Online survey

DISCUSSION PAPER

1. TITLE

Changes to the Occupational Exposure Limits for Styrene

2. ISSUE

WorkSafeBC ("WCB") is considering whether to adopt the American Conference of Governmental Industrial Hygienists ("ACGIH") Threshold Limit Values ("TLVs") for styrene.

3. BACKGROUND

3.1 Law and Policy

Section 5.48 of the *Occupational Health and Safety Regulation ("OHSR")* provides that, except as otherwise determined by the WCB, a worker's exposure to a hazardous chemical substance must not exceed the TLVs established by the ACGIH.

Policy Item R5.48-1 provides a list of exceptions where it has been determined that a TLV established by the ACGIH is not appropriate for adoption in British Columbia for the following reasons:

- The WCB occupational exposure limit ("OEL") for the substance was more protective than the ACGIH TLV;
- The ACGIH had no TLV for the substance; or
- The industry was unable to meet the TLV.

Styrene is currently on the table of excluded substances established by the Policy. Both the 8-hour Time Weighted Average ("TWA") and 15-minute short-term exposure limit ("STEL") for styrene are higher than the current ACGIH TLVs.

3.2 Where Styrene is Found

Trace levels of styrene can be found naturally in plants and some foods such as wheat, strawberries, peanuts, coffee beans, and beef. Low levels of styrene are also produced from vehicle exhaust and cigarette smoke.

Styrene is one of the most widely produced and used chemicals in the world. In Canada, it has been estimated that styrene is the second largest

petrochemical product being produced [2] and the polystyrene, acrylonitrile-butadiene styrene, and the unsaturated polyester resin productions were estimated to total over 275 kilotonnes in 2006.[3] Many household items are made from styrene as the primary raw material, such as foam egg cartons, food containers, CD storage boxes and foam insulation. In the workplace, styrene can be found where styrene is produced, and also where styrene is used as raw material to manufacture common products such as utensils, furniture, bathroom and kitchen appliances, hospital and school supplies, boats, recreational equipment, consumer electronics, automobile parts, and durable lightweight packaging.[4]

There are 6 major styrene resin groups and the type of products it produces:

- Polystyrene – cups, plates, toys, packaging, dairy containers, cassettes
- Acrylonitrile-butadiene styrene – appliances, transportation, business machines
- Styrene-acrylonitrile – appliances, battery castings, packaging, houseware
- Styrene-butadiene rubber – tires, automotive applications
- Styrene-butadiene latex – carpet and upholstery backing, coatings
- Unsaturated polyester resins – boats, bath tubs, hot tubs, shower stalls, cultured marble

In BC, styrene is primarily used as one of the raw materials to manufacture reinforced plastic products like boats, yachts, hot tubs and amusement park parts and also for plastic packaging products. A report by BC Stats Products and Services stated that BC is the third highest province for having the most plastic manufacturing plants (237 plants), after Ontario (2,363 plants) and Quebec (826 plants).[5] Another report indicated that the manufacturing activity for the *Plastics and Rubber Products* industry almost doubled from 1998 – 2006.[6] It should be noted that the plastics industry represented in these statistics includes all types of plastic manufacturers, and not just styrene based plastics.

4. DISCUSSION

In 2005, the Policy and Research Division ("PRD") advised stakeholders that the Board of Directors ("BOD") was considering adopting the ACGIH TLVs for styrene, and requested feedback on what steps would need to be taken to achieve the proposed limits.

[2] Industry Canada, 2006
[3] Camford Chemical Report, 2007
[4] The International Styrene Industry Forum
[5] BC Stats, 1998, p.1
[6] BC Stats, 2007, p.2

Table 1 below shows the current OELs that are in effect in BC and the TLVs that have been established by the ACGIH.[7]

Table 1: Current WCB OELs and TLVs for Styrene

Current WCB OELS (ppm)		ACGIH TLVs (ppm)	
TWA	**STEL**	**TWA**	**STEL**
50	75	20	40
ppm = parts per million			

Founded in 1938, the ACGIH is a private, not-for-profit, nongovernmental corporation whose members are industrial hygienists or other occupational health and safety professionals dedicated to promoting health and safety within the workplace. The ACGIH is a scientific association and is not a standards-setting body. As a scientific organization, it has established a committee that recommends airborne concentrations of agents and exposure conditions for use in the practice of industrial hygiene to protect worker health.

The PRD conducted a detailed review of available information to determine if the current TLV recommended by the ACGIH for styrene should be applied to BC workplaces. The detailed review consisted of the following activities:

a) Review of Feedback from Consultation;
b) Meetings with Industry Representatives;
c) Workplace Site Visits;
d) Literature Review on the Health Effects of Styrene;
e) Comparison of Occupational Exposure Limits;
f) Review of Past Sampling Data in BC Workplaces; and
g) Review of Past Compensation Claims in BC.

4.1 Review of Feedback from Consultation

(a) *Industry/Employer Feedback:*

Responses to the proposal to adopt the ACGIH TLVs for styrene were received from 38 employer stakeholders, with the majority (28) voicing strong opposition to adoption of the ACGIH TLVs. Opposition to adopting the ACGIH TLVs was largely received from marine craft manufacturing, reinforced plastics manufacturing and fibreglass and resin manufacturing industries. The reasons expressed for opposing the adoption of the ACGIH TLVs included:

- Based on scientific evaluation, the current TWA of 50 ppm provides adequate health protection in the workplace and is protective from adverse health effects.

[7] American Conference of Governmental Industrial Hygienists, 2007, p.53

- Lack of evidence that styrene is a carcinogen (cancer causing);
- British Columbia already has some of the lowest OELs for styrene in North America;
- A competitive disadvantage would result for BC industries in favour of their counterparts in adjacent jurisdictions; and
- Implementation of the ACGIH TLVs in BC workplaces is not feasible.

Four responses received from the marine craft manufacturing and autobody shops that were in favour of implementing the ACGIH TLVs indicated that either the workplace was already well below the ACGIH TLV of 20 ppm or that no impact would result because styrene resins were not used in the workplace. Six responses received from the marine craft manufacturing and autobody shops that provided neutral comments indicated that they were unaware of the exposure limits for styrene or its impact on their businesses.

A summary of consultation responses is included in **Appendix A**.

(b) Labour/Worker Feedback:

No submissions were received from workers or their representatives.

4.2 Meetings with Industry Representatives

At the request of several stakeholders, two meetings were held with WCB staff. The first occurred on October 11, 2005 and the second on April 5, 2006. Issues raised at both meetings essentially re-emphasized the issues brought forward in consultation submissions that boatbuilding and reinforced plastics industries would not be able to comply with the ACGIH TLVs for styrene.

Further details of the meetings are included in **Appendix A**.

4.3 Workplace Site Visits

In the fall of 2006, two occupational hygienists from the PRD visited five BC workplaces to assess the feasibility of implementing lower TLVs for styrene. Visits were focused on the reinforced plastics industry because workers employed in that industry typically sustain the highest exposures to styrene due to the fabrication processes used.

Workplaces visited included boat building, bath/shower fabrication, truck canopy production and theme park component manufacturing. Workplaces were selected in order to obtain a broad profile of styrene exposures that occur under different production circumstances, as follows:

- Small and large number of employees (6 – 250 employees);
- Large components, low volume production output;
- Small components with large volume production output;
- Variety/variability of functions performed in the workplaces; and
- Geographic location of workplaces – e.g., Vancouver Island and the Okanagan.

Several fabrication processes are used in the reinforced plastics industry to manufacture items including filament winding (tanks and pipes), pultrusion moulding (rods and tubes), press-moulding and open-moulding. Reinforced plastics industry representatives stated that open-moulding fabrication of products such as boats and bathtubs is the most common fabrication process used in the reinforced plastics industry in BC.

It has been recognized that open-moulding fabrication results in the highest exposures to styrene due to the nature of the process. During open mould processing, resin is sprayed onto a wax-coated mould. A layer of fibreglass is then added – either by a sheet or using an automated "chopper-gun" to cut filamentous glass to an appropriate size. Liquid polyester resin is then applied either by spray gun, brush or hand-roller. Resins can contain up to 40% styrene, and up to 10% of the styrene monomer can be released into the workplace air during application and curing.

Hand application of resins (also referred to as "lay-up") during open-mould fabrication of large objects such as boats and truck canopies requires workers to locate themselves directly over or inside of the objects – such as inside a boat hull. Workers sustain the highest exposures during resin lay-up and while products are curing when styrene-containing vapour is given off. During resin lay-up, workers typically wear personal protective equipment ("PPE") including respirators, gloves, coveralls and eye protection. Ventilation systems remove styrene-contaminated air and replace it with clean make-up air from the outdoors.

Exposure to styrene is determined by the concentration of styrene in workplace air as well as by the duration of their exposure. The surface area of the object that is being fabricated determines the amount of styrene released into the air – not necessarily the amount of resin used. Therefore, workers producing very large objects that have larger surface areas such as powerboats commonly sustain higher *personal* exposures than workers producing smaller items such as bathtubs. Conversely, *area* exposures will be higher in workplaces where numerous smaller components are produced due to the larger combined surface areas of products being produced.

(a) Feasibility of Adopting the ACGIH TLVs for Styrene:

Based on site visit observations, the ability to achieve the ACGIH TLVs for styrene is industry specific and site-specific: workplaces that produce a high volume of components on a daily basis would be the

least likely to be able to achieve the ACGIH TLVs for styrene. Some smaller workplaces that produce only a few components each day and some large workplaces that produce only a few large components each day would likely be able to achieve the ACGIH TLVs.

Site visits to several reinforced plastics industry workplaces found that a significant portion of the reinforced plastics industry will not be able to achieve the TLVs for styrene recommended by the ACGIH. Many of these workplaces have implemented various control measures in their attempts to reduce styrene exposures, but the stakeholders have stated that further reduction is unattainable at this time without undue hardship on the industry.

(b) Challenges Facing the Reinforced Plastics Industry:

The Styrene Information and Research Center ("SIRC") and the Canadian Plastics Industry Association estimated that there are over 3000 workers in BC who are directly employed in the reinforced plastics industry.

Several challenges facing the reinforced plastics industry were identified during consultation and site visits, including: difficulties attracting/retaining workers; local, regional, national and international competition; impacts of globalization (movement of the industry to China due to cheaper labour costs); transportation costs; stringent environmental and occupational regulations; and the rising cost of fuel has significantly increased the cost of production and of heating the make-up air for ventilation systems. Also, many components manufactured by the industry are made from petroleum-based ingredients.

Further details of the workplace visits are included in **Appendix A**.

4.4 Literature Review on the Health Effects of Styrene

As one of the widely produced and used chemical in the world, styrene has been well studied over the last few decades by numerous governmental and scientific agencies. Hundreds of animal and occupational exposure studies have been published over the years that investigated the health effects of styrene.

It is well known that inhaling styrene vapour at high concentrations causes adverse health effects to the central nervous system among other effects. In recent years, acute and chronic health effects associated with exposure to styrene have been evaluated by several expert panels throughout the world. This discussion paper attempts to provide an objective overview of the key publications as it relates to the OEL recommendation.

More detailed summaries of these expert panels' conclusions are included in **Appendix B**.

(a) Chemical Characteristics and Metabolism of Styrene:

Styrene (also known as vinylbenzene, styrole) is a colourless, viscous liquid with a pungent odour with a tendency to polymerize. Polymerization is an important chemical property of styrene as it reacts chemically to make chains of styrene molecules to give distinct characteristics of certain plastics. One such end product is called polystyrene.

Absorption

Inhalation of styrene vapour is the major route of exposure to styrene.[8,9,10] Approximately 60 – 70% of inhaled styrene is absorbed through the lungs.[11] Absorption of styrene vapour or liquid through the skin is considered to be quite low: the highest absorption of styrene vapour by the skin route is 5% of the total absorbed styrene, [12,13] while it has been estimated that skin applied with liquid styrene only absorbs approximately 2% of the applied amount.[14] Studies quoted by the IARC indicate that skin absorption of styrene is not a significant contribution to body burden.[15] Although no information is available on oral absorption in humans, it can be expected that extensive absorption would occur through the gastrointestinal tract.[16]

Distribution

Styrene is distributed throughout the body, with the highest concentrations generally found in adipose tissue (fat).[17] Styrene is eliminated slowly from adipose tissue, with a half-life of 2 – 4 days.[18]

Metabolism

In humans, styrene is highly metabolized with an estimated 97% eliminated through metabolic pathways.[19] In the main metabolic pathway in humans, styrene is converted to styrene 7,8-oxide (styrene oxide) by cytochrome P450 enzymes. Styrene oxide is metabolized to phenylethylene glycol by epoxide hydrolase. Phenylethylene glycol is metabolized to mandelic acid, which is then converted to benzoic acid.

8 National Toxicology Program, 2006, p. II-22
9 Health and Safety Commission, 2005, p.1
10 International Agency for Research on Cancer, 2002, p.479
11 International Agency for Research on Cancer, 2002, p. 479
12 American Conference of Governmental Industrial Hygienists, 2001, p.10
13 Health and Safety Commission, 2005, p.1
14 Health and Safety Commission, 2005, p.1
15 International Agency for Research on Cancer, 2002, p.480
16 Health and Safety Commission, 2005, p.1
17 National Toxicology Program, 2006, p. II-25
18 Lomax, B. et al., 2004, p. 96
19 National Toxicology Program, 2006, p. II-22

Mandelic acid and phenylglyoxylic acid are the predominant urinary metabolites in humans and are commonly used as biomarkers of exposure to estimate styrene exposure. Mandelic acid was reported to represent 57 – 80% of a styrene dose and phenylglyoxylic acid, 10 – 33%.[20]

Excretion
Small amounts of styrene are exhaled unchanged, and also excreted unmetabolized in the urine.[21]

(b) Acute Health Effects:

Neurotoxicity& Irritation
Similar to the health effects of other solvents, styrene has been well recognized to affect the central nervous system ("CNS") and cause neurological effects (i.e. drowsiness, light-headedness, dizziness, headache and balance disturbances) with exposures above 100 ppm.[22,23] There are studies that reported other types of health effects associated with styrene, such as neurobehavioural changes, changes in nerve conduction, impaired colour vision and impaired hearing (ototoxicity) at lower concentrations. These results are not as consistent as the CNS health effects and exposure information is quite limiting to make definitive conclusions.

Scientists have not agreed upon the level at which styrene starts to induce irritant and neurotoxicity effects. Also, the mechanism of how styrene affects the CNS system has not been clearly determined. Some studies hypothesized that this level is below 50 ppm and others state that the OEL at 50 ppm provides adequate protection to workers. In the studies that reported adverse health effects below the current OEL of 50 ppm, styrene's potential effects on hearing and colour vision at lower concentrations seems to be the issue. These health effects will be explained in the next two paragraphs.

A threshold of 50 ppm has been suggested for ocular and conjunctiva irritation (eye irritation) associated with styrene exposure.[24]

Ototoxicity
Ototoxicity (damage of the ear) has been reported in some studies with solvent exposures, including styrene vapour of less than 35 ppm. However, some expert panels have questioned the quality of the studies and identified inconsistencies. Several recent reviews of the

[20] National Toxicology Program, 2006, p. II-22
[21] International Agency for Research on Cancer, 2002, p.484
[22] International Agency for Research on Cancer, 2002, p.493
[23] ACGIH, 2001, p. 9
[24] ACGIH, 2001, p. 5

occupational exposure studies relating inhaled styrene vapour to hearing loss has concluded that hearing loss due to occupational exposure to low levels of styrene have not been scientifically illustrated.[25, 26, 27]

Colour Discrimination

Studies have identified sub-clinical (signs/symptoms are not apparent to the person) colour discrimination impairment in styrene-exposed workers. In these studies, colour discrimination is described as a person's ability to distinguish subtle shade differences of colours. According to recent literature reviews, the information has not been consistent about at what concentrations of styrene these effects are observed. Some studies have identified impaired colour discrimination at styrene exposures above 50 ppm;[28] while other scientific studies have stated that effects on colour discrimination were observed at concentrations lower than 20 ppm.[29, 30] Expert panels reviewing the available information have concluded that there is currently little information to make any definitive conclusions about how styrene causes colour discrimination and questioned whether this apparent reversible colour discrimination is an early sign of neurotoxicity that has health significance to workers.[31,32,33, 34] For example, some expert panels commented about workers with congenital colour discrimination being employed in industries that require them to perform high level of colour vision tasks, e.g. paint production and printing shops. Some workers who were not aware of their condition were still able to successfully complete tasks that required precise colour coordination skills.[35] Similar type of colour vision impairment has been observed with increase in age, in chronic alcohol abusers, and with some prescription drugs.[36]

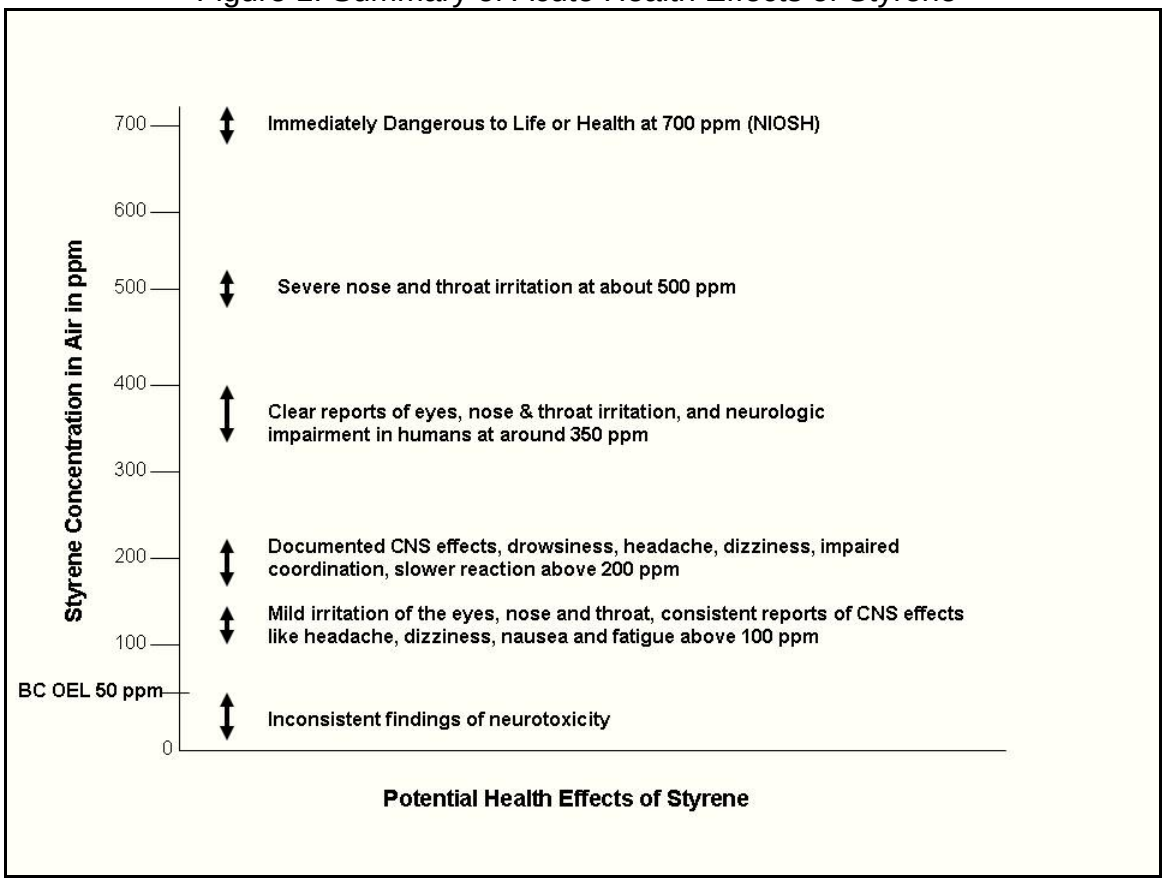
Figure 1 summarizes the current knowledge of the potential acute health effects of styrene. Because styrene's effects are observed in broad ranges, this is a simplified illustration of the effects of styrene relative to the concentration of styrene in air.

The OELs are not intended to represent a fine line between safe and harmful conditions. Due to a wide variation in individual susceptibility,

[25] ACGIH, 2001, p. 7
[26] Lawton et al., 2006, p. 100
[27] Cohen et al., 2002, p. 251
[28] Cohen et al., 2002, p. 73
[29] International Agency for Research on Cancer, 2002, p.494
[30] Triebig et al., 2001, p. 497
[31] Lomax et al, 2004, p. 120
[32] Health & Safety Commission, Annex 4, 2005, p. 6
[33] Cohen et al., 2002, p. 251
[34] Triebig et al., 2001, p.499
[35] Lomax et al, 2004, p. 119
[36] Lomax et al, 2004, p. 94

some workers may experience discomfort from some substances at concentrations at or below the exposure limit.

Figure 1: Summary of Acute Health Effects of Styrene



(c) Chronic Health Effects:

There have been many studies published over the years that investigated the chronic health effects or the long term health effects of styrene. Most of the studies are based on animal data, but some human studies have been conducted. The occupational epidemiological studies were conducted mostly on reinforced plastics industry workers since they are a group of workers exposed to styrene on a consistent basis.

Carcinogenicity & Genotoxicity

Styrene is listed as an *A4- Not Classifiable as a Human Carcinogen* by the ACGIH due to the lack of conclusive data. The ACGIH based their classification on their review of the US National Cancer Institute's conclusion that there was "no convincing evidence for the carcinogenicity" in rats and mice studies. The ACGIH also reviewed

human studies and concluded that there were no statistically significant increases in cancers among workers studied.[37]

The International Agency for Research on Cancer ("IARC") has evaluated styrene for the strength of the evidence that styrene can be linked to increased cancer risk in humans. They concluded that there is "limited evidence" of carcinogenicity in experimental animals and humans. The term "limited evidence" used by IARC in this context refers to some observed increase in cancers in animal and human studies, but they could not rule out that these cancers may have been caused by something other than styrene, i.e. other chemicals, chance, bias. Therefore, styrene was given the classification *2B - Possibly Carcinogenic to Humans*, from the following five possible categories:

Group 1: The agent is carcinogenic to humans
Group 2A: The agent is probably carcinogenic to humans
Group 2B: The agent is possibly carcinogenic to humans
Group 3: The agent is not classifiable as to its carcinogenicity to humans
Group 4: The agent is probably not carcinogenic to humans

Other expert panels have also come to similar conclusions that the evidence is not sufficient enough to associate styrene with increase in cancer risk.

It should also be noted that the current *OHSR* has provisions in place for employers to consider a substitute for chemicals with a 2B IARC designation as styrene has. It states that "the employer must replace it, if practicable, with a material which reduces the risk to workers. If it is not practicable to substitute the material which reduces the risk to workers, the employer must implement an exposure control plan to maintain workers' exposure as low as reasonably achievable below the exposure limit." (*BC OHSR* Part 5.57)

Genotoxicity describes the degree to which something causes damage to or mutation of DNA. Styrene is not likely to be genotoxic, however several expert panels have noted that evaluating the genotoxicity of styrene is difficult because although styrene itself is not considered genotoxic, one of its primary metabolites – styrene oxide, is potentially genotoxic.[38] The IARC has evaluated styrene oxide and determined there is "inadequate evidence in humans for the carcinogenicity of styrene oxide" but there is "sufficient evidence in experimental animals for the carcinogenicity of styrene oxide", and that over all, styrene oxide is probably carcinogenic in humans.[39]

[37] ACGIH, 2001, p. 9
[38] Henderson, L. & Speit, G., 2005, p. 188
[39] International Agency for Research on Cancer, 1994, p. 321

Reproductive Toxicity

Reproductive and developmental effects of styrene have been evaluated by several expert panels and they concluded that there is insufficient evidence or lack of appropriate data in animal and humans studies that styrene causes reproductive or developmental toxicity.[40,41]

Other Chronic Health Effects

Other health effects such as immunotoxicity (adverse effects on the immune system) and endocrine modulation (changes to the endocrine glands or hormones) have been identified as areas requiring further study due to limited evidence on styrene's potential effects.

4.5 Comparison of Occupational Exposure Limits

In 1997, the ACGIH reduced its recommendation for the styrene TWA and STEL from 50 ppm and 100 ppm to 20 ppm and 40 ppm respectively. No changes have been made since then to the values. The ACGIH stated that the reduction of the TLVs was primarily to minimize the potential for irritation and based on the results of occupational studies that showed styrene's effects on central and peripheral nervous systems. The ACGIH concluded from their review that some of the research studies showed changes to sensory nerve conduction at 20-50 ppm (i.e. slowed reaction times, reduction in colour discrimination). Their review of available animal and human carcinogenicity data concluded that styrene exposure did not present an excess carcinogenic (cancer-causing) risk.

All Canadian jurisdictions have set exposure limits for styrene. Some jurisdictions automatically adopt the latest ACGIH TLVs for any substance as a matter of policy or regulation. This is the case in Manitoba, Nova Scotia, Prince Edward Island and Newfoundland and Labrador. Some of these provinces have few industries that use styrene in large quantities. Other jurisdictions have adopted the ACGIH TLV for styrene established in previous years. For example, the Yukon has adopted the 1988 ACGIH TLVs for styrene (8-hour TWA and a STEL of 50 ppm and 100 ppm respectively).

Recently, the Ontario Ministry of Labour approved changes to the OELs for styrene that will take effect in December 2007. The changes will result in an 8-hour TWA and a STEL of 35 and 100 ppm respectively. Both of these limits are higher than the ACGIH TLVs of 20 ppm and 40 ppm. The rationale for the new OELs was not provided at the time of preparation of this discussion paper.

In 1993, WCB proposed a reduction in the styrene TWA to 20 ppm and STEL to 50 ppm from 100 ppm and 125 ppm respectively. However, at that time the TWA was reduced to 50 ppm and the STEL to 75 ppm, based on the scientific literature review conducted and stakeholder feedback. The

[40] Health Council of the Netherlands, 2001, p. 23
[41] National Toxicology Program, 2006, p. II-138

current 8-hour TWA for styrene was again maintained during the 1998 regulation review.

Currently, the range for the 8 hour TWA for styrene is 20 – 50 ppm among the Canadian jurisdictions, while the STEL ranges from 40 - 100 ppm. The exposure limits for styrene from all Canadian as well as select American and international jurisdictions are summarized in **Table 2** below:

Table 2
OELs for Styrene: Canadian, American and International Jurisdictions

Jurisdiction	8-Hour TWA (ppm)	Short-Term Exposure Limit (ppm)	Ceiling Exposure Limit (ppm)
Canadian Jurisdictions			
ACGIH • Manitoba • Nova Scotia • PEI • Newfoundland and Labrador • Canada Labour Code (federally regulated workers)	20	40	
Alberta	50	100	
British Columbia	**50**	**75**	
New Brunswick	20	40	
Northwest Territories (based on 2001 TLVs)	20	40	
Ontario (effective Dec 2007)	Current = 50 New = 35	Current = 200 New = 100	
Québec	50	100	
Saskatchewan	50	100	
Yukon	50	100	
American Jurisdictions			
California	50	100	500
Oregon	100	200	
Washington State	50	100	
US OSHA	100	200	600
International Jurisdictions			
Germany (MAK) (since 1987)	20	40	
UK – HSE (WEL) (since 2000)	100	250	
Sweden (since 1991)	20	50	
Finland (since 1993)	20	100	
Norway (since 1989)	25	37.5	
Netherlands	25		
Australia	50	100	
New Zealand	50	100	
France	50		
Japan (since 1999)	20		

Definitions:

TWA: the time weighted average ("TWA") concentration of a substance in air which may not be exceeded over a normal 8 hour work period.

STEL: the time weighted average ("TWA") concentration of a substance in air which may not be exceeded over any 15 minute period, limited to no more than 4 such periods in an 8 hour work shift with at least one hour between any 2 successive 15 minute excursion periods.

Ceiling: the concentration of a substance in air which may not be exceeded at any time during the work period.

4.6 Review of Past Sampling Data in BC Workplaces

From 1990 to 2005 WCB sampled and collected airborne samples of styrene in BC workplaces. A compilation of sampling data is included in **Appendix C**.

Over the 15 years, WCB Officers visited and collected approximately 123 airborne styrene concentration samples in 64 firms across BC. Most of the data collected were from firms belonging to two industry classes: the Fibreglass or Cultured Marble Product or Acrylic Household Fixture Manufacture; and the Marine Pleasure Craft Manufacture. These industry classes are also where the higher airborne styrene concentrations were found. The TWA concentrations for samples taken at various work areas (e.g. styrene resin lay-up area) ranged from non-detectable to 129 ppm, while the concentrations from sampling devices worn by workers ranged from non-detectable to 450 ppm.

Due to the variety of conditions that the samples were taken in, it is not feasible to analyze the data in great detail or apply statistical models, other than to provide a general overview of the workplace concentrations observed at these BC workplaces. Also, the data were presented in time-weighted average concentrations calculated over the varying sampling times that ranged from 14 - 720 minutes and were not adjusted to 8 hour time-weighted average concentrations.

Overall, the data collected in BC workplaces are similar in range when compared to other jurisdictional data.

4.7 Review of Past Compensation Claims in BC

Occupational Disease Claims Related to Styrene Exposure:

A preliminary review of WCB's data on occupational disease claims indicates that from 1997 to date, eight claims related to styrene have been compensated. Of these eight claims, only one claim was from a fibreglass laminator at a boat manufacturer who started to display symptoms of the styrene effects like headaches and nausea. Five claims were related to skin and eye irritation. The remaining two claims were related to accidental acute exposures by workers indirectly involved with styrene activity. In one case, a confined space attendant inhaled contaminated air being exhausted out of the space and in the other claim, an operator checking the resin level in a tank inhaled very high levels of vapours. In this claim, the WCB hygiene officer estimated the styrene exposure to be greater than 1,500 ppm.

Other than the one estimated level mentioned above, the other claim documents did not state the styrene levels the claimants may have been exposed to cause the symptoms.

5. OPTIONS AND IMPLICATIONS

The PRD has reviewed the relevant information as outlined in this document in order to recommend whether the ACGIH TLVs for styrene should be adopted. Two options for exposure limits for styrene have been considered:

(a) Option 1 – Status Quo

Under this option, the 8-hour TWA and the STEL for styrene would remain the same at 50 and 75 ppm respectively.

***Implications**:*

- The OELs will remain at a level where the weight of the evidence suggests adequate protection for workers from the adverse health effects of styrene.
- The OELs will remain at a level where there is no sufficient evidence that styrene is a carcinogen, genotoxin, reproductive toxin or causes other long term health effects at levels typically encountered in the workplace.
- The OELs will remain at a level where there are inconsistent findings on styrene's effects on hearing damage and colour vision impairment.
- Under this option, the 8-hour TWA for styrene would remain the same as other jurisdictions with a similar industry base, such as Alberta, Québec, Washington State and California, other countries like France, UK and Australia, and a reference organization such as the National Institute of Occupational Safety and Health ("NIOSH").
- Under this option, the exposure limits for styrene would remain higher than the values recommended by reference organization including the ACGIH, the German MAK, the Dutch Expert Committee on Occupational Standards and the Swedish National Institute for Work Life.

(b) Option 2 – Adopt the 8-hour and STEL exposure limits recommended by the ACGIH

Under this option, the 8-hour exposure limit is reduced to 20 ppm and the STEL is reduced to 40 ppm.

Implications:

- The exposure limits will be below the level where there are some inconsistent and subjective findings of neurotoxicity.
- Under this option, a significant portion of the reinforced plastics industry in BC would not be able to comply with these limits.
- Exposure limits of 20 and 40 ppm would trigger the implementation of control measures at lower concentrations than currently are in the workplace, i.e. ventilation systems, respiratory protection.
- Under this option, the 8-hour TWA for styrene would be more stringent than the nearby jurisdictions of Alberta, Oregon, California and Washington State, and consistent with other provincial and federal

jurisdictions such as Manitoba, Nova Scotia, PEI and Newfoundland and Labrador.

- The 8-hour exposure limit and the STEL would be consistent with the values recommended by some reference organization like the ACGIH, the German MAK, the Dutch Expert Committee on Occupational Standards and the Swedish National Institute for Work Life.

6. OCCUPATIONAL EXPOSURE LIMIT REVIEW COMMITTEE CONCLUSION

WorkSafeBC's Occupational Exposure Limit Review Committee, comprised of subject matter experts, reviewed the feedback from consultation, results of workplace visits, literature on the health effects of styrene, limits in other jurisdictions, and WorkSafeBC sampling data and claims data. Based on this information, the Committee concluded that retaining the 8-hour TWA limit of 50 ppm and a STEL of 75 ppm for styrene provides adequate levels of protection for BC workers, when used in conjunction with an effective health and safety program.

7. CONSULTATION

Stakeholders are invited to provide feedback on the discussion paper and options and any additional comments that may be relevant to the issue.

Stakeholder comments will be accepted until 4:30 pm on Wednesday, October 10, 2007. When responding, please provide your name, organization and address. Comments may be sent by mail, fax or e-mail to:

By mail: Styrene OEL Study
Policy and Research Division
WorkSafeBC
P.O. Box 5350, Stn. Terminal
Vancouver, B.C. V6B 5L5

By fax: 604-279-7599
By e-mail: regquery@worksafebc.com

WorkSafeBC's governing body, the Board of Directors, will consider stakeholder feedback before making a decision on the OEL for styrene.

Please note that all stakeholder feedback becomes part of the Policy and Research Division's database and may be published, including the identity of organizations and those participation on behalf of organizations. The identity of those who have participated on their own behalf will be kept confidential according to the provisions of the *Freedom of Information and Protection of Privacy Act*.

Meetings with Stakeholders and Consultation Feedback

Meetings with Stakeholders:

At the request of several stakeholders, two meetings were held with staff from the Policy and Research Division ("PRD"). The first occurred on October 11, 2005 and the second on April 5, 2006.

At the October 11, 2005 meeting, representatives from the following reinforced plastics sector and industry associations attended:

Oregon Reinforced Plastics Association BC
AOC Canada
Marine Plastics
Oceanus Reinforced Plastics
Kelowna Industrial Plastics
Canadian Plastics Industry Association
Styrene Information & Research Center

At the April 5, 2006 meeting, representatives from the following boatbuilding sector and industry association attended:

BC Marine Trades Association
Canmar Yacht Sales
Oceanus Reinforced Plastics Ltd

Issues raised at both meetings essentially were the same as those brought forward in the consultation submissions: that no new data on adverse health effects to warrant the reduction in OELs and boatbuilding and reinforced plastics industries would not be able to comply with the ACGIH TLVs for styrene.

Consultation Feedback:

In the fall of 2005, the PRD advised its worker and employer stakeholders that the BOD was considering adopting the ACGIH TLVs for styrene, and requested feedback on what steps would need to be taken to achieve the proposed limits.

Responses were received from a total of 38 **employer** stakeholders (none were received from workers or groups representing workers), with 28 expressing strong opposition to the adoption of the ACGIH TLVs. The reasons expressed for opposing the ACGIH TLV included:

- Based on scientific evaluation, the current TWA of 50 ppm provides adequate health protection in the workplace and is protective from adverse health effects.
- The International Agency for Research on Cancer identified styrene as a "possible" human carcinogen; and there is no scientific evidence to support the lowering of the BC limit;

- No convincing evidence exists that styrene causes any form of cancer in humans;
- Adopting the ACGIH TLV would make the province uncompetitive with Washington and Oregon, create economic burdens, lost jobs, severe impacts to local economies; and
- There is no practical way of achieving the ACGIH TLVs.

The smaller number of responses that were in favour of reducing the OELs for styrene to the ACGIH TLVs included:

- The respondent's employee exposures to styrene are already well below the ACGIH TLV of 20 ppm;
- Limited or no use of/exposure to styrene in the workplace/industry, therefore there would be no impact if the exposure limit was lowered to the ACGIH TLV of 20 ppm;
- The changes would not impact the company because styrene-containing products are not used in the workplace.

The Table below provides a breakdown of responses received from employers by industry type and response.

Table of Consultation Submissions – by Industry

Industry	Opposed	Approve	Neutral
Marine Craft Repair or Manufacturing	10	3	3
Auto Body Repair		1	3
Reinforced Plastics Manufacture	8		
Fibreglass/Resin Manufacture	4		
Composites Industry	3		
Chemical Manufacturing	1		
Styrene Research	1		
Business/Employer Association	1		
Total	**28**	**4**	**6**

Workplace Site Visits:

Staff from the Policy & Research Division ("PRD") visited several BC workplaces to assess the feasibility of implementing lower TLVs for styrene. Workplaces were initially contacted by telephone and were asked to participate in order for the WCB to collect contextual information for the decision-making process for setting exposure limits for styrene.

Industries visited included boat building, bath/shower fabrication, truck canopy production and theme park component manufacturing.

Workplaces were selected in order to obtain a broad profile of styrene exposures that would occur under different production circumstances, as follows:

- Small and large number of employees (6 – 250 employees),
- Large components, low volume production output;
- Small components with large volume production output;
- Variety/variability of functions performed in the workplaces;
- Geographic location of workplaces – e.g. Vancouver Island and Okanagan.

Issues Identified During Site Visits:

- It is well known that the largest concentration of reinforced plastics processing is located in the Okanagan region of BC.
- Adopting the ACGIH TLVs for styrene may cause at least one large employer to close because the manufacturing process used does not lend itself to meeting the ACGIH TLVs e.g. high volume of small components result in higher area exposures.
- The reinforced plastic industry in BC is highly competitive with nearby jurisdictions (Washington State, Alberta). The styrene OEL in Washington State and in Alberta is 50 ppm.
- There is increasing relocation of the reinforced plastics industry to China due to cheaper labour costs and relaxed occupational and environmental regulations. More movement is anticipated by the reinforced plastics industry.
- The industry is experiencing difficulty attracting and retaining workers – this issue was raised by all employers whose workplaces were visited.
- Substitute products such as wax-containing resins that could potentially reduce exposures have been found to be expensive and inefficient. Wax-containing resins leave behind a residue on moulds and products which then have to be cleaned and stripped. This is a labour-intensive and expensive process and damages both moulds and finished products. As well, wax residues degrade the quality of the products.
- Low-emission styrene is used whenever possible.
- The reinforced plastics industry is working with resin manufacturers to reduce emission by getting the resins to “gel” faster, thereby reducing the amount of styrene emitted during the curing process.
- The reinforced plastics industry’s ability to meet lower exposure levels depends on the product that is being manufactured. The surface area of the product being manufactured determines exposure – larger surface areas mean more styrene resin is applied which results in more evaporation and exposure to the worker.
- The workplaces visited are using a combination of engineering (e.g. spray booths), administrative (e.g. work practices) and personal protective equipment (e.g. respiratory protection) control measures in their attempts to reduce worker exposures.

- An operations manager stated that the cost of increasing the dilution ventilation at a facility will be very expensive due to the make-up air capacity that must be increased. With the rising fuel costs, heating the make up air in the cooler winter climate in the Okanagan will not be cost-effective.
- Industry representatives stated that the reinforced plastics industry is an industry that is affected by global events. The industry is seeing increased movement of production to China to take advantage of cheaper labour costs and lesser environmental standards. Increasing fuel prices has affected the reinforced plastics industry from many angles including heating costs, costs as a base-product for manufacturing components and transportation costs for finished products.

Literature Review on the Health Effects of Styrene

Due to the widespread use of styrene in industrial settings throughout the world, the health effects from occupational exposures to styrene have been particularly well studied.

Various international bodies have studied and evaluated the health effects of styrene, to make recommendations for exposure limits and classify the potential for certain health outcomes such as carcinogenicity or developmental effects.

This section provides the highlights of the rationale expressed by the international reference agencies and also some of the recent key studies and scientific reviews that were mentioned by the reference agencies. This discussion paper is not meant to be a systematic review of styrene.

American Conference of Governmental Industrial Hygienists:

"The American Conference of Governmental Industrial Hygienists ("ACGIH") is a private, not-for-profit, nongovernmental corporation whose members are industrial hygienists or other occupational health and safety professionals dedicated to promoting health and safety within the workplace. ACGIH is a scientific association; ACGIH is not a standards-setting body. As a scientific organization, it has established committees that review the existing published, peer-reviewed scientific literature. ACGIH publishes guidelines known as Threshold Limit Values ("TLVs") for use by industrial hygienists in making decisions regarding safe levels of exposure to various chemical and physical agents found in the workplace." [42]

In 1997, ACGIH reduced its TLV recommendation for styrene from a TWA of 50 ppm and a STEL of 100 ppm to the current TWA of 20 ppm and STEL of 40 ppm. The basis for recommending the lower levels is outlined in the ACGIH 2001 TLV Documentation and is partially summarized below: [43]

- There were indications of central and peripheral neurologic, optic, and irritant actions in humans when workplace styrene concentrations were greater than 50 ppm.
- Headache, fatigue, nausea, and dizziness were consistently reported after exposure to styrene concentrations at 100 ppm or more.
- Human studies into exposure from styrene indicate that the threshold for ocular and conjunctival irritation was placed at 50 ppm.
- Human genotoxicity data were conflicting due to problems with study methodologies.
- Studies where rats were exposed to high concentrations of styrene and its epoxide failed to show significant carcinogenic response.

[42] ACGIH, 2007, p. v
[43] ACGIH, 2001, p. 10

- No epidemiologic evidence or animal data to conclude that styrene exposure presents an excess carcinogenic risk.
- No specific associations of styrene inducing reproductive toxicity.
- Indications that styrene exposure can reduce sensory nerve conduction by 5-10% after exposure at 100 ppm or more.
- Styrene exposures at 50 – 100 ppm can reduce periphery nerve conduction velocity and sensory amplitude.
- Slowed reaction time appears to begin after exposures as low as 50 ppm.
- Transient loss of colour discrimination may occur after exposure to styrene concentrations greater than 50 ppm.
- Mucous membrane irritation has been reported to begin at 45 ppm to as high as 180 ppm in humans.

International Agency for Research on Cancer:

The International Agency for Research on Cancer ("IARC") is part of the World Health Organization. The IARC's mission is to coordinate and conduct research on the causes of human cancer, the mechanisms of carcinogenesis, and to develop scientific strategies for cancer control. The IARC is involved in both epidemiological and laboratory research and disseminates scientific information through publications, meetings, courses, and fellowships.

In the IARC's last review in 2002 of styrene, the IARC maintained the carcinogenic rating of *2B - Possibly Carcinogenic to Humans*. Some of their key rationale for this evaluation is as follows: [44]

- There is no evidence for an association between workplace exposure to styrene and spontaneous abortions, malformations, or decreased male fecundity.
- A European multinational cohort study of workers in the glass fibre-reinforced plastics industry revealed no excess mortality from lymphatic and haematopoietic neoplasms in the entire cohort in comparison with the general population.
- A Denmark cancer incidence study of workers in the reinforced plastics industry observed small and non-significant excess of leukemia when compared to the general population.
- A large US study of workers exposed to styrene in the reinforced plastics industry observed no overall excess of lymphatic and haematopoietic neoplasms.
- Two studies of US and UK chemical workers in the styrene manufacturing observed a weak association between exposure to styrene and lymphatic and haematopoietic cancers. However, styrene exposures were poorly documented in these studies and other chemical exposures may have been involved.
- A Finnish follow-up study of cancer incidence in workers biologically monitored for occupational exposures to styrene did not show any increase in risk for lymphatic and haematopoietic neoplasms.

[44] International Agency for Research on Cancer, 2002

- In an inhalation study in mice, there was an increase in pulmonary adenomas, but in rats there was no reliable evidence of an increase in tumour incidence.
- The IARC reviewed the evidence for styrene 7,8-oxide, a major metabolite of styrene. Sufficient evidence was found in experimental animals for the carcinogenicity.
- The IARC concluded there is limited evidence in humans for the carcinogenicity of styrene and there is limited evidence in experimental animals for the carcinogenicity of styrene.

National Toxicology Program, U.S. Department of Health and Human Services:

The National Toxicology Program ("NTP") of the U.S. Department of Health and Human Services, Center for the Evaluation of Risks to Human Reproduction ("NTP-CERHR") was established in 1998 and is "a publicly accessible resource for information about adverse reproductive and/or developmental health effects associated with exposure to environmental and/or occupational chemicals."[45]

The NTP-CERHR broadly solicits nominations of chemicals for evaluations from the public and private sectors. The NTP-CERHR follows a formal process for review and evaluation of nominated chemicals that includes multiple opportunities for public comment. The NTP-CERHR convenes a scientific expert panel that meets in a public forum to review, discuss, and evaluate the scientific literature on the selected chemical.

The NTP-CERHR recently completed an evaluation of the potential for styrene to cause adverse effects on reproduction and development in humans. The NTP-CERHR Expert Panel concluded that human studies show no evidence that occupational exposures to styrene adversely affect reproduction or development. The basis for their conclusion is partly outlined below, as follows:

- No convincing evidence of adverse developmental effects observed in lab animal studies. This conclusion was based on developmental toxicity studies in rats and rabbits where there were no observable adverse effects on the fetuses, even after inhalation exposures as high as 600 ppm of styrene.
- No evidence of reproductive toxicity observed from multi-generational animal studies. This conclusion was based on multi-generation studies in rats which failed to show any effects on reproduction or significant developmental effects on the pups, even after inhalation exposures as high as 500 ppm of styrene.
- Insufficient evidence from human studies to reach definitive conclusions. This comment was based on the lack of human studies linking DNA damage and chromosome abnormalities to styrene exposure.

[45] National Toxicology Program, 2006, p. v

Health Council of the Netherlands:

The Health Council of the Netherlands is an independent scientific advisory body. Its mandate is "to advise the government and Parliament on the current level of knowledge with respect to public health issues…"

The Health Council receives most requests for advice from the Ministers of Health, Welfare & Sport, Housing, Spatial Planning & the Environment, Social Affairs & Employment, and Agriculture, Nature Preservation & Fisheries. The Council can publish advisory reports on its own initiative. It usually does this in order to focus attention on developments or trends that are thought to be relevant to government policy.

Most Health Council reports are prepared by multidisciplinary committees of Dutch, or sometimes, foreign experts, appointed in a personal capacity. The reports are available to the public.

The Committee for Compounds Toxic to Reproduction ("CCTR"), a committee of the Health Council of the Netherlands, evaluated the effects of styrene on reproduction and published a report in 2001. The report concluded that there is a lack of appropriate animal or human data to assess styrene for effects on fertility, developmental toxicity or for lactation, and that "in view of the human and animal data, the committee recommends not to classify styrene for effects on fertility and developmental toxicity because a lack of appropriate data". [46] However, the CCTR notes that "there is clearly cause for concern for effects on fertility and development after exposure to mixtures of solvents containing styrene". [47]

The Dutch Expert Committee on Occupational Standards ("DECOS"), a committee of the Health Council of the Netherlands, is of the opinion that styrene is well investigated, but that there is insufficient evidence of a carcinogenic effect to warrant a classification as "known to be carcinogenic to humans" or as "should be regarded as carcinogenic to humans". Styrene should be classified as a suspected human carcinogen. [48]

Deutsche Forschungsgemeinschaft: Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area (Germany):

The German Commission for the Investigation of Health Hazards of Chemical Compounds in the Work Area assign "MAK values" (maximum workplace concentration) for chemical substances. MAK values are defined as the maximum concentration of a chemical substance (as gas, vapour or particulate matter) in the workplace air which generally does not have known adverse effects on the health of employees nor cause unreasonable annoyance (e.g. by a nauseous odour) even when the person is repeatedly exposed during long periods, usually for 8 hours daily over on average 40-

[46] Health Council of the Netherlands, 2001, p. 23
[47] Health Council of the Netherlands, 2001, p. 23
[48] Health Council of the Netherlands, 2001, p. 19

hour work week. MAK values are established on the basis of the effects of chemical substances; when possible, practical aspects of the industrial processes and the resulting exposure patterns are also taken into account. Generally, decisions are based on scientific criteria for the prevention of adverse effects on health and not on technical and economic feasibility. By the nature of how MAK values are determined, it is known in the international setting as having more stringent recommendations.

The German MAK value ("maximale Arbeitsplatz-Konzentration: maximum workplace concentration") for styrene was set in 1987; the 8-hour exposure value for styrene of 20 ppm and a STEL of 40 ppm. The Commission's rationale for the styrene MAK value is explained in the MAK Value Documentations, and the key findings are listed below: [49]

- Currently available epidemiological studies of workers in the styrene producing and processing industries have not yielded clear evidence of carcinogenic effects of styrene in humans.
- Findings of experimental studies have confirmed styrene has significant carcinogenic effects in mice, but not rats. It was hypothesized that the difference in the way styrene is metabolized by mice, rats and humans contributed to the different carcinogenic outcomes.
- The German Commission has assigned a classification of 5 to styrene. Classification 5 is assigned to "substances with carcinogenic and genotoxic effects, the potency of which is considered to be so low, that provided the MAK and BAT values are observed, no significant contribution to human cancer risk is to be expected.[50]

British Health and Safety Commission:

The Health and Safety Commission is responsible for health and safety regulation in Great Britain. The Health and Safety Executive ("HSE") and local government are the enforcing authorities who work in support of the Commission.

The HSE Advisory Committee on Toxic Substances has several subcommittees including the Working Group on Action to Control Chemicals ("WATCH"). The WATCH advises the Advisory Committee on Toxic Substances ("ACTS") and the HSE on issues relating to the assessment and control of health risks from chemicals. It is a government scientific advisory committee and as such is subject to the Office of Science and Technology's Code of Practice for Scientific Advisory Committees. The WATCH will also, where appropriate, provide scientific support to help progress the HSE's Chemicals Programs on occupational cancer, occupational skin disease and occupational respiratory disease.

The Health and Safety Executive Field Operations Directorate recently carried-out a review of the existing scientific evidence regarding the effects of organic solvent

[49] Deutsche Forschungsgemeinschaft, 2006, p. 413
[50] Deutsche Forschungsgemeinschaft, 2006, p. 19

exposure on colour discrimination (including styrene). The study was published in a peer-reviewed journal in 2006. The authors noted that:

- Studies of styrene-exposed workers in Germany, Italy and Japan provide a sufficiently consistent body of evidence to support a robust conclusion that styrene does cause an impairment of colour discrimination when compared to a control group matched for age.
- The limited information available on exposure-response relationships indicates that the effects on colour discrimination would not be expected at 8-hour time weighted (8hr TWA) exposures <20 ppm, although a precise threshold cannot be determined.
- The information on the reversibility of the colour impairment is limited and data is inconclusive. The most rigorous study reviewed by the authors point to a reversibility of effects after a 4-week exposure-free period, but other studies with limited credibility suggest a persistence effect. [51]

The authors explained the effects of styrene-induced effects on colour discrimination as subtle and involve an impairment of the ability to discriminate accurately between closely related shades of the same colour rather than colour blindness.[52]

The WATCH concluded that the available data from studies looking at the potential effects of styrene exposure on colour discrimination is not sufficient enough to be reliable.

National Institute for Occupational Safety and Health:

The National Institute for Occupational Safety and Health ("NIOSH") is a US federal agency responsible for conducting research and making recommendations for the prevention of work-related injury and illness. The NIOSH is also part of the Centers for Disease Control and Prevention ("CDC") in the US Department of Health and Human Services.

NIOSH develops and periodically revises recommended exposure limits ("RELs") for hazardous substances in the workplace, including styrene exposures. RELs for styrene were recommended in 1983 as 50 ppm for 10-hour workshift, 40 –hour work week and a STEL of 100 ppm.[53] The recommended standard was primarily based on reported effects on the human nervous system, irritation of the eyes, and respiratory system.

NIOSH also has documented the Immediately Dangerous to Life or Health ("IDLH") concentration for styrene as 700 ppm, an airborne concentration at which a worker could escape without injury or irreversible health effects in the event of failure of respiratory protective equipment. [54]

[51] Lomax, B. et al., 2004, p. 92
[52] Lomax, B. et al., 2004, p. 92
[53] NIOSH, 1983, p. 2
[54] NIOSH Pocket Guide, 2005, p. 287

Other Literature Reviews and Scientific Studies:

In recent years, there have been several papers published related to the potential health effects of styrene. For the purpose of this discussion paper, studies mentioned by the reference organizations that provided relevant information are summarized below:

Ruder, A.M. et al study, 2004

In 1985, the National Institute for Occupational Safety and Health ("NIOSH") published a cohort study of workers in reinforced plastic boatbuilding factories between 1959 to 1978. The study included 5,204 employees from two factories located in Washington State, in the US. The following is an update to the 1985 study to account for any latency period of diseases through to 1998, with an additional 21 years of follow-up on the workers.

After running some statistical models, the authors did observe slight increases in death rates due to cancers in the group of workers, but it was not statistically significant. [55] The study also mentions an interesting observation that mortality for all cancers was significantly elevated among workers with less than a year of employment in the reinforced plastics industry. This observation is not what was expected if styrene caused cancers. Few possible reasons were provided by the authors, but none of them were associated with styrene exposures.

Henderson, L. & Speit, G., Review Study, 2005

Researchers, Leigh Henderson and Günter Speit, recently published a review article that investigated the genotoxicity (damage to DNA) of styrene in humans. The focus of their review was on past population monitoring studies of styrene-exposed workers. The authors evaluated the adequacy of the styrene studies using the guidelines for genotoxicity monitoring developed by the International Programme on Chemical Safety (IPCS), developed jointly by the World Health Organization, United Nations Environment Programme and the International Labour Organization.

The review authors concluded that the data was not convincing that styrene induces gene mutations in occupationally exposed workers. Some of their reasons are summarized below: [56]

- The evidence for the relationship between genotoxic response and exposure level is conflicting.
- No common pattern of positive responses for the different genotoxic effects.
- No convincing evidence from animal studies that styrene is mutagenic in vivo at levels in excess of those associated with occupational exposure, although it induced genotoxic effects in some tests in animals at high-doses.

[55] Ruder et al., 2004, p. 168
[56] Henderson, L. & Speit, G., 2005, p. 188

- Genotoxic potential of styrene in humans is predicted to be lower than in rats and mice due to a lower rate of styrene oxide formation from styrene.

J.T. Cohen et al. 2002 Review Study

In 1999, the Styrene Information and Research Center ("SIRC") awarded a grant to the Harvard Center for Risk Analysis ("HCRA") to conduct a comprehensive review of the potential health risks associated with styrene exposure. The review was performed by a 12 member panel multidisciplinary team of international scientists. The panel reviewed hundreds of existing scientific literature on the health risks of styrene and published a report that summarized their findings. The key conclusions are summarized below, as follows:

The authors concluded that in animal studies:

- The current evidence indicates that styrene has been shown to cause lung tumors in mice only.
- The current evidence indicates that mice and rats develop forestomach tumors after being fed styrene oxide, a metabolite of styrene.
- Styrene produces respiratory tract toxicity in rodents at exposures as low as 20 ppm, most likely due to metabolism of styrene into styrene oxide in the nasal epithelium.

The authors concluded that with respect to neurotoxicity:

- The current evidence indicates that styrene produces central nervous system depression at levels of exposure above 100 ppm.
- The studies reported subclinical colour vision impairment in workers occupationally exposed to low concentrations of styrene, however they stated that further investigation is required to understand the importance of this effect.
- There may be a synergistic role of noise with styrene, but concluded that the current data is limited.

The authors concluded that with respect to carcinogenicity:

- Human studies shows no consistent indication that styrene is causing any form of cancer in humans.
- The currently available epidemiological evidence does not support a hazard of lung cancer in humans exposed to styrene.
- The weight of the scientific evidence supports a "suggestive evidence" that styrene is a human carcinogen from inhalation exposure.
- Further investigation into the mechanism of action in humans is needed in order to understand species differentiation.

The authors concluded that with respect to reproductive toxicity:

- It is unlikely that styrene causes reproductive toxicity, although data is limited to rule it out completely.

The authors concluded that with respect to developmental toxicity:

- There are not many studies conducted on the developmental effects of styrene.

- The current evidence does not suggest styrene has developmental toxic properties.

The authors concluded that with respect to immunotoxicity:

- Styrene be investigated further for potential immunotoxicity. There is suggestive evidence that styrene can affect the immune system of styrene exposed workers and rodents.

Lawton et al. 2006 Review Paper:

This review study attempted to answer questions related to styrene exposure affecting the hearing of exposed workers (ototoxicity) by critically assessing the available evidence. The review authors assessed the findings of 7 major studies looking into the issue and concluded that hearing damage due to occupational exposure to styrene at low concentrations has not been demonstrated by scientifically reliable means. Some of their reasons are outlined below, as follows:

- Long term inhalation exposure to styrene concentration greater than 750 ppm demonstrated hearing loss in rats, but not under 650 ppm.
- A review of a study of styrene-exposed reinforced plastics industry workers in the Netherlands (Muijser et al., 1988) found that the control group (non-exposed workers) had worse hearing thresholds than the styrene-exposed group. The study found no evidence that low level styrene exposure produced hearing loss in the high noise frequencies.
- A review of a study of plastic boat manufacturing workers (Möller et al., 1990) found that the results did not indicate hearing loss due to causes other than age and/or exposure to noise.
- A study looking at 299 Canadian reinforced plastics workers styrene exposures and noise exposures (Sass-Kortsak et al., 1995) found no consistent and significant relationship between styrene and hearing loss exposed to low levels of styrene.
- The study that investigated 20 workers from fibreglass factories in Italy (Calabrese et al., 1996) where workers were exposed to styrene levels less than 50 ppm concluded that “the auditory system does not see to be affected by the toxic effects of styrene at the exposure levels reported.”
- A study was reviewed that investigated 93 plastic and fibreglass manufacturing workers in Japan (Morioka et al., 1999). These workers were exposed to styrene concentration between 0.1 ppm – 91.6 ppm, along with other solvents like acetone, toluene, methanol and xylene. The results of this study “suggest” an ototoxic effect for solvents in combination. The review authors cautioned readers about this study due to its skewed data and the lack of explanation from the authors.
- A study that examined 154 workers from fibreglass factories for possible styrene-induced hearing effects (Morata et al., 2002) concluded that the exposure of styrene at levels below 20 ppm produced high-frequency hearing loss. The review authors commented that the researchers did not control for some of the

variables for the study groups and thus did not provide strong support for their conclusion.

- A study was reviewed that investigated the effects on hearing produced by occupational exposure to styrene and simultaneous exposure to styrene and noise (Sliwinska-Kowalska et al., 2003). The study's authors concluded that occupational exposure to styrene and to styrene and noise produces significant increase in the chance of developing sensorineural hearing loss. Lawton et al commented that these conclusions must be viewed with caution since there were a number of factors that were not considered.

Lomax et al. 2004 Review Paper:

This review article attempted to answer questions related to styrene exposures affecting colour vision in workers. The review authors assessed the recent findings of major studies looking into the issue and concluded that there is sufficient evidence to support that styrene causes an impairment of colour discrimination. However, the review authors do not recommend the use of colour vision testing on styrene-exposed workers as an early indicator of neurotoxicity. Some of their reasons are outlined below, as follows:

- A German study was reviewed that investigated 22 males working in a German boat-building plant before and after a 4 week vacation (Triebig et al. 2001). This study was able to show good association between occupational styrene exposure and poor colour discrimination. The study showed a reversible of the effects after 4 weeks vacation in the same study group. Possible confounding factors, such as age, alcohol and congenital colour vision deficiency were considered and controlled.
- Three studies reviewed that investigated reinforced plastics factory workers in Italy were consistent in linking styrene exposure and colour discrimination. An exposure-response analysis carried out in one of the studies suggested a colour discrimination impairment in workers exposed to greater than 50 ppm. The colour vision in workers exposed to less than 50 ppm was normal.
- Three Japanese studies reviewed attempted to determine the threshold of colour discrimination associated with styrene exposure. All three studies have confirmed the association between occupational styrene exposure and colour impairment. Although, one of the study's findings indicate that colour vision impairment was observed at levels as low as 12 ppm of styrene, Lomax et al commented that these studies have limitations in their methodology.
- Three Canadian studies reviewed involving workers from reinforced plastics industry concluded that these studies only provide "suggestive" association between styrene exposure and colour discrimination. Due to some limitations of the studies, these studies were not very helpful in determining a threshold level for styrene's effects.
- There is a lack of information on what mechanism this impairment occurs.
- There is a lack of information on the magnitude of impairment on colour discrimination in workers exposed to styrene.
- There is an ongoing debate as to how reversible the colour impairment is to workers exposed.

- There is an ongoing debate whether the observed colour impairment is significant to occupational health.

Environmental Health Perspective:

Environment Canada and Health Canada, Styrene Priority Substances List Assessment Report, 1993

Under the Canadian Environmental Protection Act (CEPA), the Ministry of Environment and the Ministry of Health investigated whether styrene is toxic to the environment and/or to humans. Although the focus of the report was primarily on environmental effects and the general public, the authors reviewed available human studies from occupational settings, as part of the scope. The report concluded that there was not enough evidence to associate styrene with an increase in cancers of workers occupationally exposed to styrene. [57]

The review team also concluded that "concentrations of styrene present in the Canadian environment do not constitute a danger in Canada to human life or health."

[57] Environment Canada/Health Canada, 1993, p.26

Appendix C

Workplace Exposure to Styrene

Workers are exposed to styrene in a number of industries and operations, including styrene production, production of polystyrene and other styrene-containing polymer resins, plastics and rubber products fabrication, fabrication of reinforced-polyester plastics composites and use of products containing styrene, such as floor waxes and polishes, paints, adhesives, putty, metal cleaners, autobody fillers and varnishes.

Styrene evaporates from resins, gel coats, solvents, and surface coatings used in the manufacturing process. The manufacture of objects with large surface areas, such as boats, truck parts, bath and showers by an "open-mould" process results in the highest occupational exposures to styrene. Open moulding and resin and gel coat operation is a process in which the reinforcing fibers and resin are placed in a mould and are open to the surrounding air while the reinforcing fibers are saturated with resin.

Closed moulding is a moulding process in which pressure is used to distribute the resin through the reinforcing fabric placed between two mould surfaces to either saturate the fabric or fill the mould cavity. The pressure may be clamping pressure, fluid pressure, atmospheric pressure or vacuum pressure.

It is important to note that exposure to styrene is determined by frequency of exposure and duration of exposure as well as the surface area of the object that is being fabricated, and to a lesser extent, the amount of resin used.

Reinforced Plastics Industry:

It is well known that the highest exposures have been measured in the reinforced plastics industry.[58] The largest number of workers and levels of exposure occurs in the fabrication of objects from glass fibre-reinforced polyester composite plastics such as boats, tanks, wall panels, bath and shower units and automotive parts. Styrene serves as a solvent and a reactant for unsaturated polyester resin, which constitutes about 40% by weight. During lamination and curing, about 10% of the styrene may evaporate into workplace air.[59]

Occupational Exposure to Styrene in British Columbia:

BC industries where exposure to styrene is likely to occur include the reinforced plastics industry, yacht and other boat building, marble manufacture and plastics manufacture. Similar to other jurisdictions, highest exposures occur in the reinforced plastics industry.

Styrene Exposure Levels in British Columbia Workplaces:

Between 1990 and 2005, WCB Officers visited and collected approximately 123 airborne styrene concentration samples in 64 firms across BC. Industries that have

[58] IARC, 1994 p.233
[59] WHO, 2000, p.3

been sampled include: yacht building, reinforced plastics, boat building (including fibreglass), marble manufacturing and plastics manufacture. Job titles/activities associated with the highest exposures include: lay-up, chopper gun, gel coating, pipe winding and various other tasks. WCB compliance sampling results are summarized by industrial classification unit in the table below.

Table of Styrene Exposures in BC Workplaces 1990 – 2005 (Measured by WCB Officers)

Industry Classification Unit	No. of Area Samples	No. of Personal Samples	Area Sample Range (ppm)	Personal Sample Range (ppm)
Barge Building or Servicing (712025)	2	3	1.4 – 4.5	*ND – 56.1
Industrial Chemical Manufacture (713001):	1	1	1.0 – 2.4	3.6 – 3.8
Fibreglass or Cultured Marble Product or Acrylic Household Fixture Manufacture (713011)	10	68	ND - 126	ND – 450
Hot Tub Manufacture (713025)	1	5	<1	ND – 38.3
Modular or Prefabricated Building Manufacture (715033)	1	4	40.6	0.28 – 133
Marine Pleasure Craft Manufacture (715034)	7	20	ND – 129	ND – 294

*ND = Not Detectable means the measured levels was below the detection limit of the analytical instrument – e.g. amount of styrene detected is less than the smallest amount that the analytical instrument can measure.

A styrene survey conducted on 256 workers from Ontario and Nova Scotia performing styrene resin work observed widely varying levels ranging from 0.12 ppm – 122.5 ppm. [60]

Walk-through survey reports completed by the National Institute for Occupational Safety and Health ("NIOSH"), of the US Department of Health and Human Services, of various reinforced plastics boat manufacturers also observed high styrene airborne concentrations in workplaces where open moulding takes place. [61, 62]

[60] Sass-Kortsak, et al., 1996
[61] NIOSH, 2005
[62] NIOSH, 2007

Another study analyzed a large collection of styrene exposure data in Norway.[63] The study was able to analyze over 7,000 measurements spanning over 1972 – 1996. When the annual median styrene concentrations were plotted, the samples showed a decrease in the median exposure level from 62 ppm in the 1970s to 7.1 ppm in the 1990s. Norway reduced their OEL for styrene from 50 ppm to 20 ppm in 1989. It was suggested that changes in manufacturing techniques, improved ventilation, hygienic measures, lower exposure limits and other reduction measures by the plants contributed to the reduction in the workplace concentrations. They also observed higher exposures among reinforced plastics industry workers.

[63] Lenvik, K. et al., 1999

Appendix D

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