

Analysis of CTI Foundry Dataset

Prepared by the **Health and Safety Laboratory**
for the Health and Safety Executive 2009

Analysis of CTI Foundry Dataset

Richard Cotton & Richard Underwood
Health and Safety Laboratory
Harpur Hill
Buxton
Derbyshire
SK17 9JN

This report contains a statistical analysis of an exposure dataset provided by Castings Technology International (CTI). The purpose of the analysis is to provide a 'snapshot' of exposure levels to ferrous foundry particulate and other chemicals, across a range of casting and fabrication related jobs.

The original dataset consisted of 49 994 records comprising of potential exposure level, substance exposed to, the job type, date of measurement, and where known, the use of respiratory protection equipment (RPE) and local exhaust ventilation (LEV).

The dataset was filtered to exclude records which were pre-1995 (since only current or near-current records were of interest), or that related to jobs or substances that were not of interest. Full details of the data cleaning process are given in Appendix A. After filtering, 21 885 records of exposures to 30 substances remained, covering the time period 1995–2004. Based upon the information in the 'Process Name' and 'Job Name' fields in the original dataset, records were classified according to nine generic job types. (The word 'job' refers to these new job classifications throughout the report, unless otherwise stated.)

The analysis provides summary statistics of exposures, stratified by the generic job types and by substance, and compared to current Workplace Exposure Limits (WELs) where appropriate.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

© Crown copyright 2009

First published 2009

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted in any form or by any means (electronic, mechanical, photocopying, recording or otherwise) without the prior written permission of the copyright owner.

Applications for reproduction should be made in writing to:
Licensing Division, Her Majesty's Stationery Office,
St Clements House, 2-16 Colegate, Norwich NR3 1BQ
or by e-mail to hmsolicensing@cabernet-office.x.gsi.gov.uk

CONTENTS

1	INTRODUCTION.....	1
2	ANALYSIS.....	2
3	REFERENCES	9
4	APPENDIX A—DATA CLEANING	10
5	APPENDIX B—DEALING WITH CENSORED DATA	12

EXECUTIVE SUMMARY

Objectives

The aim of this study is to provide a statistical analysis of an exposure dataset provided by Castings Technology International (CTI). The purpose of the analysis is to provide a 'snapshot' of current exposure levels to ferrous foundry particulate (FFP) and other chemicals across a range of casting and fabrication related jobs.

Main Findings

Ammonia, antimony, carbon monoxide, dimethylethylamine, formaldehyde, methylene diphenylene diisocyanate (MDI), phenol, propan-2-ol and toluene had less than 10% of exposures above the corresponding Workplace Exposure Limit (WEL) for every job. This indicates that exposures to these substances are generally well controlled.

Arsenic, cadmium, dust (respirable), FFP (respirable), manganese and xylene had less than 10% of exposures above the WEL overall, but more than 10% of exposures above the WEL for some jobs. This indicates that exposures, in general, are well controlled but that there are some areas that should be addressed.

Benzene, cobalt, dust (total inhalable), FFP (total inhalable), furfuryl alcohol, iron, lead, nickel, silica (respirable) and triethylamine had 10–30% of exposures greater than the WEL, indicating that improvements in exposure control should be considered.

Up to 62% of exposures for vanadium pentoxide exceeded the WEL. (An exact figure cannot be given because the analytical method measures vanadium, not vanadium pentoxide.) This indicates that exposures to this substance are not well controlled and further review of exposures is needed.

Recommendations

The casting industry should be made aware of these findings, in particular, the large number of exposures to vanadium pentoxide exceeding the WEL.

1 INTRODUCTION

This report contains a statistical analysis of an exposure dataset provided by Castings Technology International (CTI). The purpose of the analysis is to provide a ‘snapshot’ of current exposure levels to ferrous foundry particulate and other chemicals, across a range of casting and fabrication related jobs.

The original dataset consisted of 49 994 records comprising of potential exposure level¹, substance exposed to, the job type, date of measurement, and where known, the use of respiratory protection equipment (RPE) and local exhaust ventilation (LEV).

The dataset was filtered to exclude records which were pre-1995 (since only current or near-current records were of interest), or that related to jobs or substances that were not of interest. Full details of the data cleaning process are given in Appendix A. After filtering, 21 885 records of exposures to 30 substances remained, covering the time period 1995–2004. Based upon the information in the ‘Process Name’ and ‘Job Name’ fields in the original dataset, records were classified according to nine generic job types. (The word ‘job’ refers to these new job classifications throughout the report, unless otherwise stated.)

The analysis provides summary statistics of exposures, stratified by the generic job types and by substance, and compared to current Workplace Exposure Limits (WELs) where appropriate.

¹ Potential exposures are measured outside any protective clothing or equipment. Actual exposures (measured on the skin) are typically lower.

2 ANALYSIS

The WEL for each substance is given, where appropriate, in Table 1 alongside the units for the exposures. (Values for this table have been taken from EH40, HSE 2007.) Note that some of the units have been converted from mg/m³ to ppm or vice versa—see Appendix A for more details. Also note that exposures recorded to vanadium pentoxide are really ‘possible’ exposures to vanadium pentoxide in the sense that they are exposures to vanadium, scaled up by the molecular weight, and as such provide an upper bound rather than an estimate of exposure levels. See Appendix A for more information.

The number of records available in the dataset by job and by substance is shown in Figure 1, and the values are further broken down by job nested within substance in Figure 2. From Figure 1a it can be seen that the bulk of the records refer to ferrous foundry particulate (total inhalable and respirable), dust (total inhalable and respirable) and respirable silica. In fact, these five substances correspond to 70% of the data. Similarly, Figure 1b reveals that moulding and coremaking, melting and fettling are the jobs with the most data available. As noted in Appendix A however, the method used to classify the jobs is somewhat subjective.

Substance	WEL	Unit
Ammonia	25	ppm
Antimony	0.5	mg/m ³
Arsenic	0.1	mg/m ³
Benzene	3.25	mg/m ³
Bismuth	N/A	mg/m ³
Cadmium	0.025	mg/m ³
Carbon monoxide	30	ppm
Cobalt	0.1	mg/m ³
Dimethylethylamine	10	ppm
Dust (respirable)	4	mg/m ³
Dust (total inhalable)	10	mg/m ³
FFP (respirable)	4	mg/m ³
FFP (total inhalable)	10	mg/m ³
Formaldehyde	2	ppm
Furfuryl alcohol	8	mg/m ³
Iron	1	mg/m ³
Lead	0.15	mg/m ³
Magnesium	N/A	mg/m ³
Manganese	0.5	mg/m ³
MDI	0.02	mg/m ³
Nickel	0.5	mg/m ³
Phenol	2	ppm
Propan-2-ol	999	mg/m ³
Silica (respirable)	0.1	mg/m ³
Sulphur dioxide	N/A	ppm
Titanium	N/A	mg/m ³
Toluene	191	mg/m ³
Triethylamine	2	ppm
Vanadium Pentoxide *	0.05	mg/m ³
Xylene	220	mg/m ³

Table 1. Workplace exposure limits and units by substance.

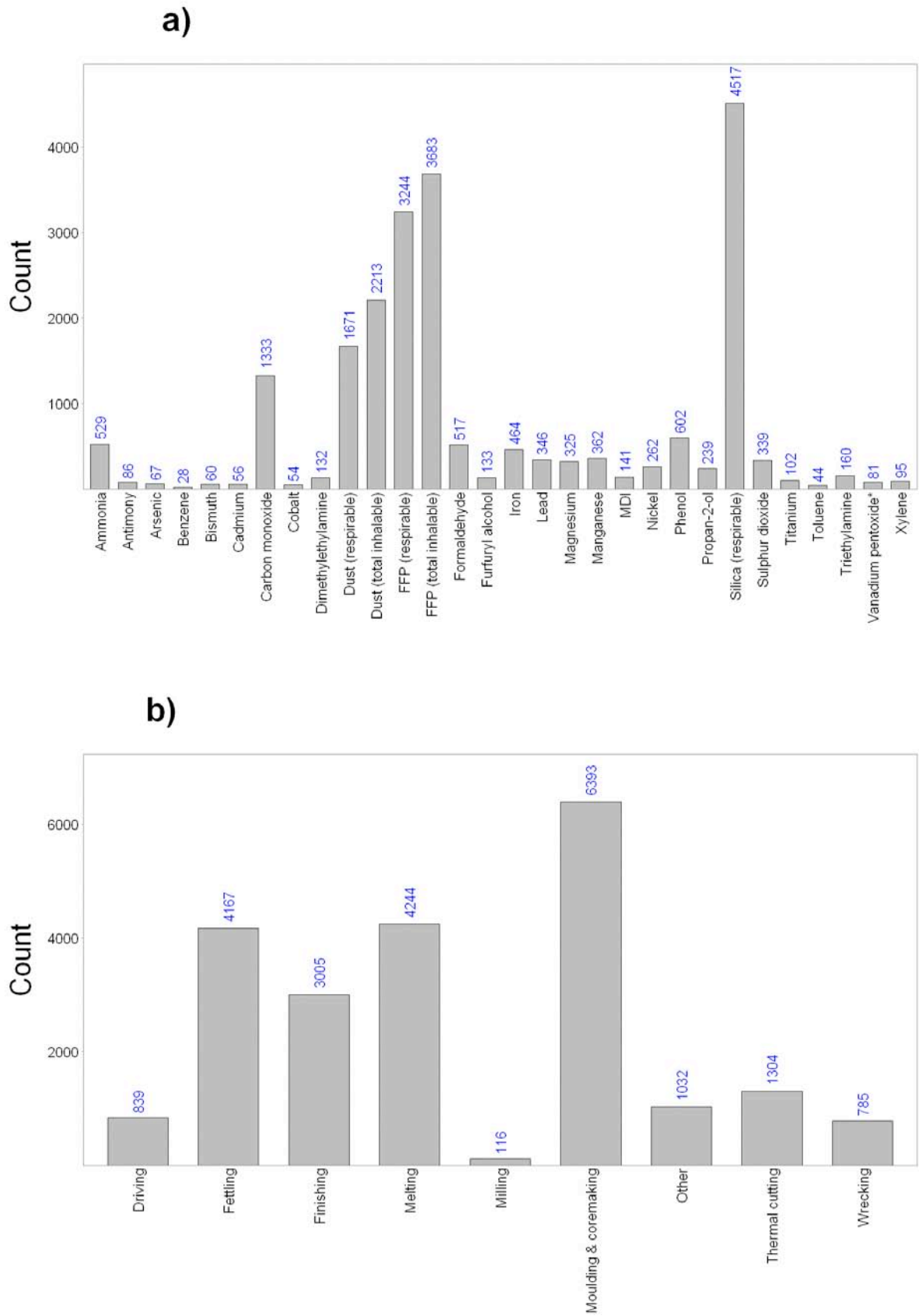


Figure 1. The number of records in the dataset by (a) Substance and (b) Job.

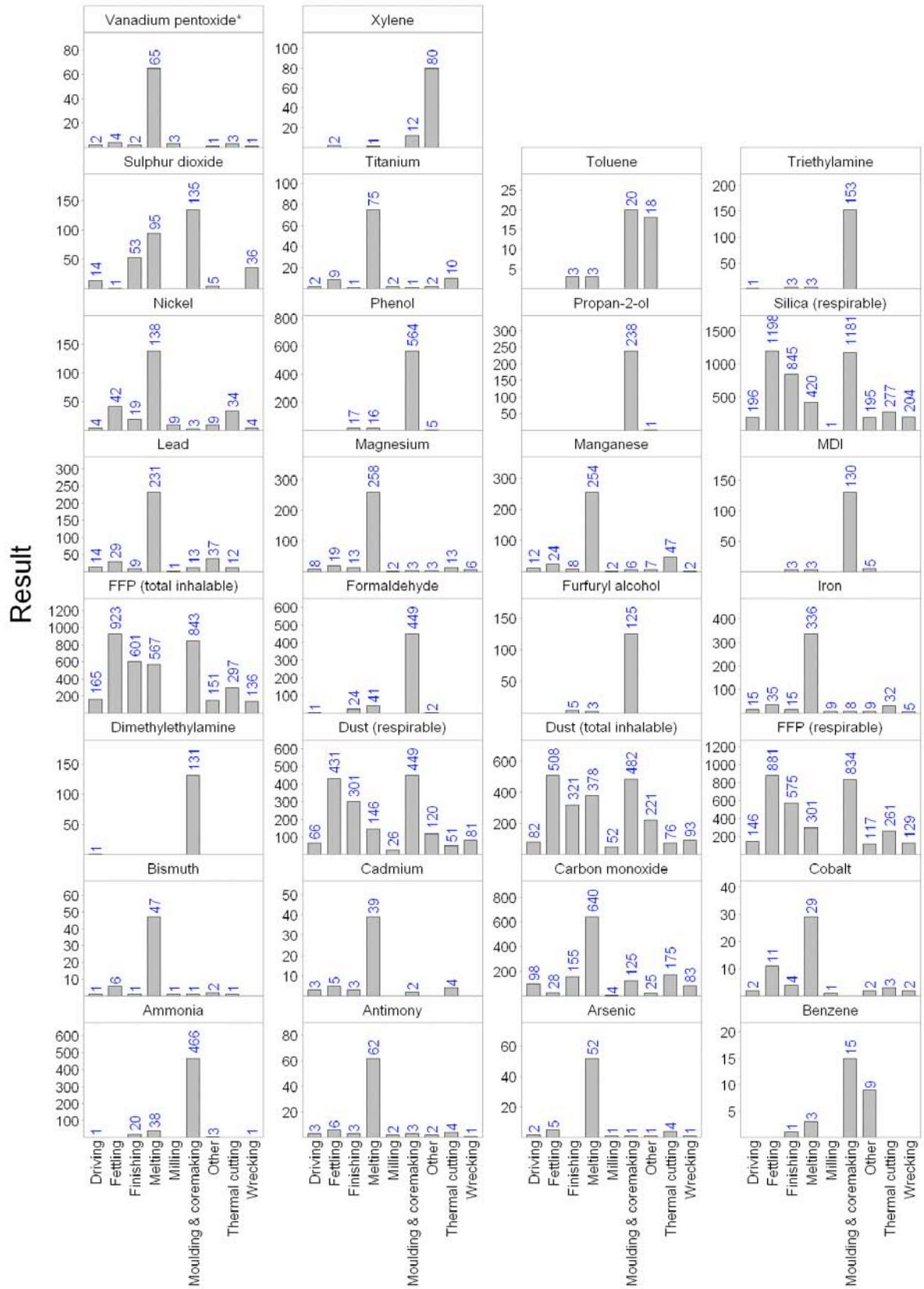


Figure 2. Breakdown of the number of records by job nested within substance.

Figures 3 and 4 show truncated boxplots of exposures divided by job and RPE status respectively, then further by substance. Truncated boxplot means that the whiskers extend to the 10th and 90th percentiles (rather than 1.5 times the interquartile range above and below the 75th and 25th percentiles respectively, as displayed on a standard boxplot). The boxplots have been further enhanced by the inclusion of the maximum exposure, and the WEL for that substance (red dashed line).

The limit of detection depends upon several factors, including the type of equipment used, and the length of sampling time. This means that the LOD is not unique, even within job/ substance combinations (and consequently it is possible for some detected values to be smaller than some of the limits of detection). The largest of the limit of detections for each job/ substance combination is shown as a blue solid line (where applicable). Note that below these lines, the graphs become unreliable since the values of the nondetects are not known. The nondetects are displayed as the limit of detection, so the percentiles shown on the graph below the blue lines are upper bounds of the exposure.

In the statistics presented in Table 2, nondetects were considered to be censored data (as opposed to substituting a value such as half the LOD). The statistics were then calculated using maximum likelihood estimation, assuming a lognormal distribution. See Appendix B for a brief explanation of this method and, for example, Helsel 2004 for a more detailed explanation. Note that for cadmium, formaldehyde and MDI more than half the records were nondetects, so statistics will be less accurate.

For ammonia, antimony, carbon monoxide, dimethylethylamine, formaldehyde, MDI, phenol, propan-2-ol and toluene, less than 10% of exposures were above the corresponding WEL for every job, indicating that exposures to these substances are generally well controlled.

Arsenic, cadmium, dust (respirable), FFP (respirable), manganese and xylene had less than 10% of exposures were above the WEL overall, but more than 10% of exposures above the WEL for some jobs. This indicates that exposures in general are well controlled, but that there are some problem areas.

Benzene, cobalt, dust (total inhalable), FFP (total inhalable), furfuryl alcohol, iron, lead, nickel, silica (respirable) and triethylamine had 10–30% of exposures greater than the WEL, indicating that improvements in exposure control should be considered.

More than 60% of ‘possible’ exposures for vanadium pentoxide exceeded the WEL. This indicates that exposures to this substance are not well controlled, and further review of exposures is needed.

Three of the 38 nondetects for cadmium had a limit of detection that exceeded the WEL. These data are problematic, since it makes it impossible to know exactly how many exposures were greater than the WEL. Without further information on the details of the sampling procedure, it is impossible to determine the reason for these high LODs, though it is likely that they are due to cadmium not being the principal substance of interest in the study. Silica (respirable) and triethylamine also had a single nondetects each where the LOD exceeded the WEL.

HSE guidelines (HSE 2005) state “Before using RPE, exposure should be controlled by reasonably practicable measures other than the use of personal protective equipment (PPE). So [employers] should use PPE only as a last line of protection to control the exposure.” Thus the use of RPE is associated with situations involving higher exposures. This is reflected in Figure 4, where the majority of chemicals display higher exposures where RPE was used.

LEV status was not recorded on 94% of records, and so no clear relationship between exposures and LEV usage could be determined.

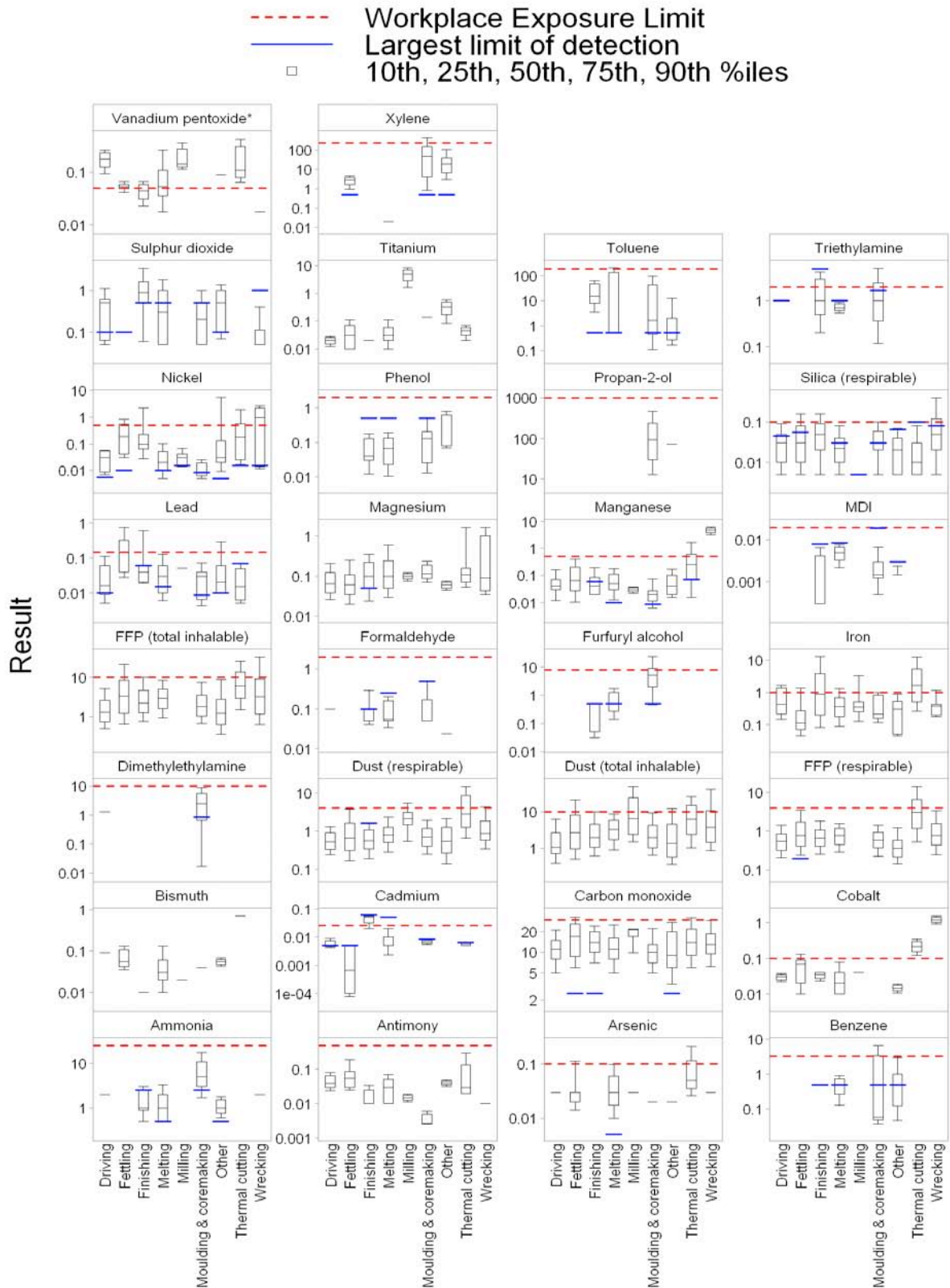


Figure 3. Truncated boxplots of exposure (10th, 25th, 50th, 75th, 90th percentiles) by job nested within substance. Percentiles below the largest limit of detection (dotted blue line) are not reliable.

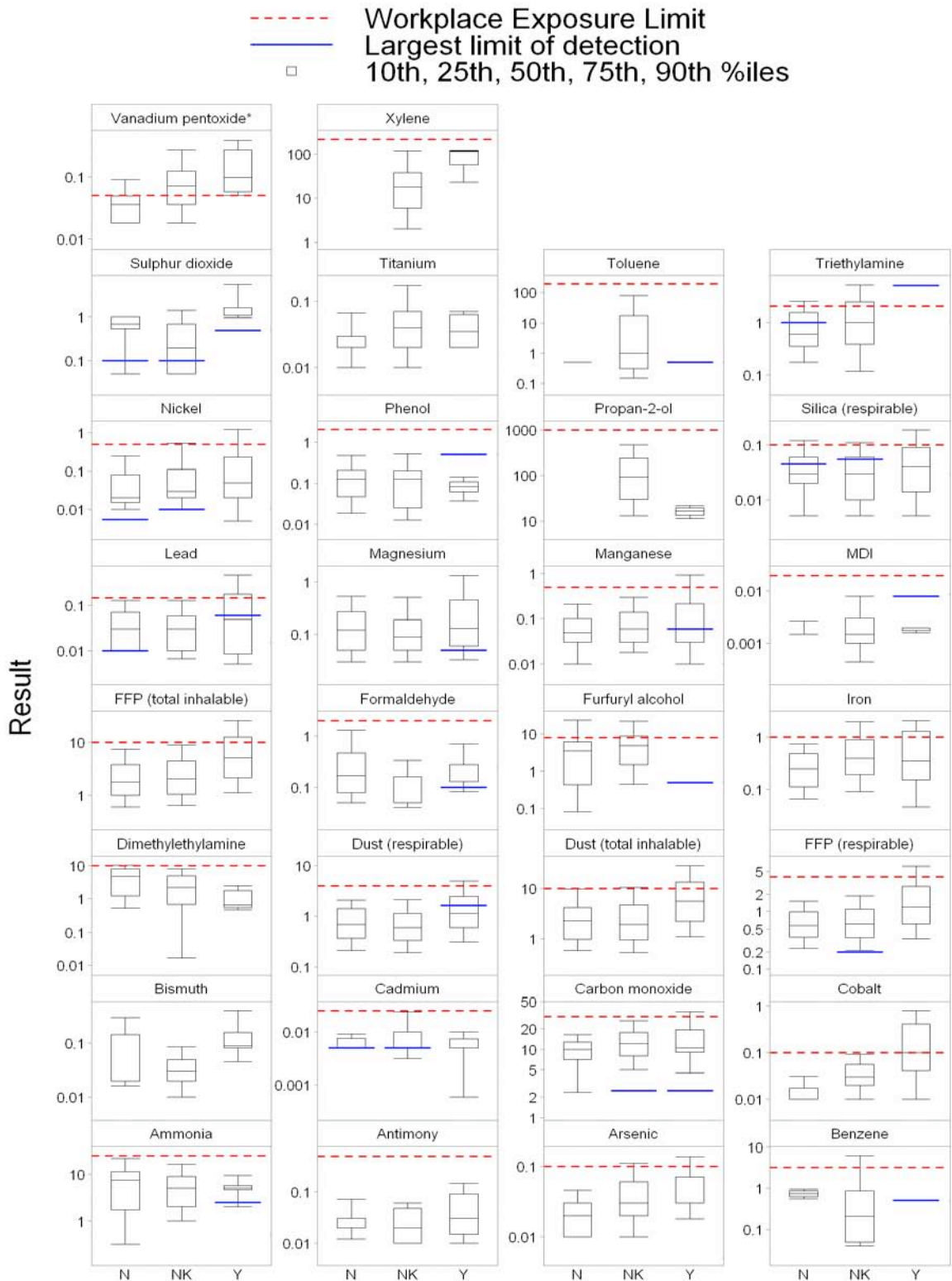


Figure 4. Truncated boxplots of exposure (10th, 25th, 50th, 75th, 90th percentiles) by RPE status nested within substance. Percentiles below the largest limit of detection (dotted blue line) are not reliable.

Substance	Mean	95% Confidence interval for mean	Median	75 th percentile	90 th percentile	95 th percentile	% records exceeding the WEL	Standard deviation	Largest LOD	% nondetects
Ammonia	9.1	(7.9, 11)	4.1	9.6	21	33	4.7	18	2.5	9.6
Antimony	0.046	(0.035, 0.061)	0.027	0.054	0.1	0.15	1.2	0.065		0
Arsenic	0.047	(0.036, 0.061)	0.031	0.057	0.1	0.14	10	0.054	0.005	1.5
Benzene	4.5	(0.48, 42)	0.096	0.62	3.4	9.2	18	213	0.5	46
Bismuth	0.069	(0.049, 0.096)	0.039	0.08	0.15	0.22		0.099		0
Cadmium	0.0086	(0.0035, 0.021)	0.0011	0.0044	0.015	0.031	8.9	0.064	0.06	68
Carbon mono.	17	(16, 18)	11	20	35	48	6.9	18	2.5	0.98
Cobalt	0.089	(0.057, 0.14)	0.04	0.094	0.2	0.32	15	0.18		0
Dimethylethyl.	24	(10, 55)	1.2	6.2	27	67	8.3	477	0.85	13
Dust (resp.)	1.3	(1.2, 1.3)	0.74	1.5	2.8	4.1	6.3	1.8	1.6	0.06
Dust (tot. inh.)	5.8	(5.4, 6.2)	2.6	6.1	13	21	14	11		0
FFP (resp.)	1.3	(1.3, 1.4)	0.77	1.6	2.9	4.2	6.8	1.8	0.2	0.031
FFP (tot. inh.)	5.4	(5.2, 5.7)	2.7	6	12	19	14	9.3		0
Formaldehyde	0.24	(0.18, 0.32)	0.032	0.12	0.42	0.86	0.97	1.7	0.5	58
Furfuryl alc.	21	(11, 39)	2.6	10	36	76	29	170	0.5	16
Iron	0.87	(0.74, 1.0)	0.38	0.9	2	3.2	21	1.8		0
Lead	0.099	(0.076, 0.13)	0.025	0.077	0.21	0.38	12	0.37	0.07	22
Magnesium	0.23	(0.19, 0.27)	0.11	0.25	0.52	0.8		0.41	0.05	0.31
Manganese	0.16	(0.13, 0.19)	0.063	0.16	0.36	0.6	7.2	0.38	0.07	4.4
MDI	0.0011	(0.00060, 0.0022)	0.00011	0.00048	0.0018	0.0039	0	0.011	0.019	87
Nickel	0.29	(0.19, 0.43)	0.043	0.16	0.52	1.1	13	1.9	0.015	13
Phenol	0.27	(0.22, 0.35)	0.053	0.18	0.54	1	1.3	1.4	0.5	33
Propan-2-ol	242	(184, 319)	79	217	538	927	2.5	703	0.5	0.42
Silica (resp.)	0.074	(0.069, 0.078)	0.025	0.068	0.16	0.28	13	0.2	0.75	21
Sulphur diox.	1.5	(1.0, 2.4)	0.14	0.62	2.3	5.2		17	1	40
Titanium	0.075	(0.057, 0.100)	0.04	0.085	0.17	0.25		0.12		0
Toluene	91	(13, 655)	1.2	8.9	53	154	4.5	6673	0.5	20
Triethylamine	4.8	(2.7, 8.5)	0.55	2.2	7.9	17	30	41	5	26
Vanadium P.*	0.11	(0.084, 0.14)	0.065	0.13	0.24	0.35	62	0.15		0
Xylene	102	(52, 200)	15	56	183	374	7.4	692	0.5	5.3

Table 2. Summary statistics to 2 significant figures, by substance.

3 REFERENCES

Helsel, D R (2004). Nondetects and data analysis: Statistics for censored environmental data. Wiley Interscience. ISBN 0-4716-7173-8.

HSE (2005). Respiratory protective equipment at work. HSE Books. ISBN 0-7176-2904-X.

HSE (2007). Table 1: List of approved workplace exposure limits (as consolidated with amendments October 2007). <http://www.hse.gov.uk/coshh/table1.pdf> (An update to EH40/2005: Workplace Exposure Limits. HSE Books, ISBN 0-7176-2977-5.)

Wells, D and Greenall, A (2005). Evaluating the effectiveness of legislation, technology and working methods for reducing occupational exposure in the foundry industry. HSE Books, ISBN 0-7176-6151-2.

4 APPENDIX A—DATA CLEANING

The following procedure was used to filter and clean the original dataset:

1. Records with a visit date before 1 Jan 1995 were removed.
2. Records with ‘static’ in the job field were removed as static samples are generally considered to be less reliable than personal samples. Similarly records with a sample type of “SL” or “SS” (“static long term” and “static short term” respectively) were removed.
3. Records with a job deemed not relevant to foundries were removed.
4. The substance field was cleaned to remove duplicate names for identical substances e.g. ‘xylene’ and ‘xylenes’ were merged.
5. Records corresponding to substances with less than 25 records were removed.
6. Records corresponding to substances of limited toxicological interest (as determined by an occupational hygienist) were removed.
7. Generic job classifications were generated, based upon information in the existing ‘Job name’ and ‘Process name’ fields. The classifications follow those in Appendix 5 of Wells and Greenall 2005 wherever possible.
8. Where records for a substance were mixed between units of mg m^{-3} and ppm, the units were converted to those of the most common type using Equation 1. For example, there were 33 ammonia records recorded in mg m^{-3} and 502 recorded in ppm, so the records reported in mg m^{-3} were converted to ppm. Vanadium pentoxide records actually display maximum possible vanadium exposures. The exposure recorded was to vanadium and then the values were scaled up assuming that all the vanadium measured was vanadium pentoxide, using Equation 2.

Note: There is a degree of subjectivity in steps 3, 6, and 7. A list of jobs deemed irrelevant (and therefore removed in step 3) is given in Table A1 below. A list of substances deemed of no toxicological interest is given in Table A2 below.

Acid bath operator	Loading	Sand laboratory
Blacksmith	Mould handling	Sealing
Cement moulding	Paint buffing/ stripping	(Silver) soldering
Chopping	Paint	Sintering
Drilling sindanyo	Plating	Tinsmith
Etching	Powder cutting auto/ manual	Waxing
FLT pitch dip	Powder painting	Wet grinding
Galvanising	Printing	Wire drawing
Handling carbide	Quench	

Hot die straightening

Rewinding

Table A1. A list of jobs removed in step 3.

Chromium

MMMF

Wood dust

Copper

Oil mist

Zinc

Ethanol

Tin

Molybdenum

Welding fume

Table A2. A list of substances removed in step 6.

$$\text{exposure in } \text{mg/m}^3 = \frac{\text{exposure in ppm} \times \text{molecular weight}}{24.05526}$$

Equation 1: Conversion from parts per million (ppm) to mg m^{-3} .

$$\begin{aligned} \text{exposure to vanadium pentoxide} &= \text{exposure to vanadium} \times \frac{\text{molecular weight of vanadium pentoxide}}{\text{molecular weight of vanadium}} \\ &= \text{exposure to vanadium} \times \frac{181.88}{101.88} \end{aligned}$$

Equation 2: Conversion from vanadium exposure to possible vanadium pentoxide exposure.

5 APPENDIX B—DEALING WITH CENSORED DATA

This appendix contains an informal introduction to the problem of analysing censored data, and the methods used in this report. Technical language has been kept to a minimum—a more formal and thorough discussion can be found in, for example, Helsel 2004.

When measuring chemical exposures it is commonplace to record nondetects. You can't be sure that what you are measuring is not present - all you know is that it is less than some LOD. This means that any statistics that require all the data (such as the mean or standard deviation) cannot be known exactly when there are nondetects.

The simplest way of calculating the statistics is to substitute some value for the nondetects, typically half the LOD. Where there is a large number of nondetects (more than 10%), this method becomes problematic - the substitution of half the limit of detection can cause the mean, standard deviation, and other statistics to be over or under-estimated. An improved method of dealing with the nondetects is to consider the data as censored.

This means making assumptions about how the exposures are distributed in order to make a 'best guess' answer for these statistics. It transpires that in a lot of cases exposures to chemicals follow a lognormal distribution surprisingly well, so this is the assumption made in this report. (Lognormally distributed means that the natural logarithm of the exposures follows a normal 'bell curve'. An example is given in Figure A1.) To find our 'best guess' for the mean and standard deviation, we ask 'what are the most likely parameters of the lognormal distribution that this data was sampled from?' This technique is called maximum likelihood estimation. Once we have the parameters of the distribution, calculating the mean etc., is straightforward.

There are two cases where maximum likelihood estimation doesn't work well. Firstly, if the majority of the data are nondetects, then the parameter estimates are based upon just a few data points in the tail of the distribution, so the estimate will not be as accurate. This results in wider confidence intervals for the statistics. Secondly, the results may not be lognormally distributed (or are a mixture of lognormal distributions). In the case of exposures to chemicals, this usually happens when the population contains control records (e.g. office workers from the same plant, who have zero exposure), which aren't marked as such.

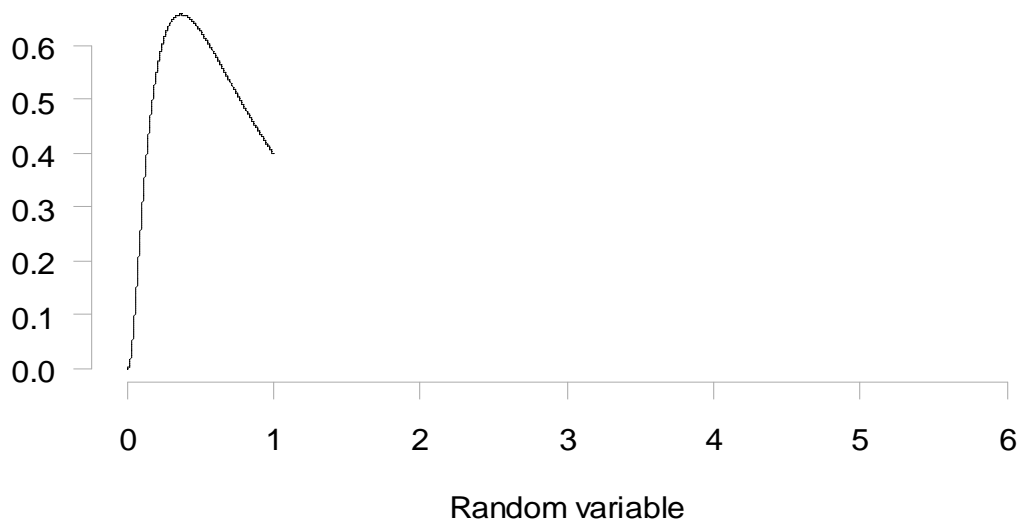


Figure A1. An example of a probability density function (pdf) for a lognormal distribution.

Analysis of CTI Foundry Dataset

This report contains a statistical analysis of an exposure dataset provided by Castings Technology International (CTI). The purpose of the analysis is to provide a 'snapshot' of exposure levels to ferrous foundry particulate and other chemicals, across a range of casting and fabrication related jobs.

The original dataset consisted of 49 994 records comprising of potential exposure level, substance exposed to, the job type, date of measurement, and where known, the use of respiratory protection equipment (RPE) and local exhaust ventilation (LEV).

The dataset was filtered to exclude records which were pre-1995 (since only current or near-current records were of interest), or that related to jobs or substances that were not of interest. Full details of the data cleaning process are given in Appendix A. After filtering, 21 885 records of exposures to 30 substances remained, covering the time period 1995–2004. Based upon the information in the 'Process Name' and 'Job Name' fields in the original dataset, records were classified according to nine generic job types. (The word 'job' refers to these new job classifications throughout the report, unless otherwise stated.)

The analysis provides summary statistics of exposures, stratified by the generic job types and by substance, and compared to current Workplace Exposure Limits (WELs) where appropriate.

This report and the work it describes were funded by the Health and Safety Executive (HSE). Its contents, including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.