Exposure to fumigants and residual chemicals in workers handling cargo from shipping containers and export logs

A study of exposure determinants and neuropsychological symptoms

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Abstract

Fumigants are widely used in shipping containers and on export logs for biosecurity reasons. This thesis aimed to: (i) assess concentrations of fumigants and off-gassed chemicals in closed containers; (ii) identify container characteristics associated with high concentrations; (iii) assess personal exposure levels of workers exposed to these chemicals; and (iv) assess whether exposed workers report more neuropsychological symptoms.

Air samples were collected from 490 sealed containers and at opening of 46 containers, and 193 personal full-shift air samples were collected for 133 container handlers, 15 retail workers, 40 workers loading export logs, and 5 fumigators. Samples were analysed by Selected Ion Flow Tube Mass Spectrometry for several common fumigants and harmful chemicals frequently found in shipping containers. Levels were compared to the New Zealand Work Exposure Standard (WES) and the Threshold Limit Value (TLV). A neuropsychological symptom questionnaire was completed by 274 container handlers, 38 retail workers, 35 fumigators, 18 log workers, and a reference group of 206 construction workers.

Fumigants were detected in 11.4% of sealed containers (ethylene oxide 4.7%; methyl bromide 3.5%). Chemicals other than fumigants were detected more frequently, particularly formaldehyde (84.7%). Some cargo types (e.g. rubber products) and countries of origin (e.g. China) were associated with higher chemical concentrations. Fumigants were detected in both fumigated and non-fumigated containers.

Ambient chemical concentrations in closed and just opened containers regularly exceeded the NZ WES and TLV. Personal exposure measurements never exceeded the NZ WES, although for 26.2% of samples the TLV for formaldehyde was exceeded. Duration spent unloading containers was associated with higher levels of ethylene oxide, C2-alkylbenzenes and acetaldehyde.

Exposed workers were more likely to report ≥10 symptoms, and particularly for the fatigue domain. Longer cumulative duration of unloading containers was associated with more symptoms (Odds Ratio (OR) 7.5, 95% Confidence Interval (CI) 1.7-32.8), and specifically for symptoms in the memory/concentration domain (OR 6.8, 95%CI 1.5-30.3), when comparing the highest exposure duration tertile to the lowest.

In conclusion, while workers' full-shift exposure levels to container chemicals are lower than previously expected (based on the high levels measured in closed containers), they may nonetheless cause long-term health effects.

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Abbreviations

ACGIH	American Conference of Governmental Industrial Hygienists
AMV	Additive Mixture Values
ATF	Accredited Transitional Facilities
ATR	Alpha-To-Theta Ratios
BMI	Body Mass Index
BROHNZ	Building Research in Occupational Health in New Zealand
CI	Confidence Interval
COVID	Coronavirus Disease
EEG	Electroencephalogram
ER	Exposure Ratio
FTIR	Fourier Transformed Infrared Light
GC/MS	Gas Chromatograph Mass Spectrometry
HRC	New Zealand Health Research Council
HRV	Heart Rate Variability
IARC	International Agency for Research on Cancer
IDLH	Immediately Dangerous to Life and Health Limit
LoD	Limit of Detection
MDF	Median Frequencies EEG
MPI	Ministry of Primary Industries
NIOSH	National Institute of Occupational Safety and Health, USA
OEL	Occupational Exposure Limit
OR	Odds Ratio
PID	Photo Ionization Detector
Ppb	parts per billion
PPE	Personal Protective Equipment
REL	Reference Exposure Levels
RIVM	Dutch National Institute for Public Health and the Environment
SD	Standard Deviation
SIFT-MS	Selected-Ion Flow-Tube Mass Spectroscopy
TEU	twenty-foot equivalent units
TLV	Threshold Limit Value
TVOC	Total Volatile Organic Compounds
TWA	Time-Weighted Average
VOC	Volatile Organic Compounds
WES	Workplace Exposure Standard (New Zealand)

1 Introduction, aims and outline of the thesis

1.1 Introduction

Globally, shipping container throughput has risen from 622 to 802 million twenty-foot equivalent units (TEU) between 2012 and 2019.[1] A proportion of these containers requires fumigation either for biosecurity reasons or to prevent damage to cargo. Commonly used fumigants include phosphine (hydrogen phosphide), methyl bromide and ethylene oxide[2], which are toxic to both pests and humans. Many of these chemicals (e.g. methyl bromide, 1,2-dichloroethane) are also known, or suspected, to cause chronic neuropsychological symptoms.[3]

The design of sealed shipping containers allows for only limited natural ventilation during transport.[4] Consequently, fumigants and chemicals off-gassed from cargo or packaging (e.g. formaldehyde, toluene, benzene) may accumulate in the air, potentially reaching unsafe levels for workers unloading or inspecting these containers.[3] Indeed, previous studies found high levels of these chemicals in the air of unopened shipping containers[3, 5-14] and acute poisonings have been reported, ranging from headaches to coma. Poisonings did not only occur in container handlers but also in retail workers and consumers due to the off-gassing of these chemicals from packaging and container goods.[7, 8, 15-17]

However, little is known about what factors affect chemical concentrations in container air, and even less is known about the exposure levels experienced by workers handling containers and/or container cargo, and whether these exposures may cause long-term health effects. Indeed, most previous studies have focused on measuring chemical concentrations in closed containers, with very few studies measuring personal exposure levels in workers entering containers, following some degree of ventilation. As a result, it remains unclear to what extent levels measured in closed containers are representative of workers' personal exposures. Health studies have largely been limited to case-reports of acute poisoning in workers, and only very few studies have assessed whether exposures experienced by container workers are associated with long-term health effects such as neuropsychological symptoms.

Despite international studies raising health concerns, as summarised in Chapter 2, occupational exposure and health studies in workers who handle shipping containers and/or cargo from shipping containers have not previously been conducted in New Zealand. As New Zealand is an island nation that is highly reliant on imports and exports via shipping containers, the container industry employs a relatively large proportion of the New Zealand workforce (approximately 116,100 workers).[18] As a consequence, there is potentially a large number of people at risk, and research to assess exposure levels and associated health risks in New Zealand is therefore urgently needed.

As part of a New Zealand Health Research Council (HRC) funded research programme ('Building Research in Occupational Health in New Zealand' (BROHNZ), HRC reference 11/1041) a cross-sectional study was developed to study exposure levels and neuropsychological symptoms among container handlers. Written consent was obtained from all participants and ethics approval was granted by the Multi-region Ethics Committee of the New Zealand Ministry of Health (MEC/12/02/010) (Appendix 9.5). This thesis presents the results of this study. Besides container handlers the study also included small groups of other workers with potential exposure to fumigants and other off-gassed chemicals, including fumigators, port workers who regularly load fumigated export logs onto ships, and retail workers who unpack container goods.

1.2 Aims

The research described in this thesis aims to fill some of the knowledge gaps related to occupational exposures to fumigants and residual chemicals and neuropsychological health of container, retail and log workers.

The specific aims of the thesis are:

1. To quantify the chemical concentrations in ambient air of shipping containers arriving in New Zealand and comparing the concentrations to New Zealand and international occupational exposure standards (OELs).
2. To assess the effect of container ventilation on chemical concentrations.
3. To assess 8-hour time-weighted average (TWA) airborne personal exposure levels of these chemicals in container handlers, retail workers, log workers, and fumigators, and compare the personal exposure levels to relevant OELs.
4. To assess the association between the duration spent inside shipping containers and 8-hour TWA personal exposure levels.

5. To assess the association between container characteristics (cargo type, country of origin, fumigation status, container size and vents) and chemical concentrations in ambient air of containers.
6. To assess the prevalence and nature of neuropsychological symptoms in container handlers, retail workers, log workers, and fumigators and compare this to a reference group of unexposed workers.
7. To assess the association between the duration of employment in the industry or unloading containers and neuropsychological symptoms.

1.3 Outline

This thesis is based on publications and includes three results chapters (one published, one accepted for publication, and one submitted for publication). The study methods are described in each of these chapters.

Chapter 1 – Introduction, aims and outline of the thesis

This chapter provides a brief introduction to the thesis including some information on the container industry, and the main findings of previous research that raised concern about potential health effects in workers. It also summarises the current knowledge-gaps. The aims are presented, followed by an outline of the thesis.

Chapter 2 – Background and literature review

This chapter provides a background about the container industry and relevant work processes (based in part on personal experience gained while conducting the research field work), describes the chemicals found in shipping containers including fumigants and other residual chemicals, and provides a brief description of commonly used exposure assessment tools and exposure standards. This is followed by a literature review of previous research on chemical concentrations in closed containers, personal exposure levels, and adverse health effects among workers.

Chapter 3 - Airborne fumigants and residual chemicals in shipping containers arriving in New Zealand (published in the Annals of Work Exposures and Health[19])

This chapter provides the methods and results of chemical concentration measurements in air samples from containers arriving in New Zealand ports. The study consists of two parts: (i) a comprehensive analysis of data from a large survey of chemical concentrations in 519 sealed containers representing a random sample of containers arriving in the Port of Tauranga in New Zealand (measurements conducted by New Zealand Customs in 2011); and (ii) a smaller, more detailed, survey on concentrations measured upon opening of 46 containers that arrived at New Zealand ports between 2013 and 2016 (measurements conducted as part of the HRC-funded study). Chemical concentrations were compared to relevant occupational exposure limits (OEL), the associations between container characteristics and chemical concentrations were assessed, and the effect of container ventilation on chemical concentrations was evaluated.

Chapter 4 - Exposures to fumigants and residual chemicals in workers handling cargo from shipping containers and export logs in New Zealand (published in the Annals of Work Exposures and Health[20])

This chapter provides the methods and results of 8-hour TWA personal exposure measurements conducted among 133 container handlers, 15 retail workers, 40 log workers, and 5 fumigators. Air samples were analysed for a range of fumigants and other chemicals using Selected Ion Flow Tube Mass Spectrometry, and the combined toxic effect of all chemicals in a sample was expressed as the additive mixture value (AMV). Personal exposure levels were compared to occupational exposure limits (OEL), and linear regression was conducted to assess associations between work characteristics (such as the duration spent inside the container) and 8-hour TWA personal exposure levels.

Chapter 5 - Neuropsychological symptoms in workers handling cargo from shipping containers and export logs (published in the International Archives of Occupational and Environmental Health [21])

This chapter provides the methods and results of a cross-sectional health survey in 274 container handlers, 38 retail workers, 18 log workers and 35 fumigators. Current (i.e. in the past three months) neuropsychological symptoms were assessed through an adapted version of the EUROQUEST questionnaire, administered face-to-face. The prevalence of symptoms and symptom domains was compared with that of a group of 206 construction workers not exposed to container chemicals (the reference group), using logistic regression adjusting for a range of potential confounders. For the group of container handlers additional analyses were conducted to assess the association between employment duration in the container industry and symptom prevalence.

Chapter 6 - Discussion and conclusions

This chapter summarises the main findings of the research and discusses specific results. It also provides conclusions and practical implication of the research and discusses the strengths and limitations of the research. In addition, recommendations for the industry and future research are provided.

2 Background and literature review

The literature review was conducted using Web of Science and Google Scholar and the following search terms (methyl bromide and health), (phosphine and health), (ethylene oxide and health), (hydrogen phosphide and health), (1,2-dibromoethane and health), Topic=(fumigants) AND Topic= (human health), and Topic=(fumigant) AND Topic=(container). Additionally, research alerts for the citation of specific authors who were known to work in these areas were placed, and references of identified publications were checked. The grey literature was also accessed through Google searches using the same search terms. In addition to the English-language literature, research published in languages for which translation could be provided by any of the research team members were also considered (i.e. German, Dutch).

2.1 Background on the industries and work processes

2.1.1 Shipping containers

Shipping containers are an important part of New Zealand's freight supply chain. They commonly have two sizes, 20ft and 40ft, and two doors, and they may be refrigerated (Figure 2.1).

Figure 2.1 40ft container (R. Hinz)

There are also specialised containers, with different sizes (e.g. 10ft) that may have opening sides, open tops, or doors at both ends, but these are not commonly used. Cargo is loaded into shipping containers overseas, the doors are closed with a Customs seal and shipped to New Zealand. Most containers are then transported by trucks or trains to distribution centers or retail stores. Here the Customs seal is broken, the doors opened, the container ventilated, and the goods unloaded. The containers are ventilated naturally (opening of the doors to let outside air circulate), or by using a fan (positioned in front of the open doors blowing air towards the cargo), or by commercial extraction units. The latter are only rarely used in New Zealand and overseas.[3] Containers that have not been fumigated are naturally ventilated for 5 to 15 minutes and most containers are located outside during this time. For containers that have been fumigated, longer ventilation periods are applied with the duration determined by the fumigator and displayed at a notice outside the container (Figure 2.2). Although the labelling of fumigated containers is strictly enforced in New Zealand, previous studies observed a lack of labelling on containers which were recently fumigated overseas.[4, 16, 22-24] Suggested reasons might be avoidance of additional cost and possible delays for importers.[22, 23]

Figure 2.2 Certificate of Clearance after fumigation (R. Hinz)

Workers opening and unloading containers generally do not use personal protective equipment (PPE), except for gloves and steel capped boots.

There is very little air exchange in closed containers, as this can occur only through 2 or 4 ventilation slots (vents) on the top of the containers (Figure 2.3) or through broken rubber seals of the doors.

Figure 2.3 Ventilation slot (vent) outside a container (R. Hinz)

This lack of air exchange allows harmful chemicals, from previous fumigation and/or off-gassed from the cargo, to accumulate in the container, the packaging, or the actual goods. Fumigants found in containers may include 1,2-dibromoethane [CAS No. 106-93-4], chloropicrin [76-06-2], ethylene oxide [75-21-8], hydrogen cyanide [74-90-8], hydrogen phosphide [7803-51-2], and methyl bromide [74-83-9]. Other commonly measured harmful chemicals include: 1,2-dichloroethane [107-06-2], C2-alkylbenzenes [108-38-3, 95-47-6, 106-42-3, 100-41-4], acetaldehyde [75-07-0], ammonia [7664-41-7], benzene [71-43-2], formaldehyde [50-00-0], styrene [100-42-5], and toluene [108-88-3].[4, 8, 11, 15, 22]

2.1.2 Occupational groups working with shipping containers

The unloading of containers is done manually and/or by using forklifts depending on the cargo. Container handlers may consequently be exposed to airborne chemicals in the container. Containers are usually unloaded from the front (where the doors are positioned) to the rear. However, sometimes workers ‘tunnel’ into the container to retrieve a specific good, which has the potential to expose them to pockets of high concentration in the rear of the container (Figure 2.4).

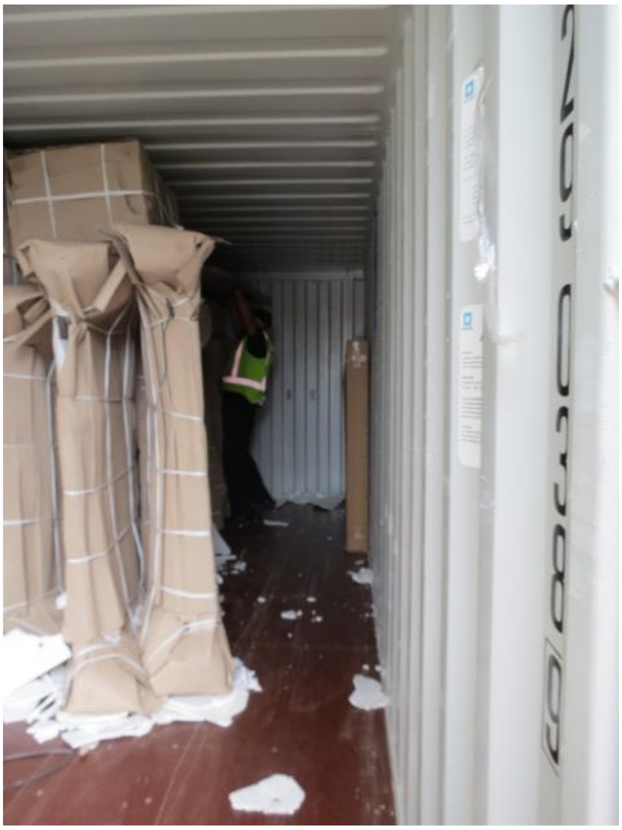


Figure 2.4 ' Tunnelling' into a container showing how workers may be exposed to air pockets trapped in the back of the container (R. Hinz)

How long workers spend unloading the container depends on the cargo type (e.g. driving two cars out of a container would only take a few minutes (Figure 2.5) and whether the cargo is unloaded by hand (Figure 2.6) or a forklift (Figure 2.7).

Figure 2.5 Cars transported in containers (R. Hinz)

Figure 2.6 Container requiring unloading by hand (R. Hinz)

Figure 2.7 forklift unloading (R. Hinz)

In addition to unloading containers, workers may also remove bulk packaging from goods such as goods stacked on pallets and wrapped in plastic, during which trapped chemicals can be released (Figure 2.8).

Figure 2.8 Cargo staked on pallets and secured with shrink wrap and unloaded by forklift (R. Hinz)

Customs officers and biosecurity inspectors may also be exposed to airborne hazardous chemicals from containers, especially biosecurity inspectors because containers arriving in New Zealand require bio-security inspection immediately after opening of the doors. This inspection is either done by staff from the Ministry of Primary Industries (MPI) or specifically trained and certified staff in the distribution centers or retail stores. Exposure to chemicals from containers may also occur among other occupational groups, including truck drivers and workers handling the cargo, even days after being unloaded.[7, 11, 25]

2.1.3 Fumigation processes

Shipping containers are considered high-risk carriers of pests. Pests may hide in the cargo, in packaging materials, wooden pallets and on parts of the container itself.[26] Hence, for bio-security reasons some overseas containers arriving in New Zealand require fumigation, which is done either overseas or in New Zealand (or both). Fumigants are toxic, volatile gases that can penetrate packaging and goods. They do not provide long-term protection, and pests entering after fumigation may not be killed. Besides imported goods, export goods may also require fumigation, especially export logs from New Zealand require fumigation on the request of the importing countries. Fumigation of logs is either done in New Zealand by licensed fumigators or during the voyage when the fumigation is done in the ship's hold.

Methyl bromide and phosphine are the most commonly used cargo fumigants in New Zealand.[27] Overseas, sulfuryl fluoride is also used, mainly for used car imports. Methyl bromide production or importation for use was to cease in 2005 under the terms of the Montreal Protocol, a United Nations agreement on ozone depleting substances.[28] However, New Zealand worked under an exemption agreement and continued the use of methyl bromide with export forest products accounting for about 94% of methyl bromide use.[29] By 2035 all methyl bromide used for fumigation needs to be recaptured and destroyed.[30] The industry is working on improving recapture technology and the use of alternative fumigants, which requires approval from the Environmental Protection Authority.[31]

Before any container is fumigated, the fumigator must ensure the air tightness of the container to maintain the prescribed concentration of fumigant in the container and to avoid potential exposure to the outside environment. For this reason, the ventilation shafts of the containers are taped with impervious tape (Figure 2.9).

Figure 2.9 Taped vent (R. Hinz)

Methyl bromide, which is liquid under pressure and stored in canisters, is applied through a vaporiser into the container until a prescribed concentration is reached and then left for a prescribed exposure period. The concentration and exposure period depend on the cargo, size of the container and potential pest species. Concentration and exposure duration are prescribed by MPI or for export goods by the bio-security regulations of the importing country. A fan is used to distribute gas evenly throughout the container. At the end of the fumigation period the container is ventilated until concentrations drop at least below the occupational exposure limit (OEL) of the fumigant used. Before release of the container a ‘Certificate of Clearance’ stating the recommended period of ventilation before unloading the container is attached to the outside of the container doors (Figure 2.2). This additional ventilation is necessary because once the doors of the container are closed, methyl bromide, which previously may have been absorbed by the cargo/packaging, may off-gas and accumulate in the container air. For phosphine fumigation either aluminum phosphide or magnesium phosphide tablets or pellets are placed in the container either in disposable trays or sachets (Figure 2.10).

Figure 2.10 Phosphine tablets (copyright Wikipedia)

Phosphine gas is produced when the tablets or pellets react with atmospheric moisture. The exposure period typically lasts from 4 to 17 days. Phosphine is also available as a gas and applied in a similar way as methyl bromide. After fumigation, the gas must be vented to the legal level for human exposure.[32]

For cargo not enclosed in containers (e.g. export logs), tarpaulin or tent fumigation is used to create temporary fumigation enclosures, using gas proofed sheets to surround the consignment and to retain the fumigant in the enclosure. To seal the enclosure and to prevent the sheet from blowing off, two rows of sand or water snakes surrounding the enclosure are laid on the sheets along the ground (Figure 2.11 – Figure 2.19).

Figure 2.11 Tarpaulin getting rolled off with a metal rope (R. Hinz) – arrows at rope

Figure 2.12 Straightening out tarpaulin (R. Hinz)

Figure 2.13 Stretching out tarpaulin over log stack. Note methyl bromide introduction tubes and measuring tubes run from the stack to the orange cone (R. Hinz)

Figure 2.14 Rolling tarpaulin over log stack (R. Hinz)

Figure 2.15 Filling and placing water snake to seal enclosure (R. Hinz)

Figure 2.16 Tubing running out of enclosure (R. Hinz)

Figure 2.17 Tubing connected to methyl bromide canister on the back of the Ute (R. Hinz)

Figure 2.18 Log stacks under fumigation at a port (R. Hinz)

Figure 2.19 Previously fumigated logs being loaded into the hold of the ship. Logs are getting spray painted to mark which part of the cargo is getting unloaded at the first port before transiting to the next port for unloading (R. Hinz)

After fumigation is completed, the water snakes are removed, except for a few down both sides of the enclosure to weigh the tarpaulin down. The sheet is subsequently lifted on both corners to no more than waist height and secured. This is done first on the downwind site so the wind cannot lift it off before the fumigator is ready. This procedure is repeated at the upwind end and then the sheets are pulled out on the sides. The few sand snakes left down the sides will hold sheets in place creating a wind tunnel effect. The wind tunnel remains for 5 to 10 minutes until most of the fumigant has dissipated after which the sheet is removed entirely. During the venting process fumigators use respiratory protective equipment and carry measurement devices. An exclusion zone is created and relevant authorities are informed before fumigation starts. [33, 34] If logs are fumigated at a New Zealand port, the logs must be loaded in a time frame specified by the importing country and this can be as short as 24 hours.[35]

All fumigators in New Zealand are required to have a controlled substance license, be an approved handler under the Hazardous Substances Act 1996 and be a Ministry for Primary Industries approved treatment supplier.[36]

2.1.4 Effectiveness of container ventilation prior to unloading

A small number of studies have investigated the effectiveness of different methods of container ventilation, summarised below.

A Swedish study evaluated three ventilation methods using tracer gas and measurements taken 12 meters into a 40 ft container tightly packed with cardboard boxes containing consumer goods.[37] Natural ventilation ('passive ventilation') and fan ventilation ('blowing') had little impact on gas levels, while forced extraction ventilation (a fan extracting air from the back of the container and fresh air entering via the doors) using non-commercial equipment resulted in rapid reduction of the gas (Figure 2.20). The authors concluded that current container design makes safe and speedy sampling and ventilation prior to opening the doors technically difficult.

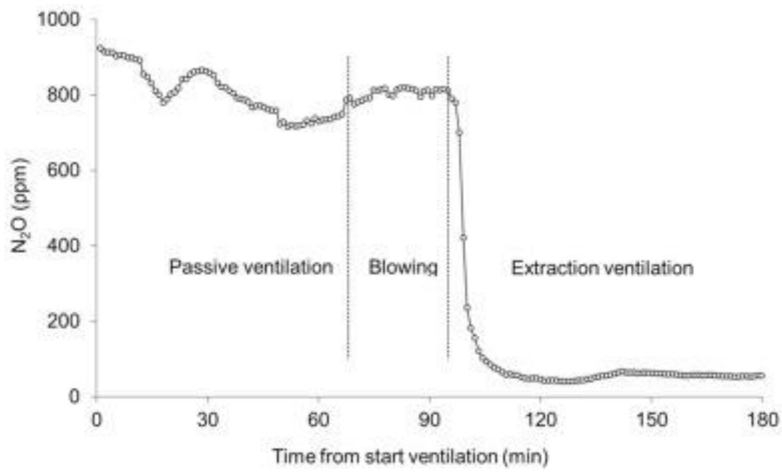


Figure 2.20 Effect of different types of container ventilation by using tracer gas as an indicator. Copyright ELSEVIER [37]

A similar study examined container ventilation processes using tracer gas measurements and numerical airflow simulations.[38] Three sets of container ventilation conditions were investigated: natural with or without an additional fan; mixed mode ventilation, which combined the opening of the door with mechanical air supply or extraction through an orifice drilled in the rear wall; and forced ventilation where the door remained closed, and air introduction and extraction were performed through orifices in the container walls. Container size, degree of filling of the container and cargo type were also considered. The efficiency of natural ventilation was highly variable especially in containers positioned outside, depending on environmental conditions, particularly wind velocity and direction. The authors observed that the ventilation rate decreased towards the rear of the container. Using an additional fan increased the ventilation rate indoors but it was variable and even counterproductive when the container and the fan were positioned outdoors, and the rates were dependent on wind direction and velocity. Under mixed mode ventilation, ventilation times when using the rear wall orifice as an extraction outlet proved to be markedly shorter than those obtained with this orifice used as an air supply inlet. When using forced ventilation, the ventilation rate was proportional to the applied flow rate. Additionally, the ventilation rate depended largely on the location of the air supply, with the most favourable location being above the cargo. The authors also noted that vertical gaps between the cargo increased the ventilation rate. The authors concluded, although concentrations may be lower, the risk of elevated exposure continues to be present under natural and mixed mode when the doors are opened, or when ventilation occurs in an enclosed area.

A Swedish study described a novel ventilation approach based on extraction of air from the closed container via the existing top corner vents, creating negative pressure inside the container.[37] A suction plate was developed to fit tightly over the corner vents of the container and connected with a flexible hose to an extraction fan. The study used experimental conditions (20ft containers loaded with acetone emitting cardboard boxes) and field trials (40 ft containers). Volatiles in container air were continuously recorded with Photo Ionization Detectors (PIDs) in various positions before, during and after ventilation. Using experimental conditions, after 1 and 4 hours, the initial acetone levels were reduced to 11% and 4.9%, respectively in a tightly packed container, and to 6.0% and 3.1% in a loosely packed (pallets) container at an air flow 100 m^3/h. The reduction was less when measured in nine 40ft field containers, where levels reached 22% and 11%, respectively. In both experimental and field containers the concentration rose quickly when ventilation ceased. The authors concluded that the new ventilation method allows for convenient, safe, and efficient ventilation of high-risk containers but that a container should be continuously ventilated until it is opened, or rapid re-accumulation of volatiles will occur.

2.1.5 Legislative and regulative framework for fumigation

The most important international regulations to provide the overarching framework for safe work are[3] the International Labour Organization (ILO) Convention 155 - Occupational Safety and Health Convention;[39] Occupational Safety and Health Recommendation 164;[40] and the EU Directive 89/391/EEC.[41] However, these are not specific to fumigation. The ILO “Code of Practice on Safety and Health in Ports” (revised, 2016)[42] is more specific for working with shipping containers. It recommends that no container should be entered unless the atmosphere inside is confirmed to be safe and not to rely on the absence of dangerous goods or fumigation warning signs, or on previous ventilation (6.3.6.1 Opening containers). The “Code of Practice for Packing of Cargo Transport Units” (CTU Code),[43] a non-mandatory global code, provides information about the risks from harmful substances in containers and how to manage these, including recognising clues of potential high chemical concentrations (e.g. taped vents), ventilation prior to entering the containers, labelling of fumigated containers and potential options to measure chemicals in containers (Chapter 12 and Annex 5). However, it is acknowledged that there is no single device available that can detect all hazardous substances.

In New Zealand, the management of fumigants and their use in fumigation is controlled under the Hazardous Substances and New Organisms Act 1996,[44] while the Health and Safety at Work (Hazardous Substances) Regulations

2017[45] regulate how hazardous chemicals are stored, disposed and used in workplaces. Compliance activities for both regulations are undertaken by WorkSafe New Zealand.[46] In the Health and Safety at Work (Hazardous Substances), Regulations 2017 Chapter 14 regulates the fumigation process, with a focus on outcomes, while the “Code of Practice Fumigation”,[46] which is not mandatory and set out by the Pest Management Association of New Zealand (Inc), describes how compliance may be best achieved. The WorkSafe New Zealand industry guidance, “Keeping safe from harmful substances while inspecting or unpacking containers”,[47] provides advice specifically to container handlers and inspectors about hazardous chemicals in shipping containers, and is described in more detail below.

2.1.6 Guidelines on safely unloading shipping containers in New Zealand

Studies have pointed out the need to establish improved and standardised strategies for the safe inspection and unpacking of shipping containers[3, 4, 11, 48, 49]. In New Zealand, companies are responsible for the health and safety of their employees and WorkSafe New Zealand published a guide on ‘Keeping safe from harmful substances while inspecting or unpacking containers’, containing a flow chart (Figure 2.21) on how to safely unload and inspect containers.[47]

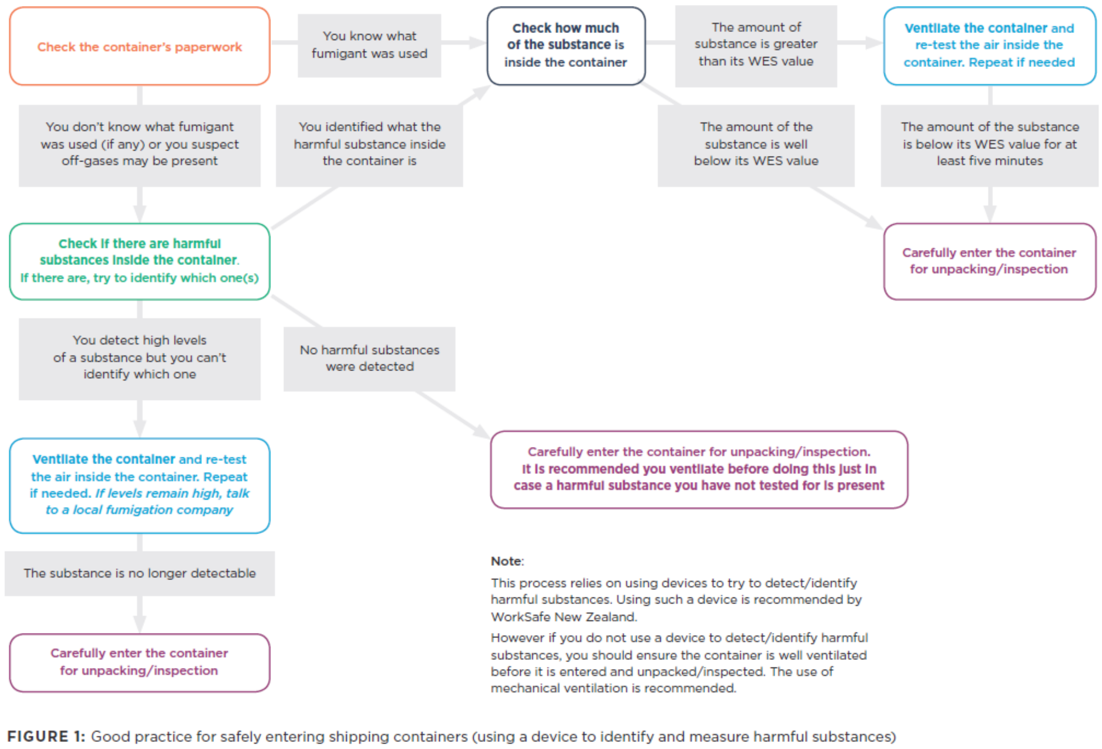


Figure 2.21 WorkSafe New Zealand: Good practice for safely entering shipping containers.[47]

The flow chart assumes that harmful chemicals in the container air can be measured and suggests that suitable measuring devices are colorimetric gas detection tubes, PIDs, portable mass spectrometers and electrochemical sensors. Colorimetric gas detection tubes detect concentrations of specific chemicals and consequently the chemical of interests needs to be known before testing. Hence, these tubes are useful when testing containers known to be fumigated with a known fumigant as recorded by the fumigator. However, this is often not the case, particularly for containers that are not fumigated in New Zealand. A PID monitor estimates the total concentrations of the combined volatile organic compounds present inside a container. As a result, PIDs do not identify specific chemicals. Also, some OEL levels are set below the Limit of Detection (LoD) of most PIDs (1000ppb) thus resulting in measurements that may not be able to protect workers from hazardous exposures e.g. the WES for chloropicrin and ethylene oxide is 100 ppb, for phosphine it is 300 ppb and for formaldehyde it is 500 ppb. Of interest, the WES for 1,2 dibromoethane is set 0.3 ppb, which is below the detection limit of any current measurement device.[50] Finally, PIDs may provide false positive findings[4] leading to delays in unloading the container. This is the case when volatiles are present at very high levels, but with low toxicity (e.g. methanol).

Portable mass spectrometers and electrochemical sensors are able to detect a multitude of chemicals, but they are expensive, require staff with highly specialised training in analytical chemistry for the maintenance and operation of these devices, and some chemicals may not be detectable by the instrument e.g. sulfuryl fluoride.

Thus, due to a lack of suitable devices that are affordable, specific, sufficiently sensitive, and that can be operated by container handlers or management, companies will likely not be able to apply the recommended guidelines.[3, 11, 22, 49] If a measuring device is not used, the guidelines recommend ventilating the container, using mechanical ventilation, but a safe time period for ventilation is not prescribed. Due to these limitations, workers will likely continue to work in an environment with the risk of elevated exposures and associated health risks.

2.1.7 Risk assessment and risk indexation

To facilitate risk classification of containers, risk evaluation and risk indexation systems of chemical concentrations in closed containers have been established at some major ports in European countries.[3, 23, 51-53] This involves dedicated staff at each port to take air samples from closed containers, which are tested for several chemicals using several measurement devices. As 100% safety would require measuring 100% of all containers, a risk indexation system is used to reduce the number of measurements needed. The risk index is created from measurements of harmful substances and associations with cargo type, supplier, and country of origin. The containers are then classified into several risk categories. The frequency of sampling in each category is then determined by the risk classification.[53] The findings are reported back to the importer, which in turn may lead to production changes by the importer e.g. using solvent free glue in the production of shoes. Some of the ports also have commercial ventilation facilities. The efficacy of these systems has not been tested but are likely to contribute to reduced exposures in container handlers in these ports. In New Zealand, these systems have not been employed and it appears this is not currently being considered by the industry or WorkSafe New Zealand.

2.1.8 Workers' knowledge of potential health risks

Three studies investigated container workers' knowledge regarding the potential risks associated with chemicals in shipping containers, and how to mitigate these risks.

An Australian report conducted a hazard survey in 21 workers and informal discussions were held with five experienced managers and 15 workers in 2011.[24] About 70% of the workers had completed specific work health and safety training on unpacking shipping containers. None knew much about the risks of chemical concentrations in containers, but 67% knew a little.

Preventative measures taken were extract chemicals using extraction units for longer than 30 minutes (4.8%), using natural ventilation for more than 12 hours (9.5%), test the air in the container with an (unspecified) device (14.3%), wear (unspecified) PPE (33.3%), and partially unpack container followed by period of venting and then unload remaining goods (23.8%). The most significant reasons for not taking safety precautions were lack of training (33%), and lack of awareness that the container atmosphere may contain harmful chemicals (29%). Although most workers had received work health and safety training, there was still a large degree of uncertainty regarding the risks associated with fumigated containers and workers' ability to identify such containers. As the number of workers who completed the surveys was low, the authors suggested that the results should not be used to make generalisations for the wider industry on health risks and prevention practices during handling of containers.

The practice of handling containers was investigated in a qualitative study in Denmark based on semi-structured interviews with nine key informants, including managers and health and safety representatives of organisations that handle containers.[49] The interviewees estimated the frequency of containers with harmful chemicals to be between 5 to 50%, although recognisable health effects were suggested to be rare. The authors concluded there was limited knowledge about the types of chemicals that can be released into the container air, even in occupational health professions. Ventilation of the container (2 to 48 hours) and use of PPE were listed as preventive measures. However, the use of PPE was inconsistent, and the masks used were dust masks that do not adequately protect from chemical exposure. The interviewed managers were aware of the existence of relevant international and national regulations but were typically not able to specify them, but interviewees were more familiar with the local instructions. However, these lacked detailed risk assessment and risk management instructions. Due to the small number of participants in the study, the authors stated that their findings could only, and with caution, be applied to the Danish context.

A Hungarian study of knowledge and attitudes to workplace chemical exposures found that in 122 warehouse workers in the logistics industry, most workers (62.3%) had never heard about harmful chemicals in warehouse settings without dangerous goods.[54] Workers who completed health and safety training specifically adapted to their workplace (31.8 %) had more detailed knowledge relating to this workplace issue (Odds Ratio (OR) 8.18; 95% Confidence Interval (CI) 3.47–19.27), and they were significantly more likely to use certain preventive measures if available. These measures were: checking the documentation of potentially polluted transport devices (OR 5.49; 95%CI 2.13–14.14), opening transport devices taking reasonable care to avoid the exposure to pollutants (OR 7.16; 95%CI 2.78–18.44), using a blower or extractor to remove chemical pollutants (OR 8.90; 95%CI 1.96–40.27), and using natural ventilation to remove pollutants (OR 2.48; 95%CI 1.03–5.96). This study was adjusted for sex, age and time spent in the company.

In conclusion, these studies show that knowledge of chemical exposures at the workplace among workers is low and that an increase in knowledge would likely increase the uptake of preventative measures if available.

2.2 Shipping container chemicals and their toxicity

The following paragraphs list the specific chemicals that have commonly been found in shipping containers. Information about acute toxicity is also briefly described (health effects observed in container handlers exposed to these chemicals are summarised in section 2.4).

2.2.1 Fumigants

A limited number of fumigants are commonly used in shipping containers (Table 2.1). As noted earlier, fumigants are used for pest control for bio security reasons and may also be used in storage facilities to avoid spoilage of food commodities, in holding facilities e.g., silos and ship holds, to eradicate pests from other structures such as houses, and in horticulture as soil disinfectant.

Because their function is to kill pests, all fumigants have toxic properties (Table 2.1), and human exposure may result in acute health effects.
Symptoms of acute fumigant poisoning include: salivation, rhinitis, weakness, fatigue, headache, tremor, fast heart rate and arrythmia, anaemia, shock, abdominal symptoms (nausea, vomiting, abdominal pain and jaundice), pulmonary symptoms (chest tightness, dyspnoea, wheezing, cough, cyanosis, pulmonary oedema), and neurological symptoms (paraesthesia, impaired vision, impaired speech, incoordination, lethargy, hallucinations, confusion, intoxication, fainting, convulsion, fainting delirium).[55]

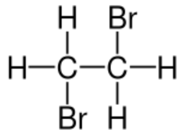
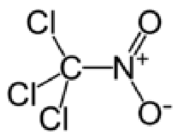
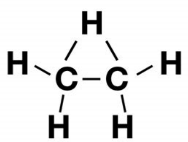
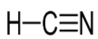
Chemical asphyxiation may also occur, which blocks the delivery of oxygen to the cells and may lead to cardiac arrest. Symptoms associated with chemical asphyxiation are nausea and vomiting, weakness, dizziness, headache, dyspnea, fast or slow heart rate and arrythmia and neurological symptoms (incoordination, confusion, intoxication, convulsion, unconsciousness, and coma).[55]

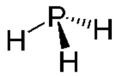
Exposure to fumigants may also result in pneumonitis, of which the most common symptoms are pharyngitis, rhinitis, and respiratory symptoms (chest tightness, dyspnea, wheezing, cough cyanosis, pulmonary oedema). Pulmonary oedema may be delayed for up to 24 hours after exposure. In addition, fumigants may cause acute skin, eye and respiratory tract irritation, and, in high enough concentrations, death.[55, 56]

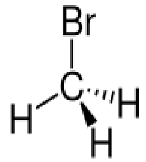
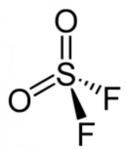
2.2.2 Other residual chemicals

Other chemicals that may commonly be found in shipping containers are listed in Table 2.2. Some of these are occasionally also used as fumigants (e.g., ethylene oxide, formaldehyde, 1,2-dichloroethane, carbon monoxide and carbon dioxide), but their presence in shipping containers is more commonly the result of off-gassing from cargo or packaging materials. Many of the chemicals listed in Table 2.2 are solvents and may result in solvent poisoning. The main symptoms of solvent poisoning are dizziness, fatigue, headache, arrythmia and neuropsychological and neurological symptoms (difficulty concentrating, irritability, impaired speech, incoordination, lethargy, confusion, intoxication, unconsciousness, and coma).[55, 56]

Table 2.1 Fumigants commonly used in shipping containers and their properties (from Haz-Map[55] and PubChem[56])

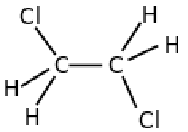
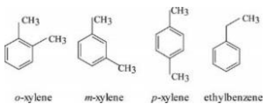
Name/ Synonyms	chemical description	olfactory detection	commercial use	acute health effects	chronic health effects
Fumigants					
1,2-dibromoethane ethylene dibromide	$C_2H_4Br_2$ or $Br(CH_2)_2Br$ 	chloroform-like odour	used as a fumigant of logs for termites and beetles, control of moths in beehives used to make dyes and pharmaceuticals, as a solvent and as a scavenger for lead in leaded gasoline	fumigant poisoning, solvent poisoning, acute liver, spleen, and kidney damage	male infertility International Agency for Research on Cancer (IARC) Carcinogen: probable
chloropicrin trichloronitromethane	CCl_3NO_2 	strong irritating odour	used as a grain, crop, and soil fumigant particular strawberries and a warning odorant for odourless fumigants and gases. used in the past as warfare agent	fumigant poisoning, pneumonitis,	chronic bronchitis ACGIH Carcinogen: not classifiable
ethylene oxide	C_2H_4O 	sweet ether-like odour	used as a fumigant to control insects in some stored agricultural products. used to manufacture other chemicals and to sterilize medical equipment and supplies.	fumigant poisoning, pneumonitis symptom onset may be delayed by 6 hours or more after exposure.	sensorimotor polyneuropathy, asthma, cataract (chemical induced), contact dermatitis, miscarriage IARC carcinogen: established
hydrogen cyanide prussic acid	CHN or HCN 	strong pungent bitter almond-like odour the ability to smell cyanide is a genetically determined	used to fumigate enclosed spaces e.g. ships, railroad cars, buildings. used to manufacture nylon and other chemicals and	chemical asphyxiant, fumigant poisoning,	ACGIH Carcinogen: not classifiable

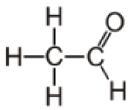
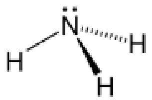
		trait, absent in 20% to 40% of the population.	used in the following processes: electroplating, metallurgy, and photo development. is a by-product of blast furnaces, coke ovens, photo engraving, petroleum refining, and some metal mining processes, released when burning nitrogen containing compounds, e.g. wool, silk, and plastics.		
phosphine hydrogen phosphide	H_3P or PH_3 	odour of fish or garlic	used as a fumigant of grains, animal feed, and leaf-stored tobacco. used in in microelectronics manufacturing. law enforcement officers dismantling methamphetamine production labs have died from inhalation of phosphine.	fumigant poisoning, pneumonitis, affecting the cardiovascular system causing peripheral vascular collapse leading to cardiac arrest later symptoms are acute respiratory distress syndrome, acute renal failure, and acute hepatitis. convulsions may ensue after an apparent recovery.	methemoglobinemia (a form of haemoglobin which does not release oxygen to the cells. If its production is increased, it will replace normal haemoglobin resulting in oxygen deprivation to the cells) ACGIH Carcinogen: not classifiable
methyl bromide	CH_3Br	usually odourless, but has a sweetish chloroform-like	used to sterilise soil to control fungi, nematodes, and weeds. in fumigation of	fumigant poisoning, pneumonitis	long-term neuromuscular and cognitive deficits,

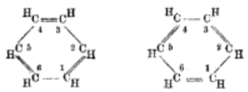
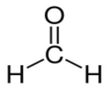
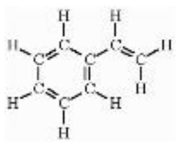
bromomethane		odour at high concentrations	food commodities (e.g., grains); and in storage facilities (such as mills, warehouses, vaults, ships, and freight cars) to control insects and rodents. used in the manufacture of other chemicals and as a solvent to remove oil out of nuts, seeds, and wool.	symptom onset may be delayed by 1 hr up to 48 hrs after exposure.	neuropsychological function impairment IARC Carcinogen: not classifiable
sulfuryl fluoride sulfonyl fluoride sulfuryl difluoride Vikane®	F_2SO_2 or SO_2F_2 or F_2O_2S 	odourless	used as an insecticide and fumigant in storage buildings to control insects and rodents.	fumigant poisoning, pneumonitis,	chronic liver damage USEPA Office of Pesticide Programs, Health Effects Division, Science Information Management Branch: "Chemicals Evaluated for Carcinogenic Potential" (April 2006) Not Likely to be Carcinogenic to Humans

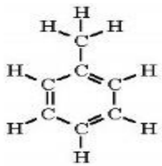
1. US National Library of Medicine. Haz-Map [Available from: https://haz-map.com/.
2. National Center for Biotechnology Information. PubChem [Available from: https://pubchem.ncbi.nlm.nih.gov.

Table 2.2. Other chemicals commonly found in shipping containers and their properties (from Haz-Map[55] and PubChem[56])

Name/ Synonyms	chemical description	olfactory detection	commercial use	acute health effects	chronic health effects
1,2-dichloroethane ethylene dichloride	$C_2H_4Cl_2$ or $ClCH_2CH_2Cl$ 	pleasant chloroform-like odour	primarily used to produce vinyl chloride used in the past as a solvent, degreaser, paint remover, and fumigant. has been used as a dry-cleaning agent and solvent for degreasing, resins, adhesives, cosmetics, and pharmaceuticals.	fumigant poisoning, solvents acute toxic effect, blood disorders, liver and kidney damage symptom onset may be delayed by 2 to 48 hrs (usually about 4 to 6 hr) after exposure	chronic solvent encephalopathy, neuropsychological function impairment, anaemia, hyperthyroidism, chronic liver and kidney damage IARC Carcinogen: possible (2b)
C2-alkylbenzenes	m-,o-, p-xylene C_8H_{10} ethylbenzene C_8H_{10} 	a sweet or aromatic odour	xylenes: solvent, also emitted from industrial sources, from auto exhaust. ethylbenzene: used as a solvent and an intermediate in the production of styrene (90%) and other chemicals. also emitted with gasoline, car emissions, domestic products containing solvents, and cigarette smoke.	mixed xylene: solvents acute toxic effect pneumonitis blood disorder ethylbenzene: solvent poisoning	xylene exposure: chronic solvent encephalopathy, neuropsychological function impairment, chronic liver and kidney damage, reproductive disorders IARC Carcinogen: Not classifiable ethylbenzene exposure: chronic solvent encephalopathy, neuropsychological function impairment, imbalance of neurotransmitters. hearing loss,

					chronic liver damage IARC Carcinogen: possible (2b)
acetaldehyde	C_2H_4O or CH_3CHO 	pungent, fruity odour	used to manufacture other chemicals , resins, dyes, pesticides, disinfectants, cosmetics, gelatine, glue, lacquers, varnishes, casein products, explosives, and pharmaceuticals. other uses include: hardener in photography, flavouring agent, leather preservative and used in leather tanning, in glue products, in hydraulic fracturing fluids and in the paper industry. main source of exposure to acetaldehyde in the general population is through metabolism of ethanol and it is also present in cigarette smoke.	similar symptoms to acute alcohol intoxication	dermatitis, chronic bronchitis, similar symptoms to chronic alcoholism IARC Carcinogen: possible (2b)
ammonia	H_3N 	pungent, suffocating odour exposure may cause loss of smell	about 80% is used in fertilizers; it also is used as a refrigerant gas, and in the manufacture of plastics, explosives, pesticides, detergents, and other chemicals.	blindness if in contact with eyes, pneumonitis, toxic, bronchiolitis obliterans (an inflammatory condition, in which the bronchioles become damaged and inflamed leading to extensive scarring that blocks the airways),	chronic irritation of eyes, nose and throat, chronic bronchitis, chronic obstructive lung decease

				is fibrogenic to the lungs.	
benzene benzol	C_6H_6 	gasoline-like odour	used mainly in closed manufacturing processes of other chemicals including nylon and synthetic fabrics. also used to make some types of rubbers, lubricants, dyes, detergents, drugs, and pesticides. benzene is also a part of crude oil, gasoline, and cigarette smoke. ranks in the top 20 chemicals for production volume in the USA.	solvent poisoning	anaemia and excessive bleeding due to effects on the bone marrow, lowering of the immune system response, menstrual periods and a decrease in the size of the ovaries IARC Carcinogen established
formaldehyde formalin	CH_2O or H_2CO 	pungent, suffocating odour	used in the production of formaldehyde resins, plywood, particle board, paper, and urea-formaldehyde foam. used as an antiseptic, disinfectant, histologic fixative in laboratory and embalming setting. also be found in smoke from fires, car exhaust and cigarettes.	fumigant poisoning	asthma, contact dermatitis, contact urticaria, anaemia, in females: menstrual disorders, inflammatory disease of the reproductive tract, sterility, and low birth weights among offspring IARC Carcinogen established
styrene vinylbenzene	C_8H_8 	sweet, floral odour	used to make products such as rubber, plastic, insulation, fiberglass, pipes, automobile parts, food containers, and carpet backing. billions of pounds of styrene are used in the USA yearly.	solvent poisoning	asthma, chronic solvent encephalopathy, chronic liver damage, in females: decreased frequency of births and increased frequency of miscarriage.

					IARC Carcinogen probable (2a)
toluene toluol	C_7H_8 	sweet, pungent, benzene-like odour	used in making of other chemicals. component in paints, paint thinners, fingernail polish, lacquers, adhesives, and rubber and in some printing and leather tanning processes. used in solvent abuse.	solvent poisoning , renal failure	chronic solvent encephalopathy, chronic liver damage liver damage, in females: menstrual disorders and increased frequency of miscarriage, infertility IARC Carcinogen not classifiable
carbon monoxide	CO :C≡O:	odourless	used in metallurgical processes, manufacture of metal carbonyls and inorganic synthesis especially in Fisher-Tropsch for petroleum type products. used as fumigant in grain storage and for rodents.	chemical asphyxiation	Parkinson symptoms, low birth weight and miscarriage, effects on intellectual functioning, spasticity, and cortical blindness.
carbon dioxide	CO_2 O=C=O	odourless	used as a refrigerant. used in fire extinguishers, in carbonated drinks, dry ice and propellants. preservation of fruits products. fumigant for food and rodents	chemical asphyxiation, impairment of central nervous system	permanent central nervous system impairment, blindness

1. US National Library of Medicine. Haz-Map [Available from: https://haz-map.com/.
2. National Center for Biotechnology Information. PubChem [Available from: https://pubchem.ncbi.nlm.nih.gov.

2.3 Chemical concentrations in and around containers

Most of the literature on potential exposure of workers reported on chemical concentrations in closed containers. These are more likely to reflect potential peak exposures rather than an 8-hour time weighted average personal exposure measured in the breathing zone of the worker during unloading.[48] Only two studies were identified that estimated personal exposure levels in workers unloading containers. Before studies on closed containers and personal exposures are summarised, the different exposure assessment tools and exposures standards used in these studies are briefly reviewed.

2.3.1 Exposure assessment tools and exposure standards

Studies on chemical concentrations in closed containers generally used a probe pushed through the rubber seals of the container door with Tedlar bags used to collect air samples from inside the closed container over a period of few seconds or less. Samples were generally analysed using either one of two methods, and sometimes both: Selected Ion Flow Tube Mass Spectrometry (SIFT-MS) or Gas Chromatograph Mass Spectrometry (GC/MS).[4, 16, 22-24, 53, 57, 58] In addition, PIDs for non-specific analyses of volatile organic compounds (VOCs) were used. Also, one study used a Fourier Transformed Infrared Light (FTIR) instrument, and two studies used additional electrochemical sensors and colorimetric tubes.[4, 22, 51]

Although these levels are not directly related to full-shift worker exposures, all studies compared the concentrations measured for individual chemicals found in containers to occupational exposure limits (OELs). OELs have been set for most hazardous chemicals encountered in containers by various regulatory authorities and scientific advisory groups and vary by country. The limits are based on evidence from epidemiological, clinical and animal studies as to the level at which harm may occur; for example, an 8-hour work exposure limit is defined as the level at which nearly all workers could be exposed (for 8-hours a day and 40 hours a week over an average working lifetime) without experiencing significant adverse health effects.[59] In addition to reporting concentrations of individual chemicals, one study reported the additive mixture value (AMV)[59], which calculates an estimate of the combined toxic effect of chemicals in each sample.[4] The AMV is calculated by dividing the concentration found in the sample by the OEL for each chemical and then summing up the values for all chemicals in the sample. A value of one is classified as above the OEL of the AMV. The AMV may vary depending on which OEL is used in the calculation. The percentage of measurements exceeding OELs and AMVs exceeding 1 are commonly reported in epidemiological studies of workers with low-level, long-term exposures, as these limits are set to protect the majority of workers from long-term health effects.[59] However, when comparing epidemiological studies that express results as a proportion of measurements that exceed local OELs, it should be kept in mind that OELs may vary between countries and may change over time, which affects the percentage of reported samples above an OEL. This also affects the AMVs because its calculation is based on the OEL for each individual chemical in the sample.

2.3.2 Chemical concentrations in closed containers

The studies reporting on chemical concentrations measured in closed shipping containers are summarized below.

A Dutch study analysed a total of 303 samples, collected from a randomly chosen sample of sealed containers arriving in the port of Rotterdam at 3 terminals for four commonly used fumigants in 2002: methyl bromide, formaldehyde, phosphine and sulfuryl fluoride.[22] Carbon monoxide, carbon dioxide, ammonia, explosive gases, and oxygen levels were also measured as these are hazards generally associated with confined spaces. Field measurements were performed using detector tubes and electrochemical cells. Field measurements were verified for methyl bromide, formaldehyde, and sulphuryl fluoride by GC/MS. Samples (collected over a period of a few seconds) were taken in Tedlar bags from the center of the container after opening the doors (presumably taken immediately after opening and without the container being vented) and analysed within three days of collection, which may have reduced concentrations for some chemicals.[24] The authors used Dutch OELs for comparison. Methyl bromide was detected in 19 containers and in seven containers it exceeded the OEL (0.25 ppm), phosphine was detected in 28 containers exceeding the OEL (0.3 ppm) in 6 containers, formaldehyde was detected in 42 containers exceeding the OEL (1 ppm) in 3 containers, and sulfuryl fluoride was never detected. Ammonia was detected in 9 containers but never exceeded the OEL, carbon dioxide was detected in 12 containers exceeding the OEL (5000 ppm) in 5 containers, carbon monoxide was detected in 74 containers exceeding the OEL (25 ppm) in 41 containers, and 2 containers each had explosive or oxygen deficient atmospheres. In total 60 (20%) containers posed a risk to workers either due to chemical concentrations, low oxygen levels or risk of explosion. Several containers had multiple risks. The authors found little differences in the percentage of containers with detectable levels of methyl bromide, formaldehyde, or phosphine by the continent of origin. Containers carrying food items were almost twice as likely to have these chemicals detected than containers that did not, and all six containers with phosphine detection carried food items. Additionally, the authors reported that even fairly safe types of cargo can be associated with unexpected risks e.g. a container carrying computer monitors had a high risk of explosion due to butane and pentane, and a container carrying bathroom slippers had ammonia concentrations above 700 ppm, causing a worker to become ill. There was a difference in detection frequency between the three investigated terminals, which could not be explained.

In a study at the port of Hamburg, Germany, conducted in 2006, a total of 2113 randomly selected shipping containers were sampled over a ten-week period.[57] Samples were analysed for methyl bromide, phosphene, 1,2-dichloroethane, ethylene oxide, formaldehyde, benzene, and trichloronitromethane using Sift-MS and GC/MS. Sampling results were compared against acute and chronic reference exposure levels (RELs) defined by the Californian Office of Environmental Health Hazard Assessment.[60] These chronic RELs are based on the most sensitive health effect reported in the medical and toxicological literature and are designed as population-based protection standards. Consequently, they are significantly lower than the relevant OELs. If acute

RELs were not available, limits from the National Institute of Occupational Safety and Health (NIOSH) were used.[61] Airborne chemicals were detected in a total of 1,684 (79%) shipping containers and in 23.3% of containers multiple chemicals were detected. In total, 1478 (70%) containers had at least one chemical that exceeded the chronic REL and 761 (36%) containers had at least one chemical that exceeded the acute REL. The most commonly detected chemicals were formaldehyde, benzene, methyl bromide, and phosphine. Formaldehyde and/or benzene detection rates (31% and 5%, respectively) were four times greater than fumigant detections. Sulphuryl fluoride was identified in three containers. In total, 0.6% of containers sampled had concentrations of chemicals exceeding the NIOSH Immediately Dangerous to Life and Health limit (IDLH).[61] One container had a concentration of phosphine 120,000 times the acute REL of 0.3 ppm and well above any set OEL for short term or ceiling (maximum) exposure. Because of the use of the much lower RELs as reference, the results reported in this study are difficult to compare with other studies that used OELs and may overestimate the extent of the risk posed to workers. Chemical concentrations above the chronic REL were observed in 62.9-74.5% of containers from Southeast Asia, India, Europe/ North America, South America, Middle East, and China, while 51.4% of containers from Africa had concentrations above the chronic REL, but this was based on only 70 containers. Concentrations above the acute REL were found in 35.3-40.9 % of containers from South America, India, the Middle East, and China. For containers from Africa, North America, and Southeast Asia, 20.0-26.5% had levels above the acute REL. Concentrations above the chronic REL were detected in 71.2-87.3% of containers carrying electrical appliances, food, furniture/ household items, and shoes; containers carrying clothes/ textiles, natural products, and manufactured goods had detection rates between 61.8 to 67%. For the acute REL, detection rates varied between 24.7-55.6% depending on the cargo type. Detection rates above chronic and acute RELs were the highest for shoes (87.3% and 55.6%, respectively) due to high concentrations of benzene.

In a study by Australian Customs, 14,943 containers were tested for the presence of fumigants in five ports between July 2007 and December 2008.[58] Air samples collected from sealed shipping containers were analysed by SIFT-MS. A total of 2503 of samples (17%) had fumigant concentrations above the relevant Australian OELs. The most prevalent fumigants were: formaldehyde (31%), 1,2-dibromoethane (26%), chloropicrin (18%), and methyl bromide (13%) and ethylene oxide (5%).

In an Italian study, conducted between 2004 and 2010, approximately 10,000 air samples (collected from three ports) were analysed from closed containers prior to opening the doors for Customs inspection or other purposes using a PID, multi-gas meters and colorimetric tubes.[51] Of 9,482 containers, 20% had chemical concentrations higher than the TLV and/or oxygen depletion and/or explosion risks. In total, 5.7% had concentrations of chemicals exceeding the relevant IDLH values, 2.83% were oxygen depleted, and formaldehyde and sulfuryl fluoride were detected in 4.7% and 0.063% of containers, respectively. Methyl bromide was detected at concentrations between 1-250 ppm in 9.1% of 1362 containers and at concentrations above the IDLH in 4.7% of the tested containers. Phosphine was detected at concentrations between 0.1-50 ppm in 40.6% of 5415 containers and above the IDLH in 6.6% of containers.

In 2010, 42,888 containers were air-sampled and analysed for 20 chemicals in Belgium and the Netherlands.[53] After pre-screening with a PID and sensors for specific chemicals (CO, CO_2, O_2, PH_3) and the lower explosive limit, samples were analysed using Sift-MS. Ninety percent of the containers were examined at main ports, and rail and barge terminals, while the remainder were examined at the end-user location or at the customs scanning facilities. In total, 11% of containers had chemical concentrations above the relevant Dutch OEL, and containers carrying food had a higher percentage (20%) compared to containers carrying non-food cargo. The chemicals found most frequently in concentrations above OELs were 1,2-dichloroethane (2.73%), carbon monoxide (2.72%), formaldehyde (2.58%), toluene (2.31%), and benzene (2.18%). The authors stated that industrial chemicals occur more frequently in containers than classical fumigants, which is consistent with other studies.[22, 57] The fumigants found most frequently in concentrations above the OEL were phosphine (0.9%), methyl bromide (0.7%), chloropicrin (0.2%) and sulfuryl fluoride (0.0005%). The highest proportion of containers with chemicals above the OEL came from Southeast Asia.

In 2011, a similar study was conducted in several European countries, including Austria, Belgium, Denmark, Germany, the Netherlands, and Spain. This study measured 123,349 containers for 17 chemicals using the same analytical tools as in the previous study.[23] OELs according to the respective occupational safety legislation were used. Chemical concentrations above the relevant OEL were found in 13% of containers, but higher frequency rates were recorded for the cargo categories of food (15%), electronics (17%), consumables such as garden furniture, tools and pet-related items (19%), and shoes (42%). The chemicals found most frequently in concentrations above the OEL were carbon monoxide (4.18%), 1,2-dichloroethane (3.85%), formaldehyde (3.7%), toluene (2.78%), benzene (2.67%), and carbon dioxide (2.45%). The fumigants found most frequently in concentrations above the OEL were 1,2-dichloroethane (3.8%), phosphine (1.5%) and methyl bromide (0.4%). The highest proportion of containers with chemicals above the OEL came from Southeast Asia. The authors stated that industrial chemicals are found more frequently than fumigants and that many containers contain a cocktail of harmful chemicals, which may act in a synergistic way.

Between 2010 and 2013, a Swedish study, involving six container ports and two inland distribution centers, sampled container air in 372 packed and 119 empty containers using FTIR and PID measurements and some additional GC/MS analyses.[4] FTIR analysis showed that 30 of 249 containers (12%) contained concentrations of fumigants and off-gassed chemicals above the Swedish OELs, and close to 7% were above the short-term exposure limits and of these, four containers had chemicals below the OEL, although the combined toxic effect of all chemicals in each of these four containers exceeded the exposure limit for mixtures. The authors suggested that all measurements were attributable to off-gassed chemicals rather than undeclared previous fumigation, except for one measurement of phosphine at 3 ppm, and possibly three instances of carbon dioxide. Considerable differences in the proportion of containers with concentrations above the relevant OEL were observed between ports, ranging from 0.0-33.0% across the six ports. In a container carrying shoes, 1,2-dichloroethane was recorded at 30 times the OEL, and benzene at 17 times the OEL.

A literature review on health risks and prevention practices in workplaces that handle fumigated containers arriving in ports was published in 2018. To verify and supplement the previously collected information, the authors visited a port of unknown location, which had a gas measurement station that measured fumigants and other harmful chemicals between 2016 and 2017.[3] Representatives from the station stated that they analysed chemicals in about 60,000 containers per year. Approximately 10% of containers had chemical concentrations above the Dutch OELs. Of which 9% were related to off-gassed chemicals while less than 1% was attributable to fumigants.

Temporal trends in chemical concentration in closed containers

While practices in container fumigation have changed over time, only a small number of studies have reported on temporal trends in the detection of fumigants and other chemicals in container air.

The Dutch National Institute for Public Health and the Environment (RIVM) conducted a trend-analysis on fumigants and other harmful chemicals based on air samples collected from 277 containers between 2003 and 2006.[62] The containers were not randomly sampled but specifically selected for inspection by the Dutch Inspectorate for VROM (Housing, Spatial planning and the Environment). However, the authors stated that the method for selection had not changed over the years. An increasing trend was observed in the percentage of containers in which fumigants were detected, mainly attributed to the increase in detection of 1,2- dichloroethane, which increased from 7% to 33%, and to a lesser extent to the increase in detection of phosphine. Methyl bromide was found most frequently in containers (25%), but a trend was not observed. Sulfuryl fluoride was not found in any of the containers. The percentage of containers with methyl bromide concentration exceeding the Dutch OEL decreased (11% of containers) after an initial increase (20% of containers), while containers exceeding the OEL for 1,2-dichloroethane showed a rising trend (from 0% to 9% of containers). In 2006, a quarter of all containers exceeded the OEL for at least one chemical.

The previously mentioned study [23] conducted in several European countries also observed a trend of the numbers of containers exceeding the OEL for methyl bromide decreasing from 0.7% of containers in 2010 to 0.4 % in 2011, which the authors suggested may be due to reduced use of methyl bromide following the adoption of the Montreal Protocol. The authors noted that sulfuryl fluoride had not taken the place of methyl bromide in container fumigation. They suggested as possible reasons the higher cost of sulfuryl fluoride and that sulfuryl fluoride was not listed in the International Standards for Phytosanitary Measures Publication No. 15 at that time. However, the total number of containers with chemical concentrations above the Dutch OEL had increased slightly from 11% in 2010 to 13% in 2011.

The previously mentioned Swedish study conducted between 2010 and 2013,[4] observed lower fumigant detection frequency compared to two previous studies that were conducted in 2002[22] and 2006[16]. The authors discussed several possible reasons for the observed trend, including poorer detection limits of the measurement devices used in their study, the phasing out of certain fumigants such as methyl bromide, changes in retailer and consumer demands for a reduction in fumigation of imported products or the development of alternative techniques (ionizing radiation, heat treatment, controlled atmospheric technique, oxygen treatment, and the use of non-wooden pallets).

2.3.3 Personal exposure measurements in container workers

Only two studies were identified that report on personal exposure measurements in container workers, which are summarised below.

An experimental study used a tracer gas method to assess workers' exposure when unloading 40ft containers by measuring concentrations of the gas and VOCs in the breathing zone of workers who began unloading immediately after opening the doors.[48] Average 8-hour TWA personal samples showed levels of 1-7% of the concentrations measured in the closed containers. Peak exposures were occasionally observed especially when the container doors were opened. These peaks were usually <10% of the concentration in the closed container but reached 70% in one case. The authors concluded that, even if average exposures during unloading are significantly lower than concentrations in the closed container, they may still be well above OELs in some containers.

Additionally, they hypothesised that the low average exposures and the brief peak exposures may explain the low number of case reports in the scientific literature that can be directly related to work inside containers. Personal exposures were continually measured in intervals of 0.5 minutes during opening of the doors and 2-minute intervals during unloading. The graphs in Figure 2.22 display the measurements in four containers. Container 5 represents the only personal measurement while the other three containers are work zone measurements. The work zone was defined as the work area within an arm's length distance from the worker and used as close approximation of the personal exposure.

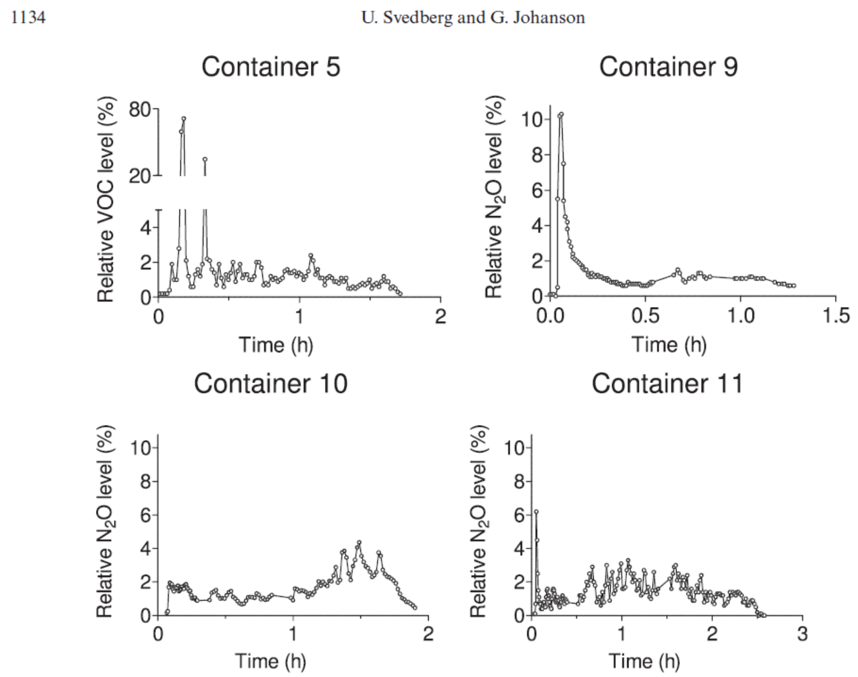


Figure 2.22 Results from personal monitoring of VOCs by PID (container 5) and work zone monitoring of nitrous oxide (N_2O) tracer gas by FTIR (containers 9–11). The concentrations are expressed relative to the initial concentration inside the door prior to opening the container. Note the broken y-axis of the VOC graph.[48] Copyright Oxford University Press

An Australian report collected 12 air samples (collected from their breathing zone) from 10 workers over a two-to-three hour period while the workers were unloading containers.[24] Six businesses were recruited from Melbourne and Brisbane, including one large retail outlet, three distribution centers, and two trucking and distribution centers. The samples were analysed for 1,2-dibromoethane, 1,2-dichloroethane C_2-alkylbenzenes, ammonia benzene, chloropicrin, ethylene oxide, formaldehyde, hydrogen cyanide, hydrogen phosphide, methyl bromide, styrene, and toluene. Toluene and C_2-alkylbenzenes were most frequently detected in the personal exposure samples (91.7% and 50%, respectively) but only at trace levels. The Australian OEL was never exceeded and the Dutch OEL was exceeded in one sample for formaldehyde. These results were compared to ambient concentrations inside the container by collecting 131 samples taken over a period of 20-30 seconds during unloading of 74 containers. The most frequently detected chemicals in all containers were toluene (92.1%), C2-alkylbenzenes (73.7%) and methyl bromide (68.4%). In 8% of the containers, chemical concentrations were above the relevant Australian OEL (chloropicrin: 5.3%, formaldehyde: 2.6%). Chemical concentration above the relevant Dutch OEL were detected in a third of the containers with the two most detected chemicals being formaldehyde (19.7%) and methyl bromide (18.4%). The authors noted that containers with outdoor wooden furniture had the highest concentration of chemicals. The authors concluded, based on the results of personal samples collected for a period of two to three hours, that eight-hour shift exposures may be significantly lower than ambient concentrations as assessed by short term air sampling. However, they concluded that these findings may not be representative of the industry as it was based on only a small number of samples and because containers and workers were not randomly selected.

2.4 Adverse health effects among container workers

Despite the large workforce involved in handling shipping containers, there are only a few reports in the literature on adverse health effects in container handlers exposed to chemicals. Most are case reports of acute poisoning and mainly from Europe, and very few studies investigated long-term health effects including neuropsychological symptoms. Deaths from chemical exposure have not been reported for container workers, but this has occurred in incidences involving bulk cargo ship fumigation and in structural fumigation, with relevant exposure routes involving inhalation and to a lesser extend skin absorption.[63] Studies on structural and soil fumigators have not been included because their work environments differ considerably from that of quarantine fumigators and container workers.

2.4.1 Acute health effects in container workers

In the literature there have been multiple reports of incidents of acute intoxications and other acute health effects among container workers and cargo fumigators, which are summarised below.

A case report from The Netherlands reported an incident of two workers losing consciousness after opening the doors of a container in Rotterdam in 2006.[6] There was no indication the container was fumigated or that the cargo (glass ware) required fumigation. Both workers suffered from pulmonary oedema and one worker had several epileptic seizures. Some responders later showed signs of mild poisoning (sore throat, red skin, and increased salvation) too. Methyl bromide was established as the exposure agent at the time of the incident. An additional two conference proceedings[5, 64] described the same incident.[3]

A case report from Korea of a quarantine facility fumigator, who had increased bromine levels in urine, blood and spinal fluid, still showed neurological symptoms such as visual and gait disturbances, and erectile dysfunction, after exposure had ceased for two month.[65]

The Expertise Center Environmental Medicine in Arnhem in The Netherlands described incidences associated with exposure to chemicals in shipping containers.[13, 14] Of 33 workers being referred to the center for the period October 2008 to October 2009, >50% had acute symptoms, with the remainder believed to suffer from chronic symptoms. Nearly all workers showed dysfunction of the central nervous system especially decreased concentration and short-term memory, and some also exhibited changes in personality. The implicated chemicals were 1,2-dichloroethane (20 cases), phosphine (9 cases), carbon dioxide (2 cases), methyl bromide (2 cases). Symptoms in another 4 workers, who had experienced phosphine poisoning after opening shipping containers, were unspecific symptoms of: nausea and vomiting; headache and dizziness; unsteady legs; muscle pain, which in some cases persisted for weeks; and severe chest pressure.[13] However, there was a lack of information on exposure data and time between exposure and clinical examination.[3]

Between September 2006 to July 2010, 26 patients were seen in the occupational outpatient clinic in the University Medical Center Hamburg-

Eppendorf, Germany with presumed exposure to fumigants, including workers entering containers, warehouse workers, workers handling previous cargo and members of the public.[8] However, most of these patients were seen weeks or months after the incident. The predominant symptoms were headaches, concentration and memory problems, dizziness and nausea, irritation of the skin and mucous membranes, and a reduced ability to exercise. Also, 14 out of 26 patients were diagnosed with reactive airway dysfunction syndrome. The implicated chemicals were 1,2-dichloroethane, methyl bromide, phosphine, and methylene chloride. The author also described case studies in two other papers,[7, 66] which appear to relate to the same workers as the examinations occurred during the same time period, with the exception of one case study that described exposure due to fumigation in a shipping haul during transit.[7]

Another case report from Germany described exposure of six workers unpacking containers and the cargo from plastic wrapped pallets in a storage room in three separate incidences between 2010 and 2012.[10] Five of the six workers displayed symptoms while the remaining worker was the supervisor who was not involved in the tasks and therefore not exposed. After the first incidence, five workers had symptoms of itchy skin, red eyes and recurrent nose bleeds, headaches and numbness in fingers and toes. After the second incident, four workers additionally complained about pins and needles in the legs, dizziness, breathing difficulties and increasing irritability. After the third incident, one patient was on sick leave for several weeks and two patients developed immediate nose bleeds and severe headaches. Air measurements in the storage room implicated methyl bromide (2.5 to 200 ppm after five days of the first incidence) and ethylene oxide.

A literature review published in 2015 found 21 reports on incidents (involving symptoms such as dizziness, severe headaches, nosebleeds, breathing difficulties, increasing irritability, neuropathy) of exposure to fumigants or other harmful chemicals while unloading or inspecting containers; it also described 6 incidents of people working in a warehouses or storage rooms, two incidents while someone was ironing imported textiles and one report of a person unpacking household items after the items had been sent in a container from South America to Germany.[11] However, the review also included incidents already described in previous studies and chemicals were often not identified and quantified.

Frequency and trends of reported incidents

To investigate the frequency of exposure incidents a survey was undertaken in poison centers in Germany, Switzerland, Austria and France.[67] The centers were asked whether they had had any enquiries regarding the fumigation of shipping containers, and 30 incidents were discovered between 2003 and 2007, with 71 workers being affected. Symptoms were mainly mild, and one worker had moderate symptoms. The chemicals implicated were methyl bromide, 1,2-dichloroethane, dichloromethane, phosphine, and unknown substances.

A similar investigation by the Dutch poison center found 14 notified incidents of exposure involving 33 container handlers over the period February 2011 to

January 2013.[68] Symptoms were mild (headache (18), dizziness (13), irritation of oral mucosa (12), gastrointestinal symptoms such as nausea and vomiting (8) and muscle weakness (6)). In six incidents the chemicals could be identified: phosphine (3), methyl bromide (2) and organic solvents (1).

To investigate the frequency and trend of exposure incidents to hydrogen phosphide a recent study analysed reports to the Belgium Poison Center between 1 January 1999 and the 31 December 2018.[25] However, the study included incidents in shipping hulls and workers who remained asymptomatic. The study showed gastrointestinal, neurological (mostly headaches) and respiratory symptoms that often seemed to be nonspecific. The authors also reported on a retrospective study published by the French Agency for Food, Environmental and Occupational Health & Safety. This study reported 9 incidents and 12 workers with symptoms from 1999 to 2017. In neither of the studies severe symptoms were observed. Comparing the time periods of 2000 to 2009 and 2010 to 2018, an increasing trend in phosphine exposures were observed in both poison centers. The authors attributed this trend to the phasing out of methyl bromide and replacement with phosphine. Alternatively, the authors suggested increased awareness and knowledge of the risk among workers initiated an increase in incident reporting. It is unclear whether this trend also applied for container incidents specifically because both studies also included ship hull incidents.

2.4.2 Physiological changes in fumigators before and after work

Two studies were identified that measured physiological changes after exposure to methyl bromide, one measuring changes in the central nervous system through electroencephalograms,[63] the other measuring changes in the autonomous nervous system through heart rate variability.[69]

From February to August 2019, a study examined electroencephalograms (EEGs) and urinary bromide ion levels of 44 fumigators before and after fumigation in Busan, Korea to determine whether workers experienced changes in the central nervous system.[63] The work included 42 container and 6 tent fumigations with methyl bromide. A control group consisted of 20 inspectors, who worked at the same premises but were not involved in fumigation. The mean post-work concentration of bromide ion in the urine of fumigators was more than double that of the mean pre-work level. After work, median frequencies (MDF) and alpha-to-theta ratios (ATR) in the EEGs of fumigators were significantly decreased compared to the pre-work values. When comparing these decreases to the reference range for aging and cognitive decline, fumigators had a functional age increase of about 20 years. However, workers were asymptomatic. In contrast, there were no significant differences in EEG indices and urinary bromide ion levels in the control group of inspectors. The urinary bromide ion levels in all subjects were negatively correlated with MDF.

Between September and November 2018 and between March to June 2019, another Korean study measured urinary bromide ions and heart rate variability indices (HRV), a measurement of the autonomous nervous system, before and after work in 62 fumigators, who used methyl bromide.[69] A control group consisted of 34 inspectors. It appears that the workplace was the same as in the previous study (same location and same government agency).[63] In the fumigator group urinary bromide levels increased significantly in the post-work samples compared to the pre-work samples, while all HRV indices sharply decreased. When comparing these HRV decreases to the reference range for aging, fumigators were functionally aged by about 10 years. Again, workers were asymptomatic. There were no significant differences in HRV indices and urinary bromide ion in the control group of inspectors. The HRV indices in all the subjects were negatively correlated with urinary bromide ion levels.

2.4.3 Long term neuropsychological effects in container workers

Three small studies were identified that investigated long term neuropsychological health effects in container workers and one in warehouse workers; one study used neuropsychological test batteries and three studies used neuropsychological symptom questionnaires, which are summarised below.

Four workers who had been exposed to 1,2-dichloroethane and/or methyl bromide while unloading import containers, were referred to an outpatient clinic for occupational health in Hamburg[8] where they underwent neuropsychological examinations and standardised neuropsychological test batteries.[70] The workers complained about headaches, tiredness, concentration and memory deficits, irritability, and muscle cramps. In all four cases exposure occurred at least 13 months previously. There was evidence of persisting neuropsychological impairment in the areas of information processing speed, selective and shared attentiveness and (working) memory, while in the areas of ability to reason, spatial-constructive abilities, and executive functions no deficits were detected.

A small Australian health survey of 22 workers unloading shipping containers investigated the prevalence of neuropsychological symptoms via questionnaire.[24] The greatest and most consistent difference between the workers and a reference group were in the memory domain. However, the authors stated that the result should be treated as inconclusive because the finding was based on only a few positive responses and workers had only been in the industry for less than 10 years with an average employment duration of 3 years.

Long-term health effects including neuropsychological symptoms were investigated in health survey among 125 French dock workers and those working in related occupations.[71] Overall, there was a low prevalence of neuropsychological symptoms, which the author suggested could be due to the healthy worker effect. Most frequently reported symptoms were fatigue and neurological disorders mainly headaches, for dockworkers and respiratory irritation for workers in related occupations. They also reported a positive association between fumigant exposure in the past years and memory disorders, but analyses were not controlled for potential confounders, and no comparisons were made with a non-exposed control population.

Another study investigated neuropsychological symptoms in 165 warehouse workers in the logistics industry, who were involved in transportation and storage of goods, but who did not enter containers.[54] The authors observed that workers were more likely to report ‘heaviness in the arms and feet’ compared to a control group of 185 office workers (adjusted OR: 3.99 95% CI: 1.72–9.26). They were less likely to report ‘forgetfulness’ (OR: 0.40 95% CI: 0.18–0.87), ‘sleep disturbances’ (OR: 0.36 95% CI: 0.17–0.78) and ‘feeling tired when waking up’ (OR: 0.40 95% CI: 0.20–0.79) compared to office workers. Trembling of hands, slurred speech, and an unpleasant taste in the mouth were reported significantly more frequently among warehouse workers compared to reference workers, but this was no longer statistically significant when controlled for confounders (sex, age, smoking, exposure to second-hand smoke, frequency of alcohol consumption, time spent at the company, past and present work with chemicals, and prescription drug used in the past 12 months, head injury, coma, and concussion).

2.5 Summary

The literature indicates that chemical concentrations in closed containers may reach levels above the OEL, either from previous fumigation or from off-gassing from the cargo and/ or packaging[4, 16, 22-24, 51, 53, 58] but little is known about concentrations in containers arriving in New Zealand. Also, it is unclear how these concentrations relate to personal exposure levels, which was only examined in two studies, with one based on only 12 samples and the other being an experimental study using tracer gas.[24, 48] It is also unclear how many containers have chemical concentrations that exceed exposure limits for mixtures (which considers the combined toxic effect of all chemicals present) as this was reported in only one study.[4] Some studies suggested links between high chemical concentrations and some specific cargo types and countries of origin, but no formal statistical tests of an association with these and other container characteristics were conducted.[22, 23, 51, 53]

There are multiple reports in the literature on workers experiencing acute health symptoms after exposure to hazardous chemicals in containers.[6-8, 10, 11, 13, 14, 65] Additionally, two studies examining physiological changes in fumigators before and after work found changes corresponding to an increase in functional age of approximately 10 years.[63, 69] However, long-term health effects including neuropsychological symptoms were only investigated in a few studies.[24, 70, 71] One study reported a low prevalence of neuropsychological symptoms and a positive association between fumigant exposure in the past years and memory disorders, but analyses were not controlled for potential confounders.[71] Memory disorders were also found in a small health survey on 22 workers and in neuropsychological test batteries in 4 workers.[24, 70] The latter study also showed deficits in information processing speed, selective and shared attentiveness.[70]

In conclusion, major knowledge gaps exist with regards to exposure levels of fumigants and off-gassed chemicals in workers involved in handling shipping containers and cargo. Although research has been conducted, it mainly involved chemical concentrations in closed containers. Major knowledge gaps still exist in the areas of personal exposure measurements, trends in the chemical composition and concentrations of chemicals in containers over time, determinants of high concentrations in containers, health effects associated with long-term exposure, and research into preventative measures.

3 Airborne fumigants and residual chemicals in shipping containers arriving in New Zealand

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(published in Annals of Work Exposures and Health[19], see Appendix 9.2)

Abstract

Background: Airborne fumigants and other hazardous chemicals inside unopened shipping containers may pose a risk to workers handling containers. Methods: Grab air samples from 490 sealed containers arriving in New Zealand were analysed for fumigants and other hazardous chemicals. We also collected grab air samples of 46 containers immediately upon opening and measured the total concentration of volatile organic compounds in real time during ventilation. Additive Mixture Values (AMV) were calculated using the New Zealand Workplace Exposure standard (WES) and ACGIH Threshold Limit Values (TLV) of the 8-hour, time-weighted average (TWA) exposure limit. Regression analyses assessed associations with container characteristics.

Results: Fumigants were detectable in 11.4% of sealed containers, with ethylene oxide detected most frequently (4.7%), followed by methyl bromide (3.5%). Other chemicals, mainly formaldehyde, were detected more frequently (84.7%). Fumigants and other chemicals exceeded the WES/TLV in 6.7%/ 7.8%, and 7.8%/20.0% of all containers, respectively. Correspondingly, they more frequently exceeded "1" for the AMV-TLV compared to the AMV-WES (25.7% versus 7.8%). In samples taken upon opening of doors, fumigants were detected in both fumigated and non-fumigated containers, but detection frequencies and exceedances of the WES, TLV and AMVs were generally higher in fumigated containers. Detection frequencies for other chemicals were similar in fumigated and non-fumigated containers, and only formaldehyde exceeded both the WES and TLV in both container groups. Volatile compounds in container air reduced rapidly during ventilation. Some cargo types (tyres; personal hygiene, beauty and medical products; stone and ceramics; metal and glass; and pet food) and countries of origin (China) were associated with elevated airborne chemical and fumigant concentrations.

Conclusion: Airborne chemicals in sealed containers frequently exceed exposure limits, both in fumigated and non-fumigated containers, and may contribute to short-term peak exposures of workers unloading or inspecting containers.

3.1 Introduction

Globally, shipping container throughput has risen from 622-802 million twenty-foot equivalent units (TEU) between 2012-2019.[1] A proportion of containers requires fumigation either for biosecurity reasons or to prevent damage to the cargo. Commonly used fumigants include phosphine (hydrogen phosphide), methyl bromide and ethylene oxide,[2] which are toxic to both pests and humans.

Sealed shipping containers allow for only limited natural ventilation during transport;[4] fumigants and off-gassed chemicals (e.g. formaldehyde, toluene and benzene) from cargo or packaging may therefore accumulate in the air, potentially reaching unsafe levels.[3] High levels of airborne chemicals have been found in sealed containers, and several acute poisonings in workers handling shipping cargo have been reported,[3, 5-14] with symptoms ranging from skin irritation to severe respiratory distress and persistent neurological deficits.

Personal exposures to fumigants and off-gassed chemicals measured in container workers are generally lower than levels measured in sealed containers,[20] likely due to the rapid decline in concentration following the opening of containers and subsequent ventilation.[38, 48] Nonetheless, high exposure may still occur,[48] particularly upon opening of container doors.[38, 48]

Although several factors may affect chemical concentrations in shipping containers such as cargo, packaging materials, number of vents, etc.[15, 16, 22, 37, 38, 48, 72], it is difficult to identify which containers may pose a health risk to workers, mainly due to a lack of suitable and affordable devices to measure exposure.[3, 4]

Annually, approximately 500,000 import containers arrive in New Zealand by sea[73] with some always being fumigated (for specific types of cargo) and others being fumigated only in particular seasons (e.g. during marmorated stink bug season) or when biosecurity intrusions are detected. In this study we assessed fumigant and residual chemical concentrations inside sealed containers imported into New Zealand and upon opening of container doors. We also assessed associations with cargo and container characteristics and compared chemical concentrations inside sealed containers with international findings.

3.2 Methods

Study design

This study involved measurements of airborne chemicals in shipping containers arriving in New Zealand and consisted of two parts: (i) a survey of chemical concentrations in 519 sealed containers; and (ii) a smaller, more detailed, survey of concentrations measured upon opening of 46 containers. Sample sizes were based on practical considerations balancing research funding, minimising disruption for workers, and the need to have enough samples to draw conclusions.

The larger survey conducted February-June 2011 involved a random sample of imported containers arriving in the Port of Tauranga in New Zealand, with information collected (from the Customs database) on cargo categories and country of origin (see Supplementary Table 3.6); information on fumigation status and whether the container was full or only partially loaded was also collected. Most containers were loaded directly from the vessels onto rail carriages for further transport. The measurements were taken by Customs officers when containers were on rail carriages, with a small proportion of containers measured at the port customs inspection facility.

The smaller survey, conducted between 2013-2016, was nested in a cross-sectional exposure and health study of workers handling cargo from shipping containers and export logs.[20] It involved 16 New Zealand Ministry of Primary Industries Accredited Transitional Facilities (ATF) that open and inspect overseas containers. The cargo and country of origin of the containers differed widely (Table 3.6) and included containers previously fumigated overseas and/or in New Zealand. Management provided permission for sampling and identified suitable containers based on workplace requirements as well as an interest in specific containers (e.g. when they gave off chemical odours or were previously fumigated), leading to an oversampling of fumigated containers. Information was collected on fumigation status from signage on the container, and/or shipping documentation obtained from container handlers and management. Information on cargo category, country of origin, container size, number of open container vents, whether cargo was on pallets, temperature in the container and barometric pressure, was based on observations by research staff and/or provided by container handlers and management.

Sampling

For the larger survey, grab air samples (samples taken for ≤1 second) were collected using a probe penetrated between the rubber seals at the bottom of the container door to a depth of 10-25cm. Air was collected into a Tedlar® bag and analysed (see details below) immediately on site.[74]

For the smaller survey, we took grab air samples at medium height (1.5-1.7 meters) at the entrance of the container immediately when the doors were opened (most containers were positioned outdoors). Samples were taken by connecting a Teflon tube to a 400cc stainless steel and Siltek treated sampling canister (Restek Corporation, PA, USA) negatively pressurised to near full vacuum (i.e. ~0 mmHg) by opening the canister valve. Samples were sent to an external laboratory (see below) for analyses. At the same time of collecting grab air samples, we also used a Velocicalc 9565-P/985 photoionization detector (PID) (TSI, Inc., MN, USA) fitted with a 10.6 electron-volt lamp (Ion Science LTD., Cambridge, UK), with a working range of 1,000 to 2,000,000 ppb at a temperature range of -10 to 60°C with an accuracy ± 0.5°C and a resolution of 1,000 ppb, to measure, in real time, the total concentration of volatile organic compounds (TVOC). The PID was placed on the cargo mainly in the front row at a height of 1.5-2.5 m. If the initial PID reading was above the lower Limit of Detection (LoD, 1000 ppb), we continued to record until the TVOC concentration fell below the LoD. Readings above 1000 ppb for >2 minutes were displayed in a graph (Figure 3.1) and zero readings were given the value 0.5 ppb to be able to display them on a log-scale.

Laboratory analyses

Samples were analysed using Selected Ion Flow Tube Mass Spectrometry,[75-77] which provides instant results, is relatively affordable, and allows simultaneous analyses of multiple compounds. However, there is an upper limit to the total amount of reactive compound that can be introduced to the instrument, which, although not a major issue for this study (see results), is a disadvantage of this method.

Samples from the larger survey were analysed on-site by research staff within an hour of collection using the Voice 100 (Syft Technologies Ltd, Christchurch, New Zealand) for the following chemicals (CAS numbers in brackets): fumigants: 1,2-dibromoethane [106-93-4], chloropicrin [76-06-2], ethylene oxide [75-21-8], hydrogen cyanide [74-90-8], phosphine (hydrogen phosphide) [7803-

51-2], methyl bromide [74-83-9]; and for other harmful chemicals frequently detected in containers: benzene [71-43-2], formaldehyde [50-00-0] and toluene [108-88-3]).

Samples from the smaller survey were analysed by Syft Technology using the Voice 200 (Syft Technologies Ltd, Christchurch, New Zealand), an updated version of the Voice 100. Sampling canisters were sent to Syft Technology, with most samples analysed within 24 hours and none later than 48 hours. In addition to the fumigants and other chemicals also analysed in the larger survey (see above), the following chemicals frequently detected in containers were measured: 1,2-dichloroethane [107-06-2], C2-alkylbenzenes [108-38-3, 95-47-6, 106-42-3, 100-41-4], acetaldehyde [75-07-0], ammonia [7664-41-7], methanol [67-56-1] and styrene [100-42-5]. Methanol, although not a chemical of concern to human health in this context, was included later (for 35 of 46 samples) because it has been found frequently at high levels in container air and could be a significant contributor to high PID readings.[4] Blank canisters (field blanks) were analysed with each analysis series, which returned results in the trace-range level only.

As canister samples were stored up to 24 hours, and in some cases up to 48 hours, prior to analysis, we conducted an experiment to assess the stability of several chemicals (formaldehyde, methyl bromide, and benzene) in canisters. This showed an average reduction of 14% (formaldehyde), 6% (methyl bromide), and 10% (benzene) when stored for 24 hours, and 22%, 10% and

22%, respectively, when stored for 48 hours, suggesting that decay was generally modest.

LoDs were calculated from laboratory blanks as follows: LoD = blank result + 3*standard deviation. The LoDs were comparable or somewhat lower for most chemicals in the second survey using the updated Syft Technology Voice 200 device, with the exception of formaldehyde for which the LoD was higher (25ppb vs 14ppb; see Tables in results section for the LoDs of all tested chemicals).

Concentrations were expressed in parts per billion (ppb). In addition to reporting levels for each chemical, we also calculated the additive mixture value (AMV), an estimate of the combined toxic effect of chemicals. To calculate the AMV, each chemical was given a toxicity score by dividing the measured level by the exposure standard, followed by summation of the toxicity scores of all chemicals measured in the sample. The "AMV-TLV" ($\sum \mathrm{C}_i/\mathrm{TLV}_i\,, C = concentration, i = \text{number of chemicals}$) was based on the American Conference of Governmental Industrial Hygienists Threshold Limit Values (TLV)[59]; the "AMV-WES" ($\sum C_i/WES_i$) was based on the New Zealand Workplace Exposure standards (WES)[50]. An AMV exceeding "1" was considered to be above the exposure limit for that mixture. For the calculation of AMVs, measurements below the LoD were assigned a value of half the LoD. We also calculated AMVs separately for fumigants and other chemicals (non-fumigants), and we calculated AMVs including and excluding methanol. We excluded 1,2-dibromoethane from the calculation of AMVs because the ACGIH did not specify a TLV or ceiling limit and the New Zealand WES is below the LoD of 1,2-dibromoethane.

Statistical analyses

Analyses were conducted using Stata version 15.1 (StataCorp LP, Texas, USA). Medians, 25-75 percentiles and maximum levels were used to summarise chemical concentrations, with samples with concentrations below the lower limit of detection or above the upper limit of quantification excluded.

Associations between container characteristics and chemical concentrations and/or AMVs were initially assessed using univariate linear regression (data not shown); variables that showed statistically significant associations were subsequently tested in multivariable analyses (mutually adjusting for other co-variables). To assess associations with cargo and country of origin, cargo was grouped into 14 categories (see Supplementary Table 3.5) and country into 6 groups: Australia, China, North America, Europe, other Asian countries, and “other regions”. Concentrations were ln-transformed; regression coefficients were therefore expressed as a relative difference or ratio (calculated as $e^{(\text{regression coefficient})}$), with e.g. a ratio of 2 indicating that the AMV for a particular cargo category was two times higher compared to the reference category, while a ratio of e.g. 0.7 indicates a 30% lower AMV level. Due to the high number of concentrations below the lower LoD we used left-censored regression (Tobit). Reference groups were chosen such that they represented a sufficient sized group and were characterised by relatively low chemical concentrations, hence they vary between both surveys. Analyses were repeated for AMVs calculated for fumigants only, or other chemicals only.

We conducted similar analyses for the smaller survey, but with additional variables: fumigation status (yes/no), container size (20ft/40ft), and number of container vents (0/2/4). We also applied linear regression to assess associations with fumigation status and concentrations of individual chemicals. Concentrations of individual chemicals were ln-transformed, and we used left-censored (at the LoD level) regression (Tobit) due to the high number of measurements below the lower LoD.

3.3 Results

In the larger survey, 26 samples were excluded due to containers not being able to be linked to Customs data, being empty, or having arrived from an intermediate destination, leaving 493 samples for analyses. From these, three had levels above the upper limit of quantification and were excluded because no value could be allocated to any of the chemicals tested. Only two containers had been identified as fumigated. For the smaller survey, 46 samples were available, 29 from non-fumigated and 17 from fumigated containers. TVOCs measurements were available for 41 containers.

Samples taken from sealed containers

Fumigants were detectable in 11.4% of containers (Table 3.1), with ethylene oxide detected most frequently (4.7%), followed by methyl bromide (3.5%). Other chemicals were detected more frequently (84.7%), with the highest detection rate for formaldehyde (81%, Table 3.1). Levels of fumigants and other chemicals exceeded the WES in 6.7% and 7.8% of all containers, respectively. As the WES for 1,2 dibromoethane is below the LoD, the proportion of containers in which fumigant levels exceeded the WES is likely higher. Levels exceeding the TLV were more common (7.8% and 20.0% of containers for fumigants and other chemicals, respectively; Table 3.1). Correspondingly, compared to the AMV-WES, the AMV-TLV more frequently exceeded “1” (25.7% versus 7.8%).

Table 3.1. Descriptive statistics (medians are based on samples with levels >LoD) of sealed container air samples (n=490)

variable (ppb[a])	WES[b]	TLV[c]	LoD[d]	>LoD (n/%)	Median[#] (p25- p75)	maximum	>WES (%)	>TLV (%)
Fumigants				**56/11.4**			**6.7**	**7.8**
1,2-Dibromoethane	0.3	n/a[e]	13	10/2.0	239.2 (66.5-693.9)	1066.1	> 2.0[f]	n/a
Chloropicrin	100	100	20	1/0.2	50.2	50.2	0	0
Ethylene oxide	100	1,000	10	23/4.7	1,241.5 (689.6-1922.2)	9717.02	4.7	2.9
Hydrogen cyanide	10,0000[g]	4,700[g]	2	9/1.8	232.7 (132.4-448.2)	539.54	0	0
Phosphine	300	50	5	5/1.0	51.5 (20.0-82.9)	144.03	0	0.6
Methyl bromide	5,000	1,000	13	17/3.5	415.3 (78.6-2,734.7)	49890.9	0.2	1.2
Other chemicals				**415/84.7**			**7.8**	**20.0**
Benzene	1,000	500	10	17/3.5	210.0 (112.0-299.0)	3069.9	0.2	0.6
Formaldehyde	500	100	14	397/81.0	45.3 (26.4-87.6)	6562.0	2.9	18.0
Toluene	20,000	20,000	10	156/31.8	115.5 (61.2-244.1)	6840.7	0	0
Overall				**416/84.9**			**7.8**	**20.2**
Cumulative							**AMV >1 (%)**	**AMV >1 (%)**
AMV – WES	1	1	n/a	n/a	0.2 (0.2-0.4)	97.9	7.8	-
AMV – TLV	1	1	n/a	n/a	0.6 (0.4-1.0)	70.3	-	25.7

n/a not applicable

[#] based on samples with concentrations >LoD (i.e. samples with concentrations <LoD were not included)

[a] ppb: parts per billion

[b] 8-hour Workplace Exposure Standards (WES) set by WorkSafe NZ (2019)

[c] 8-hour Workplace Exposure Standards (TLV-Threshold Limit Value) set by American Conference of Governmental Industrial Hygienists (ACGIH) (2020)

[d] Limit of detection

[e] The ACIGH has not set a TLV for 1,2-dibromoethane

[f] for 1,2-dibromoethane, the number of occurrences exceeding the WES could be higher as its WES is below its LoD

[g] These chemicals do not have a TWA limit but only a ceiling limit which was used instead

The cargo category ‘rubber products including tyres’ was associated with higher AMVs compared to the reference category, for both fumigants (AMV-WES: Ratio 4.0, 95%CI 2.2-7.2; AMV-TLV: Ratio 2.6, 95%CI 1.8-3.9) and other chemicals (7.6, 4.0-14.7 and 7.9, 4.1-15.6, respectively; Table 3.2). AMVs (WES and TLV) for fumigants were also positively associated with: ‘personal hygiene, beauty and medical products’, ‘stone, ceramics and articles thereof’, and ‘metal and glass’. AMVs for other chemicals were positively associated with ‘pet food’, due to high formaldehyde levels, and negatively for ‘metal and glass’ (Table 3.2). Containers from Europe had a higher AMV-WES for fumigants compared to containers from North America (Ratio 1.7, 95%CI 1.0-2.5) even after adjusting for container cargo; containers from China had higher AMVs for other chemicals (Ratio 1.7, 95%CI 1.1-2.6 for both AMV-WES and AMV-TLV; Table 3.2). Supplementary Table 3.5 provides the percentage of detectable fumigants/chemicals in container air for each cargo type and country, showing that detectable levels of fumigants, formaldehyde and toluene were observed in most cargo and country categories.

Table 3.2. Multi-variate regression of AMVs with cargo category and country of origin, sealed container survey (n=490)

		fumigants		other chemicals		overall	
		AMV-WES[a]	AMV-TLV[b]	AMV-WES	AMV-TLV	AMV-WES	AMV-TLV
Variable	**n**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**
Cargo							
Food, beverages, tobacco	78	reference	reference	reference	reference	reference	reference
Personal hygiene, beauty and medical products	42	1.5(1.0-2.1)*	1.3(1.0-1.7)*	1.2(0.8-1.7)	1.2(0.8-1.8)	1.5(1.0-2.1)*	1.3(0.9-1.7)
Plastics	58	1.4(1.0-1.9)	1.2(1.0-1.5)	0.9(0.6-1.3)	0.9(0.6-1.3)	1.3(0.9-1.8)	1.0(0.8-1.4)
Rubber products including tyres	13	4.0(2.2-7.2)***	2.6(1.8-3.9)***	7.6(4.0-14.7)***	7.9(4.1-15.6)***	6.4(3.5-11.6)***	6.5(3.8-11.2)***
Wood and articles there of	20	1.4(0.8-2.3)	1.1(0.8-1.6)	1.1(0.6-1.9)	1.1(0.6-1.9)	1.2(0.7-2.0)	1.0(0.7-1.6)
Paper and paperboard and articles there of	62	1.1(0.8-1.5)	1.0(0.8-1.3)	0.9(0.7-1.4)	1.0(0.7-1.4)	1.0(0.7-1.4)	1.0(0.7-1.3)
Stone, ceramics and articles there of	16	1.8(1.1-3.0)*	1.7(1.2-2.4)**	1.1(0.6-2.0)	1.1(0.6-2.0)	1.6(1.0-2.7)	1.4(0.8-2.2)
Metal and glass	36	1.9(1.3-2.8)**	1.5(1.2-1.9)**	0.6(0.4-0.9)*	0.6(0.4-0.9)**	1.5*(1.0-2.2)	0.9(0.6-1.3)
Machinery, equipment, appliances, electronics	49	1.1(0.8-1.6)	1.0(0.8-1.3)	1.0(0.6-1.4)	1.0(0.6-1.4)	1.0(0.7-1.5)	1.0(0.7-1.4)
Vehicles and part there of	7	1.8(0.9-3.8)	1.2(0.7-2.0)	0.5(0.2-1.2)	0.5(0.2-1.2)	1.3(0.6-2.7)	0.7(0.4-1.4)
Furniture and other man-made fibre articles	32	1.2(0.8-1.9)	1.1(0.8-1.4)	0.9(0.6-1.4)	0.9(0.6-1.4)	1.1(0.7-1.6)	0.9(0.6-1.4)
Pet food	9	1.1(0.6-2.1)	1.0(0.6-1.6)	3.1(1.5-6.5)**	3.3(1.6-7.1)**	1.7(0.9-3.3)	2.4(1.3-4.4)**
Chemicals	36	1.5(1.0-2.2)*	1.2(0.9-1.5)	1.0(0.6-1.5)	1.0(0.6-1.5)	1.4(1.0-2.1)	1.1(0.8-1.5)
Miscellaneous	32	1.1(0.7-1.6)	1.0(0.8-1.3)	1.1(0.7-1.7)	1.1(0.7-1.7)	1.1(0.7-1.7)	1.1(0.7-1.6)
Country							
North America	56	reference	reference	reference	reference	reference	reference
Australia	283	1.1(0.8-1.4)	1.0(0.8-1.2)	0.9(0.6-1.2)	0.9(0.6-1.2)	0.9(0.7-1.3)	0.9(0.7-1.1)
China	74	1.2(0.8-1.7)	1.1(0.9-1.4)	1.7(1.1-2.6)*	1.7(1.1-2.6)*	1.4(1.0-2.0)	1.5(1.1-2.1)*
Asia other than China	33	0.9(0.6-1.4)	1.1(0.8-1.4)	1.2(0.7-1.9)	1.2(0.7-1.9)	1.0(0.6-1.5)	1.1(0.8-1.7)
Europe	21	1.7(1.0-2.8)*	1.3(0.9-1.8)	1.1(0.6-1.8)	1.1(0.6-1.9)	1.6(0.9-2.6)	1.1(0.7-1.8)
Other regions	23	1.6(1.0-2.5)	1.2(0.9-1.7)	1.1(0.6-1.9)	1.1(0.6-1.9)	1.3(0.8-2.2)	1.1(0.7-1.7)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$

[a] Additive Mixture Value using the WES (8-hour Workplace Exposure Standards set by WorkSafe NZ (2019)) and excluding 1,2-dibromoethane

[b] Additive Mixture Value using the TLV (8-hour Workplace Exposure Standards (Threshold Limit Value) set by American Conference of Governmental Industrial Hygienists (ACGIH) (2020)) and excluding 1,2-dibromoethane

Samples taken upon opening of container doors

Fumigants were detected in both fumigated and non-fumigated containers, but detection frequencies were generally higher in fumigated containers. Similarly, samples collected in fumigated containers more frequently exceeded the WES and TLV for fumigants, except for ethylene oxide and hydrogen cyanide, the latter of which never exceeded the WES or TLV (Table 3.3). Regression comparing all fumigated and non-fumigated containers (including those with levels below the lower LoD) showed that phosphine, methyl bromide and ammonia levels were significantly higher (4.7, 78.0 and 53.4 times higher, respectively) in fumigated containers (Table 3.3). Excluding one container with very high levels of methyl bromide (319,000 ppb) did not change the results (data not shown).

The detection frequencies for other chemicals were similar in fumigated and non-fumigated containers, except for ammonia, which was detected more frequently in fumigated containers (47.1% vs 10.3%). Methanol was detected in all samples that were analysed for methanol. Formaldehyde was the only chemical exceeding the WES and TLV, in both fumigated and non-fumigated containers. Across all fumigants and other chemicals and excluding 1,2 dibromoethane as the actual number of containers exceeding the WES or TLV is unknown, levels in 10 (22%) containers exceeded the WES, while levels in 31 (67%) containers exceeded the TLV (data not shown in Table).

Table 3.3 Concentrations (medians are based on samples with levels >LoD) of fumigants and non-fumigants in containers upon opening of container doors (n=46)

				non-fumigated containers (n=29)[e]					fumigated containers (n=17)[f]					Ratio (95%CI) fumigated vs non-fumigated containers [g]
Chemical (ppb[a])	**WES[b]**	**TLV[c]**	**LoD[d]**	**>LoD (n/%)**	**Median[#] (p25-p75)**	**max**	**>WES (%)**	**>TLV (%)**	**>LoD (n/%)**	**Median[#] (p25-p75)**	**max**	**>WES (%)**	**>TLV (%)**	
Fumigants														
1,2-dibromoethane	0.3	n/a	5	13/44.8	10.0 (8.0-13.0)	20.1	>44.8[h]	n/a[i]	10/58.8	13.8 (7.2-107.3)	271.8	>58.8[h]	n/a[i]	2.4 (0.9-6.4)
Chloropicrin	100	100	5	7/24.1	10.0 (7.2-25.0)	42.7	0	0	7/41.2	21.9 (6.4-40.4)	193.1	5.9	5.9	2.6 (0.7-9.9)
Ethylene oxide	100	1,000	10	7/24.1	62.6 (37.8-184.0)	2,510.5	6.9	3.4	4/23.5	51.2 (39.4-308.3)	564.5	5.9	0	0.9 (0.1-14.0)
Hydrogen cyanide	10,0000[j]	4,700[j]	3	1/3.4	115.0	115.0	0	0	3/17.6	3.9 (3.0-17.0)	17.0	0	0	8.3 (0.1-554.8)
Phosphine	300	50	3	16/55.2	20.1 (12.7-39.0)	122.0	0	10.3	15/88.2	22.0 (9.7-177.0)	536.3	11.8	29.4	4.7 (1.4-16.0)**
Methyl bromide	5,000	1,000	5	12/41.4	23.4 (7.5-55.6)	352.0	0	0	12/70.6	811.6 (52.5-8,118.1)	319,000.0	17.6	35.3	78.0 (6.0-1020.6)***
Other chemicals														
1,2-dichloroethane	5,000	10,000	5	14/48.3	10.5 (7.6-48.1)	420.4	0	0	10/58.8	30.4 (11.2-73.2)	112.2	0	0	1.9 (0.6-6.5)
C2-alkylbenzenes	50,000	20,000	5	24/82.8	61.0 (17.1-123.8)	978.8	0	0	13/76.5	35.0 (25.7-70.0)	584.7	0	0	0.8 (0.3-2.3)
Acetaldehyde	20,000	25,000[j]	25	25/86.2	143.9 (116.8-453.0)	4,350.0	0	0	15/88.2	201.2 (95.2-534.9)	5,985.1	0	0	1.4 (0.5-3.5)
Ammonia	25,000	25,000	15	3/10.3	93.6 (31.9-330.7)	330.7	0	0	8/47.1	288.5 (117.3-814.7)	1,482.1	0	0	53.4 (2.6-1082.2)**
Benzene	1,000	500	5	7/24.1	18.0 (7.9-37.2)	93.8	0	0	6/35.3	15.9 (11.6-20.6)	161.5	0	0	1.9 (0.4-9.2)
Formaldehyde	500	100	25	22/75.9	187.1 (130.0-248.3)	560.2	3.4	58.6	14/82.4	145.0 (57.6-519.8)	936.6	23.5	47.1	1.1 (0.5-2.5)
Methanol	200,000	200,000	10	25/100.0	1,557.9 (702.4-2,81.0)	25,695.3	0	0	10/100.0	3,435.9 (3,071.5-28,939.0)	72,187.2	0	0	3.2 (0.9-11.9)
Styrene	20,000	10,000	2	10/34.5	3.1 (2.8-15.2)	89.7	0	0	6/35.3	20.3 (7.0-29.3)	702.0	0	0	2.0 (0.3-12.8)
Toluene	50,000	20,000	3	20/69.0	15.7 (7.7-96.3)	459.9	0	0	15/88.2	51.1 (6.9-121.3)	1,559.1	0	0	3.5 (0.9-13.2)
Cumulative							**AMV >1 (%)**					**AMV >1 (%)**		
AMV-WES[k]	1	1	n/a	n/a	0.7 (0.2-1.0)	26.4	17.2	-	n/a	1.6 (0.8-2.9)	64.4	52.9	-	3.7 (1.6-8.2)**
AMV-WES fumigants	1	1	n/a	n/a	0.2 (0.1-0.4)	25.3	6.9	-	n/a	0.8 (0.5-2.7)	64.1	41.2	-	5.2(2.2-12.4)***
AMV-WES other chemicals	1	1	n/a	n/a	0.3 (0.1-0.5)	1.2	3.5	-	n/a	0.3 (0.1-1.0)	2.8	23.5	-	1.2 (0.6-2.4)
AMV-TLV[l]	1	1	n/a	n/a	1.6 (0.5-2.9)	8.7	-	69.0	n/a	4.0 (1.8-12.9)	320.5	-	88.2	4.6 (1.9-11.0)***
AMV-TLV fumigants	1	1	n/a	n/a	0.2 (0.1-0.6)	3.0	-	17.2	n/a	3.6 (0.9-7.6)	319.5	-	64.7	12.1 (4.5-32.6)***
AMV-TLV other chemicals	1	1	n/a	n/a	1.5 (0.4-2.3)	5.7	-	62.1	n/a	1.1 (0.3-4.1)	10.4	-	52.9	1.1 (0.5-2.4)

*** p<0.001, ** p<0.01, * p<0.05
n/a not applicable
[#] based on samples with concentrations >LoD (i.e. samples with concentrations <LoD were not included) .
[a] ppb: parts per billion
[b] 8-hour Workplace Exposure Standards (WES) set by WorkSafe NZ (2019)
[c] 8-hour Workplace Exposure Standards (TLV-Threshold Limit Value) set by American Conference of Governmental Industrial Hygienists (ACGIH) (2020)
[d] Limit of detection
[e] n (methanol) = 25 [f] n (methanol) = 10
[g] The ratio represents the relative difference in concentration between fumigated and non-fumigated containers with non-fumigated containers selected as the reference category e.g. a ratio of 2 indicates that the concentration of a particular chemical (or the AMV fo all chemicals combined) is twice as high in fumigated compared to non-fumigated containers, while a ratio of 0.7 indicates a 30% reduction in concentration or AMV level
[h] The WES is below the Limit of Detection
[i] The ACGIH has not set a TLV for 1,2-dibromoethane
[j] These chemicals do not have a TWA limit but only a ceiling limit which was used instead
[k] Additive Mixture Value using the WES and excluding 1,2-dibromoethane
[l] Additive Mixture Value using the TLV and excluding 1,2-dibromoethane

The overall AMV-WES and AMV-TLV frequently exceeded “1” in both non-fumigated and fumigated containers, although this occurred more often in fumigated containers (52.9% (WES) and 88.2% (TLV) vs 17.2% and 69%; Table 3.3). This was most pronounced for AMVs calculated for fumigants only, with fumigated containers exceeding the AMV-WES and AMV-TLV for fumigants 5 (WES) and 12 (TLV) times more frequently than non-fumigated containers ($p<0.001$; Table 3.3). Adjusting for cargo, country of origin, container size and number of open vents resulted in only a minor change (AMV-WES for fumigants: Ratio 7.5, 95%CI 2.1-27.3; AMV-TLV for fumigants: Ratio 7.3, 95%CI 1.6-33.3; Table 3.4). Also, exclusion of methanol did not change the results (results not shown).

Higher AMV levels for other chemicals were observed for the cargo category ‘tyres’ and for larger containers (40ft); containers from Asia also had higher overall AMV levels (Table 3.4). Although AMV levels were higher in containers without open vents (when vents were taped over) and lower in containers with 4 open vents, when compared to 2 open vents, these differences were not statistically significant (Table 3.4).

Table 3.4 Multi-variate regression of AMVs with cargo category, country of origin and other variables from air samples taken upon opening the container door (n=45)

		fumigants		other chemicals		overall	
		AMV-WES[a]	AMV-TLV[b]	AMV-WES	AMV-TLV	AMV-WES	AMV-TLV
Variable	**n**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**	**Ratio (CI)**
Fumigation status							
not fumigated	28	reference	reference	reference	reference	reference	reference
fumigated	17	7.5 (2.1-27.3)**	7.3 (1.6-33.3)*	1.4 (0.6-3.1)	1.2 (0.5-2.9)	5.3 (1.8-15.3)**	3.3 (1.0-11.0)*
Cargo							
Miscellaneous	32	reference	reference	Reference	Reference	reference	reference
cars and metal car parts	4	0.6 (0.1-2.8)	0.8 (0.1-5.3)	0.4 (0.2-1.2)	0.4 (0.1-1.4)	0.5 (0.1-1.7)	0.6 (0.1-2.6)
Tyres	4	0.9 (0.2-4.7)	2.8 (0.4-20.6)	5.1 (1.7-15.2)**	6.2 (1.9-19.9)**	1.1 (0.3-4.6)	2.8 (0.6-13.2)
Unknown	5	2.1 (0.4-10.0)	3.2 (0.5-19.6)	2.8 (1.0-7.7)*	2.8 (0.9-8.2)	3.2 (0.9-11.5)	3.3 (0.8-14.0)
Country							
world excluding Asia	18	reference	reference	Reference	Reference	reference	reference
Asia	20	2.5 (0.9-6.8)	2.5 (0.8-8.0)	1.7 (0.9-3.3)	1.6 (0.8-3.3)	2.7 (1.2-6.2)*	2.6 (1.1-6.6)*
Unknown	7	6.4 (1.7-23.7)**	1.3 (0.3-6.1)	3.4 (1.5-8.0)**	3.6 (1.4-9.0)**	5.2 (1.7-15.4)**	2.6 (0.8-8.8)
Container size							
20 ft	24	reference	reference	Reference	Reference	Reference	reference
40 ft	21	1.3 (0.5-3.0)	2.0 (0.7-5.4)	1.8 (1.0-3.1)*	2.1 (1.1-3.7)*	1.4 (0.7-2.9)	1.8 (0.8-4.0)
Container Vents							
2 open vents	23	Reference	reference	Reference	Reference	Reference	reference
no open vents	10	1.6 (0.4-6.2)	2.9 (0.6-14.7)	1.3 (0.5-3.1)	1.3 (0.5-3.4)	1.6 (0.5-5.0)	3.2 (0.9-11.6)
4 open vents	6	0.8 (0.2-3.0)	0.4 (0.1-2.0)	0.6 (0.3-1.4)	0.5 (0.2-1.3)	0.8 (0.3-2.3)	0.6 (0.2-2.0)
Unknown	6	0.2 (0.0-1.1)	0.5 (0.1-3.3)	0.3 (0.1-0.9)*	0.4 (0.1-1.1)	0.2 (0.1-0.9)*	0.4 (0.1-1.9)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$

[a] Additive Mixture Value using the WES (8-hour Workplace Exposure Standards set by WorkSafe NZ (2019)) and excluding 1,2-dibromoethane

[b] Additive Mixture Value using the TLV (8-hour Workplace Exposure Standards (Threshold Limit Value) set by American Conference of Governmental Industrial Hygienists (ACGIH) (2020)) and excluding 1,2-dibromoethane

Of the 41 PID measurements collected upon opening containers, 10 had an initial reading of >1,000 ppb (lower LoD). For 7 containers readings dropped below 1,000 ppb within 2 minutes, while for one container, which had been fumigated twice with methyl bromide, it took an hour for levels to drop below 1,000 ppb (Figure 3.1). For this container an additional sample was taken 33 minutes after opening the doors, showing a drop of methyl bromide from the initial 319,000 ppb to 5,826 ppb (1.8%), which remained above both the WES and TLV.

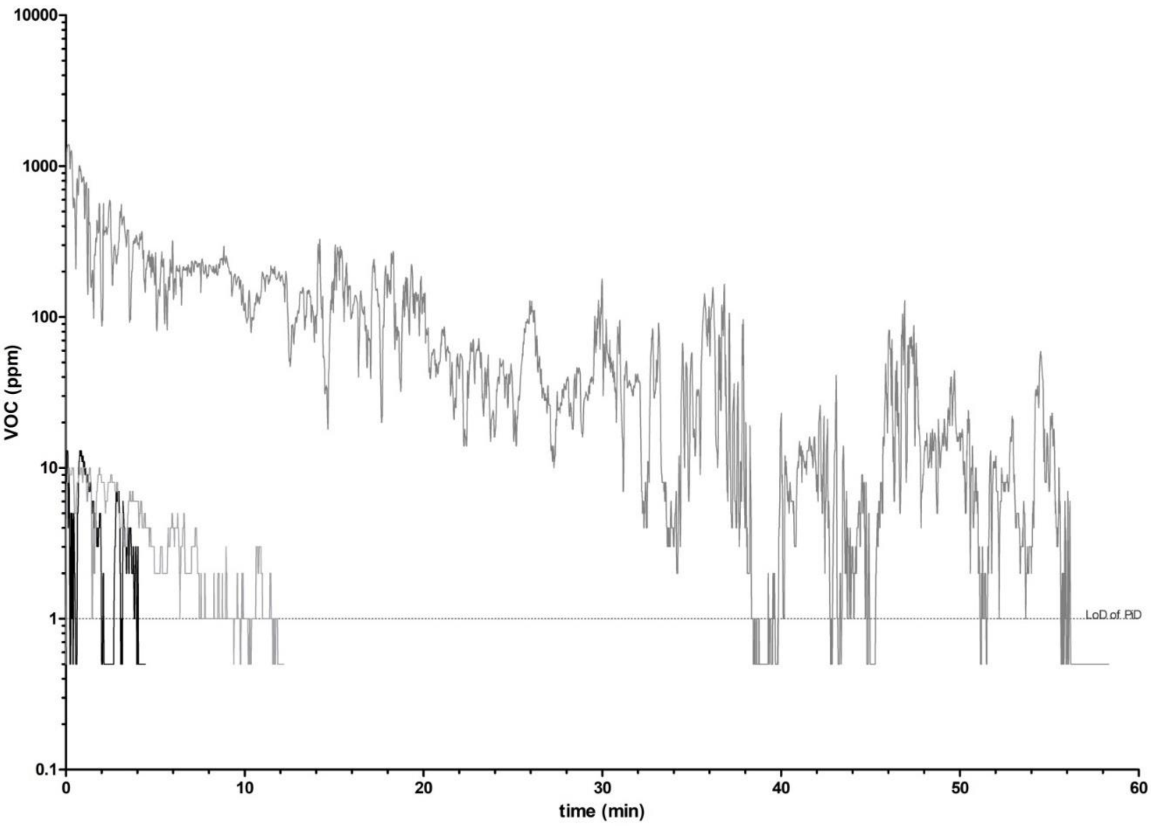

Figure 3.1 PID readings (ppm) upon opening containers. Data shown for three containers that had PID readings of >1 ppm for >2 minutes.

3.4 Discussion

This is the first study that comprehensively assessed airborne fumigants and other chemicals in containers imported into New Zealand. Concentrations in sealed containers were compared with New Zealand (WES) and international (ACGIH TLV) 8-hour exposure limits, which, although not directly applicable to short-term ambient concentrations, provide a conservative comparison. Levels regularly exceeded these limits for one or more chemicals (8% WES; 20% TLV), and additive mixture values (AMV) above "1" were common (AMV-WES 8%, AMV-TLV 26%).

A direct comparison of median levels (based on detectable results only) with results from international studies was not possible as most reported only the frequency of measurements exceeding exposure limits. Two studies reported medians,[4, 22] but the analytical detection limits were considerably higher than in our study, hampering a valid comparison. Using the Dutch occupational exposure limit (OEL), as also applied in a recent review,[3] we compared the proportion of exceedances for fumigants and formaldehyde with those reported in 9 international studies (Supplementary Table 3.7). This showed fewer exceedances for chloropicrin and phosphine in our survey. Ethylene oxide exceeded the OEL in 4.5% of containers in our study, similar to the 5.4% reported for Australia, while percentages reported for European countries were generally lower. For methyl bromide and formaldehyde, our results were in the mid-range compared to European countries, and lower than Australia. Despite these differences, which may be due to factors such as cargo, length of travel, differences in measuring methods and changes in fumigation trends over time,[4] this comparison suggests that ambient air concentrations in a significant proportion of containers exceed current exposure standards.

One other study reported AMV values[4] with ~10% of containers exceeding ‘1’ compared to 7.8% (AMV-WES) and 25.7% (AMV-TLV) in our study (Table 3.1). However, LoDs and the number of chemicals used in the calculation of the AMVs varied between studies, hampering a valid comparison.

As reported previously,[38, 48] and illustrated in Figure 3.1, ambient concentrations decrease rapidly after opening containers. Also, containers may be ventilated prior to entry, reducing levels further.[20, 48] In our smaller survey, all fumigated containers were ventilated for up to 24 hours prior to entry, whilst non-fumigated containers had ventilation times ranging from a few minutes up to an hour. Therefore, concentrations in closed containers are unlikely to be a valid estimate of worker exposures as also suggested by the few studies that reported 8-hour personal exposures of well-below ambient concentrations.[20, 24, 48] Nonetheless, they represent potential peak exposures that may occur when opening containers. This may be particularly relevant for biosecurity surveillance workers who inspect containers immediately upon opening container doors. Although air extraction units are available, these require container doors to be opened first and are not often used. A recently reported method for pre-ventilation without the need to open container doors[37] may mitigate this.

Although many chemicals were frequently detected in a large proportion of containers with a wide range of cargo and from a range of countries, rubber products, including tyres, were particularly associated with elevated AMVs (for both fumigants and other chemicals), with exposure ratios ranging from 2.6 - 7.9 (Table 3.2). Tyres were also associated with elevated AMVs for other chemicals in the smaller study (exposure ratio AMV-WES, 5.1 and AMV-TLV, 6.2, Table 3.4). To our knowledge this has not previously reported, although one study found airborne formaldehyde and benzene concentrations above the Dutch OEL in containers carrying rubber products.[53] As rubber fumes contain hazardous chemicals not measured in our survey (several of which associated with cancers and respiratory symptoms),[78] the reported AMVs are likely an underestimation.

Concentrations of fumigants were positively associated with ‘personal hygiene, beauty and medical products’, ‘stone, ceramics and articles thereof’, and ‘metal and glass’. To our knowledge, this has not previously been reported. AMVs for other chemicals were positively associated with ‘pet food’. Other studies have shown that airborne phosphine more frequently exceeded the Dutch OEL in containers carrying ‘food and feed’ items[3, 22] and one study showed that exposure limits were more frequently exceeded in containers carrying ‘foodstuffs’, mainly due to formaldehyde.[16] Previous studies have also shown exposure limit exceedances for other cargo types and specific airborne chemicals (shoes/benzene;[4, 16, 53] furniture and household items/formaldehyde;[16] medical devices/ethylene oxide;[3] and decoration materials/methyl bromide[3]). Most of these associations were not observed in our study (or could not be studied). However, we found an association with ‘personal hygiene, beauty and medical products’ (Table 3.2) but further analyses showed that this was attributable to other non-medical products (data not shown). The lack of consistent findings between studies may be due to differences in the sample of containers measured, local and international fumigation practices, fumigation requirements for different countries, air-sampling methodology, categorisations used to combine cargo types, and/or differences in exposure limits used.

The country of origin was not strongly associated with chemical concentrations, although concentrations of other chemicals appeared higher in containers from China (Table 3.2). A previous study also found that containers from China had the highest frequency of containers with airborne chemicals exceeding chronic and acute exposure limits, but differences between countries were relatively small.[16] This lack of a clear association with country of origin was also found in another study,[22] which showed no difference between countries in the proportion of containers exceeding the Dutch OEL.

Our study found that fumigation status, which has not been studied previously, was strongly associated with elevated levels of methyl bromide and phosphine. However, fumigants were also detected in non-fumigated containers, albeit less frequently. Likewise, exceedances of exposure limits were more frequent in fumigated containers, but these also occurred in non-fumigated containers. The presence of fumigants in non-fumigated containers may be due to earlier fumigation of the same container with different cargo; alternatively, some fumigated containers may not have been labelled as fumigated. Regardless, these findings demonstrate the potential for workers to be exposed to fumigants and other harmful chemicals even when handling containers that are not labelled as fumigated, which represent the majority of containers arriving in New Zealand.[29] Methyl bromide and phosphine were the main drivers of elevated AMVs in fumigated containers, while formaldehyde, a carcinogen and dermal sensitiser,[50] was the main driver for elevated AMVs in non-fumigated containers. This again suggests that handling non-fumigated containers may not be without risk.

As reported by others,[3, 38, 48] the current study has shown that ventilation is effective at reducing ambient concentrations of fumigants and off-gassed chemicals. However, it is difficult to assess when safe levels are reached, especially when relying on natural ventilation.[3, 38, 48] Therefore, suitable devices to measure fumigants and off-gassed chemicals are required. [3, 11, 22, 49] A PID monitor is often used, but this does not identify specific chemicals and some of the WES/TLV values are below the LoD of most PIDs. Also, it can provide false positive findings, as volatile compounds with low toxicity (e.g. methanol) are also measured. Other devices are available (gas chromatography-mass spectrometry), but these are often unaffordable, require specialised analytical skills, and often do not provide results in real time. Therefore, in the absence of more affordable, specific and sensitive equipment that does not require specialist training, workers will continue to be at risk of occasional high exposures. Thus, there is a need to establish improved and standardised strategies for the safe inspection and unpacking of shipping containers.[3, 4, 11, 48, 49]

The smaller survey included a higher proportion of fumigated containers than the larger survey. There are several reasons for this. Firstly, the larger study did not include containers fumigated in New Zealand. Secondly, there was selection towards fumigated containers in the smaller study due to preferences of container handlers and management to sample specific containers, which were often fumigated. Thirdly, many of the fumigated containers in the smaller study were fumigated in New Zealand, which, due to strict rules around fumigation, would have increased the number of containers appropriately labelled as fumigated.

Study limitations include the relatively small size of the second survey. It also involved a selective sample; hence, containers were not representative of all containers arriving in New Zealand. Nonetheless, although not representative, the oversampling of fumigated containers ensured sufficient numbers of fumigated containers to meaningfully compare results with non-fumigated containers. For the larger study, containers were selected from one port, which may not be representative all containers arriving in New Zealand i.e. some studies have shown large differences between ports.[4, 22] In addition, the larger study lacked some information on container characteristics such as number of container vents and the size of the container. Furthermore, the linear regression analyses described in Table 3.2 and 3.4 involve many comparisons, which may risk false positive results. However, we observed considerably more statistical findings than expected based on chance alone i.e. 23 vs 6 (Table 3.2) and 16 vs 4.5, when defining statistical significance as $p<0.05$. Therefore, results are unlikely to be due to chance alone.

As air samples were tested only for selected chemicals and the LoD for 1,2 dibromoethane was above the WES, the AMV values are likely underestimated. Similarly, for the second survey we used canister samples that were stored up to 24 or even 48 hours, prior to analysis, which may have resulted in decay and subsequent underestimation of the true concentrations. However, validation experiments (see methods) showed that decay was modest and is therefore unlikely to have significantly affected our results. Nonetheless, as not all tested chemicals were included, we cannot exclude more significant decay for some chemicals. Furthermore, in the larger study, samples were taken at the bottom of the container doors, which may have also resulted in an underestimation of concentrations.[4]

Another limitation of the larger study is that samples were taken in 2011 and may therefore not accurately represent the current situation. However, although some changes may have happened in this industry, it is unlikely that results would be very different, as relevant policies and/or fumigation requirements in New Zealand have not been changed since 2011. Nonetheless, this cannot be objectively verified, and recent changes in import/export patterns due to the 2020/2021 Coronavirus Disease (COVID-19) pandemic may have, at least temporarily, resulted in some changes.

In conclusion, this study showed that airborne chemicals in containers arriving in New Zealand frequently exceed exposure limits, both in fumigated and non-fumigated containers. Workers may therefore experience hazardous peak exposures particularly upon opening container doors, also in non-fumigated containers. Although fumigation status and some cargo types and countries of origin were associated with elevated ambient chemical concentrations, results were not always consistent with those reported in other studies and it therefore remains difficult to predict which containers represent the greatest risk.

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Supplementary Table 3.5 Frequency table of percentage of detected chemicals in each cargo and country category in the survey on sealed containers (n=490)

	total containers	total containers %	1,2-Dibromoethane	Chloropicrin	Ethylene oxide	Hydrogen cyanide	Phosphine	Methyl bromide	Fumigants	Benzene	Formaldehyde	Toluene	>AMV-WES	>AMV-TLV
Total	490	100.0	2	0.2	4.7	1.8	1	3.5	11.4	3.5	81	31.8	7.8	25.7
Cargo														
Food, beverages, tobacco	77	15.7												
Beverages, spirits and vinegar	27	5.5	3.7	0	0	0	0	0	3.7	3.7	81.5	14.8	11.1	33.3
Preparations of cereals, flour, starch or milk	19	3.9	0	0	0	0	0	5.3	5.3	0	84.2	10.5	5.3	5.3
Sugars and sugar confectionery	6	1.2	16.7	0	0	0	0	16.7	33.3	33.3	83.3	50	0	33.3
Miscellaneous edible preparations	6	1.2	0	0	0	0	0	0	0	0	83.3	33.3	0	16.7
Dairy produce; bird eggs; natural honey; edible products of animal origin	5	1.0	0	0	0	0	0	0	0	0	100	40	0	0
Coffee, tea and spices	5	1.0	20	0	0	0	0	0	20	0	80	20	0	40
Edible vegetables and certain roots and tubers	3	0.6	0	0	0	0	0	0	0	0	100	0	0	0
Cereals	2	0.4	0	0	0	0	0	0	0	0	0	50	0	0
Edible fruit and nuts; peel of citrus fruit or melons	1	0.2	0	0	0	0	0	0	0	0	100	0	0	0
Cocoa and cocoa preparations	1	0.2	0	0	0	0	0	100	100	0	100	100	0	100
Preparations of meat, of fish or of crustaceans, molluscs or other aquatic invertebrates	1	0.2	0	0	0	0	0	0	0	0	100	100	0	0
Tobacco and manufactured tobacco substitutes	1	0.2	0	0	0	0	0	0	0	0	100	0	0	0
Paper and paperboard and articles there of	62	12.7												
Paper and paperboard; articles of paper pulp, of paper or of paperboard	58	11.8	0	0	0	0	0	1.7	1.7	0	82.8	5.2	0	15.5
Printed books, newspapers, pictures and other products of the printing industry	4	0.8	0	0	0	0	0	0	0	0	50	0	0	0
Plastics	57	11.6												
Plastics and articles thereof	57	11.6	1.8	0	5.3	3.5	0	5.3	15.8	3.5	80.7	40.4	5.3	24.6
Machinery and equipment including appliances and electronics	49	10.0												
Nuclear reactors, boilers, machinery and mechanical appliances; parts thereof	23	4.7	0	0	4.3	0	0	4.3	8.7	4.3	78.3	39.1	4.3	21.7
Electrical machinery and equipment and parts thereof; sound recorders, TV	22	4.5	0	0	0	0	0	0	0	0	100	40.9	4.5	31.8

Optical, photographic, cinematographic, measuring, checking, precision, medical or surgical	4	0.8	0	0	0	0	0	0	0	0	75	25	0	25
Personal hygiene, beauty and medical products	43	8.8												
Essential oils and resinoids; perfumery, cosmetic or toilet preparations	22	4.5	0	0	9.1	9.1	0	9.1	27.3	4.5	86.4	27.3	9.1	50
Pharmaceutical products	14	2.9	0	0	7.1	7.1	0	0	14.3	0	78.6	28.6	7.1	7.1
Soap, organic surface-active agents, washing preparations, lubricating preparations, artificial	6	1.2	0	0	0	33.3	0	0	33.3	16.7	83.3	33.3	16.7	66.7
Albuminoidal substances; modified starches; glues; enzymes	1	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Chemicals	39	8.0												
Miscellaneous chemical products	16	3.3	6.3	0	0	6.3	0	0	12.5	6.3	87.5	37.5	6.3	31.3
Tanning or dyeing extracts; tannins and their derivatives; dyes, pigments and other	12	2.5	0	0	8.3	0	0	0	8.3	0	83.3	50	8.3	16.7
Salt; sulphur; earths and stone; plastering materials, lime and cement	3	0.6	0	0	0	0	0	0	0	0	66.7	0	0	0
Organic chemicals	3	0.6	0	0	0	0	0	0	0	0	100	0	33.3	33.3
Mineral fuels, mineral oils and product	2	0.4	0	0	50	0	0	0	50	0	100	0	50	50
Inorganic chemicals; organic or inorganic compounds of precious metals, of rare-earth metals,	2	0.4	0	0	50	0	0	0	50	0	50	0	50	0
Photographic or cinematographic goods	1	0.2	100	0	0	0	0	0	100	0	100	100	0	0
Metal and glass	36	7.3												
Articles of iron or steel	15	3.1	6.7	0	13.3	0	0	0	20	6.7	53.3	80	20	20
Glass and glassware	9	1.8	11.1	0	0	0	0	11.1	11.1	0	55.6	33.3	11.1	22.2
Miscellaneous articles of base metal	5	1.0	0	0	0	0	0	0	0	0	80	20	0	0
Tools, implements, cutlery, spoons and forks, of base metal;	4	0.8	0	0	0	0	0	0	0	0	25	0	0	0
Aluminium and articles thereof	2	0.4	0	0	100	0	0	50	100	0	50	100	100	100
Iron and steel	1	0.2	0	0	0	0	0	0	0	0	100	100	0	0
Man-made fibre articles there of	34	6.9												
Furniture; bedding, mattresses, mattress supports, cushions and similar stuffed furnishings	16	3.3	0	0	6.3	0	0	6.3	12.5	0	93.8	31.3	6.3	25
Carpets and other textile floor coverings	5	1.0	0	0	0	0	0	0	0	0	80	20	0	0
Man-made filaments; strip and the like of man-made textile materials	3	0.6	0	0	0	0	0	0	0	0	100	0	0	0
Other made up textile articles; sets; worn clothing and worn textile articles; rags	3	0.6	0	0	0	0	0	0	0	0	100	33.3	0	33.3
Footwear, gaiters and the like; parts of such articles	3	0.6	0	0	0	0	0	0	0	0	100	33.3	0	0
Man-made staple fibres	2	0.4	0	0	0	0	0	0	0	0	0	0	0	0
Impregnated, coated, covered or laminated textile fabrics	1	0.2	0	0	0	0	0	0	0	0	0	0	0	0
Articles of apparel and clothing accessories, knitted or crocheted	1	0.2	0	0	0	0	0	0	0	0	100	0	0	0
Miscellaneous	32	6.5												

LCL (multiple commodities)	11	2.2	0	0	0	9.1	0	0	9.1	9.1	54.5	18.2	0	27.3
Miscellaneous New Zealand Provisions	9	1.8	0	0	0	0	0	0	0	0	77.8	66.7	0	33.3
Toys, games and sports requisites; parts and accessories thereof	7	1.4	0	0	0	0	0	0	0	0	85.7	42.9	14.3	28.6
Manufactures of straw, of esparto or of other plaiting materials; basketware and wickerwork	2	0.4	0	50	0	0	0	0	50	50	100	100	50	100
Articles of leather and animal gut	1	0.2	0	0	0	0	0	0	0	0	100	0	0	0
Miscellaneous manufactured articles	1	0.2	0	0	0	0	0	0	0	0	100	0	0	0
Umbrellas, sun umbrellas, walking-sticks, seat-sticks, whips, riding-crops	1	0.2	0	0	0	0	0	0	0	0	100	100	0	100
Wood and articles there of	18	3.7												
Wood and articles of wood; wood charcoal	18	3.7	0	0	5.6	0	5.6	0	5.6	5.6	77.8	55.6	5.6	27.8
Stone, ceramics and articles there of	14	2.9												
Articles of stone, plaster, cement, asbestos, mica or similar materials	11	2.2	0	0	18.2	0	0	36.4	36.4	9.1	90.9	36.4	18.2	45.5
Ceramic products	3	0.6	0	0	0	0	0	0	0	0	66.7	33.3	0	0
Rubber products inclusive tyres	13	2.7												
Rubber and articles thereof	13	2.7	15.4	0	30.8	0	30.8	0	46.2	23.1	100	69.2	53.8	69.2
Pet food	9	1.8												
Residues and waste from the food industries; prepared animal fodder	9	1.8	0	0	0	0	0	0	0	0	100	0	0	77.8
Vehicles other than railway or tramway rolling-stock, and parts	7	1.4												
Vehicles other than railway or tramway rolling-stock, and parts	7	1.4	0	0	14.3	0	0	0	14.3	0	71.4	57.1	14.3	0
Country														
Total	**490**	**100**	**2.0**	**0.2**	**4.7**	**1.8**	**1.0**	**3.5**	**11.4**	**3.5**	**81.0**	**31.8**	**7.8**	**25.7**
Australia	283	57.8	1.0	0.0	2.2	1.2	0.0	2.0	6.1	1.2	45.9	16.3	3.1	11.0
China	74	15.1	0.8	0.0	1.2	0.0	0.2	0.6	1.8	1.0	12.7	6.5	2.2	5.9
North America	56	11.4	0.2	0.0	0.2	0.2	0.0	0.2	0.8	0.6	9.2	3.3	0.4	4.1
Other Asia countries	33	6.7	0.0	0.2	0.0	0.2	0.4	0.2	1.0	0.4	5.5	3.7	0.6	2.0
Europe	21	4.3	0.0	0.0	0.6	0.0	0.2	0.2	0.8	0.0	3.5	1.4	1.0	1.4
Other regions	23	4.7	0.0	0.0	0.4	0.2	0.2	0.2	0.8	0.2	4.3	0.6	0.4	1.2

Supplementary Table 3.6 Cargo and country of origin of containers by fumigation status in containers upon opening of container doors (n=46)

Cargo	non-fumigated containers (n=29)	fumigated containers (n=17)	Country	non-fumigated containers (n=29)	fumigated containers (n=17)
unknown	6	0	China	7	3
food & tobacco	5	6	unknown	6	1
textiles	5	0	Chile	4	0
household items, hardware	5	1	Asia unknown	2	0
eucalyptus pulp	4	0	Brazil	2	0
miscellaneous	2	0	Zimbabwe	2	0
cars and metal car parts	1	3	Thailand	1	2
tyres	1	3	Australia	1	1
wood & wooden furniture	0	4	Pakistan	1	0
			Belgium	1	0
			UK	1	0
			Honduras	1	0
			Malawi	0	3
			Indonesia	0	4
			Malaysia	0	1
			USA	0	1
			Ghana	0	1

Supplementary Table 3.7 Comparison of chemicals detected in containers above the Dutch occupational exposure limit (OEL) in the survey on sealed containers with previous studies. Table adapted from the European Agency for Safety and Health at Work[3]

Study	n (containers)	Percentage of containers with chemical level > Dutch OEL (highest detected concentration in ppm)*				
		Chloropicrin	Ethylene oxide	Phosphine	Methyl bromide	Formaldehyde
Dutch OEL (ppm)		**0.1**	**0.5**	**0.1**	**0.25**	**0.1**
Current study - Tauranga, New Zealand 2011 [74]	490	0.0 (0.05)	4.5 (9.7)	0.2 (0.14)	1.8 (49.9)	17.9 (6.6)
Sweden, 2013 [4]	249	n.d.	0.7 (1.7)	0.4	n.d.	3.6 (2)
Australia, 2012 [24]	76	5.3 (1.6)	0	1.3 (0.15)	21.1 (4.4)	21.1 (2)
Europe, 2011 [23]	123,439	0.01 (26)	n.d.	1.5 (329)	0.4	3.7 (38)
Belgium and the Netherlands, 2010 [53]	42,888	0.2 (26)	n.d.	0.9 (368)	0.7 (88)	2.6 (40)
Italy, 2004-2010 [51]	5414/1362/9,482[a]	n.d.	n.d.	47.2 (680)	> 13.8 (1,380)[b]	4.7
Australia, 2007-2008 [58]	14,943	18.0	5.4	3.5	13.0	31.6
Hamburg, Germany, 2006 [16]	2,113	1.3	0.9	0.9	7.1	30.9
The Netherlands, 2003-2006 [62]	277	2.4	n.d.	2.9	13.4	n.d.
Rotterdam, the Netherlands, 2002 [22]	303	n.d.	n.d.	2.0 (> 20)	3.4 (90)	1.3 (13.4)

[*] 1,2 dichloroethane was not included as it was not measured in the NZ survey. Additionally, the European Agency for Safety and Health at Work noted that both the Australian studies found 1,2-dibromoethane in several containers; in particular, the larger survey found that 26.1 % of the containers had 1,2-dibromoethane levels exceeding the OEL. In the NZ survey > 2% of containers exceeded the OEL. The exact value is unknown as the OEL is below the Limit of Detection.
n.d. not determined.
[a] n=5414 for phosphine, n=1362 for methyl bromide, and n=9482 for formaldehyde
[b] 13.8 % >1 ppm.

4 Exposures to fumigants and residual chemicals in workers handling cargo from shipping containers and export logs in New Zealand

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Abstract

Background: Previous studies have reported high concentrations of airborne fumigants and other chemicals inside unopened shipping containers, but it is unclear whether this is reflective of worker exposures.

Methods: We collected personal 8-hour air samples using a whole-air sampling method. Samples were analysed for 1,2-dibromoethane, chloropicrin, ethylene oxide, hydrogen cyanide, hydrogen phosphide, methyl bromide, 1,2-dichloroethane, C2-alkylbenzenes, acetaldehyde, ammonia, benzene, formaldehyde, methanol, styrene and toluene. Additive Mixture Values (AMV) were calculated using the New Zealand Workplace Exposure standard (WES) and ACGIH Threshold Limit Values (TLV) of the 8-hour, time-weighted average (TWA) exposure limit. Linear regression was conducted to assess associations with work characteristics.

Results: We included 133 workers handling shipping containers, 15 retail workers unpacking container goods, 40 workers loading fumigated and non-fumigated export logs, and 5 fumigators. A total of 193 personal 8-hour air measurements were collected. Exposures were generally low, with >50% below the limit of detection for most chemicals, and none exceeding the NZ WES, although formaldehyde exceeded the TLV in 26.2% of all measurements. The AMV-TLV threshold of 1 was exceeded in 29.0% of the measurements. Levels and detection frequencies of most chemicals varied little between occupational groups, although exposure to methyl bromide was highest in the fumigators (median 43 ppb) without exceeding the TLV of 1000 ppb. Duration spent inside the container was associated with significantly higher levels of ethylene oxide, C2-alkylbenzenes and acetaldehyde, but levels were well below the TLV/ WES.

Exposure levels did not differ between workers handling fumigated and non-fumigated containers.

Conclusion: Personal exposures of workers handling container cargo in New Zealand were mainly below current exposure standards, with formaldehyde the main contributor to overall exposure. However, as it is not clear whether working conditions of participants included in this study were representative of this industry as a whole, and not all relevant exposures were measured, we cannot exclude the possibility that high exposures may occur in some workers.

4.1 Introduction

Globally, goods transported in containers have risen from 100 million metric tons in 1980 to 1.7 billion metric tons in 2015.[79] In New Zealand, over 500,000 containers were imported from the third quarter of 2018 to the end of the second quarter in 2019, representing more than 15 million tonnes of container goods.[80] A proportion of these containers require fumigation either for biosecurity reasons or to prevent damage to the cargo.

Several case reports of acute poisoning in workers handling shipping cargo have been reported,[5-8, 10-12] with exposure to fumigants or chemicals off-gassed from products or packaging materials the most likely causes.[3, 7, 8, 11]Symptoms varied from skin irritation, respiratory distress, to seizures and persistent neurological deficits.[5, 7, 8, 10, 11] Subsequent studies, reviewed by the European Agency for Safety and Health at Work (2018), found elevated concentrations of fumigants and other chemicals in the air of unopened shipping containers,[4, 16, 22, 51, 62, 74, 81, 82] with the latest study showing that levels exceeding Swedish occupational exposure limits occurred in 13% of all tested containers, with exceedance rates varying from 0-33% dependent on the port where samples were taken.[4] Several studies have also reported elevated levels of fumigant and other residual chemicals in packaging and container goods,[15, 17] suggesting that retail staff and consumers may also be at risk.[7, 8, 15, 16]

One small study that measured airborne personal exposures of fumigants and other off-gassed chemicals in 12 container workers over a 2 to 3 hour period showed that all exposures were below the relevant workplace exposure limits.[24]

This is consistent with an experimental study using tracer gas showing exposures in workers, averaged over the time of unloading, of only 1-7% of the initial tracer gas concentrations in the container.[48] The lower personal exposures were attributed to the rapid decline in concentration following the opening of containers and subsequent ventilation.[38, 48] Nonetheless, both experimental studies showed that high exposure may still occur as demonstrated by peak exposures of up to 70% of the original tracer gas concentrations.[48]

Thus, despite health concerns for workers involved in unloading shipping containers and/or handling container goods, little is known about work exposures to fumigants and chemicals off-gassed from products or packaging material. This study assessed, for the first time on a large scale, full shift (8-hour) exposures to fumigants and other off-gassed chemicals in workers handling cargo from shipping containers, including a small number of retail workers. In addition, we measured the same chemicals in a small group of fumigators and a group of port workers who were loading export logs, some of which had previously been fumigated with methyl bromide, a toxic chemical that is associated with both acute poisoning[5, 7, 10, 11] and chronic health effects[5, 7, 9].

4.2 Methods

Study design

This study is an exposure survey nested in a larger cross-sectional health study of workers handling cargo from shipping containers and export logs and was aimed to assess personal exposures to fumigants and other residual chemicals. The health survey involved 493 participants from 100 companies selected from a list of Accredited Transitional Facilities (ATF) published by the New Zealand Ministry of Primary Industries. These are companies accredited to open and inspect (for biosecurity reasons) overseas containers. The average age of the participants was 39 years (range: 17-79 years), 79% were male, and average employment duration at the current workplace was 6.7 years (median: 4 years). We randomly invited 31 companies to participate in the exposure survey all of whom accepted, with air sampling provided at no cost often being the primary reason for participation.

The exposure survey involved 8-hour personal airborne exposure measurements in workers handling shipping containers, retail workers handling cargo, export log workers involved in loading logs onto ships, and fumigators. Measurements were conducted year-round and across a range of working conditions e.g. different seasons and meteorological conditions, company size, night and day shifts, and throughput of cargo. All workers who entered shipping containers recorded the time spent unloading each container, the nature of the cargo and packaging, and the country of origin of the container. Before entry, all containers were passively ventilated (open door), except for two containers that had fan-ventilation, and one container that had an extraction unit. Ventilation times for passive ventilation were not routinely recorded, but observations by fieldworkers suggest it varied greatly from a few minutes to 30 minutes for non-fumigated containers and up to 24 hours for fumigated containers.

Written consent was obtained from all participants and ethics approval was granted by the Multi-region Ethics Committee of the New Zealand Ministry of Health (MEC/12/02/010).

Participant recruitment

The 31 companies that participated in the air sampling had a workforce size and total throughput of cargo reflective of this industry in New Zealand, but no formal test was done to assess whether this sample was representative of the industry as a whole. The companies comprised distribution centres (n=3), third party logistics providers (n=13) or companies unloading their own imported containers (n=9). We also recruited a government department involved in inspecting overseas containers (n=1), a company specialising in export log operations (n=1), port companies (n=2), a fumigation company (n=1) and a retail store company (n=1; Fig 1). The companies, situated at nine locations throughout New Zealand, ranged in size from owner-operated to large distribution centres, with the number of participants mostly reflecting the size of the company (1-2 participants, 13 companies; 3-6 participants, 11 companies; and 7-39 participants, 7 companies). In these 31 companies, management identified potential participants based on availability and workplace requirements resulting in 193 workers participating in the study (Figure 4.1), with four participants declining to participate.

Air sampling

We collected full-shift (8-hour) airborne personal measurements in the period 2013-2016, using a whole-air method (Restek Corporation, PA, USA) .[83] Briefly, teflon tubing running from the participant's breathing zone was connected to a 400cc stainless steel and Siltek treated sampling canister (Restek Corporation, PA, USA) negatively pressurised to near full vacuum (-30 mmHg). A flow controller (Restek Corporation, PA, USA) was used to maintain a flow rate of 0.9 ml/min and sampling was stopped when air pressure in the canisters reached between -5 and -3 mmHg. All workers wore the sampling equipment continuously throughout their work-shift, except for fumigators who removed the sampling equipment when wearing respiratory protective equipment (no other workers wore respirators).

Workers entering a container spent on average 3.8 hours (Standard Deviation (SD) 2.4; range 0.02-8 hrs) on these duties. The cargo, packaging, the origin of the container and the way the containers were packed varied widely (Figure 4.1).

We sampled 15 shipping container handlers twice on different days. Because the cargo and the countries of origin of the containers unloaded were different, we treated these “repeat” measurements as independent observations. In addition, and to allow comparisons to be made between handling fumigated and non-fumigated logs, eight log workers were sampled twice, with the first measurement taken when non-fumigated logs were handled and the second when handling fumigated logs. Working conditions were very similar on both days with sampling done on two consecutive days with similar meteorological conditions and work tasks.

Laboratory analyses

Air samples were analysed by Syft Technologies, Christchurch, New Zealand using Selected Ion Flow Tube Mass Spectrometry[75-77] for several common fumigants and harmful chemicals frequently found in shipping containers. The fumigants included: 1,2-dibromoethane [CAS NO: 106-93-4], chloropicrin [76-06-2], ethylene oxide [75-21-8], hydrogen cyanide [74-90-8], hydrogen phosphide [7803-51-2] and methyl bromide [74-83-9]. Other hazardous chemicals included: 1,2-dichloroethane [107-06-2], C2-alkylbenzenes [108-38-3, 95-47-6, 106-42-3, 100-41-4], acetaldehyde [75-07-0], ammonia [7664-41-7], benzene [71-43-2], formaldehyde [50-00-0], styrene [100-42-5] and toluene [108-88-3]. Blank canisters were analysed with each series of measurements. Formaldehyde concentrations of 10 measurements were excluded because of high readings of the blanks.

For each chemical the limits of detection (LoD), the 8-hour, time-weighted average exposure limit based on the New Zealand Workplace Exposure standards (WES) and the Threshold Limit Values (TLV) set by the American Conference of Governmental Industrial Hygienists (ACGIH) are provided in Table 4.1. Exposures were expressed in parts per billion (ppb). In addition to reporting levels for each chemical separately, we also calculated the combined exposure expressed as the ‘sum-value’ i.e. the concentrations of all chemicals added up, and the additive mixture value (AMV), i.e. an estimate of the combined toxic effect of chemicals. To calculate the AMV as defined by the ACIGH,[59] each chemical was given a toxicity score by dividing the measured level by the appropriate TLV and WES followed by summation of the toxicity scores of all chemicals measured in the sample, thus providing an AMV-TLV and an AMV-WES for each sample. An AMV exceeding 1 was considered to be above the exposure limit for that mixture.

Statistical analyses

Statistical analyses were conducted using Stata version 13.1 (StataCorp LP, Texas, USA). Measurements below the LoD were assigned a value of half the LoD. Medians, 75 percentiles and maximum levels were used to summarise exposure data for the 4 different occupational groups (container handlers, retail workers, export log workers, fumigators) and for subgroups of container handlers.

We used linear regression to assess differences in exposure between occupational groups using container handlers as the reference group. Analyses were left-censored (using the Tobit function in Stata) for individual chemicals due to the large number of samples with concentrations below the LoD;[84, 85] for sum value and AMVs there was no need to left-censor the analyses. Within the group of container handlers, we compared personal exposure levels of participants entering containers with those not entering containers (n=35) but who were working at the same premises. This allowed us to assess whether entering containers was associated with higher exposures due to the presence of residual fumigants and/or off-gassed chemicals from cargo or packaging in these containers. Within this group of workers, we also assessed associations with the fumigation status of the cargo (11 measurements were excluded due to unknown fumigation status) and duration of unloading containers (4 measurements were excluded due to unknown duration). As exposure-values were ln-transformed prior to regression analyses, regression coefficients represent relative differences, or exposure ratios (ER), with an ER of e.g. 2 indicating that the exposure for a particular occupational group is twice as high compared to the reference group. When modelling the number of hours spent unloading containers, the ER represents an increase or decrease in exposure associated with 1 additional hour of unloading containers (i.e. an ER of 1.3 indicates that an hour of unloading is associated with a 30% higher exposure, with and ER of 0.7 indicating a 30% reduction in exposure for each hour worked).

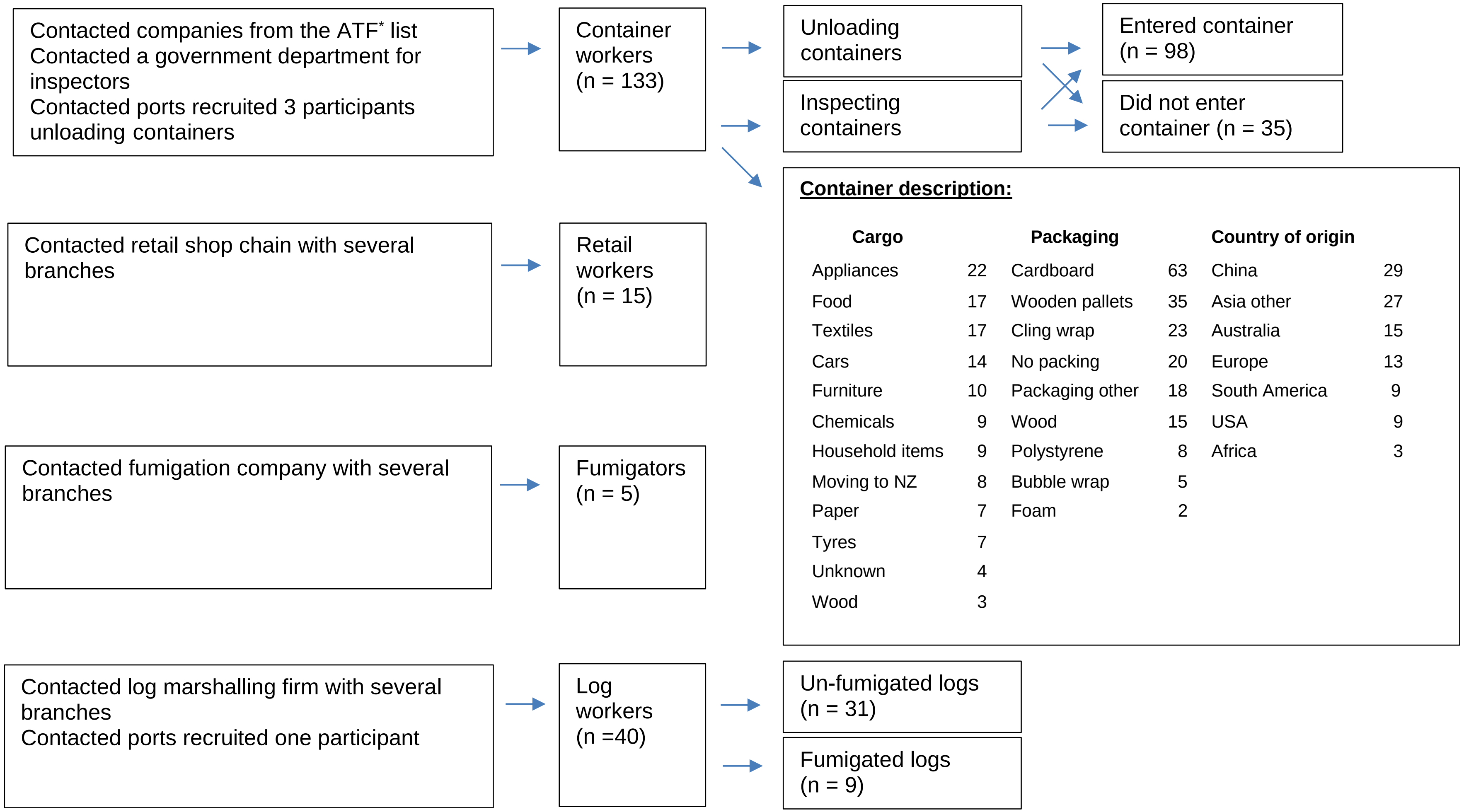
Analyses to assess associations with cargo type, packaging materials and country of origin were not conducted due to participants often unloading multiple containers with different cargo and from different countries on the same day (samples were collected during an 8-hour shift rather than it being targeted towards work related to a specific container).

In log workers we compared (using left censored linear regression) exposures measured on days that fumigated logs were loaded (n=10) with those of days that non-fumigated logs were loaded (n=9).

Spearman correlation analyses were conducted to estimate the contribution of each chemical and sum-value to the AMV-TLV and AMV-WES.

4.3 Results

A total of 193 personal air samples were collected from 133 workers handling shipping containers, 15 retail workers unpacking container goods, 40 workers loading fumigated and non-fumigated export logs, and 5 fumigators. Of those handling shipping containers, 98 entered one or more containers whilst 35 did not enter any container on the day that measurements were taken (they did dispatch and office work; Figure 4.1). Of the 98 participants who entered containers, 31 stated they had unloaded at least one fumigated container on the day that exposures were measured (Figure 4.1). Of the 40 measurements in log workers, 9 involved sampling workers who were loading fumigated logs. Four of 5 fumigators applied fumigation at the time of sample collection (Figure 4.1). All retail workers and workers who did not enter a container stated that they did not know whether the goods they handled were fumigated or not.



* ATF Accredited Transitional Facilities are companies, which are certified by the NZ Ministry for Primary Industries to biosecurity, inspect import

Figure 4.1 Flowchart of participant recruitment and grouping

Overall, detection frequencies of individual chemicals were below 50%, except for formaldehyde (Table 4.1). Maximum exposure levels were below 30% of the corresponding WES/TLV, except for formaldehyde (Table 4.1). The New Zealand WES was never exceeded for any of the chemicals and the WES-based AMV never exceeded “1”. The ACGIH TLV was only exceeded for formaldehyde, which occurred in 26.2% of measurements (container handlers, 29%; retail workers, 20%; export log workers, 20%; and fumigators, 20%). The TLV-based AMV exceeded “1” in 29% of all measurements (container handlers, 29%; retail workers, 27%; export log workers, 30%; and fumigators, 20%), which was largely due to formaldehyde, i.e. of the 56 measurements exceeding the AMV-TLV, 48 also exceeded the TLV for formaldehyde, with the remaining six measurements very close to the TLV (data not shown). This is also evident from the high correlation between AMVs and the toxicity score for formaldehyde (WES $r=0.93$, $p<0.001$; TLV $r=0.96$, $p<0.001$; $n=183$). For fumigators, methyl bromide was detected in all measurements, but levels were still well below the WES and the TLV (Table 4.1).

Table 4.1 Descriptive statistics for personal 8-h exposure of participants by occupational group

				container handlers (n=133)[a]			retail workers (n=15)			export log workers (n=40)			fumigators (n=5)		
chemical/ (ppb[b])	**WES[c]**	**TLV[d]**	**LoD**	**<LoD (%)**	**Median (p75)**	**Max**	**<LoD (%)**	**Median (p75)**	**Max**	**<LoD (%)**	**Median (p75)**	**Max**	**<LoD (%)**	**Median (p75)**	**Max**
Fumigants															
1-2-dibromoethane	500	-	5	71.4	< LoD (<LoD)	61.2	86.7	< LoD (<LoD)	6.7	55.0	< LoD (7.0)	11.5	80.0	< LoD (<LoD)	8.6
chloropicrin	100	100	5	88.7	< LoD (<LoD)	27.8	100.0	< LoD (<LoD)	< LoD	100.0	< LoD (<LoD)	2.5	60.0	< LoD (9.6)	13.9
ethylene oxide	1000	1000	10	88.7	< LoD (<LoD)	130.1	66.7	< LoD (16.5)	33.7	60.0	< LoD (19.8)	54.8	100.0	< LoD (<LoD)	5.0
hydrogen cyanide	10000[e]	4700[e]	3	78.9	< LoD (<LoD)	36.7	93.3	< LoD (<LoD)	19.4	75.0	< LoD (2.5)	47.2	80.0	< LoD (<LoD)	6.6
hydrogen phosphide	300	50	3	75.9	< LoD (<LoD)	39.1	80.0	< LoD (<LoD)	12.0	50.0	2.3 (6.8)	29.6	60.0	< LoD (5.0)	10.6
methyl bromide	5000	1000	5	66.2	< LoD (7.2)	66.2	100.0	< LoD (<LoD)	< LoD	62.5	< LoD (7.0)	133.9	0.0	43.3 (108.7)	156.9
Non-fumigants															
1-2-dichloroethane	5000	10000	5	79.7	< LoD (<LoD)	43.3	100.0	< LoD (<LoD)	< LoD	75.0	< LoD (3.8)	14.9	60.0	< LoD (26.7)	40.0
C2-alkylbenzenes	50000	20000	5	51.9	< LoD (9.8)	219.6	100.0	< LoD (<LoD)	< LoD	97.5	< LoD (<LoD)	5.6	60.0	< LoD (8.1)	12.1
acetaldehyde	20000	25000[e]	25	61.7	< LoD (41.7)	526.4	80.0	< LoD (<LoD)	62.8	45.0	29.6 (51.9)	459.6	40.0	48.6 (193.1)	251.2
ammonia	25000	25000	15	83.5	< LoD (<LoD)	183.8	93.3	< LoD (<LoD)	18.0	50.0	18.0 (65.0)	193.2	100.0	< LoD (<LoD)	< LoD
benzene	1000	500	5	88.0	< LoD (<LoD)	25.7	86.7	< LoD (<LoD)	6.6	97.5	< LoD (<LoD)	8.4	60.0	< LoD (9.7)	13.4
formaldehyde	500	100	25	44.7	31.4 (123.8)	389.0	13.3	58.0 (97.2)	304.3	37.5	45.9 (96.2)	164.6	20.0	38.4 (40.1)	254.1
styrene	20000	20000	2	92.5	< LoD (<LoD)	6.7	100.0	< LoD (<LoD)	< LoD	100.0	< LoD (<LoD)	1.0	60.0	< LoD (4.7)	5.4
toluene	50000	20000	3	29.3	6 (14.8)	926.6	40.0	3.8 (5.4)	19.4	32.5	4.2 (9.4)	102.2	0.0	4.2 (3.6-8.9)	10.1
Other				**AMV >1(%)**			**AMV >1(%)**			**AMV >1(%)**			**AMV >1(%)**		
sum-value	n/a	n/a	n/a	n/a	148.1 (83.6-291.5)	1011.1	n/a	117.5 (89.5-152.3)	451.8	n/a	190.6 (114.9-280.5)	704.7	n/a	387.8 (103.1-486.7)	496.5
AMV[f] (WES)	1	1	n/a	0	0.1 (0.1-0.3)	0.8	0	0.2 (0.1-0.2)	0.7	0	0.2 (0.1-0.3)	0.4	0	0.2 (0.1-0.3)	0.6
AMV[g] (TLV)	1	1	n/a	29.3	0.4 (0.2-1.3)	3.9	26.7	0.7 (0.5-1.0)	3.1	30.0	0.7 (0.3-1.1)	1.7	20.0	0.6 (0.5-0.9)	2.6

[a] n (formaldehyde) = 123
[b] ppb: parts per billion
[c] 8-hour Workplace Exposure Standards (WES) set by WorkSafe NZ (2018)
[d] 8-hour Workplace Exposure Standards (TLV-Threshold LIMIT Value) set by American Conference of Governmental Industrial Hygienists (2019)
[e] These chemicals do not have a TWA limit but only a ceiling limit which was used instead
[f] Additive Mixture Value using the WES
[g] Additive Mixture Value using the TLV and excluding 1,2-dibromoethane because the ACIGH has not set a TLV for 1,2-dibromoethane

Regression comparing different occupational groups with container handlers showed significantly higher exposures to methyl bromide, 1,2-dichloroethane, and styrene in fumigators (Table 4.2). Log workers had significantly greater exposures of ethylene oxide and ammonia whilst exposure to C2-alkylbenzenes was lower. Retail workers had significantly lower exposures of toluene. Although the highest detection rate and median value for formaldehyde were observed in retail workers (Table 4.1), exposure levels were not significantly different from other occupational groups (Table 4.2).

Table 4.2 Exposure ratios (ER) of personal 8-hours exposures for retail workers, log workers and fumigators, compared to container handlers (n=133)) [a]

chemical (ppb[b])	retail workers (n=15) ER (95% CI)	log workers (n=40) ER (95% CI)	fumigators (n=5) ER (95% CI)
Fumigants			
1,2-dibromoethane	0.5 (0.2 - 1.1)	1.2 (0.8 - 1.9)	0.7 (0.2 - 2.6)
chloropicrin	-	-	3.7 (0.7 - 21.2)
ethylene oxide	1.1 (0.9 - 1.4)	1.2* (1.0 - 1.4)	0.9 (0.6 - 1.3)
hydrogen cyanide	0.9 (0.6 - 1.2)	0.9 (0.8 - 1.2)	0.9 (0.5 - 1.5)
hydrogen phosphide	0.9 (0.6 - 1.2)	1.2 (1.0 - 1.5)	1.1 (0.6 - 1.8)
methyl bromide	-	1.1 (0.6 - 1.9)	16.2*** (5.0 - 52.7)
Non-fumigants			
1,2-dichloroethane	-	1.1 (0.6 - 1.9)	3.3* (1.0 - 11.2)
C2-alkylbenzenes	-	0.10*** (0 - 0.3)	0.7 (0.2 - 2.7)
acetaldehyde	0.4 (0.1 - 1.1)	1.4 (0.8 - 2.5)	2.7 (0.7 - 10.1)
ammonia	0.2 (0 – 2.0)	5.8*** (2.3 - 15.1)	-
benzene	0.9 (0.4 - 2.4)	0.4 (0.2 - 1.1)	2.8 (0.8 - 9.1)
formaldehyde	1.5 (0.8 – 3.0)	1.0 (0.6 - 1.7)	1.2 (0.4 - 3.7)
styrene	-	-	4.4* (1.0 - 19.2)
toluene	0.5* (0.3 - 0.9)	0.7 (0.5 - 1.1)	0.6 (0.2 - 1.7)
Other			
sum-value	0.7 (0.5 - 1.1)	1.1 (0.8 - 1.4)	1.4 (0.8 - 2.7)
AMV[c] (WES)	1.0 (0.9 - 1.1)	1.0 (0.9 - 1.0)	1.0 (0.9 – 1.2)
AMV[d] (TLV)	1.0 (0.6 – 1.5)	0.9 (0.7-1.2)	1.1 (0.5-2.4)

*** $p<0.001$, ** $p<0.01$, * $p<0.05$

- insufficient data

[a] *n (formaldehyde) = 123*

[b] ppb: parts per billion

[c] Additive Mixture Value using the WES

[d] Additive Mixture Value using the TLV and excluding 1,2-dibromoethane because the ACIGH has not set a TLV for 1,2-dibromoethane

Among container handlers, the AMV-TLV was more often exceeded in those who entered containers (36.7%) compared to those who did not (8.6%; Table 4.3), with AMV-TLV levels 70% higher (Table 4.4). Entering a container, was also associated with higher exposure to formaldehyde, ethylene oxide, and acetaldehyde whilst exposures to 1,2-dibromoethane, chloropicrin, methyl bromide, 1,2-dichloroethane, benzene, and styrene were reduced (Table 4.4). When comparing workers handling fumigated versus non-fumigated containers, we found that fewer measurements exceeded the AMV-TLV threshold level of 1 in those who handled fumigated containers (Table 4.3).

Table 4.3 Descriptive statistics of personal 8-hour exposures for container handlers (n=133), by whether they entered containers or not, and for those entering containers by whether they were fumigated or not.

				Container handlers (n=133)				Container handlers entering containers with known fumigation status (n=87)[e]			
				Participants entering containers (n=98) [a]		Participants not entering container (n=35) [b]		handled fumigated container (n=31) [c]		did not handle fumigated container (n=56) [d]	
chemical (ppb[f])	**WES[g]**	**TLV[h]**	**LoD**	**<LoD (%)**	**Median (p75)**	**<LoD (%)**	**Median (p75)**	**<LoD (%)**	**Median (p75)**	**<LoD (%)**	**Median (p75)**
Fumigants											
1,2-dibromoethane	500	-	5	77.6	< LoD (<LoD)	54.3	< LoD (14.9)	77.4	< LoD (<LoD)	73.2	< LoD (<LoD)
chloropicrin	100	100	5	95.9	< LoD (<LoD)	68.6	< LoD (7.5)	93.5	< LoD (<LoD)	96.4	< LoD (<LoD)
ethylene oxide	1000	1000	10	84.7	< LoD (<LoD)	100.0	< LoD (<LoD)	87.1	< LoD (<LoD)	85.7	< LoD (<LoD)
hydrogen cyanide	10000[i]	4700[i]	3	78.6	< LoD (<LoD)	80.0	< LoD (<LoD)	83.9	< LoD (<LoD)	71.4	< LoD (5.4)
hydrogen phosphide	300	50	3	77.6	< LoD (<LoD)	71.4	< LoD (5.8)	83.9	< LoD (<LoD)	73.2	< LoD (4.4)
methyl bromide	5000	1000	5	73.5	< LoD (5.2)	45.7	5.9 (10.8)	64.5	< LoD (9.2)	78.6	< LoD (<LoD)
Non-fumigants											
1,2-dichloroethane	5000	10000	5	83.7	< LoD (<LoD)	68.6	< LoD (6.9)	90.3	< LoD (<LoD)	76.8	< LoD (<LoD)
C2-alkylbenzenes	50000	20000	5	52.0	< LoD (9.8)	51.4	< LoD (13.6)	74.2	< LoD (6.4)	46.4	5.5 (10.2)
acetaldehyde	20000	25000[i]	25	57.1	< LoD (50.7)	74.3	< LoD (31.7)	64.5	< LoD (32.2)	55.4	< LoD (55.1)
ammonia	25000	25000	15	85.7	< LoD (<LoD)	77.1	< LoD (<LoD)	87.1	< LoD (<LoD)	82.1	< LoD (<LoD)
benzene	1000	500	5	91.8	< LoD (<LoD)	77.1	< LoD (<LoD)	90.3	< LoD (<LoD)	91.1	< LoD (<LoD)
formaldehyde	500	100	25	41.7	38.3 (144.6)	55.6	< LoD (32.3)	50.0	21.1 (65.1)	36.4	38.4 (196.2)
styrene	20000	20000	2	95.9	< LoD (<LoD)	82.9	< LoD (<LoD)	96.8	< LoD (<LoD)	96.4	< LoD (<LoD)
toluene	50000	20000	3	32.7	5.6 (13.7)	20.0	6.6 (19.5)	48.4	3.2 (8.0)	28.6	5.4 (12.1)
Other				**AMV >1(%)**		**AMV >1(%)**		**AMV >1(%)**		**AMV >1(%)**	
sum-value	n/a	n/a	n/a	n/a	183.5 (83.6-308.7)	n/a	125.8 (82.9-248.6)	n/a	134.9 (75.3-266.6)	n/a	189.6 (79.6-337.9)
AMV[j] (WES)	1	1	n/a	0	0.2 (0.1-0.4)	0	0.1 (0.1-0.2)	0	0.1 (0.1-0.2)	0	0.2 (0.1-0.5)
AMV[k] (TLV)	1	1	n/a	36.7	0.5 (0.2-1.6)	8.6	0.2 (0.3-0.6)	19.4	0.4 (0.2-0.8)	48.2	0.5 (0.2-2.2)

[a] n (formaldehyde) = 96 [b] n (formaldehyde) = 27 [c] n (formaldehyde) = 30 [d] n (formaldehyde) = 55 [e] n (formaldehyde) = 85

[f] ppb: parts per billion
[g] 8-hour Workplace Exposure Standards (WES) set by WorkSafe NZ (2018)
[h] 8-hour Workplace Exposure Standards (TLV-Threshold LIMIT Value) set by American Conference of Governmental Industrial Hygienists (2019)
[i] These chemicals do not have a TWA limit but only a ceiling limit which was used instead
[j] Additive Mixture Value using the WES [k] Additive Mixture Value using the TLV and excluding 1,2-dibromoethane because the ACIGH has not set a TLV for 1,2-dibromoethane

Table 4.4 Exposure ratios (ER) of personal 8-hours exposures for container handlers entering containers, handling fumigated containers, and by duration spent unloading containers

	All container handlers (n=133)	Container handlers entering containers (n=98)	
	participants entering containers (n=98) vs. not entering (n=35) [a]	handled fumigated container (n=31) vs. not fumigated (n=56) [b]	duration of unloading containers (hours) (n=94) [c]
chemical (ppb[d])	ER (95% CI)	ER (95% CI)	ER (95% CI)
Fumigants			
1,2-dibromoethane	0.4** (0.2 - 0.7)	0.7 (0.4 - 1.4)	0.9 (0.8 - 1.0)
chloropicrin	0.2*** (0.1 - 0.5)	1.6 (0.3 - 8.1)	0.6 (0.3 - 1.1)
ethylene oxide	1.2* (1.0 - 1.4)	1.0 (0.8 - 1.2)	1.1*** (1.1 - 1.1)
hydrogen cyanide	1.0 (0.8 - 1.3)	0.9 (0.6 - 1.1)	1.0 (0.9 - 1)
hydrogen phosphide	0.8 (0.6 - 1.0)	0.9 (0.7 - 1.1)	1.0 (1.0 - 1.1)
methyl bromide	0.5* (0.3 - 0.9)	2.0 (0.9 - 4.5)	0.9 (0.7 - 1)
Non-fumigants			
1,2-dichloroethane	0.5* (0.3 - 0.9)	0.6 (0.3 - 1.3)	1.0 (0.8 - 1.1)
C2-alkylbenzenes	1.1 (0.6 - 1.9)	0.4** (0.2 - 0.8)	1.3*** (1.1 - 1.4)
acetaldehyde	2.2* (1.1 - 4.5)	0.6 (0.3 - 1.4)	1.2 ** (1.1 - 1.4)
ammonia	0.4 (0.1 - 1.6)	0.8 (0.2 - 4.3)	0.8 (0.6 - 1.2)
benzene	0.5* (0.2 - 0.9)	1.1 (0.5 - 2.3)	1.0 (0.9 - 1.2)
formaldehyde	2.5** (1.3 - 4.8)	0.5 (0.3 - 1.1)	1.0 (0.9 - 1.2)
styrene	0.4* (0.2 - 0.9)	1.0 (0.2 - 4.4)	0.9 (0.7 - 1.2)
toluene	0.9 (0.6 - 1.4)	1.1 (0.7 - 1.8)	1.0 (0.9 - 1.1)
Other			
sum-value	1.3 (1.0 - 1.7)	0.8 (0.6 - 1.2)	1.1 (1.0 - 1.1)
AMV[e] (WES)	1.1 (1.0 - 1.2)	0.9* (0.8 - 1.0)	1.0 (1.0 - 1.0)
AMV[f] (TLV)	1.7** (1.2-2.4)	0.6* (0.4 - 1.0)	1.0 (1.0 - 1.1)

*** p<0.001, ** p<0.01, * p<0.05
[a] n (formaldehyde) = 123 [b] n (formaldehyde) = 85 [C] n (formaldehyde) = 92
[d] ppb: parts per billion
[e] Additive Mixture Value using the WES
[f] Additive Mixture Value using the TLV and excluding 1,2-dibromoethane because the ACIGH has not set a TLV for 1,2-dibromoethane

Similarly, in those handling fumigated containers the AMV-TLV and AMV-WES levels were 40% and 10% lower, respectively; a significantly reduced exposure (Table 4.4) to C2-alkylbenzenes was also found (Table 4.4).

Regression showed that for one additional hour of unloading a container, exposures to ethylene oxide, C2-alkylbenzenes and acetaldehyde increased by 10%, 30% and 20%, respectively (Table 4.4). No significant associations were found for other chemicals, sum-value, or AMVs. Further analyses controlling for whether a container was fumigated did not significantly affect the ERs (data not shown).

Log workers loading fumigated logs, compared to those loading non-fumigated logs, were exposed to significantly higher methyl bromide (median 14.6 ppb versus 3.9 ppb; ER 4.1, CI 1.6-10.9; n=19,) and formaldehyde (median 98.9 ppb versus 61.4 ppb; ER 1.9, CI 1.1-3.0; n=19) levels compared to workers loading non-fumigated logs, while ammonia levels were lower (median 7.5 ppb versus 49.79 ppb; ER 0.3, CI 0.1-0.9; data not shown in tables). However, all methyl bromide exposures (maximum 133.9 ppb, Table 4.1) were well below the WES (5000 ppb) and the TLV (1000 ppb). The median AMV-WES and AMV-TLV were both significantly higher in log workers loading fumigated logs (AMV-WES 0.27 versus 0.17; ER 1.1, CI 1.0-1.2; and AMV-TLV 1.1 versus 0.69; ER 1.5, CI 1.0-2.1; n=19; data not shown in tables) and AMV-TLV values exceeded “1” in three (30%) measurements from log workers loading non-fumigated logs versus eight (88.9%) in those loading fumigated logs (data nor shown). All exceedances were attributable to levels above (or very close) to the TLV for formaldehyde (AMV-WES limits were never exceeded).

4.4 Discussion

This study showed that personal 8-hour exposures of fumigants and other chemicals in New Zealand workers handling cargo from shipping containers or loading logs were below current national and international exposure standards. The exception was formaldehyde, for which 26.2% of all measurements exceeded the ACGIH TLV, and exposure levels for formaldehyde were significantly higher in container handlers entering containers compared to those who did not. We also found a significant association between duration of unloading containers and exposures to ethylene oxide, acetaldehyde, and C2-alkylbenzenes exposures, but all measurements were below the WES/TLV. Exposure levels differed between container handlers handling fumigated and non-fumigated containers with lower exposures to ethylene oxide and both AMVs in those unloading fumigated containers.

Our findings are consistent with a previous, but much smaller study, which showed low exposures to fumigants and other chemicals in workers (n=10) unloading containers.[24] In addition, an experimental study using tracer gas measured low personal exposures in workers unloading containers.[48] This is in contrast with the considerable higher detection rates and concentrations reported for air measurements taken from unopened containers,[3, 4, 16, 22, 51, 62, 74, 81, 82] which had led to the assumption that workers are likely to be highly exposed, potentially contributing to the adverse health effects reported for workers in this industry.[5, 7, 8, 10-12]

The considerably (and somewhat unexpected) lower exposures measured in our study may be due to a rapid decline in chemical concentrations inside the container following the opening of container doors, as shown in previous studies.[38, 48] In our study, most containers were not entered until at least a few minutes after opening the doors. Fumigated containers are required to have longer ventilation periods (up to 24 hours) and this may explain why we observed some lower exposures for workers entering containers that had been fumigated compared to those not fumigated (Table 4.4). Containers were also generally positioned outside, thus further increasing natural ventilation. Moreover, in this study most containers were transported by trucks from the port to the distribution network and/or final destination, which may increase air exchange rates in the container,[4, 86] thus reducing the concentration of chemicals inside the containers. Furthermore, participants carried out only part of their work inside the containers.

An alternative explanation for why exposures were low may be bias due to participants being selected by management (see methods) who may have favoured workers who were less likely to have high exposure, thus potentially resulting in an underestimation of exposure. However, based on job descriptions and field observations, the group of participants appeared representative of the general workforce in these areas, but this was not formally tested. In addition, as workers and management were aware measurements were being taken, longer venting times may have been applied, potentially underestimating exposure but again this was not supported by field observations. Other reasons why exposures may have been lower than expected based on previous studies measuring container air, could be due to: changes in fumigant-use in recent times (our study was conducted several years after most previous studies); different patterns in cargo and transport times compared to previous studies which were mainly conducted in Europe; and changes to work practices.

In this study, formaldehyde, which is both a carcinogen and sensitizer,[50, 59] was the main contributor to overall exposure to volatiles in all occupational groups. It exceeded the ACGIH TLV in 26.2% of all measurements and was the main predictor of higher AMV levels, with the AMV-TLV exceeding “1” in 29% of all measurements. Thus, detection rates and exposure levels of formaldehyde were high compared to most other chemicals, which is consistent with the findings of a small study involving personal exposures[24] and several studies measuring container air.[4, 16, 22, 51, 74] Formaldehyde is ubiquitously found in the environment as a result of combustion processes and is used in a wide range of manufacturing processes, such as the textile industry, car manufacturing and plywood and carpet manufacturing (where it is part of the adhesives used). Higher exposures in container handlers may therefore be due to its wide use and subsequent off-gassing from cargo, packaging, and wooden container floors.[4] Formaldehyde also has a slower decay rate compared to many other volatile organic components potentially resulting in longer exposure durations.[87] Retail workers had the highest detection rate and median exposure for formaldehyde, potentially due to its release when opening packaging or from continuous off-gassing from products.[10, 11, 15, 17] In addition, many workers from all occupational groups were likely exposed to formaldehyde from exhaust fumes of trucks and heavy machinery operating in close vicinity. To put these exposures into context, levels were generally higher than exposures among the general population in five Swedish cities (mean 15.8 ppb),[88] but median values for formaldehyde were similar or only slightly above levels typically observed in the home environment.[89]

Levels and detection frequencies of most chemicals varied little between occupational groups, although methyl bromide exposure was clearly higher for fumigators compared to other groups. However, the fumigant levels measured in fumigators were low compared to the exposure standards. This may be because the fumigators' personal sampling equipment was removed when they were wearing respirators (i.e. during active fumigation), in order not to overestimate their personal exposure. It was not possible for the sampling head to be placed inside the respirator during fumigation, as this would have compromised the seal of the respirator.

As expected, workers handling fumigated logs were exposed to higher levels of methyl bromide compared to workers handling non-fumigated logs, although levels were still well below the exposure standards. Exposures to formaldehyde were also higher on days when workers handled fumigated containers; the reasons for this are not clear as working conditions were very similar for fumigated and non-fumigated containers.

We found positive associations with duration spent unloading containers for some chemicals, but not for others. It is possible that the overall time spent unloading containers is too crude a proxy for exposure, particularly as many workers unloaded multiple containers during a single work-shift, with each containing different cargo and therefore contributing to different types and level of exposures. In addition, short–term peak exposures may contribute most to the average exposure as has been shown for other exposures in other occupational settings,[90] which if true, could be another, or additional, explanation why duration was not always associated with exposure.

A strength of this study was that exposures were measured for a full 8-hour shift, enabling comparisons with the corresponding exposure standards. However, as a consequence, information on peak exposures was not available despite this potentially posing a greater health risk to workers.[48] Also, and this is an important limitation, as it is not clear whether working conditions of participants included in this study were representative of this industry as a whole, and that all relevant exposures were measured, we cannot exclude the possibility that high exposures may occur in at least some workers. Other limitations include the high number of non-detectable measurements and the relatively small number of workers measured, particularly when considering the large number of possible exposure determinants, such as cargo, packaging, and container ventilation time. In addition, as participants frequently unloaded several containers with different cargo and packaging, and from countries of different origin as part of the same 8-hour shift, we were not able to measure the impact of these parameters or other determinants of exposure such as concentrations of chemicals inside the containers prior to opening them, meteorological factors, or ventilation times. Furthermore, and as noted above, while this study included a wide range of chemicals, it did not measure all possible pollutants in container air (e.g. terpenes were not included), and the AMVs presented may therefore be under-estimates. Also, the choice of assigning a fixed concentration (i.e. LOD/2) to samples that were not detectable might have affected the calculated AMVs. However, using a concentration that is equivalent to the LOD for samples <LOD did not appreciably change the results (i.e. the AMV of only 2 samples increased to a level >1 and only when using TLVs; no difference was found for WES-based AMVs), indicating this is not a significant issue.

In conclusion, this study has shown low exposures to fumigants and residual chemicals (with the exception for formaldehyde) in a sample of New Zealand workers handling cargo and export logs, likely due to the container ventilation periods observed before entry. Formaldehyde was the main contributor to overall exposure in all occupational groups. Its ubiquitous presence in the environment could be due to combustion processes and its use in a wide range of manufacturing processes. However, more work is required to assess whether these results are representative for these industries as a whole. Likewise, this study cannot exclude the possibility of occasional high peak exposures.

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5 Neuropsychological symptoms in Workers Handling Cargo from Shipping Containers and Export Logs

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See Appendix 9.4)

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Abstract

Background: Acute neuro toxic symptoms due to poisonings of workers handling shipping containers by fumigants and other hazardous chemicals off-gassed from cargo, have been reported. However, chronic health effects have not been well studied.

Methods: This cross-sectional study assessed current (past 3 months) neuropsychological symptoms in 274 container handlers, as well as 38 retail workers, 35 fumigators, and 18 log workers, who are also potentially exposed to fumigants and residual chemicals. Prevalence odds ratios (OR), adjusted for confounders (age, ethnicity, smoking, alcohol consumption, education, personality traits, Body Mass Index), comparing exposed and reference workers (206 construction workers), and sub-groups of exposed workers with reference workers, were calculated using logistic regression. Within container handlers, workers with the two highest exposure-durations (assessed using employment duration and average time handling containers per day/week/month) were compared with those who had the lowest exposure duration (based on tertiles). Associations were assessed with the total number of reported symptoms (≥3, ≥5 or ≥10) and with symptom domains (neurological, psychosomatic, mood, memory/concentration, fatigue, and sleep).

Results: Compared to the reference group, exposed workers were more likely to report ≥10 symptoms; this was statistically significant only for retail workers (OR 6.8, 95%CI 1.9-24.3) who also reported more symptoms in the fatigue domain (OR 10.7, 95% CI 2.7-42.7). Workers handling containers with the highest exposure duration were more likely to report ≥10 symptoms, both when compared with reference workers (OR 4.0, 95%CI 1.4-11.7) and with container handlers with shorter exposure duration (OR 7.5, 95%CI 1.7-32.8). The duration of container handling was particularly associated with symptoms in the memory/concentration domain, with ORs of 8.8 (95% CI 2.5-31.4) and 6.8 (95% CI 1.5-30.3) for workers in the highest exposure-duration tertile when compared to reference workers and workers in lowest exposure-duration tertile, respectively.

Conclusion: Container handlers may have an increased risk of neuropsychological symptoms, especially in the memory/concentration domain. Retail workers may also be at risk, but this requires confirmation in a larger study.

5.1 Introduction

The design of sealed shipping containers allows for only limited natural ventilation during transport.[4] As a result, fumigants (e.g. ethylene oxide, methyl bromide, phosphine, chloropicrin), used for biosecurity reasons or to prevent damage to cargo, and chemicals off-gassed from cargo or packaging (e.g. formaldehyde, toluene, benzene) may accumulate in the air, potentially reaching unsafe levels for workers unloading or inspecting these containers.[3] Indeed, high levels of these chemicals have been found in the air of sealed containers and acute poisonings in container handlers have been reported,[3, 5-14] ranging from headaches to coma. In addition to container handlers, inspectors and fumigators, retail workers, bystanders and consumers may also be exposed potentially resulting in health effects also in those groups.[7, 8, 15-17]

While acute neurotoxicity has been the primary concern, it is possible that chronic health effects, associated with long-term exposure to these chemicals, such as sustained memory and concentration deficits, fatigue, and severe persistent neurological outcomes, may also occur. In particular, many of these chemicals (e.g. methyl bromide, 1,2-dichloroethane) are known, or suspected, to cause both acute and chronic neuropsychological symptoms.[3] However, research on long-term health effects in container handlers, fumigators, and retail workers is scant. One health survey among 125 French dockworkers and those working in related occupations reported an overall low prevalence of neuropsychological symptoms, which the authors suggested could be due to a healthy worker effect[71]. They also reported a positive association between fumigant exposure in the past years and memory disorders, but this was based on a very small sample, and analyses were not controlled for potential confounders. To our knowledge, no comprehensive epidemiological studies have been conducted in this workforce.

Globally, shipping container throughput has risen from 622 to 802 million twenty-foot equivalent units (TEU) between 2012 and 2019.[1] In New Zealand, an island nation reliant on import and export via sea cargo ships, this sector employs 116,100[18] workers. Considering the volume of world-trade and the size of the workforce, studies on the health risks of chemical exposures in workers employed in the container industry and those who fumigate and/or handle container goods are warranted.

This study assessed neuropsychological symptoms through standardised questionnaires in 274 container handlers and three other groups with potential exposure to fumigants and residual chemicals: 38 retail workers, 35 fumigators, and 18 log workers, who load export logs onto ships, some of which are fumigated. Symptom prevalence was compared with a reference group of 206 construction workers who are unlikely to be exposed to these chemicals. Internal comparisons within exposed workers to assess associations with duration of employment in these jobs were also conducted.

5.2 Methods

Study design

This study is a cross-sectional health survey that assessed neuropsychological symptoms in workers who handle shipping containers and export logs, retail workers, and fumigators, as well as a reference group of construction workers who are unlikely to be exposed to fumigants and chemicals off-gassed from container cargo. For this paper, container and export log workers, fumigators, and retail workers are described collectively as “exposed workers”.

Written consent was obtained from all participants and ethics approval was granted by the Multi-region Ethics Committee of the New Zealand Ministry of Health (MEC/12/02/010).

Participant recruitment

Companies accredited to open and inspect (for biosecurity reasons) overseas containers were randomly selected from a list of Accredited Transitional Facilities (ATF), published by the New Zealand Ministry of Primary Industries. The companies that participated had a workforce size and total throughput of cargo approximately reflective of this industry in New Zealand., They comprised distribution centres (n=8), third party logistics providers (n=22), and companies unloading their own imported containers (n=48). We also recruited a government department involved in inspecting overseas containers (n=1), a company specialising in export log operations (n=1), port companies (n=4), fumigation companies (n=5) and a retail chain (n=1). In total, 90 companies agreed to participate and 111 declined. Participants who inspected containers were combined with the container handler group as their tasks frequently overlapped.

The companies, situated at eleven locations throughout New Zealand, ranged in size from owner-operated to large distribution centres, with the number of participants mostly reflecting the size of the company (1-2 participants, 50 companies; 3-6 participants, 27 companies; and 7-110 participants, 13 companies). Management identified potential participants based on availability and workplace requirements resulting in 493 workers (321 container handlers, 110 retail workers, 21 log workers and 35 fumigators) participating in the study. In total, 38 workers declined to participate in the study of which 21 (56.8 %) were woman (who were excluded from the analyses; see below). The response rate, based on all males invited to the study, was 96%.

A reference group (n=222; response rate, 64%), which was not involved in container handling and/or fumigation, consisting of construction workers from various trades (scaffolders, carpenters, electricians, builders and building labourers, fire safety system installers, plumbers and associated management staff), was recruited throughout the North Island of New Zealand, with a focus on the main centres (Wellington and Auckland). Companies were identified from the Yellow Pages and Internet searches.

Questionnaire

Current (i.e. in the past three months) neuropsychological symptoms were measured using an adapted version of the EUROQUEST questionnaire

(Appendix 9.1), which was developed to evaluate neuropsychological health effects associated with long term solvent exposure.[91] The questionnaire, which was administered face-to-face, consists of 59 questions covering the following symptom domains: neurological symptoms, psychosomatic symptoms, mood, memory/concentration, fatigue and sleep quality (see Supplementary Table 5.5). In addition, six questions on acute symptoms that occurred in the last three months were included (see Table 5.4). Symptom frequency for these and the 59 core symptoms was reported on a 4-point scale: 'seldom or never', 'sometimes', 'often' or 'very often'. The EUROQUEST also contains eight questions on sensitivity to environmental conditions (see Table 5.4) and six anxiety related questions ('I am generally a nervous person', 'I think I am generally less capable than others in overcoming my difficulties', 'I worry a lot about trivial things', 'I often feel that something bad might happen at any moment', 'I often feel that even trivial problems are too much for me', 'I usually feel insecure') rated on a different 4-point scale: 'strongly disagree', 'disagree', 'agree' or 'strongly agree'. The EUROQUEST assesses perceived general health in four questions ('How good is your health', 'How is your health now compared to what it was five years ago', 'How do you feel about your life in general', 'How do you feel about your life now compared to five years ago') rated on a 4-point scale: 'very good' 'good', 'poor' or 'very poor'.

Symptoms were initially dichotomised with 'strongly disagree' or 'disagree', 'seldom or never' or 'sometimes', and 'very good' and 'good' comprising a negative response and 'agree' or 'strongly agree', 'often' or 'very often', and 'poor' or 'very poor' comprising a positive response.[92] If this classification resulted in a positive response of <5% (as was the case for 15 questions), resulting in insufficient power for subsequent analyses, a positive response was reclassified with ‘sometimes’, ‘often’ and ‘very often’ constituting a positive response. Likewise, if the initial classification resulted in a positive response of >10% (7 questions), suggesting that the outcome response was insufficiently discriminatory, a positive response was reclassified with only ‘very often’ constituting a positive response.

Anxiety and perceived general health questions were used to calculate an aggregated individual personality trait score, which has been found to be associated with participants under or over reporting symptoms.[92] Analyses were controlled for this (see below). Additional questions were asked on demographics, work characteristics and potential confounders.

Statistical analyses

All statistical analyses were conducted using Stata version 15.1 (StataCorp LP, Texas, USA). Because the reference group had only two female participants, and, apart from the retail workers, relatively few females were employed in the other occupational groups, we excluded all females (n=107) from the analyses. Additionally, four container handlers were excluded from the exposed group because of additional exposure to welding fumes; 19 workers involved in container handling were excluded as they did not unload containers; and 13 reference workers were excluded because of exposure to paint fumes, and one reference worker did not complete the questionnaire. For the analyses, we therefore had data for 274 container handlers, 38 retail workers, 18 log workers, 35 fumigators and 206 reference workers.

Neuropsychological symptoms were analysed using two approaches: 1) grouped based on the total number of positive symptoms reported (≥3 symptoms, ≥5 symptoms, ≥10 symptoms); and 2) grouped based on the number of positive symptoms (≥3) in each symptom domain (described above), an approach previously shown to be highly sensitive and specific in the classification of chronic solvent neurotoxicity patients.[92] We also considered non-aggregated individual neuropsychological symptoms (yes/no), as well as acute symptoms and sensitivity to environmental conditions. Prevalence odds ratios (OR), comparing symptoms between the exposed and the reference group, and between sub-groups of exposed workers and the reference group, were calculated using logistic regression.

The effect of exposure duration was assessed only for container handlers because the number of participants in the other occupations was too small. We used two approaches: 1) based on the years spent in the industry unloading containers; and 2) a more refined version of the first approach, based on the years spent in the industry combined with the actual time unloading containers per day, week or month. For approach 2, we calculated annual hours spent unloading containers and divided this by 1920, the total annual workable hours (48 weeks x 40 hours/week) and multiplied this by the number of years employed in this industry, resulting in an “exposure years equivalent”. Both duration metrics were subsequently categorised in three exposure groups (low, medium, high) based on tertiles. Prevalence ORs were calculated comparing the symptom prevalence of container handlers in the three exposure duration categories with that in the reference group (external comparison). We also made internal comparisons (within the group of container handlers) by calculating prevalence ORs that involved comparing the two highest with the lowest exposure duration category.

Regression analyses were adjusted for age, ethnicity, smoking, alcohol consumption, education status, Body Mass Index (BMI) and personality trait score. For analyses involving individual symptoms, which often had a relatively low prevalence, ORs were adjusted for age and personality trait score only to avoid non-convergence.

5.3 Results

Compared to the reference group, exposed workers consumed more alcohol and tobacco, received less education, were slightly older, scored higher in the personality traits scale, had a higher BMI, and were more likely to be Māori or of Pacific descent (Table 5.1). All analyses were controlled for these factors (with exception of analyses focused on individual symptoms; see above).

Table 5.1. Demographic and work characteristics

	reference group (n=206)		exposed group (n=365)		exposed group by occupation							
					container handler (n=274)		retail worker (n=38)		log worker (n=18)		fumigator (n=35)	
	n	%	n	%	n	%	n	%	n	%	n	%
Ethnicity												
Māori/Pacific	92	44.7	141	38.6	106	38.7	12	31.6	9	50.0	14	40.0
Other (incl. New Zealand European)	113	54.9	223	61.1	167	61.0	26	68.4	9	50.0	21	60.0
Smoking Status												
Non-smoker	91	44.2	170	46.6	125	45.6	27	71.1	4	22.2	14	40.0
Ex-smoker	43	20.9	80	21.9	64	23.4	2	5.3	4	22.2	10	28.6
Current smoker	72	35.0	113	30.9	84	30.7	8	21.1	10	55.6	11	31.4
Education level												
Primary/ secondary	104	50.5	239	65.5	184	67.2	17	44.7	16	88.9	22	62.9
Tertiary/ trade cert.	102	49.5	125	34.3	89	32.5	21	55.3	2	11.1	13	37.1
	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range	Median	Range
Age	36.8	17.1-66.5	39.2	17.2-76.7	39.3	18.0-76.0	28.4	18.8-63.2	42.3	21.0-67.4	38.4	17.2-65.9
Alcohol (standard drinks / week)	6.0	0-80.0	12.2	0-140.0	8.0	0-85.0	6	0.0-52.0	14.5	1-140.0	8.8	0-44.0
EUROQUEST personality score	0	0-8	1	0-7	1	0-7	1	0.0-6	1	0-4	0	0-7
BMI	27.6	14.6-42.2	29.4	16.4-64.3	29.1	16.4-64.3	25.8	18.2-44.3	29.4	17.3-36.8	28.4	21.5-45.4
Working hours (hours/ week)	40.0	3.0-100.0	40.0	7.0-80.0	40.0	7.0-70.0	40.0	9.0-60.0	45.0	20.0-80.0	40.0	10.0-60.0

The likelihood of reporting ≥3 symptoms and ≥5 symptoms overall was similar for exposed and reference workers (Table 5.2); however, exposed workers were more likely to report ≥10 symptoms, although this did not reach statistical significance (OR 2.0, 95% CI 0.9-4.7). Elevated ORs for ≥10 symptoms were observed for all exposed subgroups, reaching statistical significance for retail workers only (OR 6.8, 95%CI 1.9-24.3; Table 5.2). Exposed workers were also more likely to report ≥3 symptoms for the following two symptom domains: memory/concentration (OR 2.6, 95% CI 0.9-7.5) and fatigue (OR 2.3, 95% CI 0.9-6.2; Table 5.2). Increased risks for these domains were observed for all exposed sub-groups, but this was statistically significant only for fatigue in retail workers (OR 10.7, 95% CI 2.7-42.7; Table 5.2).

Table 5.2. Prevalence odds ratios (OR) of neuropsychological symptoms and symptom domains comparing exposed with reference workers

	reference group (n=206)	exposed group (n=365)		Exposed group by occupation (compared to the reference group)							
				container handler (n=274)		retail worker (n=38)		log worker (n=18)		fumigator (n=35)	
	n (%)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)
number of symptoms											
≥ 3 symptoms	78 (37.9)	150 (38.9)	0.9 (0.6-1.3)	103 (36.9)	0.8 (0.5-1.2)	15 (39.5)	1.3 (0.6-2.9)	12 (66.7)	2.5 (0.8-7.4)	12 (34.3)	0.7 (0.3-1.7)
≥ 5 symptoms	45 (21.8)	98 (25.8)	1.1 (0.7-1.8)	69 (24.7)	1.0 (0.6-1.7)	10 (26.3)	1.5 (0.6-3.8)	8 (44.4)	2.4 (0.8-7.4)	7 (20.0)	0.9 (0.3-2.5)
≥ 10 symptoms	12 (5.8)	35 (9.6)	2.0 (0.9-4.7)	22 (7.9)	1.5 (0.6-3.7)	7 (18.4)	6.8 (1.9-24.3)**	2 (11.1)	2.0 (0.3-13.6)	4 (11.4)	2.6 (0.6-11.8)
symptom domains (≥ 3)											
neurological symptoms	9 (4.4)	20 (5.5)	1.1 (0.4-2.6)	13 (4.8)	0.9 (0.4-2.4)	3 (7.9)	2.0 (0.5-8.6)	3 (16.7)	3.0 (0.6-15.2)	1 (2.9)	-
psychosomatic symptoms	20 (9.9)	39 (10.7)	0.8 (0.4-1.4)	29 (10.7)	0.7 (0.4-1.4)	5 (13.2)	1.3 (0.4-3.9)	1 (5.6)	0.3 (0.0-2.7)	4 (11.4)	0.5 (0.1-2.5)
mood	11 (5.3)	29 (8.0)	1.2 (0.5-2.7)	21 (7.7)	1.1 (0.4-2.5)	4 (10.5)	2.7 (0.7-10.4)	1 (5.6)	0.8 (0.1-7.7)	3 (8.6)	1.3 (0.2-6.8)
memory/concentration	8 (3.9)	27 (7.4)	2.6 (0.9-7.5)	18 (6.6)	2.2 (0.7-6.7)	4 (10.5)	4.4 (0.9-21.4)	2 (11.1)	3.2 (0.4-27.0)	3 (8.6)	3.3 (0.6-20.3)
fatigue	8 (3.9)	27 (7.4)	2.3 (0.9-6.2)	17 (6.2)	1.6 (0.5-4.6)	7 (18.4)	10.7 (2.7-42.7)***	1 (5.6)	1.6 (0.1-18.1)	2 (5.7)	3.3 (0.6-19.8)
sleep	5 (2.4)	18.(4.9)	1.5 (0.5-5.0)	14 (5.1)	1.6 (0.5-5.4)	1 (2.6)	1.2 (0.1-12.7)	1 (5.6)	1.4 (0.1-16.9)	2 (5.7)	1.4 (0.1-13.8)

*p<0.05, **p<0.01, ***p<0.001; All analyses were adjusted for age, ethnicity, smoking, alcohol consumption, education, personality traits and BMI.

In container handlers we assessed whether the risk of symptoms increased by: (i) the number of years worked with containers; and (ii) the number of equivalent years unloading containers (Table 5.3). When comparing workers in the highest exposure tertiles of these exposure metrics with the reference group, the risk of reporting ≥10 symptoms overall increased, with ORs of 3.8 (95%CI 1.1-12.4) and 4.0 (95%CI 1.4-11.7), respectively. When comparing container handlers in the highest exposure tertile with those in the lowest, associations were more pronounced, with ORs of 91 (95%CI 4-2000) and 7.5 (95%CI 1.7-32.8) for each exposure metric, respectively. For the domains of psychosomatic symptoms, memory/concentration, and fatigue, odds ratios increased with duration using either exposure metric. However, most consistent trends were observed for the memory/concentration domain. In particular, using “number of years working with containers”, we found ORs of 10.7 (95%CI 2.4-46.9) and 174 (95%C I7.5-4064) for the highest tertile when compared to the external reference group and lowest exposure tertile, respectively; using “equivalent years unloading”, ORs of 8.8 (95%CI 2.5-31.4) and 6.8 (95%CI 1.5-30.3) were found (Table 5.3).

Table 5.3. Prevalence odds ratios of neuropsychological symptoms and symptom domains for container handlers (n=274) stratified by employment and exposure duration

	External comparison (compared to the reference group)							Comparison within container handlers (compared with lowest exposure duration)	
	n (%)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Number of years working with containers	reference (n=206)	0.01-2.5 years (n=92)		2.51-9.75 years (n=91)		9.76-44.42 years (n=91)		2.51-9.75 years (n=91)	9.76-44.42 years (n=91)
number of symptoms									
≥ 3 symptoms	78 (37.9)	30 (10.9)	0.7 (0.4-1.2)	39 (14.2)	1.1 (0.6-1.9)	34 (12.4)	0.8 (0.4-1.5)	1.4 (0.7-2.9)	1.0 (0.5-2.3)
≥ 5 symptoms	45 (21.8)	14 (5.1)	0.4 (0.2-0.9)*	30 (10.9)	1.6 (0.8-2.9)	25 (9.1)	1.6 (0.8-3.3)	4.2 (1.7-10.8)**	5.1 (1.7-15.4)**
≥ 10 symptoms	12 (5.8)	1 (0.4)	0.1 (0.0-1.3)	11 (4.0)	2.0 (0.7-6.0)	10 (3.6)	3.8 (1.1-12.4)*	32.6 (2.0-543)*	91.4 (4.1-2,038)**
symptoms domains (≥ 3)									
neurological symptoms	9 (4.4)	5 (1.8)	1.4 (0.4-4.5)	2 (0.7)	0.5 (0.1-2.4)	6 (2.2)	1.3 (0.4-4.6)	0.4 (0.1-2.7)	1.1 (0.2-6.0)
psychosomatic symptoms	20 (9.9)	6 (2.2)	0.5 (0.2-1.5)	9 (3.3)	0.6 (0.2-1.5)	14 (5.1)	1.2 (0.5-2.9)	0.9 (0.3-3.2)	2.1 (0.6-7.8)
mood	11 (5.3)	3 (1.1)	0.3 (0.1-1.3)	11 (4.0)	1.8 (0.6-5.1)	7 (2.6)	1.6 (0.5-5.3)	9.4 (1.4-62.4)*	9.1 (1.1-77.7)*
memory/concentration	8 (3.9)	1 (0.4)	0.1 (0.0-1.5)	8 (2.9)	3.0 (0.8-11.2)	9 (3.3)	10.7 (2.4-46.9)**	35.9 (2.3-565)*	174.4 (7.5-4,064)**
fatigue	8 (3.9)	2 (0.7)	0.4 (0.1-2.4)	9 (3.3)	2.2 (0.6-7.4)	6 (2.2)	2.3 (0.6-9.1)	6.6 (0.9-46.7)	10.1 (1.0-99.1)*
sleep	5 (2.4)	4 (1.5)	1.8 (0.4-8.0)	6 (2.2)	1.3 (0.3-5.9)	4 (1.5)	1.4 (0.3-6.8)	1.0 (0.2-4.6)	1.2 (0.2-7.8)
Number of equivalent years[1] unloading containers	reference (n=206)	0.0003-0.1 eq. years (n=94)		0.11-0.9 eq. years (n=89)		0.91-41.3 eq. years (n=91)		0.11-0.9 eq. years (n=89)	0.91-41.3 eq. years (n=91)
number of symptoms									
≥ 3 symptoms	78 (37.9)	22 (8.0)	0.5 (0.3-0.9)*	36 (13.1)	0.9 (0.5-1.5)	45 (16.4)	1.2 (0.7-2.2)	2.0 (1.0-3.9)	2.6 (1.3-5.1)**
≥ 5 symptoms	45 (21.8)	13 (4.7)	0.5 (0.2-1.0)	22 (8.0)	0.9 (0.5-1.8)	34 (12.4)	2.0 (1.0-3.8)*	2.1 (0.9-5.0)	4.0 (1.7-9.3)**
≥ 10 symptoms	12 (5.8)	3 (1.1)	0.5 (0.1-2.1)	5 (1.8)	1.0 (0.3-3.7)	14 (5.1)	4.0 (1.4-11.7)*	1.8 (0.3-9.5)	7.5 (1.7-32.8)**
symptom domains (≥ 3)									
neurological symptoms	9 (4.4)	1 (0.4)	0.2 (0.0-2.0)	7 (2.6)	1.8 (0.6-5.5)	5 (1.8)	1.3 (0.4-4.4)	2.4 (0.5-11.7)	2.1 (0.4-9.9)
psychosomatic symptoms	20 (9.9)	5 (1.8)	0.4 (0.1-1.2)	9 (3.3)	0.7 (0.3-1.8)	15 (5.5)	1.1 (0.5-2.6)	1.5 (0.4-5.0)	3.0 (1.0-9.0)*
mood	11 (5.3)	4 (1.5)	0.4 (0.1-1.5)	8 (2.9)	1.6 (0.5-4.5)	9 (3.3)	1.4 (0.5-4.1)	2.0 (0.5-8.0)	2.3 (0.6-8.6)
memory/concentration	8 (3.9)	3 (1.1)	1.1 (0.2-5.3)	1 (0.4)	0.3 (0.0-2.9)	14 (5.1)	8.8 (2.5-31.4)***	0.7 (0.1-5.2)	6.8 (1.5-30.3)*
fatigue	8 (3.9)	3 (1.1)	0.8 (0.2-3.6)	5 (1.8)	1.5 (0.4-5.5)	9 (3.3)	2.1 (0.6-7.3)	3.7 (0.6-21.0)	4.2 (0.8-21.3)
sleep	5 (2.4)	4 (1.5)	1.8 (0.4-7.8)	5 (1.8)	1.6 (0.4-6.7)	5 (1.8)	1.3 (0.3-5.5)	1.2 (0.3-5.2)	1.1 (0.2-4.8)

*p < 0.05, **p < 0.01, ***p < 0.001; All analyses were adjusted for age, ethnicity, smoking, alcohol consumption, education, personality traits and BMI.

[1] equivalent years unloading is the time spend unloading containers over the work life expressed in years.

When considering individual symptoms, we observed statistically significant associations with the exposure metric “equivalent years unloading containers” for symptoms in several domains (Supplementary Table 5.5), but not for symptoms in the mood domain. A four-fold increased risk of the symptom ‘changes in sense of smell or taste’ (neurological symptoms domain) was shown for the highest tertile compared to the lowest exposure duration tertile. The risk of ‘sweating for no obvious reason’ was 2 and 3 times greater for the two highest tertiles when compared to the reference group and the lowest exposure tertile, respectively. The risk of ‘loss of sexual interest’ (psychosomatic symptoms domain) was 11 times greater for the highest exposure tertile compared to the reference group. Participants in the highest exposure tertile were four times more likely to report ‘forgetfulness’ (memory/-concentration domain) and three times more likely to report ‘general weariness or tiredness’ (fatigue domain), when compared to the external reference group, respectively. Participants in the two highest tertiles were two times more likely to report ’snoring that someone else has complained about’ (sleep domain) when compared to the group with the shortest duration (Supplementary Table 5.5). However, further adjustment for alcohol consumption and BMI, which are contributing factors to excessive snoring, resulted in the association with snoring no longer being statistically significant (medium duration: OR 0.9, 95%CI 0.4-1.8; longest duration: OR 1.5, 95%CI 0.7-3.3).

For acute symptoms, no statistically significant differences between the reference and the exposed group were observed (Table 5.4). For self-reported sensitivity to environmental conditions (Table 5.4), exposed workers and all sub-groups, except the log workers, were less likely to report to be sensitive to heat compared to the reference group. The overall group of exposed workers, and the subgroup of container handlers were also less likely to report to be sensitive to bright lights compared to the reference group.

Several workers in the exposed group reported night shift work (n=77) whilst none in the reference group reported this. As this may have an effect on neuropsychological symptoms, we repeated the analyses related to the results described in Tables 5.2 and 5.3 excluding all night shift workers. This did not appreciably alter the results (data not shown).

Table 5.4. Prevalence odds ratios of acute symptoms and sensitivity to environmental conditions comparing exposed with reference workers

	reference group (n=206)	exposed group (n=365)		each occupation within the exposed group (compared to the reference group)							
				container handler (n=274)		retail worker (n=38)		log worker (n=18)		fumigator (n=35)	
	n (%)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)
Acute symptoms											
irritation of the eyes	17 (8.3)	31 (8.5)	1.2 (0.6-2.4)	24 (8.8)	1.3 (0.6-2.7)	1 (2.6)	0.4 (0.0-3.2)	4 (22.2)	3.5 (0.9-13.3)	2 (5.7)	0.5 (0.1-4.0)
feeling drunk without drinking alcohol	0	2 (0.5)	-	2 (0.7)	-	0	-	0	-	0	
dryness of the mouth or throat	22 (10.7)	23 (6.3)	0.6 (0.3-1.2)	19 (6.9)	0.7 (0.3-1.4)	2 (5.3)	0.5 (0.1-2.3)	1 (5.6)	0.6 (0.1-5.0)	1 (2.9)	
throat irritation	9 (4.4)	16 (4.4)	1.7 (0.6-4.8)	13 (4.7)	1.9 (0.6-5.5)	1 (2.6)	0.8 (0.1-7.6)	1 (5.6)	3.3 (0.3-33.9)	1 (2.9)	1.5 (0.2-13.6)
runny nose	20 (9.8)	19 (5.2)	0.5 (0.3-1.1)	15 (5.5)	0.6 (0.3-1.2)	1 (2.6)	0.2 (0.0-1.9)	2 (11.1)	1.5 (0.3-7.9)	1 (2.9)	0.4 (0.0-3.1)
unpleasant taste in mouth	5 (2.4)	11 (3.0)	1.3 (0.4-4.8)	9 (3.3)	1.6 (0.4-6.1)	0	-	1 (5.6)	4.4 (0.4-50.8)	1 (2.9)	
Sensitivity to environmental conditions											
bright lights	70 (34)	96 (26)	0.6 (0.4-0.9)*	71 (26)	0.6 (0.4-0.9)*	12 (32)	0.8 (0.3-1.8)	6 (33.3)	0.9 (0.3-2.6)	7 (20)	0.4 (0.2-1.1)
loud music or other loud noises	49 (24)	81 (22)	0.8 (0.5-1.3)	62 (23)	0.8 (0.5-1.3)	7 (18)	0.5 (0.2-1.6)	5 (27.8)	1.1 (0.3-3.6)	7 (20)	0.8 (0.3-2.2)
strong smells	79 (39)	132 (36)	0.8 (0.5-1.2)	106 (39)	0.9 (0.6-1.3)	8 (21)	0.3 (0.1-0.8)*	8 (44.4)	1.1 (0.4-3.1)	10 (28.6)	0.6 (0.3-1.4)
rough fabrics next to my skin	62 (30)	111 (31)	0.8 (0.5-1.2)	87 (32)	0.9 (0.6-1.3)	8 (21)	0.5 (0.2-1.3)	6 (33.3)	0.6 (0.2-1.9)	10 (28.6)	1.0 (0.4-2.2)
heat	81 (40)	116 (32)	0.5 (0.4-0.8)**	95 (35)	0.6 (0.4-1.0)*	8 (21)	0.3 (0.1-0.7)**	5 (27.8)	0.5 (0.2-1.4)	8 (22.9)	0.4 (0.2-1.0)*
cold	73 (36)	123 (34)	0.9 (0.6-1.4)	90 (33)	0.9 (0.6-1.3)	14 (37)	0.9 (0.4-1.9)	7 (38.9)	1.1 (0.4-3.1)	12 (34.3)	1.2 (0.5-2.6)
tobacco smoke	79 (39)	145 (40)	1.0 (0.7-1.6)	111 (41)	1.0 (0.7-1.6)	15 (40)	0.9 (0.4-2.1)	6 (33.3)	1.2 (0.4-4.1)	13 (37.1)	1.1 (0.5-2.6)
certain foods	42 (21)	78 (21)	0.9 (0.5-1.4)	61 (22)	0.9 (0.5-1.5)	6 (16)	0.5 (0.2-1.4)	5 (27.8)	1.4 (0.4-4.3)	6 (17.1)	1.0 (0.4-2.6)

*p<0.05, **p<0.01, ***p<0.001; All analyses were adjusted for age, ethnicity, smoking, alcohol consumption, education, personality traits and BMI.

5.4 Discussion

This is the first comprehensive health survey assessing (non-acute) neuropsychological symptoms in workers exposed to fumigants and chemicals off-gassed from cargo of shipping containers, compared to a reference group of non-exposed workers. Container handlers overall did not report more symptoms than the reference group, but those handling containers for more than 10 years were more likely to report symptoms, both when compared to an external reference group and when compared to container handlers with shorter employment in the industry. The duration of container handling was particularly associated with symptoms in the memory/concentration domain. Retail workers were more likely to report ≥10 symptoms overall, and they were also more likely to report fatigue symptoms.

Consistent with our study, the only other study on non-acute health effects in container handlers found a relatively low prevalence of symptoms, which the authors attributed to the healthy worker effect.[71] Our results provide further evidence for this, as workers in the shortest duration group were less likely to report symptoms compared to the reference group (Table 5.3 and 5.4), suggesting that workers entering the highly physical occupation of container handler may indeed be healthier.

The previous study, which was relatively small and did not include a reference group, assess duration-response associations, or control for potential confounders, also found that workers exposed to fumigants in the past years were more likely to report memory disorders.[71] This is consistent with the positive duration-response association we observed for symptoms in the memory/concentration domain. This finding is also consistent with a study on methyl bromide and sulfuryl fluoride exposed structural fumigators (fumigation of structures such as houses) who were shown to perform worse on the 'Pattern Memory' test compared to a reference group;[93] the same study also found an association between methyl bromide exposure and poorer test results for the 'logical memory test of the Wechsler Memory Scale'. In addition, memory/-concentration symptoms have also frequently been reported as a late and sometimes chronic symptom in case reports of acute intoxications.[13, 14, 94, 95] Taken together, these findings suggest that workers exposed to fumigants may be particularly at risk of experiencing symptoms in the memory/concentration domain. While this is important in itself, it may also contribute to additional risks for workers. In particular, deficits in memory and concentration may contribute to an increased risk of work-related injuries, with cargo handling ranked as one of the highest potential accident risk activities in container ports.[96] It also has the potential to increase the risk of accidents while driving home from work.

Container handlers with longer exposure duration were more likely to report 'sweating for no obvious reasons' (Supplementary Table 5.5). Body temperature and sweating are regulated by the autonomic nervous system[97] and previous research in fumigators comparing pre and post work heart rate variability (HRV), a measure to assess autonomic dysfunction, has shown a significant association between methyl bromide exposure and reduced HRV indices.[69] Although speculative, this suggests that our finding may be explained by fumigant (or other chemical) exposure.

Container handlers with longer exposure duration were also more likely to report ‘changes in sense of smell or taste’ (Supplementary Table 5.5). Olfactory dysfunction has previously been attributed to exposure to formaldehyde and possibly styrene, as well as several fumigants (methyl bromide, sulfuryl fluoride and chloropicrin).[93, 98] However, as these fumigants are often used together it is difficult to differentiate between the effects of these chemicals.[93, 98] Exposure duration was also associated with ‘loss of sexual interest’ (Supplementary Table 5.5). While this may not be directly related, erectile dysfunction has also been reported in case reports on fumigators.[65, 99]

The positive associations observed between exposure duration and neuropsychological symptoms in container handlers suggest that long-term exposure may be important. We have previously reported personal full-shift exposure measurements for 133 container handlers who were also included in the current study, with levels generally below current occupational exposure limits for most measured fumigants and residual chemicals, except formaldehyde.[20] This suggests that symptoms may occur after long-term exposure at levels below current occupational standards, possibly due to the combined effect of multiple chemical exposures, or repeated incidental high peak exposures. Alternatively, symptoms may be attributable to other chemicals not measured as part of the panel tested. It is also possible that symptoms may be due to high historical exposures.

The study included an external reference group of construction workers, which was comparable to the exposed workers in terms of age, smoking, working hours, and occupational physical activity. Nonetheless, the groups differed in terms of alcohol consumption, and some minor differences in education and BMI were also observed. However, analyses were adjusted for these factors, which are therefore unlikely to explain the associations observed. Importantly, similar associations were observed in internal analyses that did not rely on the external reference group.

Only a small number of participants in occupations other than container handlers were included, limiting the ability to detect associations for these workers. Nonetheless, we did observe an increased risk of reporting ≥10 symptoms and for reporting fatigue symptoms for the group of retail workers; however, associations with exposure duration could not be determined. Thus, results remain largely inconclusive for retail workers. Nonetheless, given the potential exposures to fumigants and other hazardous substances, and possible health risks that these workers may experience, we consider that further research focusing on this common occupational group is warranted.

Other limitations include the cross-sectional nature of the study and the fact that neurobehavioral symptoms were self-reported and not objectively assessed. Also, due to low number of females in the exposed group, except in the subgroup of retail workers, and only two females in the reference group, we excluded all female participants. It therefore remains unclear whether results can be extrapolated to female workers. Also, although one-off exposure measurements were available for a proportion of the study populations (see above), this was insufficiently detailed; this study can therefore not indicate which specific exposures may be responsible for the observed associations. Finally, analyses of individual symptoms were adjusted for age and personality trait score only (due to non-convergence of fully adjusted models), so for those analyses confounding by other factors cannot be excluded.

In conclusion, this study suggests that container handlers may have an increased risk of neuropsychological symptoms, particularly related to memory and concentration. Retail workers may also be at risk of neuropsychological symptoms, but due to the relatively small population size, results are inconclusive.

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Supplementary Table 5.5. Prevalence odds ratios of individual neuropsychological symptoms for container handlers (n=274) stratified by exposure duration (using number of equivalent years[1] unloading containers)

	External comparison (compared to the reference group)							Internal comparison (within container handlers)	
Number of equivalent years[1] unloading containers	reference (n=206)	0.0003-0.1 years (n=94)		0.11-0.9 years (n=89)		0.91-41.3 years (n=91)		0.11-0.9 years (n=89)	0.91-41.3 years (n=91)
	n (%)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	n (%)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Domain and Symptom									
Neurological symptoms									
Dropping things unintentionally	2 (1)	2 (2.1)	-	0 (0)	3.6 (0.3 - 41.4)	0 (0)	-	-	-
Weakness of your arms and feet	4 (1.9)	2 (2.1)	-	2 (2.3)	2.0 (0.4 - 10.0)	3 (3.3)	1.4 (0.3 - 6.6)	1.8 (0.3 - 10.0)	-
Decreased sensation in arms and legs	10 (4.9)	5 (5.3)	1.0 (0.3 - 3.3)	2 (2.3)	0.6 (0.2 - 2.3)	8 (8.9)	1.5 (0.5 - 3.9)	0.6 (0.1 - 2.8)	1.5 (0.4 - 5.2)
Numbness or heaviness in your arms or legs	8 (3.9)	1 (1.1)	-	3 (3.4)	0.8 (0.2 - 3.3)	3 (3.3)	1.0 (0.3 - 3.6)	0.8 (0.2 - 4.0)	-
Tingling in your arms or legs	6 (2.9)	4 (4.3)	0.4 (0.1 - 3.8)	2 (2.3)	1.3 (0.4 - 4.8)	5 (5.5)	1.6 (0.5 - 5.5)	3.0 (0.3 - 28.0)	3.6 (0.4 - 31.6)
Problems with balance	13 (6.3)	8 (8.5)	1.3 (0.5 - 3.6)	9 (10.2)	1.5 (0.6 - 3.7)	9 (9.9)	1.4 (0.6 - 3.4)	1.1 (0.4 - 3.2)	1.0 (0.4 - 2.9)
Changes in sense of smell or taste	17 (8.3)	4 (4.3)	0.5 (0.1 - 1.7)	13 (14.6)	1.6 (0.7 - 3.4)	14 (15.6)	1.9 (0.9 - 4.1)	3.5 (0.9 - 12.8)	4.2 (1.2 - 15.5)*
Decreased sensation on your face	3 (1.5)	2 (2.1)	0.8 (0.1 - 8.3)	2 (2.3)	2.0 (0.4 - 10.2)	2 (2.2)	1.2 (0.2 - 7.2)	2.1 (0.2 - 21.1)	1.4 (0.1 - 15.5)
Difficulties controlling your hand movements	13 (6.3)	3 (3.2)	0.3 (0.1 - 1.6)	6 (6.7)	1.1 (0.4 - 2.9)	3 (3.3)	0.4 (0.1 - 1.4)	3.4 (0.6 - 18.5)	1.1 (0.2 - 7.0)
Slowness in carrying out your daily activities	3 (1.5)	0 (0)	-	2 (2.3)	2.2 (0.3 - 16.2)	1 (1.1)	0.7 (0.1 - 7.2)	4.1 (0.3 - 54.2)	-
Trembling of hands	6 (2.9)	3 (3.2)	1.4 (0.3 - 5.6)	4 (4.5)	1.0 (0.2 - 4.0)	5 (5.5)	2.0 (0.6 - 6.4)	0.8 (0.1 - 3.9)	1.4 (0.3 - 5.9)
Psychosomatic symptoms									
Headache	11 (5.3)	5 (5.4)	0.9 (0.3 - 3.0)	7 (7.9)	1.3 (0.5 - 3.6)	10 (11)	1.7 (0.7 - 4.3)	1.4 (0.4 - 5.1)	2.0 (0.6 - 6.7)
Sweating for no obvious reason	15 (7.3)	6 (6.5)	0.7 (0.2 - 2.2)	12 (13.5)	1.7 (0.8 - 3.8)	13 (14.3)	2.2 (1.0 - 4.9)*	2.5 (0.7 - 8.3)	3.2 (1.0 - 10.4)*
Nausea e.g., feeling sick in your stomach	18 (8.7)	7 (7.5)	0.7 (0.3 - 2.1)	12 (13.5)	1.7 (0.8 - 3.5)	9 (9.9)	1.0 (0.4 - 2.4)	2.2 (0.7 - 6.6)	1.4 (0.4 - 4.3)
Stomach pains	17 (8.3)	6 (6.4)	0.4 (0.1 - 1.6)	9 (10.1)	1.3 (0.6 - 3.0)	5 (5.5)	0.7 (0.2 - 1.8)	2.8 (0.7 - 10.6)	1.5 (0.4 - 6.2)
Dizziness	2 (1)	1 (1.1)	1.2 (0.1 - 16.3)	2 (2.3)	4.5 (0.4 - 48.7)	2 (2.2)	2.7 (0.3 - 26.2)	2.5 (0.2 - 33.5)	1.7 (0.1 - 20.7)
Shortness of breath without physical exertion	19 (9.3)	7 (7.5)	0.8 (0.3 - 2.0)	9 (10.1)	1.1 (0.5 - 2.4)	11 (12.1)	1.0 (0.5 - 2.3)	1.5 (0.5 - 4.6)	1.4 (0.5 - 4.0)
Heart fluttering (palpitations)	18 (8.8)	6 (6.4)	0.4 (0.1 - 1.6)	10 (11.4)	1.5 (0.7 - 3.3)	8 (8.8)	1.0 (0.4 - 2.4)	3.2 (0.8 - 11.8)	2.5 (0.6 - 9.6)
Ringing in your ears (tinnitus)	19 (9.2)	5 (5.3)	0.5 (0.2 - 1.5)	6 (6.7)	0.6 (0.2 - 1.6)	8 (8.8)	0.8 (0.3 - 1.9)	1.2 (0.3 - 4.6)	1.6 (0.5 - 5.5)
Feeling of general exhaustion	9 (4.4)	2 (2.1)	0.5 (0.1 - 2.3)	3 (3.4)	0.7 (0.2 - 2.7)	8 (8.8)	1.6 (0.6 - 4.5)	2.1 (0.3 - 15.8)	4.3 (0.8 - 24.6)
Loss of sexual interest	1 (0.5)	2 (2.2)	4.7 (0.4 - 54.1)	2 (2.3)	4.6 (0.4 - 54.2)	6 (6.6)	10.8 (1.2 - 94.3)*	0.8 (0.1 - 6.4)	2.1 (0.4 - 11.1)
Lowered alcohol tolerance	18 (9.1)	4 (4.4)	0.3 (0.1 - 1.2)	3 (3.5)	0.5 (0.2 - 1.5)	10 (11.1)	1.1 (0.5 - 2.4)	2.1 (0.4 - 11.8)	4.1 (0.8 - 19.5)
Diarrhoea	1 (0.5)	0 (0)	-	0 (0)	-	1 (1.1)	1.7 (0.1 - 31.7)	-	-
Constipation	5 (2.4)	6 (6.4)	2.0 (0.5 - 7.7)	5 (5.6)	2.8 (0.8 - 9.6)	3 (3.3)	1.4 (0.4 - 5.4)	1.4 (0.4 - 5.4)	0.7 (0.2 - 3.0)
Loss of appetite	6 (2.9)	1 (1.1)	0.5 (0.1 - 3.9)	2 (2.3)	0.7 (0.1 - 3.3)	3 (3.3)	1.0 (0.2 - 4.4)	1.4 (0.1 - 15.7)	2.3 (0.2 - 22.9)
Feeling of a tight band around your head	5 (2.4)	1 (1.1)	0.5 (0.1 - 4.5)	4 (4.5)	1.6 (0.4 - 6.2)	6 (6.6)	2.3 (0.7 - 7.9)	3.4 (0.4 - 32.5)	4.6 (0.5 - 39.1)
Mood									
Difficulty getting started at work	8 (3.9)	1 (1.1)	0.3 (0.0 - 2.7)	0 (0)	-	2 (2.2)	0.5 (0.1 - 2.6)	-	1.9 (0.1 - 25.6)
Feeling irritable	12 (5.8)	4 (4.3)	0.3 (0.1 - 1.7)	6 (6.7)	1.3 (0.5 - 3.5)	5 (5.5)	0.7 (0.2 - 2.0)	4.2 (0.8 - 23.6)	2.1 (0.4 - 11.6)
Feeling depressed	3 (1.5)	2 (2.1)	0.7 (0.1 - 7.9)	3 (3.4)	2.7 (0.5 - 15.7)	1 (1.1)	1.1 (0.2 - 7.6)	4.5 (0.4 - 55.9)	1.7 (0.1 - 21.7)

Feeling impatient	20 (9.7)	7 (7.5)	0.5 (0.2 - 1.5)	4 (4.5)	0.5 (0.2 - 1.3)	12 (13.2)	1.2 (0.6 - 2.7)	1.0 (0.2 - 3.8)	2.6 (0.8 - 8.6)
Being upset by trivial things	10 (4.9)	6 (6.4)	0.9 (0.3 - 3.2)	2 (2.3)	0.6 (0.2 - 2.4)	6 (6.6)	1.0 (0.4 - 3.0)	0.7 (0.1 - 3.3)	1.1 (0.3 - 4.4)
Feeling restless	11 (5.4)	1 (1.1)	0.2 (0.0 - 1.9)	2 (2.3)	0.3 (0.1 - 1.6)	5 (5.5)	0.9 (0.3 - 2.6)	2.1 (0.2 - 26.5)	4.1 (0.4 - 38.0)
Rapid changes in mood	7 (3.4)	4 (4.3)	0.7 (0.1 - 3.4)	3 (3.4)	0.9 (0.2 - 3.6)	3 (3.3)	1.0 (0.3 - 3.6)	1.4 (0.2 - 9.1)	1.5 (0.3 - 8.9)
Feeling of detachment	18 (8.7)	11 (11.8)	1.5 (0.6 - 3.5)	11 (12.5)	1.3 (0.6 - 2.9)	7 (7.7)	0.8 (0.3 - 1.9)	0.9 (0.3 - 2.3)	0.5 (0.2 - 1.4)
Lack of drive, energy, enthusiasm	7 (3.4)	2 (2.1)	0.3 (0.0 - 2.7)	3 (3.4)	0.9 (0.2 - 3.7)	4 (4.4)	1.3 (0.4 - 4.3)	4.2 (0.4 - 49.5)	4.9 (0.5 - 48.1)
Lack of interest in social activities	14 (6.8)	5 (5.3)	0.6 (0.2 - 2.0)	7 (8)	1.2 (0.5 - 3.1)	6 (6.7)	0.7 (0.3 - 1.9)	1.8 (0.5 - 6.4)	1.1 (0.3 - 4.2)
Difficulty in controlling anger	5 (2.4)	4 (4.3)	2.3 (0.6 - 9.2)	1 (1.1)	0.4 (0.0 - 3.3)	3 (3.3)	1.2 (0.3 - 5.4)	0.2 (0.0 - 1.5)	0.5 (0.1 - 2.5)
Memory/ Concentration									
Forgetfulness	6 (2.9)	2 (2.1)	0.8 (0.1 - 4.1)	3 (3.4)	1.1 (0.3 - 4.5)	11 (12.1)	3.8 (1.3 - 11.0)*	1.4 (0.2 - 8.9)	4.8 (1.0 - 23.3)
Having to write notes to remember things	18 (8.8)	6 (6.4)	0.9 (0.3 - 2.3)	7 (7.9)	0.6 (0.2 - 1.7)	9 (9.9)	1.0 (0.5 - 2.4)	0.7 (0.2 - 2.4)	1.2 (0.4 - 3.6)
Forgetting what you were about to say or do	7 (3.4)	1 (1.1)	0.3 (0.0 - 2.7)	1 (1.1)	0.3 (0.0 - 2.5)	8 (8.8)	2.1 (0.7 - 6.2)	1.0 (0.1 - 16.5)	6.7 (0.8 - 57.3)
Difficulty in concentrating	4 (2)	2 (2.2)	1.3 (0.2 - 7.6)	3 (3.4)	1.1 (0.2 - 6.4)	4 (4.4)	2.3 (0.5 - 9.5)	0.8 (0.1 - 6.7)	1.8 (0.3 - 10.3)
Daydreaming	11 (5.3)	6 (6.4)	1.1 (0.4 - 3.5)	10 (11.2)	2.3 (0.9 - 5.6)	10 (11)	1.7 (0.7 - 4.4)	2.3 (0.7 - 7.6)	1.6 (0.5 - 5.1)
Feeling confused when try to concentrate	2 (1)	2 (2.1)	2.5 (0.3 - 18.6)	0 (0)		3 (3.3)	2.7 (0.4 - 17.1)	-	1.1 (0.2 - 7.0)
Difficulty remembering names and dates	14 (6.8)	9 (9.6)	1.5 (0.6 - 3.8)	6 (6.7)	0.7 (0.2 - 2.0)	10 (11)	1.6 (0.7 - 3.6)	0.4 (0.1 - 1.5)	1.1 (0.4 - 2.8)
Absent-mindedness	2 (1)	2 (2.1)	2.5 (0.3 - 18.3)	2 (2.3)	1.1 (0.1 - 12.4)	3 (3.3)	3.7 (0.7 - 21.3)	0.4 (0.0 - 5.4)	1.5 (0.2 - 9.1)
Difficulty remembering what read / TV	5 (2.4)	0 (0)		4 (4.5)	1.2 (0.3 - 5.3)	6 (6.6)	2.8 (0.8 - 9.3)	0.4 (0.1 - 1.7)	
Other people complain about your memory	12 (5.8)	3 (3.2)	0.6 (0.2 - 2.3)	3 (3.4)	0.5 (0.1 - 1.8)	8 (8.8)	1.3 (0.5 - 3.3)	0.8 (0.1 - 4.0)	2.1 (0.5 - 8.2)
Fatigue									
Falling asleep when not in bed	6 (2.9)	2 (2.1)	0.9 (0.2 - 4.5)	0 (0)	-	2 (2.2)	0.6 (0.1 - 3.0)	-	0.7 (0.1 - 5.0)
Unusual tiredness in the evening	17 (8.3)	5 (5.3)	0.5 (0.1 - 1.6)	7 (7.9)	0.4 (0.1 - 1.4)	7 (7.7)	1.1 (0.5 - 2.6)	1.0 (0.2 - 4.3)	2.3 (0.7 - 8.0)
Sleepiness	17 (8.3)	5 (5.4)	0.5 (0.1 - 1.6)	4 (4.5)	0.3 (0.1 - 1.2)	9 (9.9)	1.1 (0.5 - 2.6)	0.8 (0.1 - 4.0)	2.5 (0.7 - 9.5)
Feeling tired when you wake up	12 (5.9)	6 (6.4)	1.3 (0.5 - 3.8)	8 (9)	1.2 (0.4 - 3.2)	9 (9.9)	1.7 (0.7 - 4.4)	1.0 (0.3 - 3.2)	1.3 (0.4 - 3.9)
Lack of energy	8 (3.9)	2 (2.1)	0.5 (0.1 - 2.5)	1 (1.1)	0.3 (0.0 - 2.4)	7 (7.8)	1.7 (0.5 - 5.4)	0.9 (0.1 - 13.7)	5.8 (0.8 - 44.7)
General weariness (or tiredness)	9 (4.4)	5 (5.4)	0.9 (0.3 - 3.6)	5 (5.6)	1.4 (0.4 - 4.6)	12 (13.2)	3.0 (1.1 - 8.1)*	1.6 (0.4 - 7.5)	3.5 (0.9 - 13.3)
Needing more sleep than you used to	6 (2.9)	3 (3.2)	1.2 (0.3 - 5.0)	2 (2.3)	0.8 (0.1 - 4.0)	3 (3.3)	0.9 (0.2 - 3.6)	0.8 (0.1 - 5.4)	0.8 (0.1 - 4.2)
Sleep									
Difficulty falling asleep	11 (5.3)	7 (7.5)	1.5 (0.5 - 4.3)	7 (7.9)	1.3 (0.5 - 3.5)	10 (11)	2.1 (0.9 - 5.3)	1.0 (0.3 - 3.1)	1.4 (0.5 - 4.3)
Broken sleep	15 (7.3)	11 (11.7)	1.8 (0.7 - 4.3)	8 (9)	0.9 (0.4 - 2.4)	11 (12.1)	1.6 (0.7 - 3.6)	0.6 (0.2 - 1.6)	0.9 (0.4 - 2.3)
Waking up too early	12 (5.8)	7 (7.5)	1.5 (0.6 - 4.0)	7 (7.9)	0.8 (0.3 - 2.5)	7 (7.7)	1.3 (0.5 - 3.3)	0.6 (0.2 - 2.1)	0.9 (0.3 - 2.7)
Nightmares	16 (7.8)	9 (9.6)	1.3 (0.5 - 3.2)	4 (4.5)	0.6 (0.2 - 1.7)	8 (8.8)	0.9 (0.3 - 2.1)	0.4 (0.1 - 1.5)	0.7 (0.2 - 2.0)
Snoring someone else has complained about	22 (10.7)	11 (11.7)	0.8 (0.3 - 2.0)	15 (16.9)	1.4 (0.7 - 2.9)	17 (18.7)	2.0 (1.0 - 3.9)*	1.8 (0.7 - 4.8)	2.6 (1.0 - 6.6)*

*p < 0.05, **p < 0.01, ***p < 0.001; All analyses were adjusted for age and personality traits.

6 Discussion and conclusions

The work described in this thesis assessed exposures to fumigants and other harmful chemicals in shipping containers and neuropsychological deficits in workers entering shipping containers, and in a smaller number of workers in other occupational groups with potential exposure to the same or similar chemicals. At the start of this work, there was limited research available on personal exposure levels and neuropsychological symptoms in these occupational groups. Most previous studies focused on chemical concentrations in closed containers and/or reported on individual cases of acute poisoning in container workers. The main findings of this research are outlined below, followed by a discussion of specific results, the strengths and limitations of the research, recommendations for the industry and future research, and overall conclusions.

6.1 Main findings

- Chemical concentrations in shipping containers arriving in New Zealand exceeded the New Zealand occupational exposure limit (WES) for at least one chemical in 8% of containers; the TLV was exceeded in 20% of containers. Exceedances of the AMVs were common (Chapter 3).
- Exceedance of the OELs occurred for closed container air samples taken from fumigated as well as non-fumigated containers (Chapter 3).
- Fumigants were also detected in containers not labeled as having undergone fumigation, but at lower levels (Chapter 3).

- Personal full-shift exposures levels of workers were considerably lower than levels measured in closed containers and never exceeded the New Zealand OELs (WES and AMV-WES). However, when using commonly used international OELs (i.e. the TLV), which were generally more stringent than the WES at the time of sampling (e.g. Phosphine 50 vs 300 ppb, methyl bromide 1000 vs 5000 ppb, benzene 500 vs 1000 ppb and formaldehyde 500 vs 100 ppb), exceedances occurred in 26.2% of personal samples (Chapter 4).
- Personal 8-hour exposure levels to fumigants did not differ between workers handling fumigated and non-fumigated containers, but the AMV values were lower in workers handling fumigated containers (Chapter 4).
- Formaldehyde, a carcinogen and known cause of asthma, contact dermatitis, and reproductive disorders in females, was frequently detected in closed containers, and absolute airborne levels were high compared to most other chemicals. Personal exposures to formaldehyde also regularly exceeded the TLV (26.2%), being the only measured chemical to exceed the TLV (Chapters 3 and 4).
- Container handlers entering containers were exposed to higher levels of formaldehyde, acetaldehyde, ethylene oxide and AMVs compared to container handlers not entering containers (Chapter 4). Other chemicals were also associated, either positively or negatively, with entering a container, but the number of detectable samples for these chemicals were too low for results to be conclusive.
- Duration spending unloading containers was associated with some chemicals but not others (Chapter 4).

- Container handlers had an increased risk of neuropsychological symptoms, particularly related to memory and concentration, with risks increasing for longer exposure duration (Chapter 5).
- Retail workers were more likely to report fatigue symptoms (Chapter 5).

6.2 Discussion of specific results

In this section results from container samples and personal samples will be discussed, involving a comparison of concentrations in closed containers and worker exposures, followed by a discussion of the determinants of chemical concentration in containers and a discussion of the neuropsychological symptoms survey in the context of previous research.

6.2.1 Chemical concentrations in shipping containers

Although concentrations in sealed containers are not full-shift worker exposures, all previous studies compared container concentrations measured for individual chemicals to occupational 8-hour exposure limits. For consistency, and to allow comparisons with other studies, the same approach was taken for the studies described in this thesis.

Fumigants were detected less frequently in container air (11%), compared to the group of other chemicals, consisting of benzene, formaldehyde, and toluene (84.7%). The higher detection rate of chemicals other than fumigants was also observed in previous studies,[4, 16, 22, 62] indicating that other chemicals besides fumigants also significantly contribute to workers' exposures.[4, 16, 22, 62] Although these consisted of only three chemicals, the results presented in Chapter 3 suggest they pose at least as much risk to workers as fumigants i.e., other chemicals exceeded the WES in 7.8% and the TLV in 20% of containers whilst fumigants exceeded the WES in 6.7% and the TLV in 7.8% of containers. The difference between exceedances of the WES and TLV for other chemicals is due to the TLV generally being more stringent than the WES. For example, formaldehyde concentrations exceeded the WES (500 ppb) in 2.9% of containers whereas it exceeded the TLV (100 ppb) in 18% of containers. Of note, the WES for formaldehyde will be reduced to 100 ppb in 2022;[50] when applying this more stringent WES standard, the overall exceedances are highly comparable to those reported in this thesis when using the TLV (data not shown).

When comparing the proportion of containers exceeding the Dutch OEL with that observed in other studies (see supplementary Table 3.7 in Chapter 3), it was found that for chloropicrin and phosphine, the percentage of OEL exceedances were low for containers arriving in New Zealand (0% and 0.2%), compared to the international studies where the OEL for chloropicrin was exceeded in up to 18% of containers and for phosphine in up to 47.2% of containers.[51, 58] The OEL for methyl bromide was rarely exceeded in New Zealand containers (1.8% of containers), which is consistent with three other studies that either did not detect methyl bromide or the OEL was exceeded only in a small number of containers (0.4% and 0.7% of containers in two other studies).[4, 23, 51, 53] However, the OEL for methyl bromide was exceeded more frequently in some other studies, with the proportion of containers affected ranging from 3.4% to 21.1%.[22, 24, 51, 58, 62] Ethylene oxide exceeded the OEL more frequently in New Zealand containers (4.5% of containers) than in other studies with the exception of one previous Australian study where the OEL was exceeded in 5.4% of containers.[58] The OEL for formaldehyde was frequently exceeded in New Zealand containers (17.9%) but even more frequently in two Australian studies (21.1 and 31.6% of containers) and a German study (30.9% of containers), while studies from other countries reported exceedances in 2.6-4.6% of containers.[4, 16, 22-24, 47, 51, 53, 62]

The reasons for the observed differences in the proportion of containers exceeding exposure standards for containers imported into New Zealand compared to those reported in international studies are unclear. They may be due to changing trends over time, different sensitivity in the measurement devices, or differences in cargo, or transit times from the port of origin.[4] Also, most other research occurred in European countries, and it is uncertain if the same findings apply to other parts of the world. Nonetheless, despite these differences, this comparison suggests that ambient air concentrations in a significant proportion of closed containers may exceed current exposure standards, with the potential for elevated exposures to workers handling these containers.

Opportunities for comparing AMV levels between containers arriving in New Zealand and containers arriving in other countries are very limited, as only one other study from Sweden reported AMV values, with approximately 10% of containers exceeding the value of ‘1’ compared to 7.8% (AMV-WES) and 25.7% (AMV-TLV) in this research.[4] However, the LoD levels and the number of chemicals analysed varied widely between both studies, hampering a valid comparison. Additionally, comparison of AMV values between studies must be done with caution because the calculation of the AMV is based on OELs and if one study uses more stringent OELs, this will increase the AMV compared to studies using less stringent OELs. The above-mentioned change to the WES for formaldehyde that will happen in 2022 illustrates a further difficulty limiting the direct comparability of different studies, as OELs not only vary between countries (section 2.3.1) but also over time.

When comparing fumigated and non-fumigated containers (Chapter 3), it was shown that phosphine, methyl bromide and ammonia levels were significantly higher (4.7, 78.0 and 53.4 times higher, respectively) in fumigated containers. These findings were expected for methyl bromide and phosphine as these are commonly used fumigants, but it is unclear why ammonia was found at higher levels in fumigated containers.

Methanol was detected in all samples (that were analysed for methanol) but exclusion of methanol from the calculation of the AMV did not substantially change the results (data not shown), indicating that although methanol (median 1,555 ppb) may contribute substantially to the total VOC concentration, as measured with the PID, it does not significantly contribute to the overall toxicity of the sample (Chapter 3). This example of methanol shows how PID measurements may provide false positive findings,[4] particularly when volatiles are present at very high levels, but with these volatiles having low toxicity (section 2.1.5). This is illustrated in Figure 6.1, which plots the PID readings and

AMV levels of samples described in Chapter 3. The same figure also shows the potential of false negative measurements when collecting measurements using a PID, which is likely to occur when chemicals with an OEL level set below the LoD of most PIDs (1000ppb) are present (see section 2.1.5). Thus, some caution is required when interpreting PID measurements taken from containers.[4]

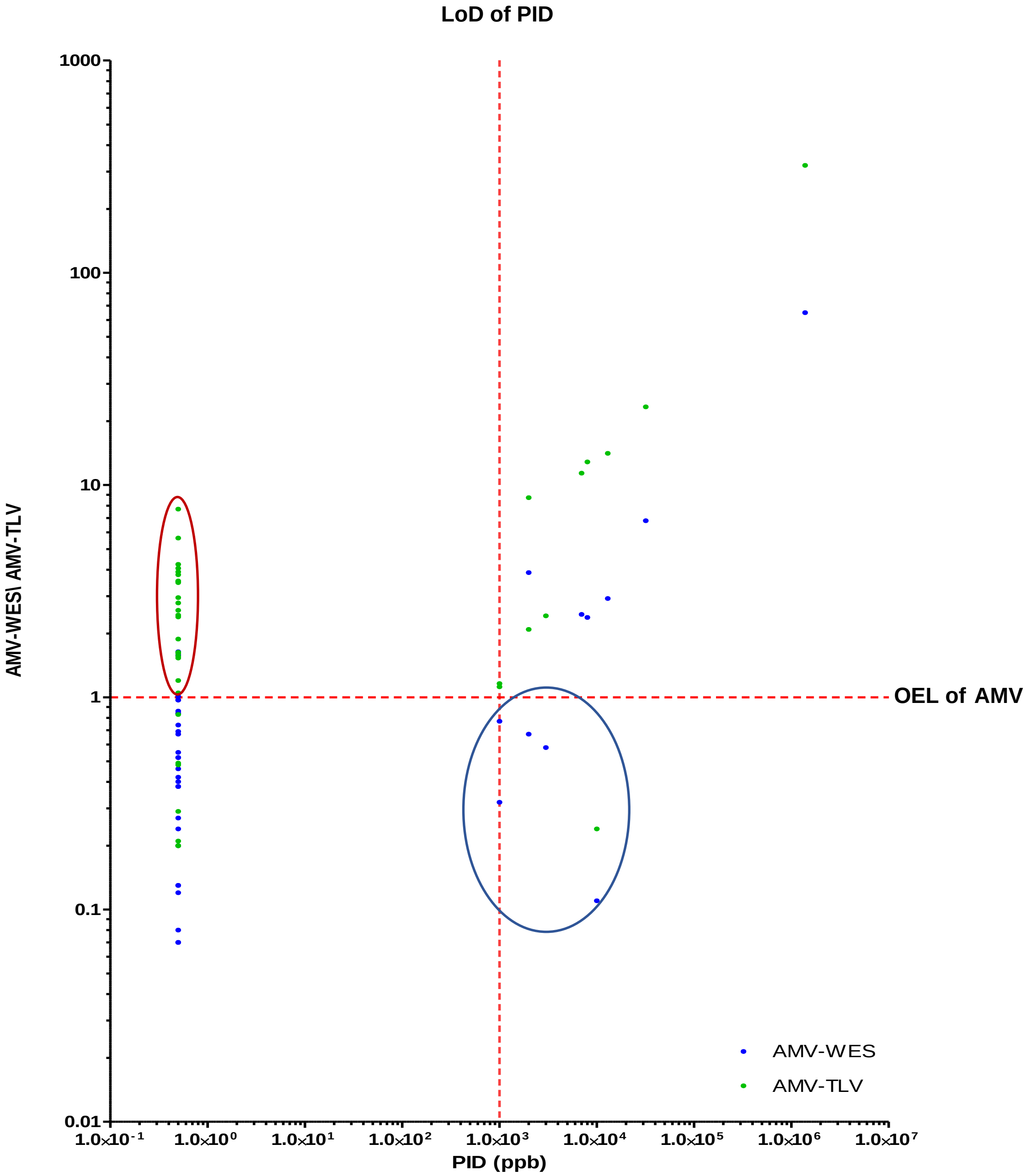

Figure 6.1 Graph AMV-WES and AMV-TLV vs PID readings. The red lines indicate the OEL of the AMV and the LoD of the PID. False positive values are in the blue circle and false negatives in the red circle.

6.2.2 Personal 8-hour exposures

OELs represent upper limits of allowed concentrations of harmful chemicals in the workplace air a worker is exposed to and is typically measured over an 8-hour work-period. Personal 8-hour exposures of fumigants and other chemicals in workers were below the WES and the TLV standards at the time of sampling.

The exception was formaldehyde, for which 26.2% of all measurements exceeded the TLV (Chapter 4), which is of concern (discussed further in 3.2.3).

This research did not measure peak exposures in workers, and it is possible that some workers may be exposed for short periods to very high levels of chemicals, as indicated by the high concentrations detected in containers and supported by the findings of the case reports describing adverse health effects after acute exposures to chemicals in containers or the cargo (see also section 2.4.1).[6, 8, 10, 11, 13, 14, 65] Indeed, in an experimental study using tracer gas such peak exposures were observed in workers unloading containers, especially during opening of the container doors when concentrations reached up to 70% of the concentration measured in the closed containers (section 2.1.4), while average personal exposures during unloading were only between 1-7% of the concentration in the closed containers.[48] Also in agreement with the findings of this thesis was an Australian study (which measured the same panel of chemicals as those described in this thesis (section 2.1.4) that showed that only one of 12 personal samples exceeded the Dutch OEL (for formaldehyde) compared to approximately a third of ambient air samples (n=100) taken from the containers during unloading, again indicating the potential for occasional high peak exposures.[24]

Additionally, workers are exposed to a ‘cocktail of chemicals’ as measured in the AMV, which may result in an additive and possibly even a multiplicative effect on possible health outcomes. Although the AMV-WES of the 8-hour personal exposure measurements never exceeded ‘1’, the AMV-TLV exceeded

‘1’ in 26.2% of exposure measurements (container handlers, 29%; retail workers, 20%; export log workers, 20%; and fumigators, 20%), suggesting that, although generally considerably lower than ambient concentrations, personal exposures may, at least in some cases, be at levels where health effects cannot be excluded (see also section 2.4.1) as also suggested by the increased risk of neuropsychological symptoms observed in container handlers, described in Chapter 5.

Of interest, at the time of sampling, the WES of 1,2-dibromoethane (used in the past as an additive to leaded gasoline and currently used for the control of wax moths in beehives and in the treatment of felled logs for bark beetles and termites) was 500 ppb; however, this was substantially lowered to 0.3 ppb in 2019 (on the basis of 1.2-dibromoethane being classified as a carcinogen by the Dutch Expert Committee on Occupational Standards).[100, 101] Applying the current standard of 0.3 ppb, the WES would be exceeded in at least 29% of container handlers, 13% of retail workers, 45% of log workers and 20% of fumigators. As the analytical LoD was above 0.3 ppb, only a lower limit of the proportion of personal exposures could be provided, suggesting that the proportion of samples exceeding the new WES may be considerably higher.

6.2.3 Concentrations in containers compared to personal exposure levels

Most previous studies measured concentrations of chemicals in container air (often for only a few seconds) and implied that these measurements may be representative of full-shift worker exposures. As noted above, these studies also often compared concentrations against occupational exposure limits, without providing a critical reflection of the difference between concentration and exposure, thus leaving the reader with the suggestion that workers are likely exposed to levels that may cause adverse health effects. However, that may not necessarily be true as these assumptions may be based on invalid extrapolations from concentration to exposures; the studies described in this thesis have attempted to address this by measuring both container air concentrations (Chapter 3) and eight-hour time weighted average exposures (Chapter 4). In particular, this research quantified different aspects of concentrations of, and exposures to, fumigants and other residual container chemicals in four different ways, by measuring: **(i)** concentrations of specific chemicals in closed containers using grab samples (Chapter 3), **(ii)** concentrations of specific chemicals immediately after opening of the containers using grab samples as a proxy of potential peak exposures (Chapter 3), **(iii)** real-time total concentrations of volatile organic compounds at the door of the container during ventilation using a photoionization detector (PID) (Chapter 3), and **(iv)** personal exposure levels of specific chemicals using 8-hour measurements (Chapter 4). These different approaches combined provide a greater understanding of (potential) exposure levels that are relevant for container workers and other related occupational groups and contribute to a better understanding of potential health risks in these workers.

Despite measurements of 8-hour personal exposure levels and chemical concentrations in closed containers not always being directly comparable (they were not always conducted at the same ports, fumigated containers were overrepresented in the study measuring concentrations upon opening containers, and chemicals measured in each survey differed slightly), contrasting findings using both metrics clearly shows that concentrations (expressed as AMVs) were considerably higher than personal exposures (Figure 6.1 (WES) and 6.2 (TLV)). In particular, AMV-WES values >1 occurred exclusively in closed containers and in samples taken upon opening of containers, with none of the 8-hour personal exposure samples exceeding an AMV-WES-value of 1. Also, the mean AMV-WES was close to 1 for samples taken upon opening of containers, but only 0.25 for the 8-hour personal exposure samples. However, 1,2-dibromoethane was excluded from the calculation because its TLV standard was not set, and it was unclear how many samples exceeded the WES as the analytical detection limit was above the WES.

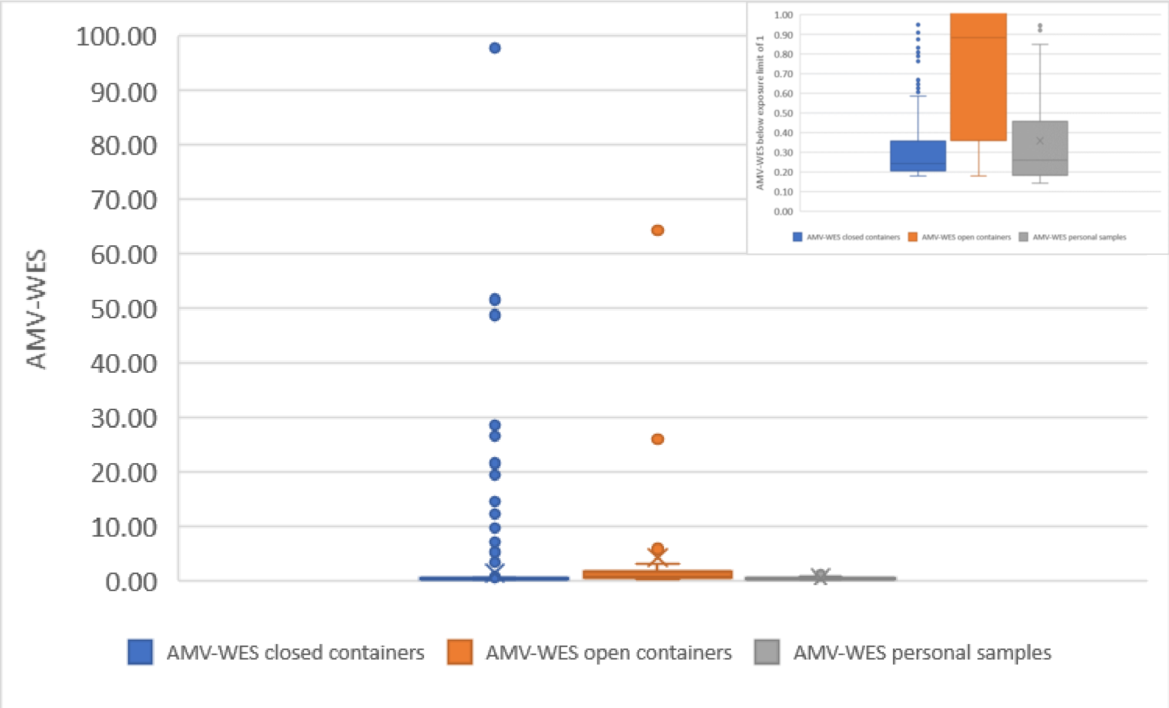

Figure 6.2 Comparison of AMV-WES values between closed containers, opened containers and personal samples. Note the open containers were not randomly selected. Insert: enlarged graph of measurements below the exposure limit of 1.

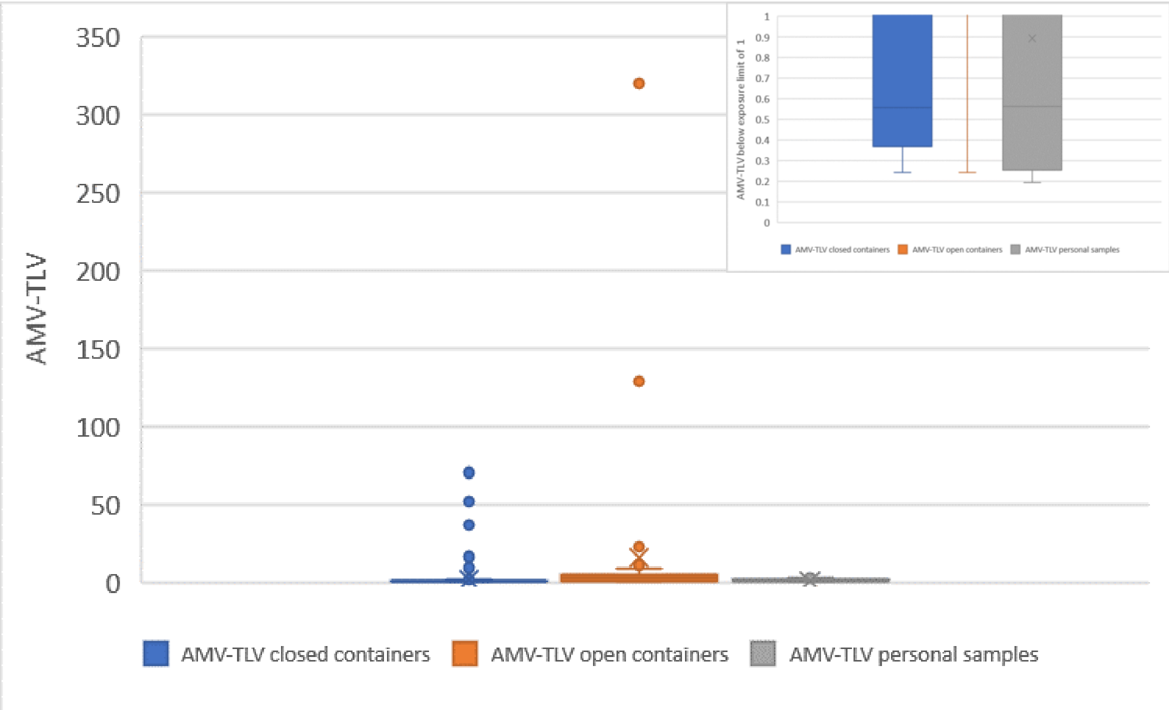

Figure 6.3 Comparison AMV-TLV values between closed containers, opened containers and personal samples. Note the open containers were not randomly selected. Insert: enlarged graph below the exposure limit of 1.

The reason that exposures are considerably lower than the measured concentrations in closed container is likely due to ventilation of containers prior to entering the container, which reduces chemical concentrations as indicated in the PID readings taken during ventilation (Chapter 3) as has also been observed in previous studies.[37, 38, 48]. While samples taken from closed containers seem to overestimate personal exposure, the high concentrations detected in containers do, as noted before, illustrate the potential of high peak exposures for workers e.g. when opening the container doors (as indicated by the high concentration detected when doors are opened) or when encountering pockets of air with high chemical concentrations being trapped between cargo, which is especially probable when ‘tunneling’ into the container (Chapter 2).

Formaldehyde was detected frequently in both personal exposures and chemical concentrations, and exceeded the TLV of 100 ppb (to be the new WES from 2022) in 26% of all personal and 18% of container samples. The higher exceedance of the TLV in personal samples is possibly due to formaldehyde from external sources (e.g. combustion processes) as workers in this study were often also exposed to exhaust fumes from truck and heavy machinery. Formaldehyde has also been observed to off-gas from wooden container floors due to natural decay.[4] Additionally, formaldehyde has a slower decay rate compared to many other volatile organic components potentially resulting in longer exposure durations.[87] The exclusion of formaldehyde from the AMV calculation showed a considerable reduction in mean and median AMV values (Figure 6.3 and 6.4), identifying formaldehyde as a major contributor to the overall toxicity (AMV) of samples, and suggesting formaldehyde to be a chemical of concern to workers. The high concentrations of formaldehyde observed in this research is consistent with the findings of a small study involving personal exposures [24] and several studies measuring container air.[4, 16, 22, 51]

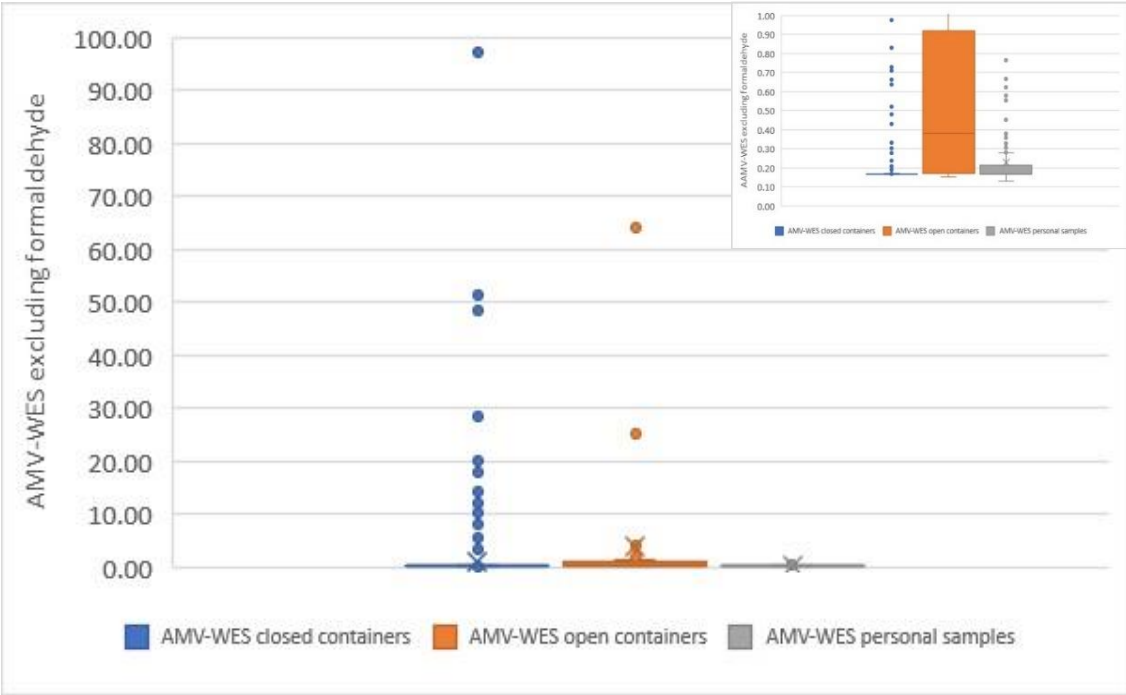

Figure 6.4 Comparison of AMV-WES values excluding formaldehyde between closed containers, opened containers and personal samples. Note the open containers were not randomly selected. Insert: enlarged graph of results below the exposure limit of 1.

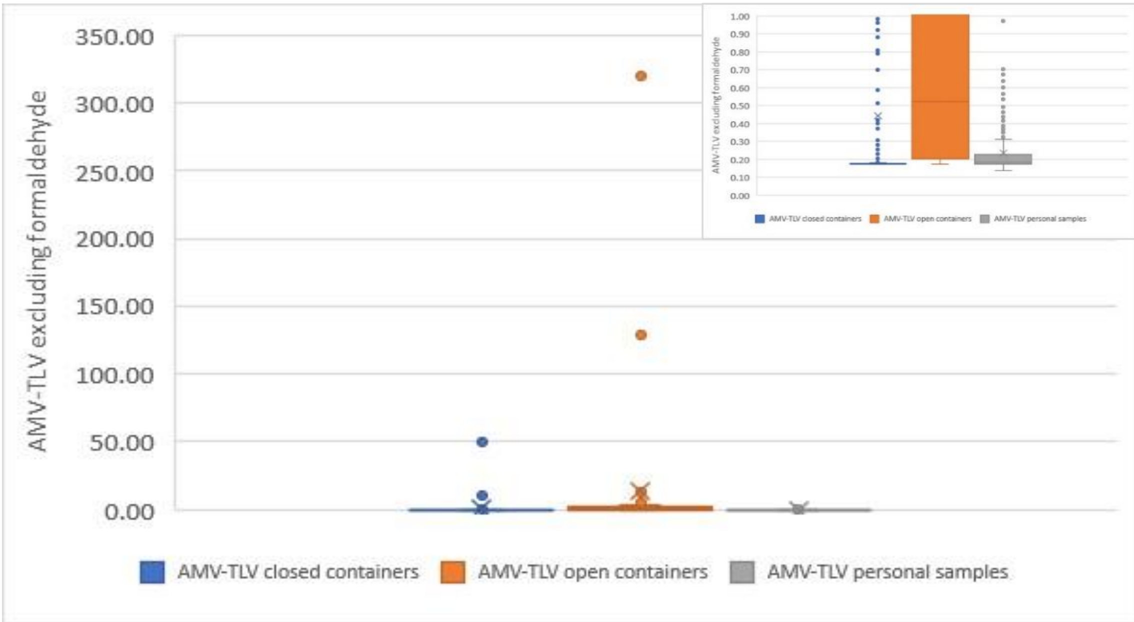

Figure 6.5 Comparison of AMV-TLV values excluding formaldehyde between closed containers, opened containers and personal samples. Note the open containers were not randomly selected. Insert: enlarged graph of results below the exposure limit of 1.

6.2.4 Determinants of chemical concentrations in containers and worker exposures

One of the aims of this thesis was to assess associations between container characteristics (cargo type, country of origin, fumigation status, container size and vents) and chemical concentrations in containers air and worker exposures. If determinants of chemical concentrations in containers and worker exposures can be identified, this information may be used to develop a container risk assessment tool to alert workers to 'high risk' containers (see below).

Cargo type and country of origin are the most studied container characteristics. Cargo type is of interest because the potential for chemicals to be off-gassed varies between goods. For example, containers carrying shoes made with solvent glue have repeatedly been shown to have high airborne concentrations of benzene.[4, 16, 53] The cargo type may also determine the need for fumigation and the type of fumigant used. Country of origin is of interest because the approved use of chemicals varies between countries and so do the transit times from the port of origin to New Zealand providing shorter or longer time periods for ventilation via container vents. There has been a lack of consistent findings linking container characteristics and chemicals in container air between studies,[3, 4, 16, 22, 53] including this study, possibly due to differences in the sample of containers measured, differences in fumigation practices and requirements for different countries, categorisations used to combine cargo types, and/or differences in OELs used (Chapter 3). Additionally, differences in air sampling and analytical methodologies between studies may also have contributed to inconsistencies. Previous studies reported findings based on the frequency of OELs exceedances in containers, while in this thesis regression analyses using AMVs was conducted, which may be another reason why results differ with that of other studies.

Other container characteristics and their influence on airborne chemical concentrations are less well studied. Fumigation status is one of these characteristics and was included in this thesis (Chapter 3). Previous studies reported that fumigated containers arriving from overseas are only rarely labelled as such, potentially leading to misclassification of fumigation status.[4, 16, 22-24] However, misclassification is unlikely to have occurred widely for the results presented in Chapter 3, because most fumigated containers were fumigated in New Zealand and clearly labelled.

A positive fumigation status was strongly associated with elevated levels of methyl bromide and phosphine (the most used fumigants) and exceedances of the AMVs. However, the high concentration of fumigants in fumigated containers (Chapter 3) were not reflected in the personal air samples from workers unloading or inspecting (fumigated) containers as neither the WES nor the TLV were exceeded, and overall levels of fumigants were relatively low (Chapter 4). This discrepancy between concentrations of fumigants in container air and personal exposures suggest that fumigated containers may not significantly increase the risk of worker exposure to fumigants, possibly due to good adherence to appropriate labelling of fumigated containers and associated recommended ventilation times.

This research also found that exceedances of AMVs occurred more often in larger 40ft containers compared to 20ft containers for chemicals other than fumigants, likely due to the decreased ventilation in the middle of the container from being further away from the container vents (Chapter 3).[38, 48] Higher AMV levels were also observed in containers without open vents (vents are sometimes taped to stop moisture entering the container and spoiling the cargo, or not removed after fumigation) and lower in containers with four open vents, when compared to two open vents (Chapter 3). This illustrates the importance of container ventilation.

Tightly packed containers have been associated with lower chemical concentrations in previous studies, most likely due to limited airspace providing less opportunity for cargo and/or packaging materials to off-gas chemicals into the air during transit (see Figure 6.4 and 6.5 for examples of tightly packed containers).[37, 38, 48]

Figure 6.6 Chemicals are able to accumulate in the gaps around the vases and in the interior of the vases, while air cannot freely flow towards the vents at the top of the container (R. Hinz)

Figure 6.7 Tightly packed container leaving little airspace (R. Hinz)

Although not a direct indication of how tightly packed a container is, regression analyses indicated that 'less than full load containers' were more likely to have higher AMV values than 'full load containers' (AMV-WES: OR 1.6, 95%CI 1.1-2.2; AMV-TLV: OR 1.5, 95%CI 1.1-2.2), which appears to confirm these earlier findings.

For personal air samples a significant association between the duration of unloading containers and exposures to ethylene oxide, acetaldehyde, and C2-alkylbenzenes exposures was found. Although all measurements for these chemicals were below the WES/TLV, it suggests that the time spent unloading containers may be an important determinant of exposure (Chapter 4).However, because an association was detected for some chemicals but not others, it is possible that this measure is too crude a proxy of exposure, suggesting that other determinants such as container characteristics may be equally or more important. However, this could not be determined because personal exposure levels and container characteristics could not be fitted in a regression model due to the large number of measurements below the LOD (<50%) for most chemicals leading to non-convergence of the model.

Collectively, these study findings indicate that chemical concentrations in containers and personal exposures are affected by a multitude of container characteristics.

6.2.5 Neuropsychological symptoms

Most previous research on health effects reported acute symptoms but less is known about symptoms due to subacute, or chronic low-dose exposures.[7, 70, 99] The neuropsychological symptom survey described in this thesis is an important addition to the small number of studies that investigated longer-term health effects in workers entering containers, fumigators and retail and log workers (Chapter 5).

This research suggests that workers may have an increased risk of neuropsychological symptoms with all occupational groups being more likely to report a larger number of symptoms (≥10 symptoms) than the reference group. Retail workers were more likely to report symptoms in the fatigue domain. However, only a small number of participants in occupations other than container handlers were included (e.g. fumigators and log workers), limiting the ability to detect associations and determine associations with exposure duration for these workers.

Container handlers were more likely to report symptoms in the memory/-concentration domain, when compared to reference workers and workers in the shortest duration group, which also was observed in three earlier studies on workers handling shipping cargo. One study that conducted neuropsychological testing found evidence of persistent neuropsychological deficits in (working) memory.[70] Additionally, two other studies examined neuropsychological symptoms in container handlers and dock workers via a health questionnaire, reporting that workers unloading shipping containers experienced more frequent symptoms in the memory domain [24] and that in dock workers who were exposed to fumigants in the past years, memory disorders may be more common.[71] However, a recent study of neuropsychological symptoms in 165 logistic transport workers who were involved in transportation and storage of goods, but not necessarily entered containers, found that workers were less likely to report ‘forgetfulness’ (statistically significant) and ‘difficulty in concentrating’ (not statistical significant) compared to a reference group.[54] However, the exposed and reference group in this study differed strongly in gender distribution (92.6% males in the exposed group compared to 20.6% in the unexposed group), and although this was adjusted for, some residual confounding cannot be excluded.

Furthermore, all questionnaire studies reported a low prevalence of symptoms possibly due to the healthy worker effect, as suggested previously.[54, 71] In this research, container handlers in the shortest duration group were less likely to report symptoms compared to the reference group (Chapter 5), suggesting that container handlers are healthier when entering the industry. If the healthy worker effect exists in this occupational group, it may have limited the ability to detect some neuropsychological deficits in these studies.

This research also assessed the association between neuropsychological symptoms and exposure duration in container handlers. Container handlers with longer exposure duration were more likely to report neuropsychological symptoms suggesting that the symptoms are work-related and that long-term exposure may be important. Considering that personal exposure levels were generally below the OEL, except for formaldehyde (Chapter 4), symptoms may occur after long-term exposure at levels below current occupational standards, possibly due to the combined effect of multiple chemical exposures, or repeated incidental high peak exposures. Alternatively, or in addition, other chemicals not included in this research, or higher or historical exposure to more toxic chemicals may have contribute to a higher symptom prevalence.

The research described in this thesis found increased reporting of symptoms in the memory and concentration and fatigue domains, but not for other domains. The study referred to above, using neuropsychological tests, also observed deficits in other domains (information processing speed and selective and shared attentiveness) which are more difficult to assess through questionnaires.[70] Additionally, in this research positive associations of individual symptoms were also observed in the domains of neurological symptoms, psychosomatic symptoms, and fatigue, suggesting that these domains may also be important. However, this and other research identified the memory and concentration domain to be of particular concern. Deficits in memory and concentration will have a direct negative impact on quality of life and may also indirectly increase the risk of work-related accidents; this is therefore of concern and may require specific work-place interventions (discussed further in section 6.4).

Finally, regression analyses in this research were adjusted for potential confounders (age, ethnicity, smoking, alcohol consumption, education, personality traits and BMI), and sensitivity analyses were conducted excluding participants who did night shift work and/or had previously experienced head injury/concussion). These adjustments or exclusions did not appreciably alter the results, suggesting these were not strong confounders. However, confounding by other factors such as chronic disease (e.g. diabetes) or prescription drug use cannot be excluded. Additionally, analyses of individual symptoms could be adjusted for age and personality trait score only; hence confounding by other factors such as ethnicity, smoking, alcohol consumption, education and BMI cannot be excluded for these analyses.

6.3 Strengths and limitations of the research

One of the major strengths of the research described in this thesis is the comprehensive assessment of personal full-shift (8-hour) exposures, which had not been conducted previously. In particular, it enabled a valid comparison with exposure standards and allowed for the comparison of airborne chemical concentrations in closed containers with personal exposures. However, 8-hour personal air sampling did not provide information on peak exposures despite peak exposures possibly posing a greater health risk to workers.[48] Additionally, associations between personal exposures and container characteristics could not be assessed because airborne levels were often below the limit of detection (with the exception of formaldehyde that was detectable in the majority of containers), and participants frequently unloaded several containers with different cargo and from different countries of origin during the 8-hour sampling period. Also, it is unclear whether working conditions of participating companies and workers included in this study were representative of the whole industry in New Zealand or that in other countries. These are limitations of the current studies.

Other limitations include that this study's field work was conducted at the workplace requiring support of management, which also meant that management identified potential participants based on availability and workplace requirements. This selection may have been biased towards workers who experience lower exposures, although there were no observations made during field work to suggest this selection actually occurred. In contrast, in the smaller container survey, management and workers often asked for containers to be sampled that were of concern due to suspected higher chemical concentrations or odour, providing a clear indication that selection towards containers with suspected higher chemical levels occurred.

Assessment of the determinants of chemical concentrations in container air was conducted using mutually adjusted regression analyses, rather than reporting crude frequencies of exceedances of the OELs associated with different types of cargo and different countries of origin as was done in most previous studies, allowing for more robust assessments. However, the larger container study lacked some information on container characteristics such as the number of container vents and the size of the containers, thus a full assessment of all potential determinants could not be done, which is a limitation. Also, for the larger container survey, sampling was conducted in 2011, and only at one port, which may not be representative for containers currently arriving in New Zealand, including those arriving in other ports, particularly considering that previous studies have shown large differences in results between ports.[4, 22]

While the smaller container survey included previously rarely investigated container characteristics such as fumigation status, size of container, and number of container vents, thus contributing to a better understanding of concentration determinants, the survey was of relatively small size. This reduced statistical power, and, as a consequence, the probability to detect statistically significant findings, which is a significant limitation. Related to this, many comparisons were made, increasing the risk of false positive findings.

However, considerably more statistically significant findings were observed than expected based on chance alone, suggesting that findings may be real, i.e. in the multi-variable regression analyses of the smaller container study (Table 3.4), overall 4.5 statistically significant findings were expected by chance alone at $p<0.05$ [(15 categories * 6 AMV values) * 0.05], but 16 significant findings were observed and in the larger container study (Table 3.2), 6 significant findings were expected in the regression analyses, but 23 were observed.

In the container and the personal exposure study, besides reporting concentration of individual chemicals, the combined toxic effect of all chemicals in a sample was also reported, which provides useful additional information as workers are generally exposed to a ‘cocktail’ of chemicals. The same novel approach had only been taken in one previous study.[4] However, due to the necessarily limited number of chemicals analysed, it is possible that the combined toxic effect was underestimated; likewise, potential exposures to other chemicals and related risks may have been overlooked.

The neuropsychological symptoms survey was considerably more comprehensive compared to previous surveys and included a reference group of non-exposed workers.[24, 71] It also controlled for potential confounders and assessed duration-response associations. These are major strengths and have contributed to a better understanding of potential health risks of workers exposed to fumigants and chemicals off gassed from container cargo. However, there are several limitations. In particular, the specific causal exposure(s) could not be identified in this study, as the only index of long-term exposure available was the duration of employment in the industry. Also, the number of participants for some occupational groups (i.e. retail workers (n=38) log workers (n=18) and fumigators (n=35)) was relatively low. As a consequence, results for these groups should be considered preliminary and largely inconclusive. This issue was compounded by excluding all 107 female participants (due to the small number (n=2) of females in the comparison group), which was particularly an issue for retail workers. In addition to reducing power, it also means that results may not be generalisable to female workers. Apart from the mismatch in female participants and minor differences in education and BMI, exposed workers had a higher alcohol consumption than the reference population (12 vs 6 standard drinks per week) which, due to the neurotoxic effects of alcohol, could have explained some of the observed associations in workers. However, at least for the container workers, these associations were also observed in the internal analyses (i.e. the analyses involving comparisons within the exposed workers), and analyses were adjusted for alcohol consumption. Therefore, alcohol consumption is unlikely to explain the associations observed. However, analyses of individual symptoms (as opposed to symptom domains in other analyses) were only adjusted for age and personality trait score (due to non-convergence of fully adjusted models), hence for those analyses confounding by other factors, including alcohol consumption, cannot be excluded.

Neuropsychological symptoms were self-reported and not objectively assessed by neuropsychological test batteries, potentially leading to reporting bias. Nonetheless, all results were adjusted for personality score, which has been found to be associated with participants under or over reporting symptoms by assessing anxiety and perceived general health.[92] Furthermore, interviews were conducted by trained interviewers reducing the likelihood of a biased response due to differences in the interpretation of questions between participants.

Finally, a further limitation is that due to the cross-sectional study design, which measured outcome and exposure variables at the same time, the causality of the observed associations could not be established.

6.4 Recommendations for the industry and future research

In this section general recommendation for the industry are provided based on the findings from this research as well as observations from international research. This is followed by potential directions for future research.

6.4.1 Recommendation for the industry

The accumulation of airborne chemicals in shipping containers can result in levels that may harm workers' health, but adequate ventilation of the containers mitigates this risk. Therefore, a solution would be to ventilate all containers for an extended period. However, there are several practical issues with using this approach. Firstly, this is a time-sensitive industry and delaying unloading would incur additional costs especially if it were applied to all containers while only a percentage of containers may present a risk to workers (6% and 25.7% of containers in this research had AMV-WES and AMV-TLV values above 1, respectively). Furthermore, leaving the doors open for ventilation may result in damage of goods and potential theft, particularly if cargo was left unsupervised. Additionally, cargo could get spoiled due to humidity or pest intrusions through the open doors. The implementation of technologies that mechanically increase ventilation and reduce ventilation times, such as described in Chapter 2, therefore needs to be considered.

Another approach would be to identify containers with harmful chemical concentrations and to establish adequate ventilation times for these containers by re-measuring the container air until safe levels are reached. As already mentioned, due to the lack of affordable and suitable measurement devices this approach can only be undertaken by very few companies. Hence, the recommended approach is to establish a central container testing facility with a risk assessment and indexation system, similar to that developed by others internationally, and described in Chapter 2. Preferably, such units would be established at all New Zealand ports. Alternatively, a unit could be established at one major port for a year (to capture seasonal variations) and then be rotated to other ports, which is important because chemical compositions and concentrations in container air have been found to vary between ports.[4, 22]

To establish such a facility, involvement from the industry, Customs Services, Ministry of Primary Industries (biosecurity section) and WorkSafe is needed as these parties have practical knowledge on how such a facility could run efficiently and be adapted to work conditions in New Zealand. Due to the high volume of testing that such a facility would conduct, the purchase of suitable measurement devices would be cost-efficient, the testing standardised, and data collection be centralised and rapid.

Further investigation into personal exposures and safe entry into the containers could also be included in such a central container testing facility. For example, if chemical concentrations are detected at unsafe levels in a container and the chemicals were identified, sufficiently sensitive and specific personal exposure measurement tools e.g. colorimetric tubes could be used by companies to test the container air before entry and personal exposure during unloading. This will likely provide a safer work environment (assuming appropriate action will be taken if/when samples exceed OELs) and further knowledge on personal exposures.

The collected data on chemical concentrations, personal exposures, and determinants of concentrations and exposure, can be used to identify high risk containers that may require further ventilation, or other measures to reduce exposure (e.g. the use of appropriate PPE if reducing levels at source cannot be achieved). The data could also be used to further refine the container risk assessment and indexation system. For the initial phase of container testing, it is recommended to test for a wide range of chemical to further ascertain which chemicals are of particular concern in New Zealand.

Preferably, a central container testing facility would also have a safe container ventilation facility and a system to report results to importers. As chemicals could reaccumulate in the container during transport, a notice should be placed outside the container stating the chemical of concern and a recommended ventilation time to reduce risk to workers unloading the container. Reporting results back to the importer and labeling containers increases awareness of the risk in the industry, and manufacturing processes could be modified to reduce chemical exposure, if problematic cargo has been identified. Finally, a central container testing facility could identify fumigated containers that are not labelled, and government agencies would be able to enforce relevant regulation.

In New Zealand, the “Code of Practice Fumigation”[46] advises on the fumigation process and the industry guidance, “Keeping safe from harmful substances while inspecting or unpacking containers”[47], advises on the process of unloading containers. Both policies provide advice, but none of the recommended processes or practices are mandatory and they are overdue for a review, which provides opportunities to introduce some changes. For example, the use of methyl bromide recapture technology that was recently amended by the Environmental Protection Authority NZ[30] could be updated in the “Code of Practice Fumigation”. The policy on “Keeping safe from harmful substances while inspecting containers” could be expanded by including the guidelines of the international “Code of Practice for Packing of Cargo Transport Units (CTU Code)”,[43] which is very detailed and includes other potential risks when unloading containers e.g. falling objects and oxygen depletion. This policy could be developed together with inspectors and the industry. Currently, each company that handles shipping containers develops its own guidelines for safe container unloading. A single policy with mandatory practices and processes could be considered, similar to the induction training at ports. If adopted, this may reduce exposure and resultant risk.

Additional recommendations to the industry are the establishment of a central incident reporting system related to chemical exposures from containers, including the identification of the chemical of concern, the concentration, and any (acute) health effects. A central reporting system would increase awareness of the risk in the industry and assist with assessment of exposure risk.

For reasons discussed previously, further research into suitable measuring devices and container ventilation techniques are also recommended.

6.4.2 Recommendations for future research

Because the focus of most previous studies had been on chemical concentrations in closed containers, which, as shown in the studies described in this thesis, are not necessary equivalent to personal exposures, and this research found container handlers to be more likely to have neuropsychological symptoms, further research into personal exposures is recommended to assist with risk assessment. Further research into personal exposures may also confirm the finding that other chemicals than fumigants, which were the main concern of many previous studies, significantly contribute to overall exposure.

Further research into chemical concentration in closed containers is also recommended, because only one large-scale study was conducted at one port in New Zealand and the findings require validation. Furthermore, most investigations of chemical concentrations in closed containers are 10 years or older and import/export patterns, and transit times and routes may have changed, particularly considering the 2020/2021 COVID-19 pandemic, which could affect the chemical composition and concentration in containers.

Previous research[48] suggested that potentially peak exposures pose an additional or even greater health risk to workers than low level long-term exposures. To research peak exposures in more detail and its contribution to overall full-shift exposure, it is recommended to conduct video exposure monitoring, which overlays real-time exposure data on a video capturing workers' tasks, thus allowing to link exposures to specific tasks. Video exposure monitoring in workplaces where solvents are an issue is often undertaken using a PID, but due to the limitations of PIDs (see section 2.1.5), it is recommended to use more recently developed portable (spectrometry) devices, which can measure several chemicals at once in real-time and at lower exposure levels. However, these devices are fragile and to prevent damage an operator may be required to hold the probe close to the workers breathing zone during unloading.

Because video exposure monitoring identifies specific tasks or container characteristics related to peak exposures, it assists with the development of safer work practices. Special consideration should be given to research into potential peak exposures during bio-security inspections because the inspections are required to be done immediately after opening of the doors, when chemical concentrations in the container air are often the highest.

More research into the determinants of chemical concentrations in containers, in particular container characteristics and ventilation, is also recommended, to assist in developing prediction models to identify high-risk containers, which may subsequently be treated differently to reduce risk to workers and to use ventilation most effectively. Additionally, further research into container characteristics and ventilation may lead to changes in container design to reduce chemical concentrations in containers.

Further research on ventilation should consider the influence of meteorological factors on ventilation rates and the efficiency of different ventilation methods. Experimental studies using tracer gas[48] may also be very useful in this area of research but also to estimate personal exposure. In particular, it may be very helpful in evaluating different intervention strategies e.g. improved ventilation.

The only determinant of personal exposure levels that could be examined in this research was the duration spent unloading containers. The findings (a positive association with some but not other chemicals) suggested that other factors such as container characteristics may also play a role in exposures (Chapter 3). However, this research could not examine the association between personal exposure and container characteristics because workers typically unloaded several containers during a workday associated with a variety of cargo characteristics (e.g. different cargo types, different container sizes). To avoid this problem, future research could focus on collecting one personal sample per container for each worker rather than one 8-hour sample. Video exposure monitoring could also assist with examining the association between exposure and container characteristics as it would not only capture the task the worker undertakes but also the characteristics of the container that is being unloaded (e.g. how tightly the container is packed).

Fumigants and other chemicals included in this research are known to affect predominantly the central nervous and the respiratory system, although knowledge on long-term health effects is scarce. Considering the size of the workforce in this industry and the finding of an association between exposure duration and symptoms in the memory/concentration domain, further research on adverse health effects on the central nervous is recommended. Due to the nature of exposure, respiratory symptoms should also be considered. When designing future research for neuropsychological symptoms, the overall low prevalence should be considered when considering the study size. Because questionnaires rely on self-reporting, the use of neuropsychological test batteries to validate the results of the questionnaire is recommended. Additionally, the test batteries could be applied before and after work to establish whether acute changes occur following exposure at work, and how these may relate to long-term health effects. Finally, although the industry is mainly male dominated, it is recommended to include females in future research because in parts of the industry (workers inspecting containers) females are well represented (26% of workers in the questionnaire study).

This research had a particular focus on container handlers, but exposure to fumigants and container chemicals are also relevant for several other occupational groups. Further research into potential exposures and adverse health effects in retail workers, container inspectors, log workers and fumigators is recommended, because the low number of participants in these occupational groups in the studies described in this thesis hindered the detection of potential associations. Another group meriting further research are consumers of products from shipping containers, which may off-gas fumigants and other chemicals into homes, even for extended periods of time after unpacking.

Finally, as cross-sectional studies are generally more affected by bias and causal relationships cannot be determined, future studies into long-term health effects would ideally use a longitudinal study design, thus reducing bias and allowing temporal associations between exposure and health effects to be more validly assessed.

7 Conclusions

Based on the studies described in this thesis and supported by observations reported in the international literature, the following conclusions can be drawn:

- Airborne concentration of fumigants and other chemicals in containers imported in New Zealand frequently exceed New Zealand and international exposure standards regardless of the fumigation status of the container (Aim 1; see Chapter 1.2).
- Natural ventilation can reduce these concentrations with, in the current study 7 out of 10 container readings dropping below 1,000 ppb within 2 minutes and one container's methyl bromide reading dropping from 319,000 ppb to 5,826 ppb (1.8%) in 30 minutes (Aim 2).
- Full-shift workers' personal exposures in container handlers are generally well below New Zealand and international exposure standards for most chemicals, except for formaldehyde. Formaldehyde exposures frequently exceed New Zealand and international exposure standards (Aim 3).
- Full-shift workers' personal exposures in retail workers, log workers, and fumigators are generally well below New Zealand and international exposure standards, with exposures for most chemicals (except formaldehyde) being similar to those of container handlers (Aim 3).
- Duration spent unloading containers increases personal exposure levels in container handlers for some chemicals (ethylene oxide, C2-alkylbenzenes and acetaldehyde) but not for others (Aim 4).

- Container characteristics are not clearly associated with airborne concentrations of fumigants and off-gassed chemicals in closed shipping containers (Aim 5).
- Workers handling cargo from containers and export logs appear to have an increased risk of neuropsychological symptoms, particularly in the memory/concentration and fatigue domains (Aim 6).
- For container handlers, the risk of neuropsychological symptoms appears to increase with longer duration of exposure (Aim 7).

Taken together, these results suggest that, while workers' full-shift exposure levels to container chemicals are lower than previously expected (with the exception of formaldehyde) and generally below current New Zealand and international standards, they may nonetheless cause long-term health effects. Workplace interventions to reduce exposures in this industry may therefore be warranted; however, although some container characteristics are linked to higher chemical concentrations, it remains difficult to predict which containers represent the greatest risk of exposures, thus hampering the development of practical and cost-effective interventions.

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9 Appendix

9.1 Questionnaire

Part 1: Questions about your work and work history

Your current work

1.	What is your job title? ______________________________ Is your job: ☐ permanent ☐ casual/ temporary ☐ temp agency ☐ other → please specify: ____________________
2.	How many years have you worked in your current job? ☐ Years
3.	Do you regularly work <u>outside</u> the hours of 8 am to 5 pm? ☐ Yes → please specify: ____________________ ☐ No
4.	How many employees work in your department? ☐
5.	What is the main activity of the company you work for, e.g.fumigation, container inspection, devanning or retail? ______________________________ ______________________________ ______________________________
6.	Please describe your specific job in detail: What do you do? How do you do it? What materials do you use? What tools or machinery do you use? What type of process is it? If you have difficulties answering this question, please describe a <u>typical</u> working day. ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________ ______________________________

2

Your work history

7. Please list all the jobs you have ever held, beginning with your current job and finishing with your first job after leaving school.
Please include all jobs that lasted at least 1 year in total.
The list should be without gaps, meaning to include periods of travel, unemployment or taking care of children.
If you worked for the same employer, but in different work areas, please state the areas separately.

Job Number	Who is/ was your employer?	What area/ department do/ did you work in, and what was your job title?	Over what period did you work in this job?	How many hours a week do/ did you work?	What was the main activity of the company or organisation you worked for? (Example: sheep farming, selling shoes, making clothes)
1.	Name: Location:	Area/ department: Job title:	From: ____/____ (mm / yy) To: ____/____ (mm / yy)		
2.	Name: Location:	Area/ department: Job title:	From: ____/____ (mm / yy) To: ____/____ (mm / yy)		
3.	Name: Location:	Area/ department: Job title:	From: ____/____ (mm / yy) To: ____/____ (mm / yy)		

Part 2: General health questions

1. Have you ever had high blood pressure?

- ☐ Yes → year of diagnosis: _______
- ☐ No
- ☐ Don't know

2. Have you ever had a heart attack?

- ☐ Yes → year of diagnosis: _______
- ☐ No
- ☐ Don't know

3. Have you ever had a stroke?

- ☐ Yes → year of diagnosis: _______
- ☐ No
- ☐ Don't know

4. Have you ever had diabetes?

- ☐ Yes → year of diagnosis: _______
- ☐ No
- ☐ Don't know

5. Have you ever had a head injury?

- ☐ Yes → please specify: ____
  → year of diagnosis: _______
- ☐ No
- ☐ Don't know

6. Have you ever had a concussion?

- ☐ Yes → please specify: ____
  → year of diagnosis: _______
- ☐ No
- ☐ Don't know

7. Have you ever had muscular tremor?

- ☐ Yes → when was this first observed or diagnosed? _______
- ☐ No
- ☐ Don't know

8. Have you ever had sensation of pins and needles?

☐ Yes → when was this first observed or diagnosed? _______

☐ No

☐ Don't know

9. Have you ever had a nerve injury/ damage, e.g. carpal tunnel, sciatica?

☐ Yes → please specify: ____________________

→ year of diagnosis: _______

☐ No

☐ Don't know

10. Do you suffer from epilepsy, Parkinson's disease, motor neuron disease (including amyotrophic lateral sclerosis (ALS), also known as Lou Gehrig's disease), multiple sclerosis (MS)?

☐ Yes → please specify: ____________________

→ year of diagnosis: _______

☐ No

☐ Don't know

11. Do you suffer from Alzheimer's disease?

☐ Yes → when was this first observed or diagnosed? _______

☐ No

☐ Don't know

12. Do you suffer from any other form of dementia?

☐ Yes → please specify: ____________________

→ when was this first observed or diagnosed? _______

☐ No

☐ Don't know

13. Have you ever been in a coma?

☐ Yes → please specify the cause: ____________________

→ year of diagnosis: _______

☐ No

☐ Don't know

14. Have you ever had chronic fatigue?

☐ Yes → please specify: ____________________

→ when was this first observed or diagnosed? _______

☐ No

☐ Don't know

15. Have you ever had any other neurological disease, e.g. meningitis, encephalitis?

- [ ] Yes → please specify: ______________________________
  → when was this first observed or diagnosed? _______
- [ ] No
- [ ] Don't know

16. Have you ever suffered from major depression?

- [ ] Yes → when was this first observed or diagnosed? _______
- [ ] No
- [ ] Don't know

17. Have you ever been diagnosed as having a learning disability or attention deficit disorder by a doctor/ other health professional?

- [ ] Yes → please specify: ______________________________
  → when was this first observed or diagnosed? _______
- [ ] No
- [ ] Don't know

18. Do you currently have any of the following symptoms?

- [ ] Do you have short memory?
- [ ] Do you often have to make notes about what you have to remember?
- [ ] Do you often have to go back and check things that you have done, e.g. turned off the stove, locked the door?
- [ ] Do you generally find it hard to get the meaning from reading newspapers and books?
- [ ] Do you often have problems concentrating?
- [ ] Do you often feel depressed without any particular reason?
- [ ] Are you abnormally tired?
- [ ] Are you less interested in sex than you think is normal?
- [ ] Do you have palpitations of the heart even when you do not exert yourself?
- [ ] Do you sometimes feel oppression in your chest?
- [ ] Do you sweat without any particular reason?
- [ ] Do you have a headache at least once a week?
- [ ] Do you often have painful tingling in some parts of your body?
- [ ] Do you have problems buttoning and unbuttoning?
- [ ] Are you having trouble sleeping?
- [ ] Do you find your mood changes frequently without cause?
- [ ] Do you find that noise bothers you more than in the past?
- [ ] **None of the above**

19. Do you suffer from cramps in your legs?

☐ Yes → How frequently? ____________________

→ Do Magnesium tablets improve the cramps? ☐ yes ☐ no

☐ No

20. Have you taken prescription drugs e.g., prescribed by your doctor, in <u>the past 12 months</u>?

☐ Yes → please name the drug and the reason for taking it: ____________________

____

____

____

☐ No

21. How many hours of sleep do you usually get (counting naps as well)? __________ hours

22. How often do you get enough sleep?

☐ Never
☐ Rarely
☐ Often
☐ Always

23. How often do you wake up feeling refreshed?

☐ Never
☐ Rarely
☐ Often
☐ Always

Part 3: Questions about neurological symptoms

Please respond to each of the following questions by indicating how often in recent months you have experienced a particular symptom.

For each question, there are four possible answers: 'Seldom or Never' 'Sometimes' 'Often' 'Very often'. Tick only one option.

If you ticked 'sometimes', 'often', or 'very often', please specify the year you first experienced this symptom (1st year of occurrence)

1. How often have you during recent months (last three) experienced any of the following symptoms and when did you first experienced this symptom?

	Seldom or never	Sometimes	Often	Very often	For how long (years)
Dropping things unintentionally					
Weakness of your arms and feet					
Decreased sensation in arms and legs					
Numbness or heaviness in your arms or legs					
Tingling in your arms or legs					
Problems with balance					
Changes in sense of smell or taste					
Decreased sensation on your face					
Difficulties controlling your hand movements e.g. how often do you notice your hands are more clumsy?					
Slowness in carrying out your daily activities					
Trembling of hands					
Headache					
Sweating for no obvious reason					
Nausea e.g., feeling sick in your stomach					
Stomach pains					
Dizziness					
Shortness of breath without physical exertion					
Heart fluttering (palpitations)					
Ringing in your ears (tinnitus)					
Feeling of general exhaustion					
Loss of sexual interest					
Lowered alcohol tolerance e.g., have you noticed it takes less drinks than before to get drunk?					
Diarrhoea					
Constipation					
Loss of appetite					
Feeling of a tight band around your head					
Difficulty getting started at work					

Note: How often in recent month	Seldom or never	Sometimes	Often	Very often	For how long (years)
Feeling irritable					
Feeling depressed					
Feeling impatient					
Being upset by trivial things, e.g. do you find little things upset you?					
Feeling restless					
Rapid changes in mood					
Feeling of detachment, e.g. do you feel out of touch with your surroundings?					
Lack of drive e.g., lack of energy, enthusiasm?					
Lack of interest in social activities					
Difficulty in controlling anger					
Forgetfulness					
Having to write notes to remember things					
Forgetting what you were about to say or do					
Difficulty in concentrating					
Daydreaming					
Feeling confused when you try to concentrate					
Difficulty remembering names and dates					
Absent-mindedness					
Difficulty remembering what you have read or seen on TV					
Other people complaining about your memory					
Falling asleep when not in bed					
Unusual tiredness in the evening					
Sleepiness					
Feeling tired when you wake up					
Lack of energy					
General weariness (or tiredness)					
Needing more sleep than you used to					
Difficulty falling asleep					
Broken sleep					
Waking up too early					
Nightmares					
Snoring someone else has complained about					

2.	How often during <u>recent months</u>, have you experienced any of the following symptoms <u>during or directly after work</u>?					
		Seldom or never	Sometimes	Often	Very often	For how long (years)
	Irritation of the eyes					
	Feeling drunk without drinking alcohol					
	Dryness of the mouth or throat					
	Throat irritation					
	A runny nose					
	An unpleasant taste in your mouth					

3.	Please indicate whether you agree or disagree with the statements below. Tick only <u>one</u> option.				
		Strongly disagree	Disagree	Agree	Strongly agree
	I am usually sensitive to bright lights.				
	I am usually sensitive to traffic noise, loud music or other loud noises.				
	I am usually sensitive to strong smells.				
	I am usually sensitive to rough fabrics next to my skin.				
	I am usually sensitive to heat.				
	I am usually sensitive to cold.				
	I am usually sensitive to tobacco smoke.				
	I am usually sensitive to certain foods.				
	I am generally a nervous person.				
	I think I am generally less capable than others in overcoming my difficulties.				
	I worry a lot about trivial things.				
	I often feel that something bad may happen at any moment.				
	I often feel that even trivial problems are too much for me.				
	I usually feel insecure.				

4.	Please answer the following questions. Tick only <u>one</u> option.				
		Very good	Good	Poor	Very poor
	How good is your health?				
	How is your health now, compared with what it was 5 years ago?				
	How do you feel about your life in general?				
	How do you feel about your life now, compared to 5 years ago?				

Part 4: Questions about respiratory symptoms

1.	Have you had wheezing or whistling in your chest at any time in the past 12 months? ☐ Yes ☐ No ⟶ go to question 5
2.	Have you been at all breathless when the wheezing noise was present? ☐ Yes ☐ No
3.	Have you had this wheezing or whistling in the chest when you did not have a cold? ☐ Yes ☐ No
4.	How many attacks of wheezing or whistling have you had in the past 12 months? ☐ None ☐ 1-3 times ☐ 4-12 times ☐ More than 12 times
5.	Have you woken up with a feeling of tightness in your chest at any time in the past 12 months? ☐ Yes ☐ No
6.	Have you been woken by an attack of shortness of breath at any time in the past 12 months? ☐ Yes ☐ No
7.	Have you been woken by an attack of coughing at any time in the past 12 months? ☐ Yes ☐ No
8.	Have you ever had asthma? ☐ Yes ☐ No ⟶ go to question 14
9.	Was the diagnosis confirmed by a doctor? ☐ Yes ☐ No

10.	How old were you when you had your first attack of asthma? ☐ Years
11.	How old were you when you had your last attack of asthma? ☐ Years
12.	Have you had an attack of asthma in the past 12 months? ☐ Yes ☐ No
13.	Are you currently taking any medicine (including inhalers, aerosols or tablets) for asthma? ☐ Yes ☐ No
14.	Do you cough almost daily for at least part of the year? ☐ Yes ☐ No → go to question 18
15.	How many month(s) a year do you have this cough? ☐ Month(s) a year
16.	How many consecutive years have you had this cough? ☐ Years
17.	Do you usually have this cough in winter? ☐ Yes ☐ No
18.	Do you cough up phlegm almost daily for at least part of the year? ☐ Yes ☐ No → go to question 22
19.	How many months a year do you have this cough (with phlegm)? ☐ Month(s) a year
20.	How many consecutive years have you had this cough (with phlegm)? ☐ Years
21.	Do you usually have this cough (with phlegm) in winter? ☐ Yes ☐ No

22. In the past 12 months, how often have you been unable to work because of respiratory symptoms e.g. cough, phlegm, wheezing/ whistling or shortness of breath?

- ☐ Never
- ☐ 1-7 times
- ☐ 8-30 times
- ☐ At least 31 days
- ☐ Don't know

23. How often, during the past 12 months (or if you had this job for less than a year, how often since you started), have you had one or more of the following symptoms?

Please indicate whether symptoms lessen or disappear during weekends and holidays

Symptoms	How often?				Lessen or disappear during weekends and holidays?	
	Never/ seldom	1-2 times per month	1-2 times per week	Daily/ almost daily	Yes	No
Dry cough						
Cough with phlegm						
Wheezing in the chest						
Breathlessness with wheezing						
Shortness of breath						
Chest tightness						

Part 5: Questions about skin symptoms

1. Have you ever had an itchy rash that has been coming and going for at least 6 months and at some time has affected skin creases?

By skin creases we mean folds of elbows, behind the knees, fronts of ankles, under buttocks, around the neck, ears or eyes

☐ Yes → When was this first observed or diagnosed? ____________________

☐ No

☐ Don't know

2. Have you ever had hand eczema?

☐ Yes

☐ No

☐ Don't know

3. Have you ever had eczema on your wrists or forearms (excluding fronts of elbows)?

☐ Yes

☐ No → if you answered 'no' to this and the previous question go to Part 6.

☐ Don't know

4. When did you last have eczema on your hands, wrists or forearms

one answer in each column if applicable	Hand eczema	Wrist/ forearm eczema
I have it just now	☐	☐
not just now but within the past 3 month	☐	☐
between 3-12 month ago	☐	☐
more than 12 month ago →please specify the year ____________	☐	☐

5. How often have you had eczema on your hands, wrists and forearms?

one answer in each column if applicable	Hand eczema	Wrist/ forearm eczema
Nearly all the time	☐	☐
More than once	☐	☐
Only once but for two weeks or more	☐	☐
Only once and for less than two weeks	☐	☐

		Hand eczema	Wrist/ forearm eczema
6.	Have you noticed that contact with certain materials, chemicals or anything else in your work makes your eczema worse?		
	one answer in each column if applicable	Hand eczema	Wrist/ forearm eczema
	Yes → please specify what you think makes your eczema worse: ____________ ______________________________	☐	☐
	No	☐	☐
	Don't know	☐	☐
7.	Have you noticed that contact with certain materials, chemicals or anything else outside your work makes your eczema worse?		
	one answer in each column if applicable	Hand eczema	Wrist/ forearm eczema
	Yes → please specify what you think makes your eczema worse: ____________ ______________________________	☐	☐
	No	☐	☐
	Don't know	☐	☐
8.	Does your eczema improve when you are away from your normal work, e.g. weekends, holidays?		
	one answer in each column if applicable	Hand eczema	Wrist/ forearm eczema
	Yes, usually	☐	☐
	Yes, sometimes	☐	☐
	No	☐	☐
	Don't know	☐	☐

Part 6: General questions about your work environment

1. Have you ever entered a cargo container except for unloading or inspecting it?

☐ Yes → please specify the reason for entering the container:________________

☐ No → go to question 7

2. Please, indicate the time period(s) when you entered containers.

From:	From:	From:
………/……… (mm/yy)	………/……… (mm/yy)	………/……… (mm/yy)
To:	To:	To:
………/……… (mm/yy)	………/……… (mm/yy)	………/……… (mm/yy)

3. During the(se) period(s), how often have you on average entered the containers?

☐ Daily	☐ Daily	☐ Daily
☐ Weekly	☐ Weekly	☐ Weekly
☐ Monthly	☐ Monthly	☐ Monthly
☐ Other	☐ Other	☐ Other

4. On a typical day, how much time did you spend inside the containers?

☐ Hours	☐ Hours	☐ Hours
☐ Minutes	☐ Minutes	☐ Minutes

5. How did you enter the containers?

☐ On foot	☐ On foot	☐ On foot
☐ By forklift	☐ By forklift	☐ By forklift
☐ Other	☐ Other	☐ Other

6. Are some of the containers reefers (refrigerated containers)?

☐ Yes, → please estimate the amount of reefers you handle ____%

☐ No

7. Have you ever unloaded or inspected cargo containers?

☐ Yes, I unload cargo containers

☐ Yes, I inspect cargo containers

☐ No → go to question 13

8. Please, indicate the time period(s) you have worked unloading or inspecting containers.

From:	From:	From:
………/……… (mm/yy)	………/……… (mm/yy)	………/……… (mm/yy)
To:	To:	To:
………/……… (mm/yy)	………/……… (mm/yy)	………/……… (mm/yy)

9. During the(se) period(s), how often have you on average unloaded or inspected containers?

☐ Daily	☐ Daily	☐ Daily
☐ Weekly	☐ Weekly	☐ Weekly
☐ Monthly	☐ Monthly	☐ Monthly
☐ Other	☐ Other	☐ Other

10. On a typical day, how much time did you spend unloading or inspecting containers?

☐ Hours	☐ Hours	☐ Hours
☐ Minutes	☐ Minutes	☐ Minutes

11. How did you enter the containers?

☐ On foot	☐ On foot	☐ On foot
☐ By forklift	☐ By forklift	☐ By forklift
☐ Other	☐ Other	☐ Other

12. Are some of the containers reefers (refrigerated containers)?

☐ Yes, → please estimate the amount of reefers you handle ____%

☐ No

13. Have you ever unloaded or inspected shipping cargo other than containers e.g. bulk cargo?

☐ Yes, I unload other shipping cargo → please specify cargo:______________________________

____

☐ Yes, I inspect other shipping cargo → please specify cargo:______________________________

____

☐ No → go to question 18

14. Please, indicate the time period(s) you have worked unloading or inspecting other shipping cargo.

From:	From:	From:
………/……… (mm/yy)	………/……… (mm/yy)	………/……… (mm/yy)
To:	To:	To:
………/……… (mm/yy)	………/……… (mm/yy)	………/……… (mm/yy)

15. During the(se) period(s), how often have you on average unloaded or inspected other shipping cargo?

☐ Daily	☐ Daily	☐ Daily
☐ Weekly	☐ Weekly	☐ Weekly
☐ Monthly	☐ Monthly	☐ Monthly
☐ Other	☐ Other	☐ Other

16. On a typical day, how much time did you spend unloading or inspecting other cargo?

☐ Hours	☐ Hours	☐ Hours
☐ Minutes	☐ Minutes	☐ Minutes

17. How did you handle/ inspect the other cargo?

☐ On foot	☐ On foot	☐ On foot
☐ By forklift	☐ By forklift	☐ By forklift
☐ Other	☐ Other	☐ Other

18. Have you ever unloaded or unpacked overseas goods out of trucks?

☐ Yes

☐ No → go to question 22

19. Please, indicate the time period(s) you have unloaded or unpacked overseas goods out of trucks.

From:	From:	From:
........./......... (mm/yy)	........./......... (mm/yy)	........./......... (mm/yy)
To:	To:	To:
........./......... (mm/yy)	........./......... (mm/yy)	........./......... (mm/yy)

20. During the(se) period(s), how often have you on average unloaded or unpacked overseas goods out of trucks?

☐ Daily	☐ Daily	☐ Daily
☐ Weekly	☐ Weekly	☐ Weekly
☐ Monthly	☐ Monthly	☐ Monthly
☐ Other	☐ Other	☐ Other

21. On a typical day during the(se) period(s), how much time did you spend unloading or unpacking overseas goods?

☐ Hours	☐ Hours	☐ Hours
☐ Minutes	☐ Minutes	☐ Minutes

22. *Have you ever removed overseas, retail-sized goods from bulk packaging e.g. removed plastic wrapping, emptied cardboard boxes or other bulk containers?*

☐ Yes

☐ No → go to question 26

23. Please, indicate the time period(s) your work involved removing bulk packaging from overseas goods.

From: ………/……… (mm/yy)	From: ………/……… (mm/yy)	From: ………/……… (mm/yy)
To: ………/……… (mm/yy)	To: ………/……… (mm/yy)	To: ………/……… (mm/yy)

24. During the(se) period(s), how often have you on average been involved in removing bulk packaging from overseas goods?

☐ Daily	☐ Daily	☐ Daily
☐ Weekly	☐ Weekly	☐ Weekly
☐ Monthly	☐ Monthly	☐ Monthly
☐ Other	☐ Other	☐ Other

25. On a typical day during the(se) period(s), how much time did you spend removing bulk packaging from overseas goods?

☐ Hours	☐ Hours	☐ Hours
☐ Minutes	☐ Minutes	☐ Minutes

26. Have you ever been involved in fumigating products?

☐ Yes → Have you fumigated logs? ☐ No ☐ Yes → How much of your overall work time ____%

☐ No → go to question 30

27. Please, indicate the time period(s) you have worked fumigating products.

From: ………/……… (mm/yy)	From: ………/……… (mm/yy)	From: ………/……… (mm/yy)
To: ………/……… (mm/yy)	To: ………/……… (mm/yy)	To: ………/……… (mm/yy)

28. During the(se) period(s), how often have you on average fumigated products?

☐ Daily	☐ Daily	☐ Daily
☐ Weekly	☐ Weekly	☐ Weekly
☐ Monthly	☐ Monthly	☐ Monthly
☐ Other	☐ Other	☐ Other

29. On a typical day during the(se) period(s), how much time did you spend fumigating products?

☐ Hours	☐ Hours	☐ Hours
☐ Minutes	☐ Minutes	☐ Minutes

30. Are you in contact with fumigants, pesticides, solvents or other chemicals in any other areas of your work?

☐ Yes → please specify by circling the options below:

fumigants   pesticides   solvents   other → please specify____________________

☐ No → go to question 35

☐ Don't know → go to question 35

31. Please, specify the task during which you are in contact with fumigants, pesticides, solvents or other chemicals

____

____

____

32. Please, indicate the time period(s) your work involved contact with these chemicals.

From:	From:	From:
........./......... (mm/yy)	........./......... (mm/yy)	........./......... (mm/yy)
To:	To:	To:
........./......... (mm/yy)	........./......... (mm/yy)	........./......... (mm/yy)

33. During the(se) period(s), how often have you on average been in contact with these chemicals?

☐ Daily	☐ Daily	☐ Daily
☐ Weekly	☐ Weekly	☐ Weekly
☐ Monthly	☐ Monthly	☐ Monthly
☐ Other	☐ Other	☐ Other

34. On a typical day, how much time were you in contact with these chemicals?

☐ Hours	☐ Hours	☐ Hours
☐ Minutes	☐ Minutes	☐ Minutes

35. Are you in contact with diesel, petrol or LPG fumes at your work?

☐ Yes → please specify______________________________

☐ No → go to question 39

36. Please, indicate the time period(s) your work involved contact with diesel, petrol or LPG fumes

From:	From:	From:
........./......... (mm/yy)	........./......... (mm/yy)	........./......... (mm/yy)
To:	To:	To:
........./......... (mm/yy)	........./......... (mm/yy)	........./......... (mm/yy)

37.	During the(se) period(s), how often have you on average been in contact with diesel, petrol or LPG fumes? ☐ Daily ☐ Daily ☐ Daily ☐ Weekly ☐ Weekly ☐ Weekly ☐ Monthly ☐ Monthly ☐ Monthly ☐ Other ☐ Other ☐ Other
38.	On a typical day, how much time were you in contact with diesel, petrol or LPG fumes? ☐ Hours ☐ Hours ☐ Hours ☐ Minutes ☐ Minutes ☐ Minutes
39.	Are you in contact with dust from products or their packaging at your work e.g. grain or cement dust? ☐ Yes → please specify ____________________ ____________________ ☐ No → go to question 43
40.	Please, indicate the time period(s) your work involved contact with this dust. From: ………/……… (mm/yy) From: ………/……… (mm/yy) From: ………/……… (mm/yy) To: ………/……… (mm/yy) To: ………/……… (mm/yy) To: ………/……… (mm/yy)
41.	During the(se) period(s), how often have you on average been in contact with this dust? ☐ Daily ☐ Daily ☐ Daily ☐ Weekly ☐ Weekly ☐ Weekly ☐ Monthly ☐ Monthly ☐ Monthly ☐ Other ☐ Other ☐ Other
42.	On a typical day, how much time were you in contact with this dust? ☐ Hours ☐ Hours ☐ Hours ☐ Minutes ☐ Minutes ☐ Minutes
43.	Do you wear personal protective equipment at your work, such as gloves or goggles? ☐ Yes ☐ No → go to question 45

44. Which of the following personal protective equipment do you use?
For which tasks and how regular do you wear it?

☐ Goggles
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Footwear
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Apron
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Overall
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Spray suit
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Gloves
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Respirator (filter cartridges)
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Respirator (air-supplied or SCBA)
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

☐ Other → please specify ____________________
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

45. Do you use a gas monitoring device (either hand-held or fixed)?

☐ Yes → please specify ____________________
☐ No → go to question 48

46. For which tasks and how regular are you using the gas monitoring device?

For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely
For which tasks:____________________
How often do you use it for these tasks: ▫ always ▫ often ▫ sometimes ▫ rarely

47. If you use a gas monitor, how often do you record levels higher than the allowed gas concentrations e.g. twice a month? Please, specify the gas if possible.

____

____

☐ Don't know ☐ n/a

48. Does your workplace have any additional preventative measures to reduce exposures to chemicals e.g., aerating containers, ventilation systems.

☐ Yes

☐ No → go to question 50

49. Which types of preventative measures are present?
For which tasks are they typically applied and how often are they used for this task?

Please specify:____________________

For which tasks:____________________

How often do you use it for these tasks: ☐ always ☐ often ☐ sometimes ☐ rarely

Please specify:____________________

For which tasks:____________________

How often do you use it for these tasks: ☐ always ☐ often ☐ sometimes ☐ rarely

Please specify:____________________

For which tasks:____________________

How often do you use it for these tasks: ☐ always ☐ often ☐ sometimes ☐ rarely

50. Are you aware whether the cargo or overseas goods you handle have been fumigated or not?

☐ Yes, always

☐ Yes, sometimes

☐ No, never → go to question 54

51. How do you notice that the cargo or the overseas goods are fumigated? (Mark as many option as required.)

☐ Smell

☐ Stickers/ Labels

☐ Shipping documents

☐ Fumigation certificate

☐ Sealed ventilation slots on container

☐ Empty capsules or cans in container

☐ Other → please specify ____________________

52. Which of the substances listed below were used to fumigate the cargo or overseas goods? Please, indicate how many containers/ goods are fumigated with this substance (%)?

☐ Methyl bromide → ____ %

☐ Phosphine → ____ %

☐ Ethylene dibromide → ____ %

☐ Other → ____ %

☐ Don't know ☐ n/a

53. Please, estimate how much of the cargo or overseas goods you handle have been fumigated (%).

______%

☐ Don't know ☐ n/a

54. Which of the following categories describe the cargo or overseas goods you handle? You may choose several options.

food paper/printing plastics/rubber construction material machinery/tools chemicals

electronic equipment electrical appliances furniture/household items clothes/textiles

Other → please specify____

☐ Don't know ☐ n/a

55. Was packaging material used for the cargo or overseas goods?

☐ Yes → please, specify packaging material by circling the options below:

wooden pallets plastic cardboard wood bubble wrap foam polystyrene

Other → please specify____

____

☐ No

☐ Don't know ☐ n/a

56. Do you know the countries of origin of the cargo or overseas goods?

☐ Yes

☐ Sometimes

☐ No → go to question 57

☐ n/a → go to question 57

57. Please list the countries of origin of the cargo or overseas goods.

____

____

☐ Don't know

58. Did you receive any OSH or other safety training on exposure to fumigants or other chemical hazards?

☐ Yes → please specify ____________________

____

____

☐ No

59. Do you have anything you would like to add or any additional comments about your work environment?

e.g. specific products/ packaging which regularly admit a smell

____

____

____

____

____

60. Have you ever been involved in an incident with high exposure to chemicals such as a spill or a leak?

☐ Yes

☐ No → go to Part 7

61. What chemicals were involved?

____

____

62. What happened?

____

____

____

____

63. When did it happen?

____

64. For how long were you exposed?

____

____

Part 7: Hobbies and other jobs

1. In addition to your current job, do you have another job at present that involves exposure to fumigants, pesticides or solvents?

☐ Yes

☐ No → go to question 3

☐ Don't know → go to question 3

2. Please, specify during which tasks you are exposed to fumigants, pesticides or solvents at your other work and for how long.

☐ Fumigants → _____hours/week → Tasks: ______________________________

☐ Pesticides → _____hours/week → Tasks: ______________________________

☐ Solvents → _____hours/week → Tasks: ______________________________

3. Do you have any hobbies that involve exposure to fumigants, pesticides or solvents e.g., work that involves solvents for cleaning, cutting fluids, spray painting, use of varnishes, lacquers or renovating?

☐ Yes

☐ No → if you answered 'no' or 'don't know' to questions 1 and 3 go to Part 8

☐ Don't know → if you answered 'no' or 'don't know' to questions 1 and 3 go to Part 8

4. Please, specify during which tasks you are exposed to fumigants, pesticides or solvents at your hobbies and for how long

☐ Fumigants → _____hours/week → Tasks: ______________________________

☐ Pesticides → _____hours/week → Tasks: ______________________________

☐ Solvents → _____hours/week → Tasks: ______________________________

5. Which of the following personal protective equipment do you use during your other jobs and hobbies? Indicate for which tasks and how regular you are using the equipment?

☐ Goggles
For which tasks:______________________________
How often do you use it for the tasks: ☐ always ☐ often ☐ sometimes ☐ rarely

☐ Footwear
For which tasks:______________________________
How often do you use it for the tasks: ☐ always ☐ often ☐ sometimes ☐ rarely

☐ Apron
For which tasks:______________________________
How often do you use it for the tasks: ☐ always ☐ often ☐ sometimes ☐ rarely

☐	Overall For which tasks:________________________ How often do you use it for the tasks: □ always □ often □ sometimes □ rarely
☐	Spray suit For which tasks:________________________ How often do you use it for the tasks: □ always □ often □ sometimes □ rarely
☐	Gloves For which tasks:________________________ How often do you use it for the tasks: □ always □ often □ sometimes □ rarely
☐	Respirator (filter cartridges) For which tasks:________________________ How often do you use it for the tasks: □ always □ often □ sometimes □ rarely
☐	Respirator (air-supplied or SCBA) For which tasks:________________________ How often do you use it for the tasks: □ always □ often □ sometimes □ rarely
☐	Other → please specify ________________________ For which tasks:________________________ How often do you use it for the tasks: □ always □ often □ sometimes □ rarely

Part 8: Questions on smoking, alcohol consumption and education

Smoking

1. Have you smoked more than 5 packs of cigarettes in total in your whole life?

- ☐ Yes
- ☐ No → go to question 5

2. Do you still smoke?

- ☐ Yes
- ☐ No   At what age did you quit smoking? ☐

3. How many cigarettes per day do you or did you smoke?

☐ Cigarettes per day

4. At what age did you start smoking?

☐ Years

Alcohol

5. How often do you currently consume alcohol?

- ☐ Never go to question 8
- ☐ Less than once a month
- ☐ 1-2 times a week
- ☐ 3-5 times a week
- ☐ Daily

6. Over a normal 5-day working week, excluding the weekend, how many of the following alcoholic drinks do you consume?

- ☐ Bottles of beer (number)
- ☐ Glasses of wine (number)
- ☐ Small glasses of spirits (number)

7. Over a normal weekend, how many of the following alcoholic drinks do you consume?

- ☐ Bottles of beer (number)
- ☐ Glasses of wine (number)
- ☐ Small glasses of spirits (number)

8. Throughout your working life to date, on average how often have you consumed alcohol?

- ☐ Never → go to question 9
- ☐ Less than once a month
- ☐ 1-2 times a week
- ☐ 3-5 times a week
- ☐ Daily

Education

9. What is the highest level of education you received?

- ☐ Primary school
- ☐ Secondary school (college)
- ☐ University or other form of tertiary education

Are you interested to participate in the personal exposure measurement: **Yes** **No** please circle

Thank you for your time answering this questionnaire. Do you have anything you would like to add or any comments e.g. illnesses?

Interview type: face to face ☐ telephone ☐ post/ self-administrated ☐

Interviewer:____

9.2 Statement of Contribution Doctorate with Publication/Manuscripts 1

DRC 16

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Ruth Hinz
Name/title of Primary Supervisor:	Professor Jeroen Douwes
Name of Research Output and full reference:	
Airborne fumigants and residual chemicals in shipping containers arriving in New Zealand	
In which Chapter is the Manuscript /Published work:	Chapter 3
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90%
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Formulated the concept, conducted the fieldwork to collect the data, conducted all statistical analyses of the collected data, and prepared the manuscript.	
For manuscripts intended for publication please indicate target journal:	
Accepted for publication in Annals of Work Exposures and Health, 2021	
Candidate's Signature:	Ruth Hinz Digitally signed by Ruth Hinz Date: 2021.10.14 15:05:05 +13'00'
Date:	13/10/21
Primary Supervisor's Signature:	Jeroen Digitally signed by Jeroen DN: cn=Jeroen, c=NZ, o=Massey University, ou=CPHR, email=j.douwes@massey.ac.nz Date: 2021.10.13 19:33:26 +13'00'
Date:	13/10/21

9.3 Statement of Contribution Doctorate with Publication/Manuscripts 2

DRC 1

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors hav consented to their work being included in the thesis and they have accepted the candidate' contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Ruth Hinz
Name/title of Primary Supervisor:	Professor Jeroen Douwes
Name of Research Output and full reference:	
Exposures to fumigants and residual chemicals in workers handling cargo from shipping containers and export logs in New Zealand (Ann Work Exp Hlth 2020;64(8):826-37)	
In which Chapter is the Manuscript /Published work:	Chapter 4
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90%
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Formulated the concept, conducted the fieldwork to collect the data, conducted all statistical analyses of the collected data, and prepared the manuscript.	
For manuscripts intended for publication please indicate target journal:	
published in Annals of Work Exposures and Health (2020;64(8):826-37.)	
Candidate's Signature:	Ruth Hinz — Digitally signed by Ruth Hinz Date: 2021.10.14 15:16:49 +13'00'
Date:	13/10/21
Primary Supervisor's Signature:	Jeroen — Digitally signed by Jeroen DN: cn=Jeroen, c=NZ, o=Massey University, ou=CPHR, email=j.douwes@massey.ac.nz Date: 2021.10.13 19:33:01 +13'00'
Date:	13/10/21

9.4 Statement of Contribution Doctorate with Publication/Manuscripts 3

DRC 16

MASSEY UNIVERSITY
GRADUATE RESEARCH SCHOOL

STATEMENT OF CONTRIBUTION
DOCTORATE WITH PUBLICATIONS/MANUSCRIPTS

We, the candidate and the candidate's Primary Supervisor, certify that all co-authors have consented to their work being included in the thesis and they have accepted the candidate's contribution as indicated below in the *Statement of Originality*.

Name of candidate:	Ruth Hinz
Name/title of Primary Supervisor:	Professor Jeroen Douwes
Name of Research Output and full reference:	
Neuropsychological symptoms in Workers Handling Cargo from Shipping Containers and Export Logs	
In which Chapter is the Manuscript /Published work:	Chapter 5
Please indicate:	
• The percentage of the manuscript/Published Work that was contributed by the candidate:	90%
and	
• Describe the contribution that the candidate has made to the Manuscript/Published Work:	
Formulated the concept, conducted the fieldwork to collect the data, conducted all statistical analyses of the collected data, and prepared the manuscript.	
For manuscripts intended for publication please indicate target journal:	
Annals of Work Exposures and Health	
Candidate's Signature:	Ruth Hinz Digitally signed by Ruth Hinz Date: 2021.10.14 14:59:16 +13'00'
Date:	13/10/21
Primary Supervisor's Signature:	Jeroen Digitally signed by Jeroen DN: cn=Jeroen, c=NZ, o=Massey University, ou=CPHR, email=j.douwes@massey.ac.nz Date: 2021.10.13 19:33:57 +13'00'
Date:	13/10/21

9.5 Ethical Approval

Health and Disability Ethics Committees

Multi-region Ethics Committee
c/- Ministry of Health
PO Box 5013
1 the Terrace
Wellington
Phone: (04) 816 2403
Email: multiregion_ethicscommittee@moh.govt.nz

18 April 2012

Dr Andrea 't Mannetje
Centre for Public Health Research
Massey University
Private Box 756
Wellington

Dear Dr 't Mannetje

Re:	Ethics ref:	**MEC/12/02/010** (please quote in all correspondence)	
	Study title:	Occupational exposures and possible health effects in workers exposed to fumigants	
	Investigators:	Dr Andrea 't Mannetje, Ms Ruth Hinz, Professor Jeroen Douwes, Dr David McLean, Professor Bill Glass, Professor Neil Pearce	

This study was given ethical approval by the Multi-region Ethics Committee on 18 April 2012. A list of members of the Committee is attached.

Approved Documents

- Part 4 signed Andrea t'Mannetje
- Locality Assessment for CPHR - Massey University
- Part 5
- Study Protocol Version 1, 20 January 2011
- Phlebotomy Procedure Version 1, 20 January 2011
- Blood Serum Processing Procedure Version 1, 20 January 2011
- Questionnaire of occupational exposure and health status Version 1, 20 January 2011
- Questionnaire for non-participating workers Version 1, 20 January 2011
- Extension Questoin A 3.1 - Study Design Version 1, 20 January 2011
- Table of Study Design Version 1, 20 January 2011
- Information Sheet Phase 1 Version 1, 20 January 2011
- Information Sheet Phase 2 (subpopulation) Version 1, 20 January 2011
- Consent Form Phase 1 Version 1, 20 January 2011
- Consent Form Phase 2 Version 1, 20 January 2011
- HRC Reviewers Comments
- Questionnaire, Version 1 dated 17 February 2012
- Maori Consultation dated 15 April 2012

This approval is valid until 14 March 2015, provided that Annual Progress Reports are submitted (see below).

Amendments and Protocol Deviations

All significant amendments to this proposal must receive prior approval from the Committee. Significant amendments include (but are not limited to) changes to:

- the researcher responsible for the conduct of the study at a study site
- the addition of an extra study site
- the design or duration of the study
- the method of recruitment
- information sheets and informed consent procedures.

Significant deviations from the approved protocol must be reported to the Committee as soon as possible.

Annual Progress Reports and Final Reports

The first Annual Progress Report for this study is due to the Committee by 18 April 2013. The Annual Report Form that should be used is available at www.ethicscommittees.health.govt.nz. Please note that if you do not provide a progress report by this date, ethical approval may be withdrawn.

A Final Report is also required at the conclusion of the study. The Final Report Form is also available at www.ethicscommittees.health.govt.nz.

Statement of compliance

The committee is constituted in accordance with its Terms of Reference. It complies with the *Operational Standard for Ethics Committees* and the principles of international good clinical practice.

The committee is approved by the Health Research Council's Ethics Committee for the purposes of section 25(1)(c) of the Health Research Council Act 1990.

We wish you all the best with your study.

Yours sincerely

Sarah Delgado
Administrator
Multi-region Ethics Committee
Email: sarah_delgado@moh.govt.nz