relevant for the best-case situations and the higher value for worst-case situations.
Dermal exposure per se is not relevant, because dermal penetration of lead is very low however direct dermal exposure and surface contamination will result in oral exposure via hand-to-mouth contact. It is estimated indeed, based on one literature source, that 0.5% of the dermal exposure will lead to oral ingestion. This is why **dermal exposure** was modelled using MEASE, RISKOFDERM and dermal ART. In addition, dermal exposure data from industrial handling of (molten) metal in baths was used as starting point for estimating via read-across. These estimations were more challenging since these models and the measured data are not fully appropriate for small-scale uses in non-industrial settings. Nevertheless, the dermal exposure is estimated at 2 to 69 mg/day (hand exposure). It should be noted that body exposure could not be estimated for small-scale users.

Even though uncertain, the exposure estimates are plausible, and based on realistic scenario and input parameters. Refinement of input parameters will not change the main conclusions of this study. The estimated exposure ranges will change, but the order of magnitude will most probably be very similar.

In conclusion, despite the uncertainties in the modelled exposure estimations, home-casting of lead will result in significant exposure levels when performed in non-industrial settings.

2 Introduction

In addition to the ‘industrial’ production, lead fishing equipment and lead ammunition can also be produced by individuals at home, or in the back rooms of shops for retail and/or personal use. Home-casting is easy to perform. The raw material for home-casting can be lead ingots, lead pieces, small metal recycling workshops, scrap sellers or directly from the internet. The lead is melted and then poured into moulds to manufacture lead sinkers or lures or ammunition of any size. Moulds and melting equipment, such as thermostatic melting pots, can be readily purchased on the internet or day-to-day kitchenware and home equipment (such as a cooking pot, or silicone baking moulds) may also be used. Finally, plenty of instructions (videos, pictures) are freely available on the internet to perform home-casting.

The risk from casting for fishers/shooters and professional workers by consumers or professionals in the Annex XV restriction report is not underpinned by exposure data and the knowledge on the extent of exposure during home-casting is limited. In order to close this gap of scientific data, and in order to be able to conclude on the risk for human health from home-casting and ‘artisanal production’ of fishing sinkers and lures, and bullets, the Dossier Submitter has looked at specific case studies performed on specific populations. In addition, the Dossier Submitter used the prevalence of home-casting equipment on the European market, and the availability of multiple home-casting tutorials (available for ex. on you tube) as an indication that this activity is widely practised in Europe.
Strengthening of the current risk assessment is intended by creating at least two exposure assessments based on modelling and/or measured exposure data. The two exposure scenarios are for home-casting by fishers/hunters (Scenario #1) and for artisanal production by professional workers (Scenario #2). In this report these scenarios of home-casting are further developed with information obtained from literature and modelling data.

3 Modelling exposure to lead

Data on casting habits is scarce and all assumptions bear uncertainties, therefore, a range of input values for the models are used to come up with a plausible range of exposure. The basis for this model is the amount of lead used for Scenario #1 and Scenario #2. The underlying data used as input comes from two surveys among anglers in the Netherlands (documents in 'Comment #3325 from the Annex XV consultation'). The first survey indicated that anglers who actively cast their own lead do this at a median of 1 time per year (inter quartal range 1 - 2) with a median of 2 kg per time (inter quartal range 0.5 to 15 kg). The second survey indicated that casting lead was performed on average 4 times per year (from once every 3 year to 20 times per year) with an average of 15.8 kg per time (ranging from 0.175 to 100 kg). In this survey it was also indicated that on average 60 kg of lead was casted per year.

Since there is quite a big difference in the outcome of these surveys, and information on casting habits for ammunition in Europe was not found, an expert judgement is made for the quantities used and frequency of casting. Considering the non-industrial melting facilities for both uses, it is assumed that a maximum of 10 kg of lead can be melted per cast. For Scenario #1 (hobby casting) it is estimated that most people will cast around 4 times per year (range 1 to 10 times). The quantities used are estimated to be around 2 kg per cast (range 0.5 to 10 kg) and will take around 1.5 hours (range 1 to 2 hours). For Scenario #2 (artisanal casting), higher frequencies and quantities are assumed: 40 times a year (range 30 to 50 times), with 5 kg per cast (range 1 to 10 kg), taking 2.5 hours (range 1 to 4 hours). Putting these values in terms of yearly quantities, for Scenario #1 a typical yearly consumption of 8 kg (range 1 to 100 kg) is used in the model and for Scenario #2 a yearly consumption of 200 kg (range 30 to 500 kg). This range is considered to be sufficient to cover both production of fishing equipment and ammunition. An overview of the scenario parameters, including assumptions on reasonable conditions and risk management measures, is given in Table 1. These assumptions and risk management measures are partly based on viewing a number of videos and instructions on internet for home-casting of fishing sinkers or bullets. They are furthermore based on general assumptions for situations in homes and small shops.

It is assumed that both uses are performed in a non-industrial setting, using an electric melting pot, pan and a gas stove, or with a gas torch. A solid piece of lead will be heated to melting temperature, 327.5 °C, and over. Higher temperatures and bad practices, such as using impure lead or quickly overheating, will lead to a higher level of exposure due to lead fume formation (Appendix 1). For this reason, exposure estimates were performed for using good practices minimizing fume formation and for using bad practices, increasing the amounts of fumes.

Table 1 Overview of scenario parameters

Scenario 1: Hobby lead casting for own use	
Process	Melting lead from various sources using kitchen cookware or similar melting pots, drossing if necessary and pouring molten lead into moulds. Handling of leaden articles produced, including some cutting, and limited polishing is possible.
Amounts used	1 to 100 kg/year, probably up to around 10 kg (~1L molten lead) per event
Frequency	1 to 10 times/year
Duration	Up to 2 hours per day of use, usually less
Temperatures of melting	Slightly over melting point of lead, via careful melting. Sometimes serious overheating up to temperatures above 800 °C, mostly by using gas torches with direct contact between flame and lead.
Conditions of use	‘Garage-type’ rooms or outdoors Usually only natural ventilation and no local exhaust ventilation Occasional cleaning
Risk management measures	Heat resistant gloves during actual melting and pouring, but usually not during handling and final working of product; probably reused regularly Normal clothing
Scenario 2: Artisanal lead casting for sales	
Process	Melting lead from various sources using kitchen cookware or similar melting pots, drossing if necessary and pouring molten lead into moulds. Handling of leaden articles produced, including some cutting, and limited polishing is possible.
Amounts used	30 to 500 kg/year, probably up to around 10 kg (~1L molten lead) per event
Frequency	30-50 times/year
Duration	Up to 4 hours per day use, usually less
Temperatures of melting	Slightly over melting point of lead, via careful melting. Sometimes serious overheating up to temperatures above 800 °C, mostly by using gas torches with direct contact between flame and lead.
Conditions of use	‘Garage-type’ rooms or outdoors Worst-case: only natural ventilation and no local exhaust ventilation Best-case: ventilation providing at least 1 ACH and (mobile) general purpose local exhaust, with an efficacy of 50% (‘Other LEV’ in the ART model) Worst-case: Occasional cleaning Best-case: Regular cleaning
Risk management measures	Generally, heat resistant gloves during actual melting and pouring, but usually not during handling and final working of product; probably reused regularly Worst-case: No respiratory protection Best-case: Respiratory protection with an APF of 4 Normal working clothing

3.1 Potentially useful models

A range of models was checked to find potentially useful models for modelling exposure due to small-scale (non-professional or artisanal) melting and casting of lead.

Various models were considered, see Table 2.

Table 2. Models considered for exposure to lead in small-scale melting and casting

Model	Original purpose	Major evaluation points	References
ConsExpo (Web 1.0.2)	Estimating exposure of consumers to chemicals for risk assessment	The tool consists of evaporation-distribution models for inhalation and very simple models for dermal exposure. There are no specific defaults or models for exposure due to molten metals	RIVM, 2017
ECETOC TRA 3.1	Estimating exposure of workers or consumers for REACH - First Tier model	The model has no specific elements relevant for the purpose of this project	ECETOC 2009, 2012, 2014
MEASE 2.00.00	Estimating exposure of workers or consumers for REACH – First Tier model	The model combines the approaches from the ECETOC TRA tool, the EASE expert system and the health risk assessment guidance for metals (HERAG project) and generates first Tier inhalation and dermal occupational exposure estimates. Results for scenarios with high temperature use of metals are based on measurements in industry. Various specific options are given, related to the specific metal activities, such as choices for specific processes and levels of automation.	EBRC - Services for Chemical Industries, 2010
RISKOFDERM	Estimating dermal exposure of workers for regulatory assessments – Further Tier model	The model is based on statistical analysis of measured data, where liquids are involved, they are generally (very) low volatility liquids. Since molten lead can be considered a very low volatility liquid, some aspects of the model might be useful. Data underneath the model include data from electroplating and degreasing.	Warren *et al.*, 2006
ART	Estimating inhalation exposure of workers – Further Tier model	The model is based on a combination of conceptual modelling and statistical analysis of measured data. Modelling of (very) low volatility liquids is possible, including e.g. exposure from evaporating surfaces. Considering molten lead as a very low volatility liquid, based on the vapour pressure at working temperatures, this model may be useful.	advancedreachtool.com/ science.aspx

Model	Original purpose	Major evaluation points	References
Dermal ART	Estimating dermal exposure of low volatility liquids	The model is based on a combination of conceptual modelling and statistical analysis of measured data. The model is specifically for low volatility liquids. Considering molten lead as a very low volatility liquid, this model may be useful.	Goede *et al.*, 2019
Dustex	Assess exposure to semi-volatile substances (SVOCs) in products that are introduced into the indoor environment.	The model may be relevant, because it is for various pathways and routes of exposure and also for articles brought into the environment. However, the model requires various parameters not available for molten lead, such as octanol-air partition coefficient, product/air partition coefficient and mass transfer coefficient for surfaces. None of these is known for lead and situations to be assessed. Most of these are also mainly relevant for organic substances. Also, the density of molten lead is outside of the domain in the model. Therefore, any assessment with this model for melting and casting of lead will be highly uncertain and the model will therefore not be used.	RIVM: https://www.rivm.nl/en/consumer-exposure-to-chemical-substances/exposure-models/DustEx
CEM (2.1)	Assess exposure to consumer products and articles	The tool is a combination of various physico-chemical calculation models, including models to estimate exposure to semi-volatile organic compounds. Lead can be considered semi-volatile (when molten), but not organic. Therefore the tool may require information not available for lead. Furthermore, the model works with a range of predefined exposure scenarios and casting of metals is not included. Any use of the model, starting from more generic predefined scenarios, for this situation will lead to highly uncertain results. The model will not be used.	US EPA, https://www.epa.gov/sites/default/files/2019-06/documents/cem_2.1_user_guide.pdf
Lasrook assistant (welding fume assistant)	Assess exposure to welding fumes	The tool is specifically for welding fumes, with exposure levels based on measured exposures at different welding techniques. Welding processes occur at much higher temperature than lead melting and casting and also involve various other substances (flux, coating) than metals. Therefore, this tool is considered not relevant for lead melting and casting	IRAS, https://www.iras.uu.nl/lasrook/index.php

ConsExpo consists of a variety of models, including some evaporation-distribution modelling (much simpler than Dustex or CEM). Its model is purely physicochemical for inhalation, while the dermal modelling in many cases consists of an estimate of amount on the skin with no clear model behind it. There are default values for various types of products and uses, not including metal casting (or any metalwork).

MEASE and the Lasrook assistant are the only considered models that specifically account for metal emissions due to melting metals at high temperatures. Both are for industrial or professional situations. However, models for industrial and professional situations may be useful if the parameters can be chosen in a way to resemble artisanal use or non-professional use. The main exposure determinants are not different between workers and non-professionals. It is just the values of determinants that may differ.
MEASE has estimates from activities that resemble melting and casting of lead. The results are from exposure measurements in industrial situations. Modifiers for control measures are available. For PROC23, Open processing and transfer operations at substantially elevated temperature, which is most relevant for casting of lead, the model does not allow a choice of manual process. Also, no scale factor is included in PROC23 and an influence of different temperatures of process in relation to melting point is not included. However, because of its specific inclusion of PROC23 estimates based on measured data, it may be useful.
Lasrook assistant is only for actual welding, which uses much higher temperatures than melting and casting and also involves various other substances being emitted and contributing to the fume. Therefore, it is considered not relevant for estimating exposures due to lead melting and casting.

CEM and Dustex are similar tools, though CEM is more extensive. Neither has specific elements relevant for exposure to metal fumes. They focus on general consumer exposure to more common consumer products and articles (e.g. glues, cleaning agents, carpets). An important element is the physicochemical modelling of emission and fate in the indoors environment of semi-volatile organic compounds (SVOC). While molten lead could be considered relatively similar to semi-volatile, the fact that it is not an organic compound will make model estimates intended for SVOC difficult or impossible. For Dustex, it appears not possible to enter relevant values (e.g. the density of lead), because the actual value is far outside the acceptable value of the model. Also values for various parameters are not available and there is no way to estimate reasonable values for these parameters. Furthermore, the fate modelling is based on (in principle) liquid substances that may condensate, aggregate, absorb to dust, etc. while emitted lead will condensate and form particles, including a substantial amount of nanoparticles (at first). Part of the modelling in Dustex may be relevant, but given the lack of reasonable estimates for input parameters, the model cannot be used for this situation.
The same largely holds for CEM as well, e.g. on parameters needed and models for fate not being aimed at metal fumes. Furthermore, CEM works with a large number of predefined exposure scenarios of which none clearly fits to the situation to be assessed.

RISKOFDERM, ART and dermal ART are tools that use statistical modelling of measured exposure data to provide exposure estimates. RISKOFDERM uses direct statistical analyses of measured exposure and therefore only provides values for situations with measured data available. ART and dermal ART first calculate unitless scores based on conceptual models of emission, distribution and inhalation/deposition of substances. The scores are converted to exposure values based on statistical analyses of measured exposure values. In all of these models, exposure levels from low to very low volatility liquids have been used in the model creation. While none of these were actually for metal fumes and the fate processes may be different, it is considered that these models may at least provide indicative results, under the assumption that molten lead can be considered as a very low volatility liquid. The difference with real liquids is in the fate after emission. Where real liquids of very low volatility will form droplets and absorb to dust, metal fumes will first form droplets that will cool down to form particles. They will also absorb to dust. This leads to increased uncertainty on the results of the models for the situations to be assessed. Furthermore, the measured data underneath the models are largely for industrial or professional situations with a higher scale of use than to be expected in small-scale melting and casting of lead at home.

Our preference for modelling is to use models which base the end results (partly) on actual measured data, since pure physicochemical models tend to ignore various factors (e.g. absorption to surfaces, resuspension), while all such factors are included in the measured data, though their influence is unknown. When an attempt is made to create more physicochemical correct models, as in Dustex or CEM, this results in requirements for parameters that are unknown for many situations or can hardly be estimated.

Based on the above considerations, it was decided to make indicative estimations for melting and casting of lead with the models MEASE, RISKOFDERM, ART and dermal ART only.

The estimates are made with the assumptions provided earlier to guide the inputs of the models.

3.2 Model estimates

3.2.1 MEASE

MEASE (version 2.00.00) is a model for estimating professional or industrial exposure. It combines the approaches from the ECETOCTRA tool, the EASE expert system and the health risk assessment guidance for metals (HERAG project) and generates first Tier inhalation and dermal occupational exposure estimates. Results for situations with use of metals at elevated temperatures are based on measurements in industry (from the HERAG project).

Estimates have been made for the following PROC:

- PROC23: Open processing and transfer operations with minerals/metals at elevated temperature; this is specifically relevant for metal casting type of activities

PROC23 options in MEASE 2.00.00 do not allow manual casting and do not show an influence of process temperature relative to melting point. Therefore, the minimum option (semi-automatic) for process type has been used and no differentiation is made between careful melting and overheating in this model.

The following inputs were used for all scenarios:

- Molecular weight: 207.2
- Melting point: 327.5 °C
- Physical form: molten
- Level of containment: Open
- Level of automation: Semi-automated (this is the minimal option for PROC23 in MEASE 2.00.00)
- Vapour pressure: 0.000005 Pa (at around 400 °C)
- Process temperature: 400 and 800 °C (lead to the same estimates)
- Content in preparation: > 25%
- Dust suppression: No
- Face/eye protection: No
- Use of gloves: Appropriately selected gloves
- Chemical protective clothing: Standard safety clothing (minimum option)

The differentiation in scenarios is described by the following inputs:

- Scenario #1: hobby use (casting for own use)

- Duration: 15 minutes - 1 hour
    - Air change rate: Open ventilation
    - Local exhaust ventilation: No
    - Respiratory protection: No
    - Cleaning activities: Occasional cleaning
- Scenario #2a: professional use (casting for sales); worst-case
    - Duration: 1 to 4 hours
    - Air change rate: Open ventilation
    - Local exhaust ventilation: No
    - Respiratory protection: No
    - Cleaning activities: Occasional cleaning
- Scenario #2b: professional use (casting for sales); best-case
    - Duration: 15 minutes - 1 hour
    - Air change rate: Basic Mechanical ventilation of at least 1 ACH or outdoor use
    - Local exhaust ventilation: Mobile LEV, general purpose LEV
    - Respiratory protection: RPE with assigned protection factor of 4
    - Cleaning activities: Regular cleaning

The resulting exposure estimates are provided in Table 3.

Table 3. Exposure estimates with MEASE

Scenario	**Dermal exposure ($\mu g/cm^2$)**	**Dermal exposure (mg/day)[a)]**	**Inhalation exposure (mg/m^3)**
Scenario #1: hobby use	62.4	94.8	1.417
Scenario #2a: Professional use; worst-case	561.4	853	4.25
Scenario #2b: Professional use; best-case	57.0	86.6	0.072

Note: a) MEASE 2.00.00 assumes 1 520 cm2 (potentially) exposed area, being two palms, two hand backsides, two forearms and neck.

For hobby use, with a higher duration (e.g. 2 hours), the exposure estimates of scenario 2a (professional use-worst case) are relevant, because MEASE does not differentiate between two and four hours. In case of good ventilation or outdoors work and regular cleaning, the values will be closer to those of the best-case for professionals (scenario 2b), but the use of RPE is not expected for hobby users.

3.2.2 RISKOFDERM

The RISKOFDERM model does not have an option for melting or evaporating from a liquid. There is an option for ‘immersion’, which was derived from measurements on electroplating. While this is clearly different process than casting, there is some similarity in the following aspects:

- It considers molten metals
- There is no direct contact with the metals, therefore exposure is due to deposition of fumes on surfaces and skin (and surface to skin transfer)

This process can therefore be considered partly similar to the actual melting of the lead, where people performing the activity may use tools to stir the lead or ensure that the still solid parts are not leading to excessive air in the partly molten material.

A further option in RISKOFDERM is ‘filling, mixing, loading’. The model for that option is based on various filling, mixing and loading processes, where in this case liquids are relevant. Exposure is due to possible splashes onto skin, but also to contact with contaminated surfaces.

However, the model is not recommended to be used at use rates lower than 1 L/min.[1] Since the use rate in pouring of molten lead is lower than 1 L/min, this option cannot be used. Estimates have therefore only been made for ‘immersion’.

Inputs for ‘immersion’ are:

- Distance of person to source: 30 cm to 1 meter
- Adequate local exhaust ventilation:
  - Worst-case: no (hobby and professional)
  - Best-case: yes (professional)
- Percentile of exposure distribution estimated: 75%
- Duration:
  - Hobby user: 30 minutes
  - Professional: 30 minutes or 2 hours

The results of the RISKOFDERM modelling are presented in Table 4. RISKOFDERM itself does not include the effects of gloves. However, an effectiveness of 95% for the actual handling of molten lead can be considered realistic, so this effect has been added separately to the results too.

Table 4. Estimates with the RISKOFDERM model

Task	**Dermal exposure unprotected hands (µL/day)**	**Dermal exposure hands with gloves (95% effective) (µL/day)**	**Dermal exposure body outside of clothing (µL/day)**
Scenario 1: hobby use; 30 minutes, no adequate ventilation			
Immersion (≈melting)	2 510	126	142
Scenario 2a1: professional use; 30 minutes, no adequate ventilation			
Immersion (≈melting)	2 510	126	142
Scenario 2a2: professional use; 30 minutes, adequate ventilation			
Immersion (≈melting)	620	31	35
Scenario 2b1: professional use; 2 hours, no adequate ventilation			
Immersion (≈melting)	2 510	126	142
Scenario 2b2: professional use; 2 hours, adequate ventilation			
Immersion (≈melting)	2 480	124	140

With a density of lead of 11.3 g/cm^3 at 20 °C, the exposure is recalculated to approximately 7 000 – 28 000 mg/day for unprotected hands, 350 – 1 400 mg/day for protected hands and 400 – 1 600 mg/day for body.

3.2.3 ART and dermal ART

The ART model is available in a complete web-based tool (https://www.advancedreachtool.com/). Recently a partial implementation (with less choices for e.g. output percentiles and confidence intervals) has been made in the Diamonds platform by TNO (https://diamonds.tno.nl/dashboard). This implementation also contains a draft version of the dermal ART tool for low volatility liquids (according to Goede *et al.*, 2019). This is an unvalidated test-version made available to the authors of this document by TNO. The publicly available part of Diamonds does not yet contain this implementation of ART/dermal ART (or dART), nor does the original webtool of ART.

[1] The general finding in the data, based on use rates mostly (much) higher than 1 L/min, was that increase in use rate leads to an increase in exposure. But, because use rate was correlated to another factor in the model, it was entered as a power function, which inadvertently led to an increase in exposure estimate with use rates decreasing below 1 L/min. This unintentional effect of the equation used was reason for the authors of the model to recommend to use the model only for use rates of 1 L/min and higher.

Exposures are estimated by ART/dermal ART with two separate estimates, one for the actual melting (evaporating surfaces) and one for the actual pouring (transfer of liquids). The inputs general for the different scenarios are provided in Table 5.

TRISKELION

Table 5. Inputs in ART and dermal ART (some explanations for the choices made are added between brackets in italics)

Parameter	Hobby use, worst-case	Hobby use, best-case	Artisanal use, worst-case	Artisanal use, best-case
Temperature of process	Hot processes (50-150°C) (*a value needs to be entered, but the emission is actually related to the vapour pressure at process temperature that is entered*)			
Viscosity product	Medium (like oil) (*molten lead is rather viscous*)			
Concentration	Pure material *(some users will start with lower quality, which might lead to lower estimates in ART, but the additional skimming needed is expected to increase the emissions again)*			
Primary emission	In the breathing zone (*worst-case option*)			
Melting				
Duration	1 hour	30 minutes	2 hours	30 minutes
Activity	Activity with open liquid surfaces or open reservoirs			
Surface area	Surface area < 0.1 m^2 (*small-scale melting with at most 30 by 30 cm area*)			
Agitation	Relatively undisturbed surfaces (*at most gentle mixing*)			
Temperature	> 800 °C	< 400 °C	> 800 °C for 30 minutes; < 400 °C for 90 minutes	< 400 °C
Vapour pressure[a)]	12.5 Pa	< 0.1 Pa	12.5 Pa for 30 minutes < 0.1 Pa for 90 minutes	< 0.1 Pa
Equipment	Control panels or equipment/devices located at the mixing/dipping activity (≤ 1 m) (*there may be some mixing with a hand-held tool, but we consider the handling of equipment nearby reasonable worst-case*)			
Agitation level	Low agitation (e.g. manual stirring/mixing)			
Orientation of work	Downward only			
Frequency of use of control panels/devices	Repeatedly (10-50% of activity)			
Process fully enclosed	No			
Housekeeping	General	Effective	General	Effective
Localised controls	None	None	None	LEV; Other LEV (50% effective)
Location	Indoors	Outdoors, close to building	Indoors	Indoors
Room size	Only small rooms	--	Only small rooms	Any size room
Ventilation	No restrictions on general ventilation	--	No restrictions on general ventilation	Mechanical ventilation providing at least 1 air change er hour
Secondary sources	No			
Pouring				
Duration	1 hour	30 minutes	2 hours	30 minutes

Parameter	Hobby use, worst-case	Hobby use, best-case	Artisanal use, worst-case	Artisanal use, best-case
Activity	Transfer of liquid products			
Transfer of liquids at	< 0.1 L/min (*because of careful pouring into small moulds*)			
Temperature	< 400 °C			
Vapour pressure	< 0.1 Pa			
Level of containment	Open process			
Type of loading	Top loading - Splash loading			
Equipment for transfer	Manual transfer using a single small/medium containers			
Contact with additional accessories or equipment	Repeatedly (10-50% of time)			
Agitation level	Low agitation (e.g. manual stirring/mixing)			
Orientation of work	Downward only			
Process fully enclosed	No			
Housekeeping	General	Effective	General	Effective
Contamination of surfaces	Thin layer of product (visible)	Invisible layer of product	Thin layer of product (visible)	Invisible layer of product
Proportion of surfaces contaminated	Partially: 10-90%	Small fraction < 10%	Partially: 10-90%	Small fraction < 10%
Localised controls	None	None	None	LEV; Other LEV (50% effective)
Location	Indoors	Outdoors, close to building	Indoors	Indoors
Room size	Only small rooms	--	Only small rooms	Any size room
Ventilation	No restrictions on general ventilation	--	No restrictions on general ventilation	Mechanical ventilation providing at least 1 air change er hour
Secondary sources	No			

[a)] The high vapour pressure was only used for inhalation exposure, because dermal ART does not provide results for vapour pressures higher than 10 Pa. Therefore, for dermal exposure the vapour pressure of lower than 0.1 Pa was used.

The results of the estimates with ART and dART are presented in Table 6.

Table 6 Estimates with the ART and dART model

Scenario	Hobby use worst-case	Hobby use best-case	Artisanal use worst-case	Artisanal use best-case
Task-based values				
Inhalation exposure melting (mg/m^3) [a]	0.13 – 0.32	0.00036 – 0.012	0.034 – 0.84 [e]	0.00034 – 0.011
Dermal exposure melting (mg/min) [b]	0.10 – 0.33	0.10 – 0.32	0.1 – 0.33	0.1 – 3.2
Inhalation exposure pouring (mg/m^3) [a]	0.0045 – 0.15	0.0011 – 0.036	0.0045 – 0.15	2.2E-05 – 0.0007
Dermal exposure pouring (mg/min) [b]	2.1 – 6.4	1.3 – 4.1	2.1 – 6.4	1.3 – 4.1
Full day exposures				
Eight-hour time weighted average inhalation exposure melting (mg/m^3) [c]	0.016 – 0.40	2.3E-05 – 0.00074	0.0084 – 0.21	0.0010 – 0.034
Full-duration dermal exposure melting (mg) [d]	6.3 – 19.6	3 – 9.5	12.5 – 39.2	1.3 – 4.1
Eight-hour time weighted average inhalation exposure pouring (mg/m^3) [c]	0.00056 – 0.018	6.8E-05 – 0.0022	0.0011 – 0.037	6.5E-05 – 0.0021
Total duration dermal exposure pouring (mg) [d]	123 – 355	39.2 – 123	246 - 771	39.2 - 123
Combined exposures total activity				
Combined inhalation exposure eight hour total average (mg/m^3) [c]	0.017 – 0.42	9.1E-05 – 0.0029	0.0095 – 0.25	8.7E-05 – 0.0028
Combined dermal exposure full-duration (mg) [d]	130 – 375	42.2 – 132	259 – 810	42.2 - 132

[a] This is the 90% confidence interval of the median exposure estimate

[b] This is the median and the 90th percentile

[c] Task-based value calculated towards eight-hour time weighted average

[d] Task-based value extrapolated to full day value

[e] This is a time-weighted average of 30 minutes at high temperature (overheating) and 90 minutes at low temperature melting, with separate values of 0.13-3.2 for high temperature and 0.0015-0.049 for low temperature.

3.3 Summary of model estimates

No truly appropriate models exist for estimating the relevant exposures in small-scale lead casting. Therefore, exposure has been estimated with a number of models using similar assumptions.

MEASE estimates dermal exposure values (forehands, forearms and neck) between 86.6 and 853 mg/day, where the variation between scenarios is mainly due to difference in duration. Without gloves these values are even higher, up to 1 288 mg/day in the worst-case scenario for professionals. The use of appropriately selected gloves, is rather questionable. Hobbyists and artisanal professionals are mainly expected to use heat-resistant gloves during actual melting and pouring of molten lead.

RISKOFDERM estimates much higher exposure levels, with values of up to 350 mg/day for protected hands and higher values for (protected) body. These are values for melting only, although the 'immersion' model does include some handling of materials with liquids attached, which is not very dissimilar to careful pouring of liquids.

Dermal ART, in the worst-case situation, estimates unprotected exposure levels up to 810 mg/day (hands only; melting and pouring combined), which would be up to 40.5 mg/day with gloves providing 95% protection. In the best-case estimate the values are up to 132 mg/day unprotected and up to 6.6 mg/day with gloves providing 95% protection.

MEASE estimates inhalation exposure levels between 0.072 and 4.25 mg/m^3 (full shift) for the different scenarios.

ART estimates are lower, with the worst-case value up to 0.42 mg/m^3 and a best-case value up to 0.0028 mg/m^3.

4 Literature data

4.1 Literature search

A literature search was done using various key words in combination. Words used included:

- Home
- Hobby
- Artisan or artisanal
- Exposure
- Lead
- Casting
- Melting
- Melting
- Soldering

Searches were made, between 21-07-2021 and 28-07-2021, in Osh Update, Pubmed and Google Scholar. Titles and abstracts were screened for potentially relevant papers.
Given the short timeframe of the project, no complete analysis of all publications and no formal inclusion or exclusion criteria were used. Papers were considered relevant and selected if they might contain measured levels of lead in air, or in dust or on hands for informal or artisanal or hobby use of lead with melting and pouring as an important activity. Welding was excluded, because of the much higher temperatures involved than used in casting and soldering or stained glass work.
Some publications on blood lead levels were also selected if they were expected to contain information in the influence of temperature or scale of use or if they contained a comparison of professionals and hobbyists.
An attempt was made to obtain potentially relevant papers directly (free access papers) or via Reasearchgate or Academia.edu. Only in exceptional cases a paper was requested directly from a non-free access journal.

4.2 Literature summary

Some publications were found that provide information on exposure levels to lead in small-scale (home or artisanal) activities where lead is melted at a relatively low temperature. In many cases details on e.g. volumes melted, duration, percentage of lead in the molten product as well as details on conditions of use are lacking. However, the studies provide an indication of possible exposure levels in home or professional casting.

Street *et al.* (2020) studied exposure levels to lead and other metals from informal foundries in South Africa. Generally scrap metals, which are usually alloys, are broken and separated manually. The metal is then melted and formed into cook pots. Hand wipes were taken and analysed. Lead in blood levels were also studied. The six participating informal foundries used one to three outdoor melting furnaces and 2 to 13 workers. The indoor pot making area was 35 to 127 m^3.
Pre-work hand wipes in 11 workers from the six foundries showed on average 2.49 µg lead per hand wipe (interquartile range 0.67-3.07) and the end of work hand wipes on average 8.67 µg lead per hand wipe (interquartile range: 5.59-17.2 µg). No inhalation exposure measurements were taken. Blood lead levels in 33 pot makers were clearly increased over those of 33 non-exposed community members.

Exposure to fine dust was measured, with real-time measuring equipment, by Shezi *et al.* (2020) in hand-made cookware operations in South Africa. Personal exposure of seventeen artisanal cookware makers was measured. The sites were five of the same sites as in the study by Street *et al.* (2020), reported above. Indoors and outdoors (stationary) values were also measured and in the sampled dust metals were analysed. The momentary concentrations of personal fine dust (PM_4)

had a minimum level of 25 µg/m^3, a 50th percentile of 124 µg/m^3, a 75th percentile of 182 µg/m^3 and a very high maximum of 100 000 µg/m^3. Indoor $PM_{2.5}$ values ranged from 6 to 371 µg/m^3, with a mean of 105 µg/m^3 and outdoor values ranged from 8.8 to 51 µg/m^3, with a mean of 19 µg/m^3. Lead levels in indoor and outdoor $PM_{2.5}$ values, recalculated to concentrations, were 2.8 and 6.6 µg/m^3, which is 2.7% and 35% of $PM_{2.5}$ indoors and outdoors respectively.

Demetska *et al.* (2019) measured the emission of lead nanoparticles during the melting of 1 kg lead at 420 °C for 60 minutes. It was shown that significant levels of nanoparticles were formed during the melting process, mainly in the nanorange of 1-100 nm. The number of nanoparticles increased during the melting process with 3.1 times (20 000 particles/cm^3 in absolute terms). Removal of the slag resulted in an additional increase of 20 000 particles/cm^3. In conclusion, melting of lead is accompanied by a significant emission of lead nanoparticles.

Matte *et al.* (1991) measured lead exposure in conventional and cottage lead melting in Jamaica. The conventional smelter operated around two weeks in a two month period. Crude backyard melting occurs in the same community. Lead exposure was not assessed directly, but lead levels in soil and dust were measured. In an area with possible backyard melting (in the same area as the conventional smelter) the geometric mean for lead in dust at possible backyard melters was 2790 µg/m^2 and at random locations 690 µg/m^2. In an area without known backyard melters, the geometric mean of lead in dust was 100 µg/m^2. Based on statistical analyses of lead in blood, Matte *et al.* (1991) conclude that backyard smelters had significantly higher levels than those not performing backyard melting, but clearly lower than formal smelters (employed in the conventional foundry). There was very poor correlation between personal measurements (over 3 hours) and indoor levels.

Monger and Wangdi (2020) found an increased number of workers in artisanal workplaces (goldsmith, bronze casting, arts and crafts centre) with elevated lead in blood levels (>5 µg/dL). There was also a high frequency of elevated mercury levels.

Rapisarda *et al.* (2013) measured exposure to lead and cadmium for radiology technicians melting low melting point alloys of lead, tin, cadmium and bismuth in Italy. Biological monitoring was used to measure total exposure. Lead in blood values of 32 technicians were measured. Twenty four of these were non-smokers. No details on their use of lead was reported and no comparison was made with non-exposed workers. The average lead in blood value was 50 µg/L with a 90th percentile of 98 µg/L.

Personal task-based 2 hour air samples were taken of workers in informal automobile repair workshops in Kenya by Odongo *et al.* (2019). Repairing lead-acid batteries lead to the highest exposure levels of 65 – 87 µg/m^3 (average 76). According to the authors, soldering and replacement of parts expose the artisans to lead dust, oxide particles and fumes. Welders had lower exposure levels (average 20 µg/m^3).

Daniell *et al.* (2015) measured lead in blood in children in a village where battery recycling was performed. Part of the study was also on levels of lead in dust. Surface samples were taken, amongst others in three homes where recycling was performed, four homes with a history of recycling and 4 homes with no history of recycling. Three floor surface samples were taken per house. In all homes surface levels of lead were high, with means of 250 µg/cm^2 in the homes with active recycling, 86 µg/cm^2 in the homes with past recycling and 60 µg/cm^2 in homes with no history of recycling.

NIOSH (1976) measured lead, copper, tin and zinc levels via personal sampling in a metal casting area of an Art school in the USA. Metal is cast in a high temperature kiln and then poured in a mould. Metal casting is done on average once per week for a few hours. The shop assistant performs the actual melting and casting and there is local exhaust ventilation over the kiln. Measurements were done on two occasions. On the first occasion bronze (containing 5% lead) was cast. On the second occasion, 85 pounds of bronze were being melted. No lead was detected in the sample of the first sampling (< 0.003 mg lead). In the follow-up sampling (approximately two hour and 20 minutes), the shop assistant had a lead concentration of 0.32 mg/m^3 and two students (not performing the actual melting or pouring themselves) of 0.13 and 0.14 mg/m^3.

Blood in lead levels were measured in 12 professional and 5 hobby stained glass workers and 4 family members by Landrigan *et al*. (1980). The workers heat, draw, bend, solder and polish the lead material. Most exposure is probably to lead dust and occasionally also to fumes (in soldering). Professionals worked 20 to 50 hours per week (mean 36.3) and hobbyists 3 to 21 hours per week (mean 8.4). Only five of 17 workers installed any sort of ventilation, of which only 2 local exhaust ventilation. Three reported wearing a mask and one wore gloves. Three dust samples in a stained glass workshop had an average of 10 696 ppm lead. The blood lead level of the professionals was on average 20.7 µg/dL and those of hobbyists and family members respectively 11.6 and 11.3 µg/dL. The blood levels were positively correlated with the number of hours worked per week (Spearman correlation: $r = 0.51$, $p = 0.02$).

Soldering was studied in a naval soldering laboratory, which was considered a somewhat idealised setting, because hygiene and quality control measures were strictly observed (Monsalve, 1984). Soldering was performed at 371 °C with a solder containing 37% lead. Personal air samples were taken during actual soldering and wipe samples were taken in the area as well. Sampling time for air samples was from 120 to 147 minutes. Soldering was performed transient and very sporadic. Only in 2 out of 13 samples lead was detected, in both at 2 µg/m^3. Wipes were taken from a 100 cm^2 surface of the work table or bench directly accessible to the solderer, using a moistened filter paper. Control wipes were from desks in other areas. Samples were also taken from hands of solderers. On 20 soldering surfaces, lead levels varied from non-detected to 92 µg/100 cm^2 (90th percentile 79). In the non-soldering area (n = 10), the maximum level on the surface was 3 µg/100 cm^2. On the solderers' hands (n=11), on average 12 µg/100 cm^2 was measured, with a 90th percentile of 30.

In an American study on people with blood lead levels ≥ 25 µg/dL or ≥ 40 µg/dL, it was found that 7.7% and 6.1% (2008 and 2009) of people with levels ≥ 25 µg/dL and 27% and 45% (2008 and 2009) of those with levels ≥ 40 µg/dL were involved in lead casting activities for e.g. bullets and fishing weights (Alarcon *et al.*, 2011). These are not the highest percentages, because complementary and alternative medicine had higher percentages for people ≥ 40 µg/dL in both years (67% and 43%). Eating food contaminated with lead was also an often reported source (63% and 41%) for ≥ 40 µg/dL. Remarkably, for ≥ 25 µg/dL target shooting was the most often mentioned non-occupational source (36% and 32%), while it was relatively less important for levels of ≥ 40 µg/dL (16% and 22%).

Mäkinen and Linnainmaa (2003), in the RISKOFDERM project, measured chromium exposure in chrome plating (electroplating) and recalculated the values to full electroplating solution. The median exposure for body (outside of clothing) was 2.97 mg solution/hour and for hands (outside protective gloves) 1.47 mg solution/hour. The maximum measured values of 16 workers, most of which sampled twice, leading to 29 values, were 28.1 mg solution/hour for body and 6.37 mg solution/hour for hands. Inhalable dust samples for chromium were between 0.01 and 0.04 mg/m^3 and there was no relation between dermal and inhalation exposure levels. There was no unambiguous effect of automation, probably because workers touched surfaces (sometimes barehanded) to solve issues in the process. The scale of activities was rather large, compared to small-scale casting, but this is one of the few studies actually measuring (protected) dermal exposure.

Roff *et al.* (2004) also measured electroplating dermal exposure in the scope of the RISKOFDERM project. Exposure levels on suits were measured to be 36 – 1450 µg/cm^2/hour, with a 95th percentile of 1300 µg/cm2/hour on hands underneath protective gloves. But only 7 out of 25 samples were above the limit of quantification. The potential body exposure (outside coveralls) showed a 95th percentile of 307 µg/cm^2/hour. If the size of hands is assumed to be 840 cm^2, the 95th percentile of protected hand exposure would be around 1000 mg/hour.

Sahmel *et al.* (2015) experimented with lead transfer to hands and from hands to mouth. Volunteers handled leaden fishing sinkers. Volunteers were instructed to handle the lead fishing sinker with a light and even pressure for ~15 s using taped fingertips of both hands, maintaining equal contact with the fishing sinker and each fingertip. The sinkers were held, rolled, and stroked by the participants. After handling, the six fingertips used for measuring (on average 23 cm^2, with a range of 19.8 to 28.6) of the volunteers contained between 86 and 188 µg lead. Expressed in µg/cm^2, the exposure was on average 5.6 µg/cm^2. With 840 cm hands, this would lead to around 4.7 mg on two hands.
The fingers from one hand were than pressed onto a sheet of wax paper with approximately 5 mL of the volunteers saliva, to test hand-mouth transfer experimentally. Between 12 and 34% of the lead on the fingertips was transferred to the saliva.

Christopher *et al.* (2007) report on lead and saliva sampling of workers in a secondary lead smelter (industrial). Cumulative hand exposure was between 0.040 and 58 mg, with a geometric mean of 4.8 mg and a GSD of 7.5. Contamination around the mouth ranged from 3.1 to 340 µg at the end of shift and oral exposure was between 0.5 and 32 µg, with a GM of 6.7 and a GSD of 2.5. The lead smelter reported in this report is described in more detail in Hughson (2004). Melting was in a furnace with a bottom outflow and monitoring and operation from a clean control room. But at the end of the process slag was removed and molten lead was tapped off into holding crucibles by two workers wearing thermal protective clothing and RPE. Exposure could occur due to workers taking off their gloves occasionally and touching contaminated surfaces. Casting was via an automated casting machine. Furnace operators had dermal lead values between 1.5 and 92.6 µg/cm^2 on their hands and between 0.7 and 79.1 µg/cm^2 on hands and forearms combined. The measurements were by wipe sampling from the skin, so for protected hands and forearms. Refinery operators had 1.1 and 1.4 µg/cm^2 on hands and forearms combined and maintenance workers between 4.4 and 9.9 µg/cm^2 on hands and forearms combined. Assuming a total surface area of hands and forearms of 1300 cm^2, the total exposure would be extrapolated to up to around 103 mg for furnace workers, 1.8 mg for refinery workers and 13 mg for maintenance workers.

None of the literature sources found provide actual inhalation exposure data on hobby lead casting. Most available studies are related to artisanal production, which in several non-Western countries is done in or at the house. Most studies also do not study exposure in casting of (more or less) pure lead, but are related to various alloys. Some studies measure lead in either airborne or settled dust and some also on hands of artisanal workers. A summary of the results is provided in Table 7.

Table 7. Summary of results on artisanal or relatively small-scale activities involving melting of lead or lead alloys

Reference	Situation	Activities	Lead source	Measured samples	Exposure levels	Unit
Street *et al.* (2020)	Informal foundries South Africa creating cookware (six foundries, 11 workers)	Breaking and separating scrap metal, melting and forming (melting outdoors)	Scrap metal	Pre-work hand wipe	Average 2.49 (interquartile range 0.67-3.07)	µg / hand wipe
				End of work hand wipe	Average 8.67 (interquartile range 5.59-17.2)	µg / hand wipe
Shezi *et al.* (2020)	Informal foundries South Africa creating cookware (five foundries)	Breaking and separating scrap metal, melting and forming (melting outdoors)	Scrap metal	Indoor $PM_{2.5}$	Mean 105 (6-371)	µg/m^3
				Outdoor $PM_{2.5}$	Mean 19 (8.8-51)	µg/m^3
				Percentage lead in indoor $PM_{2.5}$	Single value: 2.7	%
				Percentage lead in outdoor $PM_{2.5}$	Single value: 35	%
Demetska *et al.* (2019)	Laboratory	Experimental melting of 1 kg lead at 420 °C	Pure lead	Nanoparticles mainly 1-100 nm	Increase 3.1 times (20,000) Slag removal additional 20.000	particles/cm^3
Matte *et al.* (1991)	Cottage lead melting in an area with conventional lead smelter	Not described	Not described	Lead in dust in area at backyard melters	Geometric mean: 2790	µg/m^2
				Lead in dust in area at random locations	Geometric mean: 690	µg/m^2
				Lead in dust in area without conventional or backyard melting	Geometric mean: 100	µg/m^2
Odongo *et al.* (2019)	Informal automobile repair in Kenia	Soldering and replacement of parts of batteries	Lead-acid batteries	2 hour task-based inhalation exposure levels	Average 76 (65-87)	µg/m^3

Reference	Situation	Activities	Lead source	Measured samples	Exposure levels	Unit
		Welding	Not described, probably automobile parts and welding rods	2 hour task-based inhalation exposure levels	Average 20 (19-39)	µg/m^3
		Spray painting	Not described, probably paint	2 hour task-based inhalation exposure levels	Average 22 (9-44)	µg/m^3
		Radiator repair	Not described	2 hour task-based inhalation exposure levels	Average 4 (4-5)	µg/m^3
		General mechanics	Not described	2 hour task-based inhalation exposure levels	Average 10 (3-15)	µg/m^3
Daniell *et al.* (2015)	Village where home battery recycling was performed	Battery recycling	Lead-acid batteries	Lead from floor surface samples – homes with active recycling	Mean 250	µg/cm^2
				Lead from floor surface samples – homes with past recycling	Mean 86	µg/cm^2
				Lead from floor surface samples – homes without recycling history	Mean 60	µg/cm^2
NIOSH (1976)	Art school sculpture area	Melting and pouring bronze sculptures	Bronze (5% lead)	Casting sculpture (volume and duration not described)	Not detected (< 0.003 mg lead/sample)	
				Casting 85 pounds (ca. 39 kg) bronze in slightly over 2 hours	Shop assistant (actually performing the tasks): 0.32 Students (bystanders): 0.13 and 0.14	mg/m^3

Reference	Situation	Activities	Lead source	Measured samples	Exposure levels	Unit
Landrigan *et al.* (1980)	Stained glass work	Heating, drawing, bending, soldering and polishing	Lead material	Lead in blood in professionals working 20-50 hours/week	Mean: 20.7	µg/dL
				Lead in blood in hobbyists working 3-21 hours/week	Mean: 11.6	µg/dL
				Lead in blood in family members of hobbyists	Mean: 11.3	µg/dL
Monsalve (1984)	Soldering workshop	Transient and sporadic soldering (good hygiene)	Soldering at 371 °C with solder containing 37% lead	Surface wipes at soldering area	90^{th} percentile: 79	µg/100 cm^2
				Surface wipes at non-soldering area	Maximum: 3	µg/100 cm^2
				Hand wipes of solderers	90^{th} percentile: 30	µg/100 cm^2
Alarcon *et al.* (2011)	American people	Various	Various	Blood lead levels ≥ 40 µg/dL	2008: 27 2009: 45	% involved in lead casting for bullets or fishing weights
Mäkinen and Linnainmaa (2003)	Electroplating industry	Chrome plating	No lead, but chromium measured	Recalculated dermal exposure (full solution) on body (measurement suits)	Maximum: 28.1	mg/hour
				Hand washing	Maximum: 6.37	mg/hour
Roff *et al.* (2004)	Electroplating industry	Electroplating	Chromium or nickel measured	Surface of measurement suits	95^{th} percentile: 307	µg/cm2/hour
				Measuring gloves underneath protective gloves	95^{th} percentile: 1300	µg/cm2/hour
Sahmel *et al.* (2015)	Laboratory	Handling fishing sinkers	Leaden fishing sinkers	Transfer to 6 fingertips (approx. 23 cm^3)	End of shift on fingertips: up to 188	µg

Reference	Situation	Activities	Lead source	Measured samples	Exposure levels	Unit
				Transfer to saliva on filterpaper	Percentage: up to 34	% transfer to saliva
Christopher *et al.* (2007)	Secondary lead smelter	Melting, skimming tapping off	Not specified	Hand wipes	GM 4.8 Maximum 58	mg
				Perioral wipes	Range: 3.1-340	µg
				Intraoral saliva and mouth rinse	GM: 6.7 Maximum: 32	µg
Hughson (2004)	Secondary lead smelter	Melting, skimming tapping off	Not specified	Wipe samples	Furnace operators: hands:1.5-96.2 Hands and forearms: 0.7-79.1	µg/cm^2
					Refinery operators hands and forearms: Refinery operators had 1.1 and 1.4	µg/cm^2
					Maintenance workers: 4.4-9.9	µg/cm^2

4.3 Overall analysis of literature

The summary of literature sources indicates a number of relevant findings.

Measured air levels of lead were in the range of 4 to 76 µg/m^3 in informal automobile repair (Odongo *et al.,* 2019), 2.8 and 6.6 µg/m^3 in indoor fine dust ($PM_{2.5}$) in informal foundries (Shezi, *et al.*, 2020) and 140-320 µg/m^3 in relatively large scale bronze casting (NIOSH, 1976).

Hand wipe samples were 6-17 µg/hand wipe in informal foundries (Street *et al.*, 2020) and up to around 30 µg/100 cm^2 in a soldering workshop (Monsalve, 1984).

Surface dust levels were around 0.28 µg/cm^2 at backyard melters (Matte *et al.*, 1991), around 250 µg/cm^2 on the floors of homes with active battery recycling (Daniell *et al.*, 2015) and up to around 0.79 µg/cm^2 in a soldering workshop with transient and sporadic soldering (Monsalve, 1984).

In informal automobile repair, soldering and replacement of parts of lead-acid batteries leads to substantia inhalation exposure, more than welding, spray painting or other activities, for which the lead sources are less well reported (Odongo *et al.*, 2019).

Relatively large scale artisanal casting in a relatively well managed situation in the seventies, lead to very high exposure levels (more than 0.1 mg/m^3) with a higher level for person actually performing the activities than for bystanders (NIOSH, 1976).

Informal handling and melting of scrap metal leads to substantial levels of fine dust ($PM_{2.5}$) with a clearly measurable percentage of lead (Shezi *et al.*, 2020). In these situations there are however also other sources of lead than melting and pouring, such as breaking and sorting.

Professionals performing stained glass work for about 4 times the average duration of hobbyists had slightly more than twice the blood in lead levels of the hobbyists (Landrigan *et al.*, 1980).

Lead contamination of hands increases during the workday in informal foundry work, which includes breaking and sorting of scrap metal, by a factor of around 3 (Street *et al.*, 2020).

The hand wipe levels of solderers (doing transient and sporadic soldering) are about ten times the levels on surfaces in a non-soldering area, but around 2.5 times lower than the surface area samples in the soldering (Monsalve, 1984).

Surface dust lead levels at backyard melters were more than four times those than in random locations in the same area more than ten times those in areas with no known melting activities.

Dust on floors in homes with active battery recycling, had around 3 times higher levels of lead than in homes with past battery recycling and around 4 times higher than in homes with no known history of battery recycling (Matte *et al.*, 1991).

5 Comparison of model estimates and literature data

The models used to estimate exposure levels are not truly adequate for the situations to be assessed. The literature data, however, also does not fully represent the situations to be assessed.

The model estimates for inhalation exposure range from below 0.001 to 4.25 mg/m^3 for full-shift estimates (best-case ART estimate for Scenario #1 to worst-case MEASE estimate for Scenario #2. Measured air concentrations in potentially similar situations range from 0.004 (radiator repair, 2 hour average, Odongo *et al.*, 2019) to 0.32 mg/m^3 (actual bronze casting over slightly more than 2 hours, NIOSH, 1976). While the model estimates were mostly assuming pure lead handling, at least for pouring, the measurements are in large parts for melting of alloys, some of which contain a relatively low concentration of lead. Also, the model estimates from MEASE are for more industrial smelters, furnaces and ovens, as indicated by the fact that manual activities are estimated for PROC23 in MEASE. These industrial situations have much higher volumes of molten metal, often higher temperatures too. Scaling options are not given in MEASE for PROC23. Therefore, the model values may be overestimating exposures for small-scale casting.
Taking these considerations into account, it can be concluded that the model estimates and measured values in air in similar situations are not very far apart. Therefore, we conclude that in best-case situations the inhalation exposure to lead could be below 0.001 mg/m^3. Such best-case situations would imply:

- Relatively short duration of activities
- Careful melting, without overheating
- Use of local exhaust ventilation and/or proper general ventilation
- Proper hygiene measures and cleaning

To estimate the worst-case exposure levels for the non-industrial casting, it is considered that the worst-case model estimate of 4.25 mg/m will probably overestimate relevant values, because it is for more large-scale (industrial situations). However, the worst-case measured value (0.32 mg/m^3, over two hours) was for a situation considered to have relatively good control (in that period of time) as well as some local exhaust ventilation (NIOSH, 1976). It is assumed that the local exhaust ventilation in that situation was actively functioning and that home casting situations have less good ventilation and a smaller volume of air in the room than the art-school in which the measurement was made. Also, bronze was cast in the art school, while non-industrial casting in the situations to be assessed is mostly using material closer to pure lead. Therefore, it is considered that the worst-case non-industrial casting could have a clearly higher task-based exposure level than the highest measurement. But the full-shift exposure is also expected to be clearly below the estimated worst-case in the MEASE model, which is based on industrial scale use of molten metal. Via expert-judgement, the possible full-shift exposure level to lead in the worst-case situations is therefore estimated to be up to around 1 mg/m^3. Such worst-case situations would imply:

- Relatively long duration of activities, as in professional use with relatively high production
- Overheating the lead during part of the melting, by using direct flame heating
- No local controls, no proper general ventilation
- Poor hygiene situation with insufficient cleaning

For professional use, the chances of best-case situations are higher, but, due to the expected longer duration of activities and the fact that proper controls and proper methods are not assured, also the chances of the worst-case situations are higher than for hobby users.

The model estimates for dermal exposure, accounting for use of proper gloves, are highly variable. The MEASE model, assuming the use of appropriately selected gloves, gives quite substantial exposure levels in the order of 87 to more than 850 mg/day. These are values for hands, forearms and neck. The basis for these values is not very clear, because a proper description of how the values in MEASE 2.00.00 are derived is not presented. The RISKOFDERM and dermal ART model base the final estimates on analyses of actual exposure values. Although casting activities were not included in the measured activities, handling metals in liquid baths was (immersion in electroplating) and the actual exposure levels from these activities are represented by the 'immersion' model of RISKOFDERM. The dermal ART model specifically accounts for exposure due to contacting contaminated surfaces and therefore appears to be also partly relevant. Both RISKOFDERM and dermal ART in worst-case situations result in dermal exposure values up to more than 300 mg/day for protected hands. The MEASE estimates are specifically for the correct type of process, but on an industrial scale.

In the measured activities in electroplating (Mäkinen and Linnainmaa, 2003) the actually extrapolated exposure to full electroplating solution was up to 28.1 mg/hour for body and up to 6.4 mg/hour for hands. But the 95th percentile from Roff *et al.* (2003), also for electroplating, is much higher for hands: up to around 1000 mg/hour.
Hand wipe samples in informal foundries result in low levels of 6-17 µg/hand at the end of work (Street *et al.*, 2020) and 30 µg/100 cm^2 in a soldering shop (90th percentile of Monsalvo, 1984). The latter value would calculate to around 8.4 times higher for two hands: around 250 µg for two hands, assuming 840 cm^2 for two hands.
Hand exposure measurements in an industrial secondary lead smelter resulted in a geometric mean of 4.8 mg on hands (highest value 58 mg) and oral exposure of up to 32 µg (Christopher *et al.*, 2007).

The handling of fishing sinkers (experimentally) also clearly leads to transfer of lead to the hands. On six finger tips (approximately 23 cm^2), from 86 to 188 µg lead was found after handling fishing sinkers (Sahmel *et al.*, 2015).

It is clear that the electroplating situations in which measurements have been made use much higher volumes of metal containing liquids. And the evaporating surfaces are much larger than used in the small-scale metal casting. However, temperatures are much lower, since the process is not metal melting, but plating leads to emission of aerosols, since the baths are much more agitated than the melting lead is expected to be. The emitted fume in electroplating can be clearly seen in the picture in the paper by Mäkinen and Linnainmaa (2003) that shows a very visible fume. Therefore, we expect that the electroplating data and therefore also the RISKOFDERM model results are not sufficiently similar to the lead casting situation to be used.

The results of the dermal ART model and MEASE model also lead to much higher values than the (very few) measured dermal exposure values for molten lead use. However, the dermal ART values are for unprotected hands. With proper protective gloves the values should be much lower.

The difference between the dermal exposure models and the few dermal exposure data on lead is too large to allow direct derivation of a reasonable estimate for dermal exposure in small-scale lead casting activities.
Handling fishing sinkers already leads to lead on six fingertips up to 188 µg in volunteers. Based on the average measurement area (23 cm^2) and an assumed size of two hands of 840 cm^2, this would extrapolate to around 6900 µg. Extrapolating six fingertips to full hands probably overestimates exposure, since it is expected that most transfer will be on actual contact area, which is less than full hands. Soldering activities led to hand wipes extrapolated to around 250 µg for two hands. Dermal exposure in industrial lead melting can be quite high (up to 58 mg lead on hands), but this is probably higher than what can be found in small-scale lead casting.

The results of the industrial lead smelter are not very far from the results of dermal ART model (up to 390 mg on hands), in which results from industrial handling of relatively large volumes of molten

metal are incorporated. The results from Mäkinen and Linnainmaa (2003) on electroplating, around 6.4 mg/hour, extrapolated to 8 hours to a value of around 50 mg, are in the same order of magnitude as the values measured by Christopher *et al.* (2007) in a secondary lead smelter. The results of Hughson (2004) in the same lead smelter can be calculated up to 103 mg on hands and forearms or 78 mg on hands alone. It is therefore reasonable to assume that industrial use of baths with molten metal lead to dermal exposures in the range of 50 to 80 mg on hands.
With these values, it may be possible to estimate possible dermal exposure levels for small-scale casting from these data by accounting for differences.
For this purpose, the factors suggested in the read-across approach for exposure data may be useful. While these factors, described by Franken *et al.* (2020) are for inhalation exposure, they might also indicate the order of magnitude for dermal exposure.

The most important parameters that vary between the measured data and the situations to be assessed are the following:

- Task scale (volume used, area of evaporation)
- Containment
- Vapour pressure
- Weight fraction of substance
- Engineering control
- Setting
- Duration

In Table 9, the input for these parameters for the different sources and the factors (as provided by Franken *et al.*, 2020) per parameter for both the target situations (to be assessed) and the source situations (with measured data) are presented. The inputs are based on the information in the papers, as far as possible, but largely also include elements of expert judgement.
Also, the total multiplied factor is presented for these scenarios. The read-across factor from a source scenario to a target scenario is then:

Read-across factor from source to target = target multiplied factor / source multiplied factor.

The method by Franken *et al.* (2020) uses estimated and measured data to derive a calibration factor. This calibration factor is used to calculate the calibrated read-across factors in the calculations with the following equations:

Calibrated read-across factor = exp(calibration factor * ln(scenario factor/source factor))

And

Estimated exposure = source exposure * calibrated read-across factor.

An example calculation is presented below.

- Multiplied factor for target (worst-case hobby use) = 1.63
- Multiplied factor for source (Mäkinen and Linnainmaa, 2003) = 11.09
- Calibration factor (Frenken *et al.*, 2020) = 0.328
- Exposure level in the source (Mäkinen and Linnainmaa, 2003) = 50 mg/day

From these inputs, the calibrated read-across factor for source to target =
(exp(0.328 * ln(1.63/11.09)) = 0.669 and the estimated exposure for the target =
50 * 0.669 = 33 mg/day.

The estimated exposure levels are indicated in Table 8.

The read-across from the different sources, using the factors and calibration, as shown in Table 9 and explained above, leads to estimated dermal exposures of 33-69 mg/day for worst-case professional use, 2-5 mg/day for best-case professional use and 27-55 mg/day for worst-case hobby use.

Dermal exposure per se is not very relevant, because dermal penetration of lead is very low. However, as can be seen in the experimental study of Sahmel et al., a substantial part of amount on fingertips can be transferred to saliva (12-34%). Christopher found exposure in the oral cavity up to 32 µg, which is 0.6% of the highest dermal value (58 mg). Of course, only a small part of the hand will be in contact with the mouth and therefore the two findings are not per se in contradiction.

Table 8. Estimated read-across factors (calculated in Table 9) and resulting extrapolated dermal exposure levels

Scenario		**Worst-case professional use**	**Best-case professional use**	**Worst-case hobbyist use**
Multiplied factor for the scenario		3.25	0.0018	1.63
Read-across factor for the measurement situation in Mäkinen and Linnainmaa (2003)		11.09	11.09	11.09
Read-across factor for the measurement situation in Christopher *et al.* (2007)		29.22	29.22	29.22
Read-across factor for the measurement situation in Hughson (2004)		29.22	29.22	29.22
Calibration factor[a)]		0.328	0.328	0.328
Calibrated read-across factor from Mäkinen and Linnainmaa (2003)		0.669	0.050	0.533
Calibrated read-across factor from Christopher *et al.* (2007)		0.487	0.036	0.388
Calibrated read-across factor from Hughson (2004)		0.487	0.036	0.388
Estimate based on Mäkinen	Exposure measured[b)] (mg/day)	50	50	50
	Estimate scenario (mg/day)	33	2	27
Estimate based on Christopher	Exposure measured[b)] (mg/day)	58	58	58
	Estimate scenario (mg/day)	39	3	31
Estimate based on Hughson	Exposure measured[b)] (mg/day)	103	103	103
	Estimate scenario (mg/day)	69	5	55

[a)] This is the calibration factor from Franken *et al.* (2020) for the GM. Because of the very limited number of data points, the calibration factor for the 95th percentile (leading to a higher final estimate) is not used; the measured/extrapolated values from the literature may be higher values in the paper, but due to uncertainty in the method it is decided not to try and estimate high percentiles for the scenarios.
[b)] The values are actually extrapolated from measured values to full hands and 8 hours.

Table 9. Read-across parameters and factors, inspired by the factors indicated by Franken *et al.*(2020)

Parameter	Mäkinen and Linnainmaa (2003)	Christopher *et al.* (2007) and Hughson *et al.* (2004)	Worst-case scenario small-scale casting professionals	Best-case scenario small-scale casting professionals	Worst-case scenarios small-scale casting hobbyists
Task scale	Baths of 4-10 m^3;very large scale Factor: 3.33	No details, very large scale; Factor 3.33	Few liters; Factor 0.1	Less than a liter; Factor 0.03	Few liters; Factor 0.1
Containment	None; Factor 1	Partial: Factor 0.3	None; Factor 1	None; Factor 1	None; Factor 1
Vapour pressure	Not described; very low (<10 Pa); Factor 3.33[a)]	Expected high temperature; Factor 65[b)]	High temperature; Factor 65	Low temperature; Factor 1	High temperature; Factor 65
Weight fraction	100% (calculated values for full solution): Factor 1	Main component; Factor 0.9	Pure; Factor 1	Main component; Factor 0.9	Pure; Factor 1
Engineering controls	None (in worst-case situations); Factor 1	Local exhaust ventilation (other); Factor 0.5	None; Factor 1	Local exhaust ventilation (other); Factor 0.5	None; Factor 1
Setting	Indoors; Factor 1	Indoors; Factor 1	Indoors; Factor 1	Outdoors; Factor 0.7	Indoors; Factor 1
Duration correction	8 hours; Factor 1	8 hours; Factor 1	4 hours; Factor 0.5	1 hour; Factor 0.125	2 hours; Factor 0.25
Total factor (multiplied)	11.1	29.2	3.25	0.00118	1.63

[a)] This is a factor for the fact that the baths in this study were agitated, while there is no agitation in the other studies or scenarios

[b)] The vapour pressure factor is calculated as the difference of the 50 percentile for the two vapour pressures with the same values for other parameters.

6 Discussion

Based on some lead in blood values, reported in the Annex of the Annex XV report, very high risks may be expected due to home-casting of lead. Of course, information on the exact conditions, amounts, practices, etc, of the persons with lead poisoning are unknown.

In our study, we tried to model inhalation and dermal exposure to lead for home-casting and 'artisanal' casting by professionals, which is in this report sometimes referred to as hobby use and professional use.
In our view, the 'professional use' in the worst-case occurs in similar conditions as the worst-case 'hobby use', but leads to higher potential exposures, due to longer duration and higher amounts handled. The best-case professional exposure is probably lower, if some control measures (general ventilation, some exhaust ventilation) are used.

There are very few literature sources that can be used to estimate exposures for home-casting of lead. Actually, no really appropriate source was found. However, based on information in studies on artisanal use of lead at temperatures not very high above melting point, e.g. in artisanal casting or soldering, an idea of inhalation exposure can be given. Inhalation exposure has also been modelled using MEASE and ART. The range of values modelled using MEASE and ART agrees quite well with the measured ranges in small-scale work with molten lead. Therefore, we consider that these values are reasonable from a weight-of-evidence point of view.

Of course, home-casting is not the same as soldering or artisanal casting. Therefore, the inhalation values are still quite uncertain. Also, the knowledge on amounts used and temperatures of melting is rather limited, increasing the uncertainty. Nevertheless, the best estimate of inhalation exposure coming from this study is in the range of 0.004 to around 1 mg/m^3, where the lower value would be relevant for the best-case situations and the higher value for worst-case situations.

The assessment of dermal exposure is much more complicated, largely because of a lack of appropriate dermal exposure models. Also, there are no dermal exposure measurements in relatively small-scale (artisanal) use of lead. Experiments with handling fishing tackle by volunteers show that this activity alone is already sufficient to achieve clearly measurable dermal exposure levels. And the same experiments also show that a substantial amount of what reaches the fingertips can be transferred to saliva and therefore to oral exposure.
Based on the knowledge of the data underneath the models, which is mostly from large scale industrial work, it was concluded that the estimates with that model were not very appropriate.
An attempt was therefore made to read across dermal exposure data from industrial electroplating and lead melting (two studies in the same facility) to the best- and worst-case scenarios for home-casting. This leads to a number of values that are rather uncertain for the following reasons:

- The level of detail of information on the industrial situations is too limited to assess read-across factors very well
- Therefore, the factors are largely based on expert judgement, though taking account of the factors in the original publication on read-across of exposure data
- The industrial processes are rather different from the home-casting process
- Whether the same read-across factors are valid for inhalation exposure and dermal exposure is yet unknown
- Whether the calibration for inhalation exposure is valid for dermal exposure is also unknown.

Nevertheless, the best estimates of dermal exposure based on this read-across is in the range of 2 to 5 mg/day for best-case up to 33-69 mg/day for worst-case. These values are lower than the values estimated by the models, but the difference appears to be a reasonable effect of a difference in scale of the assessed scenarios compared to the model estimates. The values from read-across are only for hands, while measurements in industrial situations have clearly shown exposure to body parts as well. Therefore, total dermal exposure may be higher. Measurements in industrial situations show exposure on body parts that in total can equal the exposure on hands, but while the measurements on hands largely or partly involve handling contaminated surfaces with bare hands, the measurements on body parts are all on the outside of (often more than one layer of) clothing. Furthermore, while hand-to-mouth contact is quite common, the contamination from other body parts does not reach the mouth so easily.
While protective gloves may significantly reduce the exposure to hands, the value of gloves used in home-casting is questionable. It is expected that both hobbyists and professionals in home-casting will use the same gloves for a long period and only when actually handling molten (hot) lead. An important part of dermal exposure, as discussed in literature, comes from the moments when gloves are not used and contaminated surfaces are contacted. And donning the same gloves when the hands are already contaminated will ensure prolonged contact with contamination, even when wearing gloves.

It was requested to create two scenarios: one for persons casting for home use and one for persons casting for sales. In reality, the situations can be very similar, as indicated before. Overheating of lead, leading to sudden increase in emission can occur in both situations and with many professional users probably not having proper local exhaust and good general ventilation, the worst-case situation is expected to be the situation of professionals handling relatively large amounts with overheating in situations with limited control measures and limited cleaning. The best-case situations are also expected to be found for professionals. These will be the situations with careful melting (temperature controlled), local exhaust ventilation, good general ventilation, good general hygiene and relatively limited amounts and duration. The situations of people casting for their own use are expected to be in between these two extremes.

7 Reference list

ALARCON, W.A., GRAYDON, J.R., CALVERT, G.M., 2011. Adult Blood Lead Epidemiology and Surveillance — United States, 2008–2009. MMWR, July 1, 2011, Vol. 60, No. 25

ART. Advanced Reach Tool 1.5. https://www.advancedreachtool.com

CHRISTOPHER, Y., SEMPLE, S., HUGHSON, G.W., CHERRIE, J.W., 2007. Inadvertent ingestion exposure in the workplace. Health and Safety Executive, RR551 Research report.

CONSER, M., HOGAN, T., 2011. Arc welding health effects, fume formation, mechanisms, and characterization methods. SBN 978-953-307-642-3

DANIELL, W.E., VAN TUNG, L., WALLACE, R.M., HAVENS, D.J., KARR, C.J., BICH DIEP, N., CROTEAU, G.A., BEAUDET, N.J., DUY BAO, N., 2015. Childhood lead exposure from battery recycling in Vietnam. BioMed Research International Volume 2015, Article ID 193715

DEMETSKA, O.V., LUKIANENKO, A.O., ANDRUSISHINA, I.M.., MOVCHAN, V.O., BELIUHA, O.G., 2019. Evaluation of Nanoparticles Emission in Simulation of Experimental Model of Technological Process of Pig Lead Smelting. Earth and Environmental Science 224 (2019) 012012

EBRC Services for Chemical Industries, 2018. MEASE Version 2.00.00. https://www.ebrc.de/tools/downloads.php

ECETOC 2009. TR 107: Addendum to TR 93; Targeted Risk assessment (2004)

ECETOC 2012. TR 114: ECETOC TRAv3: Background and Rationale for the Improvements

ECETOC 2014. TR 124: Addendum to TR114 : Technical Basis for the TRA v3.1

ECETOC 2018. TR 131: Targeted Risk Assessment: Further Explanation of the Technical Basis of the TRA v3.1

FRANKEN, R., SHANDILYA, N., MARQUART, H., MCNALLY, K., FRANSMAN, W., 2020. Extrapolating the applicability of measurement data on worker inhalation exposure to chemical substances. Annals of Work Exposures and Health, 2020, 1–20

GOEDE, H.A., MCNALLY, K., GORCE, J.P., MARQUART, H., WARREN, N.D., FRANSMAN, W., TISCHER, M., SCHINKEL, J., 2018. Dermal Advance REACH Tool (dART) – Development of a dermal exposure model for low-volatile liquids. Annals of Work Exposures and Health, 2018, 1–13

GRAY, C.N., HEWITT, P.J., DARE, P.R.M., 1982. New approach would help control weld fumes at source Part two: MIG Fumes. Welding and Metal Fabrication, October, p393-397.

HUGHSON, G.W., 2004. An occupational hygiene assessment of dermal inorganic lead exposures in primary and intermediate user industries. Research report TM/04/06 January 2005

IRAS. Lasrook assistant. https://www.iras.uu.nl/lasrook/index.php

LANDRIGAN, P.J., TAMBLYN, P.B., NELSON, M., 1980. Lead exposure in stained glass workers. American Journal of Industrial Medicine 1(2):177 – 180.

MÄKINEN, M., LINNAINMAA, M., 2003. Dermal exposure to chromium in electroplating. Ann. occup. Hyg., Vol. 48, No. 3, pp. 277–283

MATTE, T.D., FIGUEROA, J.P., OSTROWSKI, S., BURR, G., JACKSON-HUNT, L., BAKER, E.L., 1991. Lead Exposure from Conventional and Cottage Lead Smelting in Jamaica. Arch. Environ. Contam. Toxicol. 21, 65-71

MONGER, A., WANGDI, K. 2020. Lead and Mercury Exposure and Related Health Problems in Metal Artisan Workplaces and High-Risk Household Contacts in Thimphu, Bhutan. The Scientific World Journal, Volume 2020, Article ID 9267181

MONSALVE, E.R., 1984. Lead ingestion hazard in hand soldering environments. NWC TP 6545

NIOSH, 1976. Health hazard evaluation determination. Report no. 75-12-321

ODONGO, O.A., MOTURE, W.N., OBONYO, M.A., 2019. Influence of task-based airborne lead exposures on blood lead levels: a case study of informal automobile repair artisans in Nakuru town, Kenya. Environmental Geochemistry and Health, July 2020. ISSN 0269-4042

RAPISARDA, V., LEDDA, C., CASTAING, M., PROIETTI, L., FERRANTE, M., 2013. Potenziale esposizione a cancerogeni nella lavorazione di leghe bassofondenti (professional low melting alloy processing in radiology technicians in a hospital; Italian paper). G Ital Med Lav Erg 2013; 35:2, 73-76

RIVM. DustEx model. https://www.rivm.nl/en/consumer-exposure-to-chemical-substances/exposure-models/DustEx

ROFF, M., BAGON, D.A., CHAMBERS, H., DILWORTH, E.M., WARREN, N., 2004 Dermal exposure to electroplating fluids and metalworking fluids in the UK. Ann. occup. Hyg., Vol. 48, No. 3, pp. 209–217

SAHMEL, J., HSU, E.I., AVENS, H.J., BECKETT, E.M., DEVLIN, K.D., 2015. Estimation of hand-tomouth transfer efficiency of lead. Ann Occup Hyg. 59(2):210-20.

SHEZI, B., MATHEE, A., CELE, N., NDABANDABA, S., STREET, R.A., 2020. Occupational exposure to fine particulate matter (pm4 and pm2.5) during hand-made cookware operation: personal, indoor and outdoor levels. Int. J. Environ. Res. Public Health 2020, 17, 7522

STREET, R.A., GOESSLER, W., NAIDOO, S., SHEZI, B., CELE, N., RIEGER, J., ETTINGER, K., REDDY, T., MATHEE, A., 2020. Exposure to lead and other toxic metals from informal foundries producing cookware from scrap metal. Environmental Research 191 (2020) 109860

US EPA. CEM 2.1. https://www.epa.gov/sites/default/files/2019-06/documents/cem_2.1_user_guide.pdf

WARREN, N.D., MARQUART, H., CHRISTOPHER, Y., LAITINEN, J., VAN HEMMEN, J.J., 2006. Taks-based dermal exposure models for regulatory risk assessment. The Annals of Occupational Hygiene, Volume 50, Issue 5, July 2006, Pages 491–503

Appendix 1. Mechanisms of fume formation

During the melting process of lead, metallic fumes may arise in which many factors are involved. There are two main processes involved which initiate fume formation. The first is the formation of airborne metal droplets. These are formed when heating of the liquid metal occurs rapidly or during agitation of the molten metal surface. The second process is vaporization of the metal during heating. Both the metal droplets and metallic vapour are oxidised and condensate in the air, forming the visible fumes (Gray et al. as cited in Conser 2011).

Metal droplets can be formed in different ways. Using impure lead or recycled lead can be a source of airborne metal droplets. Impurities, such as dirt, can burn off and form fumes. Rapid heating by using gas torches, using thin melting pots or adding pieces of metal to a hot melting pot can form airborne metal droplets. Another possible risk of exposure is water getting in contact with the metal during the melting process. When water comes in contact with the molten metal, it more or less causes small eruptions with splashes and fumes, causing high exposure. Since melting is performed at temperatures of 327.5 °C, it is likely that the person involved in melting the metal will sweat. This is also very much dependent on the duration of the melting and casting process. Also removing slag from the molten metal may cause agitation of the surface, causing airborne metal droplets. Boiling of molten lead is not considered a source of airborne metal droplets, since the boiling point of 1749 °C cannot be achieved in non-industrial settings.

Metal vapours can be formed by overheating the molten metal, at temperatures higher than its melting point, which is 327.5 °C for lead. At melting point, the relative vapour pressure is very low, far below 0.01 Pa, thus formation of metal vapours will be negligible. However, vapour pressure increases with increasing temperatures. At 500°C, which is considered to be the maximum temperature reached in electric melting pots, the vapour pressure is ~1.0E-03 Pa (documents in ‘Comment #3325 from the Annex XV consultation’). Extreme overheating, for example using torches, can result in even higher temperatures reaching 800 °C, the vapour pressure will reach ~1.0E+01 Pa. Overheating will thus result in a higher exposure level due to formation of metallic vapours. In absolute terms, the exposure to vapours is expected to be still marginable, however, during extreme overheating there will be considerable exposure to metallic vapour.

Good practices will minimize the formation of fumes. Using a specific electric stove with a thermostat which does not overheat will keep the molten lead near its melting temperature, and using a pure source of lead and gradually heat it will minimize the formation of fumes. However, in practice, lead of a variety of sources is melted in a pan on a gas stove, or sometimes even using a gas torch. This leads to a high likelihood of fume formation. Quantification of this is difficult because of the many different factors at play. It is possible to estimate the influence of vapour pressure on exposure by continuously overheating with a gas torch. However, the formation of metallic droplets is not included in this estimation.