DEVELOPMENT OF A TOOL FOR THE ADJUSTMENT OF WORKPLACE EXPOSURE STANDARDS FOR ATMOSPHERIC CONTAMINANTS DUE TO EXTENDED WORK SHIFTS

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Abstract

In December 2010, the AIOH published a position paper on "Adjustment of Workplace Exposure Standards for Extended Work Shifts". The position paper provided an overview of the workplace exposure standard (WES) adjustment methods for atmospheric contaminants, a selection of legislative approaches in Australia and other countries and examples of the varying outcomes. It concluded that the current guidelines provided by Safe Work Australia (SWA) are inadequate in that they don't consider or accommodate the varying range of health effects of different agents and their time frame for adverse effect and could lead to inconsistent advice for affected workers. The AIOH recommended moving to a model similar to that of the 'Québec model' that is computer-based and utilises current toxicological information and can provide consistent guidance.

This paper provides a brief overview of ensuing discussions with SWA and the work of the AIOH Exposure Standards Committee on the development of an Excel tool that facilitates the adjustment of SWA WESs for extended shifts, providing a choice of either the Québec model or the Brief and Scala model according to a specific logic tree.

Introduction

The recommendation of the AIOH (2013) position paper "Adjustment of Workplace Exposure Standards for Extended Work Shifts", first published in 2010, to move to a model similar to that of the 'Québec model' that is computer-based and utilises current toxicological information and can provide consistent guidance, initially led to the development of an Excel tool based on that of the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) (Drolet, 2008). We developed the tool using Safe Work Australia (SWA) workplace exposure standards (WES) tables that had been assigned adjustment factors by the AIOH Exposure Standards Committee.

The American Conference of Governmental Industrial Hygienists (ACGIH®) and SWA have in the past recommended the use of the Brief & Scala (1975) correction model for adjusting extended work schedules. Since 2004 however, the ACGIH® has also referred to the model jointly developed by the University of Montréal and the IRSST, emphasising that it generates results closer to the physiologically-based toxicokinetic models (PBPK) than the Brief & Scala model.

Safe Work Australia Documentation

Sections 17 and 19 of the Work Health and Safety (WHS) Act together require that exposure to substances in the workplace is kept as low as is reasonably practicable. Under the WHS Regulations, a person who conducts a business or undertaking (PCBU) must:

- manage risks under the WHS Regulations, including those associated with using, handling and storing hazardous chemicals safely, airborne contaminants and asbestos (r 48);
- ensure that no person at the workplace is exposed to a substance or mixture in an airborne concentration that exceeds the exposure standard for the substance or mixture (r 49); and
- ensure that air monitoring is carried out to determine the airborne concentration of a substance or mixture at the workplace to which an exposure standard applies if:
    - the person is not certain on reasonable grounds whether or not the airborne concentration of the substance or mixture at the workplace exceeds the relevant exposure standard, or
    - monitoring is necessary to determine whether there is a risk to health (r 50).

Safe Work Australia has produced the document "Workplace Exposure Standards for Airborne Contaminants" (SWA, 2013b), containing a list of workplace exposure standards (WES) for airborne contaminants and how to meet PCBU duties under the WHS Act and the WHS Regulations. It is a supplement to the Hazardous Substances Information System (HSIS; SWA, 2013a), which is available on the SWA website.

SWA has also produced the document "Guidance on the interpretation of workplace exposure standards for airborne contaminants" (SWA, 2013c), which provides more detailed information about the application of exposure standards.

A WES, the airborne concentration of a particular substance or mixture that must not be exceeded, can be a:

- 8-hour time-weighted average (TWA);
- peak limitation (similar to a ceiling value); and / or
- short term exposure limit (STEL).

SWA (2013b) clearly states that "Where workers have a working day longer than eight hours or work more than 40 hours a week, the person conducting the business or undertaking must determine whether the TWA exposure standard needs to be adjusted to compensate for the greater exposure during the longer work shift, and decreased recovery time between shifts.

Peak limitation or Short Term Exposure Limit exposure standards must not be adjusted. 8-Hour TWA exposure standards must not be adjusted (increased) for shorter work shifts."

SWA (2013c) currently mentions several different methods for adjusting WES, but recommends use of the Brief & Scala method for its simplicity of use and conservatism. However, there is currently a recommendation to update the "Guidance on the interpretation of workplace exposure standards for airborne contaminants" document such that it recommends use of either the Québec or the Brief & Scala models, supported by an on-line / computer-based tool, the Australianised Québec model.

Québec Model

This model is based on the following guiding principle "…ensuring an equivalent degree of protection to workers with a conventional schedule of 8 hours a day, 5 days a week, and to workers with unusual work schedules" and using the logic of the Occupational Safety and Health Administration (OSHA) (Paustenbach, 1994); the OSHA model. IRSST and University of Montréal toxicologists proposed adjustment categories (Table 1) for each of the substances found in Schedule I of the Quebec Regulation respecting occupational health and safety (ROHS), as well as a method for calculating adjustment factors supported by toxicokinetic modeling. This group of experts also defined the conditions and limitations of application of the adjustment procedure (Drolet, 2008).

Table 1: List of adjustment categories for the Quebec model (as also proposed by OSHA)

Adj	Adjustment classification	Type of adjustment
1A	Substances regulated by a ceiling value	**No** adjustment
1B	Irritating or malodorous substances	
1C	Simple asphyxiants, substances presenting a safety risk or a very low health risk, whose half-life is less than 4 hours. Technological limitations	
2	Substances that produce effects following *short-term* exposure	**Daily** adjustment
3	Substances that produce effects following *long-term* exposure	**Weekly** adjustment
4	Substances that produce effects following *short-* or *long-term* exposure	Daily or weekly adjustment **the most conservative of the two**

In the case of **Category 1** substances, the time-weighted average exposure standard (TWAES) does not have to be adjusted, regardless of the type of work schedule. Values for short term exposure limits (STELs) and ceiling or peak limits are not subject to the adjustment principle; only the TWAESs are subject to the adjustment principle. For substances belonging to the other categories, the TWAES is adjusted by applying one of the following equations:

$F_a = 8/H_d$ **Category 2** substances, requiring a *daily* adjustment,

$F_a = 40/H_{wk}$ **Category 3** substances, requiring a *weekly* adjustment,

Where: F_a = adjustment factor

H_d = exposure duration in hours per shift

H_{wk} = average duration of work shifts per week *based on a repetitive work cycle*.

In the case of **Category 4** substances, the F_a must be calculated for each of the two equations for Categories 2 and 3, and the lowest F_a must be applied. It should be noted that the above-mentioned computer-based tool automatically calculates the adjusted average exposure value (AAEV) from the most conservative F_a.

The TWAES adjustment process applies only to nominal schedules with shifts of no less than 4 hours and no more than 16 hours and in no case can the AAEV be greater than the TWAES. It should also be noted that OEL adjustment is based on the toxicological knowledge available in the scientific and technical literature.

The IRSST guidance document (Drolet, 2008) should be referred to for relevant definitions and other documentation of the Québec model.

Australian Workplace Exposure Standards

There are currently 673 WES for a range of substances (and mixtures) in the document "Workplace Exposure Standards for Airborne Contaminants" (SWA, 2013b) and in the HSIS (SWA, 2013a). The great majority of these were adopted from the ACGIH®, updated to reflect the values published by the ACGIH® in 1994. Between 1998 and 2005, eighty WES reviews were undertaken. The vast majority of these involved the adoption of British Health and Safety Executive (HSE) exposure standards or the National Industrial Chemical Notification and Assessment Scheme (NICNAS) Priority Existing Chemical (PEC) Report recommendations. The last update of the WESs was in August 2005, when 31 substances were amended using the fourth batch of Source A updates adopted from the British HSE and the first batch of Source A updates adopted from the NICNAS PEC report recommendations (SWA, 2013a).

There are a number of WESs that are higher than the exposure standards for other countries (eg. the arsenic and 1,3-butadiene WESs are five times higher than their respective TLV®), as well as a number that are lower (eg. the chloroform WES is five times lower than the TLV®), and there are many international exposure standards not represented in the WESs. There are also some WESs that are not represented in Schedule I of the Québec Regulations, that were compared with for determination of an appropriate adjustment category (AC).

A key point to note then is that a number of the Australian WESs have not been reviewed for a number of years, hence may not reflect the most recent research on health effects due to exposures in the workplace. In assigning an appropriate AC to each of the Australian WESs, there was no intent to also update the WES[1] itself.Current documentation was reviewed in order to assign the most appropriate AC with regard to health effects, as detailed in the next section.

[1] The AIOH Exposure Standards committee has been developing position papers on key substances (eg. asbestos, lead, diesel particulate matter, respirable crystalline silica, man-made vitreous fibres, etc) for the purpose of updating documentation relevant to known health effects due to workplace exposure and recommending occupational exposure limits. The committee is also engaging with SWA

The Australianised Québec Model

The starting point for developing the Australianised Québec model was to take the assigned adjustment category (AC) for each of the substances in Schedule I of the Québec Regulation (Drolet, 2008) and match these to corresponding substances in the list of Australian WESs from "Workplace Exposure Standards for Airborne Contaminants" (SWA, 2013b). This was thought to be the best approach as this was the most recent such assignment of ACs. Where there was no matching substance, end point health effects and toxicology were used to derive the adjustment category assignment.

Once ACs were thus assigned, the following processes were undertaken to determine the need for modification of the "Québec model" IRSST ACs:

A. WESs with a peak limitation (43 substances) were identified and assigned an AC = 1A. Not all ROHS listed substances with a peak limitation (ceiling limit) had a corresponding WES with such a limit, and *vice versa*.
B. WESs with a carcinogen designation (Carc. 1A - known to have carcinogenic potential for humans; and Carc. 1B - presumed to have carcinogenic potential for humans) were identified and assigned an AC = 3 or 4, except for LPG, which retained its AC = 1C. A Carc.2 (suspected human carcinogen) designation did not usually elicit a change to the existing AC.
C. WESs with a sensitiser designation were identified and assigned an AC = 2, 3 or 4, except for Benzoyl peroxide, which retained its AC = 1B.
D. Selected WESs were reviewed by the Exposure Standards committee members and adjusted if the more recent documented health effects (ACGIH, 2011 & 2013) suggested a different AC.

Recent ACGIH® documentation (ACGIH, 2011), and health effects as listed in the 2013 ACGIH® TLV booklet (ACGIH, 2013), were used to help validate proposed AC changes to those published by the IRSST (Drolet, 2008). Another list of assigned ACs based on the OSHA model, developed from the "Desktop Guide to Adjusting TLVs", which was based on a review of the Documentation for the chemicals in the 6th Edition of *Documentation of the Threshold Limit Values and Biological Exposure Indices* published by the ACGIH® (Wylie, 2008), was also used to help validate any proposed changes.

There were a number of substances where the ACGIH TLV® and the WES were so disparate, largely due to the WES being old, that it was difficult to discern whether the TLV® gave useful information on the sentinel effect used for developing the WES. In addition, the 'TLV basis' in the booklet (ACGIH, 2013) did not always accurately reflect the documentation detail (ACGIH, 2011).

For several substances it was difficult to understand the conclusions drawn from the documentation. For a number of substances, there was limited documentation, often based solely on animal studies (eg. the various pesticides). As an example cyclohexene, with an AC = 1B, has a TLV® of 300 ppm based on upper respiratory tract (URT) and eye irritation. The introductory paragraph reads: "A TLV–TWA® of 300 ppm (1010 mg/m^3) is recommended for occupational exposure to cyclohexene, in part by analogy with cyclohexane (see TLV® Documentation for Cyclohexane). This value is intended to minimize the potential for eye and mucous membrane irritation, based on limited data." The cyclohexane TLV® documentation barely mentions irritation and at least two of the half dozen or so times that irritation is mentioned make the point that it does NOT happen at levels of interest. In these cases professional opinion was used to decide the AC.

Those WESs with an AC that is different to those published by the IRSST (Drolet, 2008) are listed in appendix 1. In addition, a working sheet that documents AC decisions is maintained in an Excel spreadsheet kept by the AIOH Exposure Standards committee.

in their review of the workplace exposure standards regulatory framework, which will include the process for setting and reviewing WESs.

Brief and Scala Model

Brief & Scala (1975) proposed a "simple system" for adjusting the TLVs® for "novel work schedules". A reduction factor (adjustment factor - F_a) for reducing the TLV® for a novel work schedule is to be calculated using the following equation:

Daily adjustment: $F_a = (8 / H_d) \times (24 - H_d / 16)$

They suggest that the F_a value should be applied to:

- TLVs® expressed as a TWAES with respect to the mean and permissible excursion; and
- TLVs® that have a ceiling (peak) value, except where the peak limitation is based solely on sensory irritation. They suggest that in this case the irritation response threshold is not likely to be altered downward by an increase in number of hours worked and modification of the TLV® is not needed.

They then state that the F_a value should be applied to TLVs® that are based on systemic effect (acute or chronic). Acute effects are viewed as falling into two categories: (a) rapid with immediate onset and (b) manifest with time during a single exposure. They suggest that "the former are guarded by the C notation and the latter are presumed time and concentration dependent and hence, are amenable to the modifications proposed." STELs are not mentioned, but are presumed to be thus included in the adjustment process.

The number of days worked per week is not considered, except in the special case of a 7-day workweek. In this case the F_a value is calculated as follows:

Weekly adjustment: $F_a = (40 / H_{wk}) \times (168 - H_{wk} / 128)$

The Exposure Standards committee decided to only apply an adjustment factor to OELs for those substances that have a long-term chronic effect, in alignment with good occupational hygiene practice (Paustenbach, 1994) and SWA suggested practice. That is, no adjustment was made to peak and STEL values.

The AIOH / SWA TWAES Adjustment Tool

The Exposure Standards committee re-developed the Excel spreadsheet tool, which incorporated the Australianised Québec model, to include the Brief and Scale model as a choice of TWAES adjustment method. The structure of the AIOH / SWA tool is presented in figure 1 and a schematic depicting the decision logic (logic tree) embedded in the Excel tool for adjusting TWAESs is presented in figure 2. A screenshot of pages within the tool are presented in figures 3 and 4.

The tool has had many steps in its evolution and is likely to continue to evolve as we refine it and as the WESs are updated. The Exposure Standards committee will maintain a watching brief on the updating of the WESs so as to ensure that the ACs reflect the relevant known health effects.

It should be noted that OEL adjustment is based on the toxicological knowledge available in the scientific and technical literature. However, the limits of our knowledge have to be recognized regarding dose-response relationships applicable to humans, dose-absorption kinetics relating to saturation of defence mechanisms, animal-human extrapolation of toxicological data, the distribution of contaminants and their metabolites at the point of action of target organs, etc. Use of these models assumes a good knowledge of the work environment and application by a competent person.

Figure 1: Structure of AIOH / SWA tool

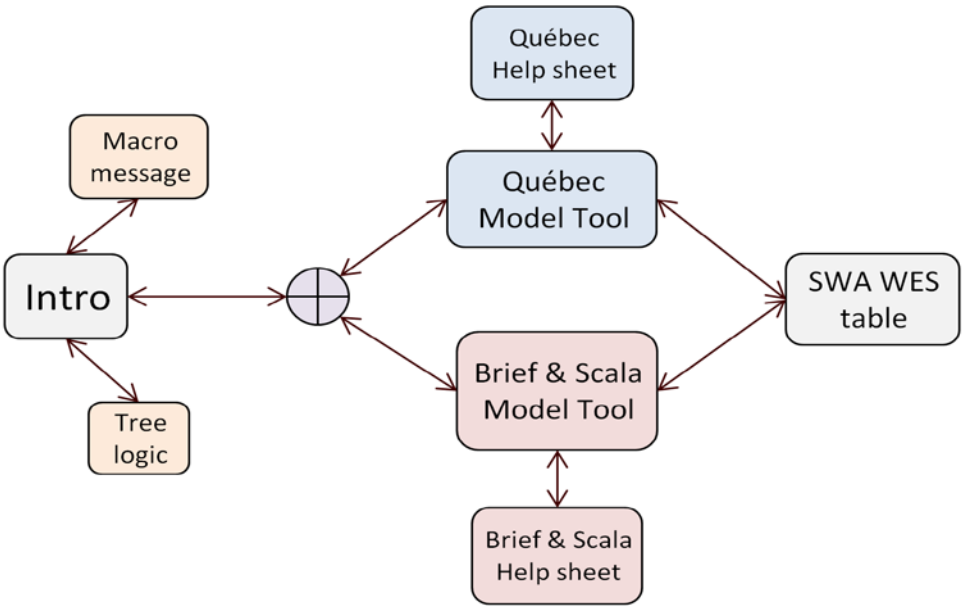


Figure 2: OEL adjustment process (logic tree) for unusual work schedules

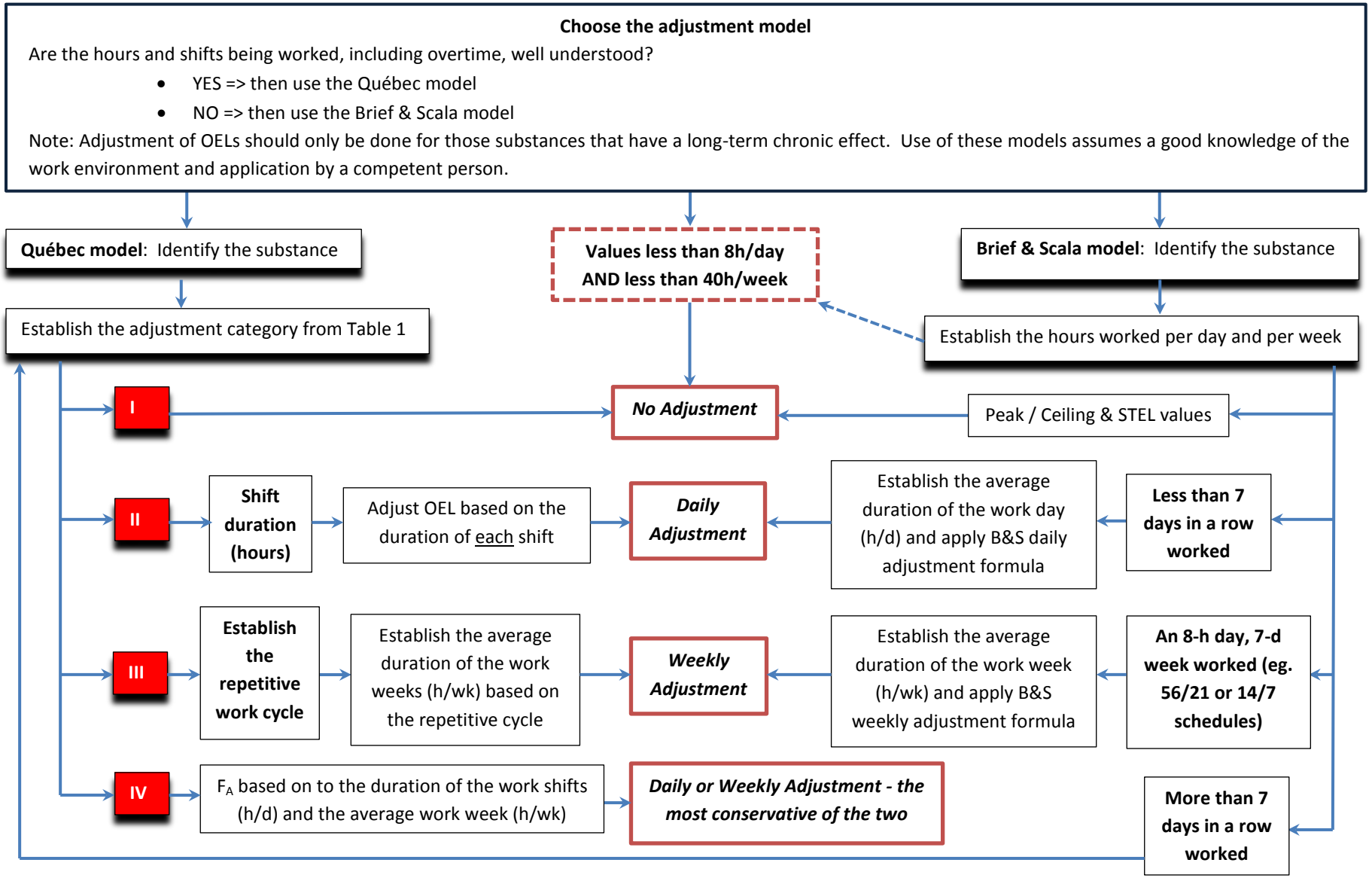


Figure 3: Introductory page to the AIOH / SWA tool

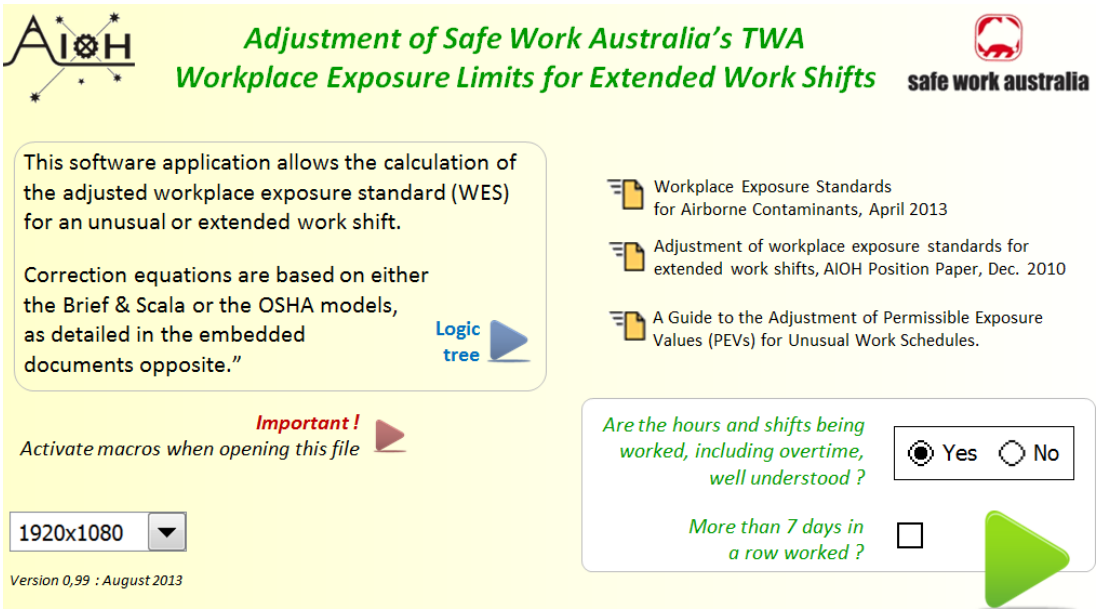
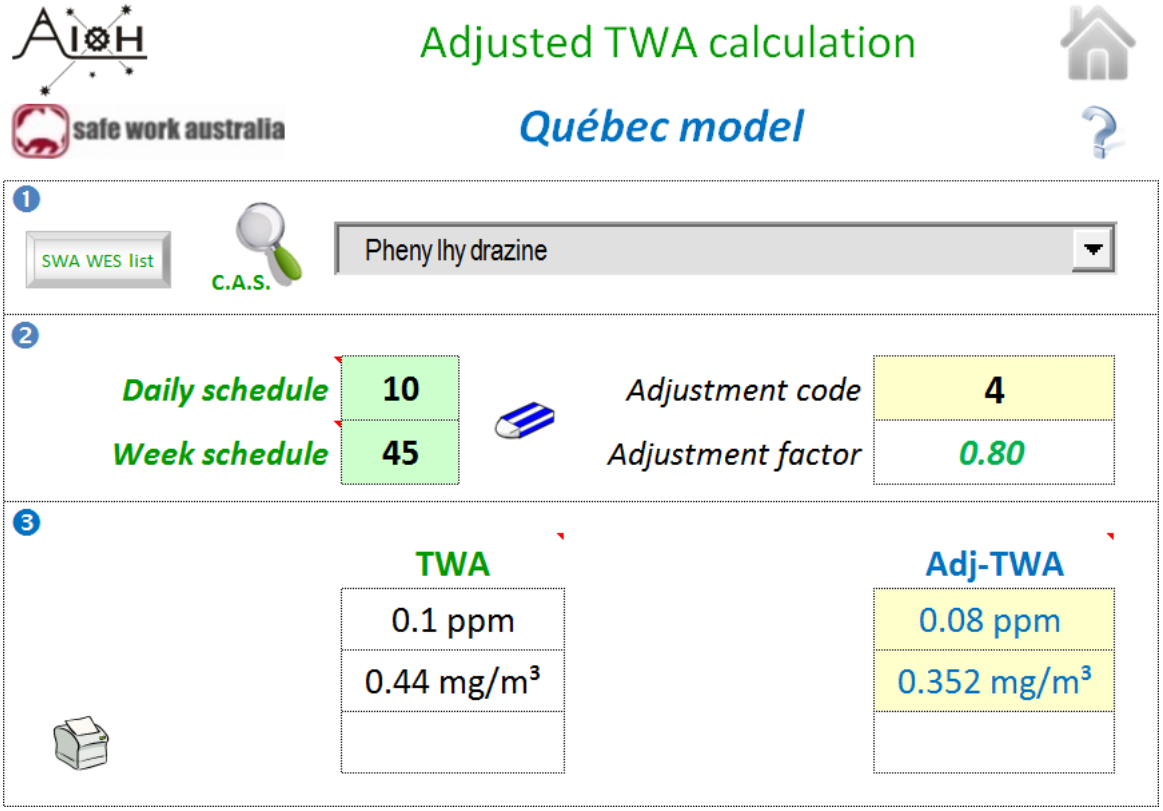
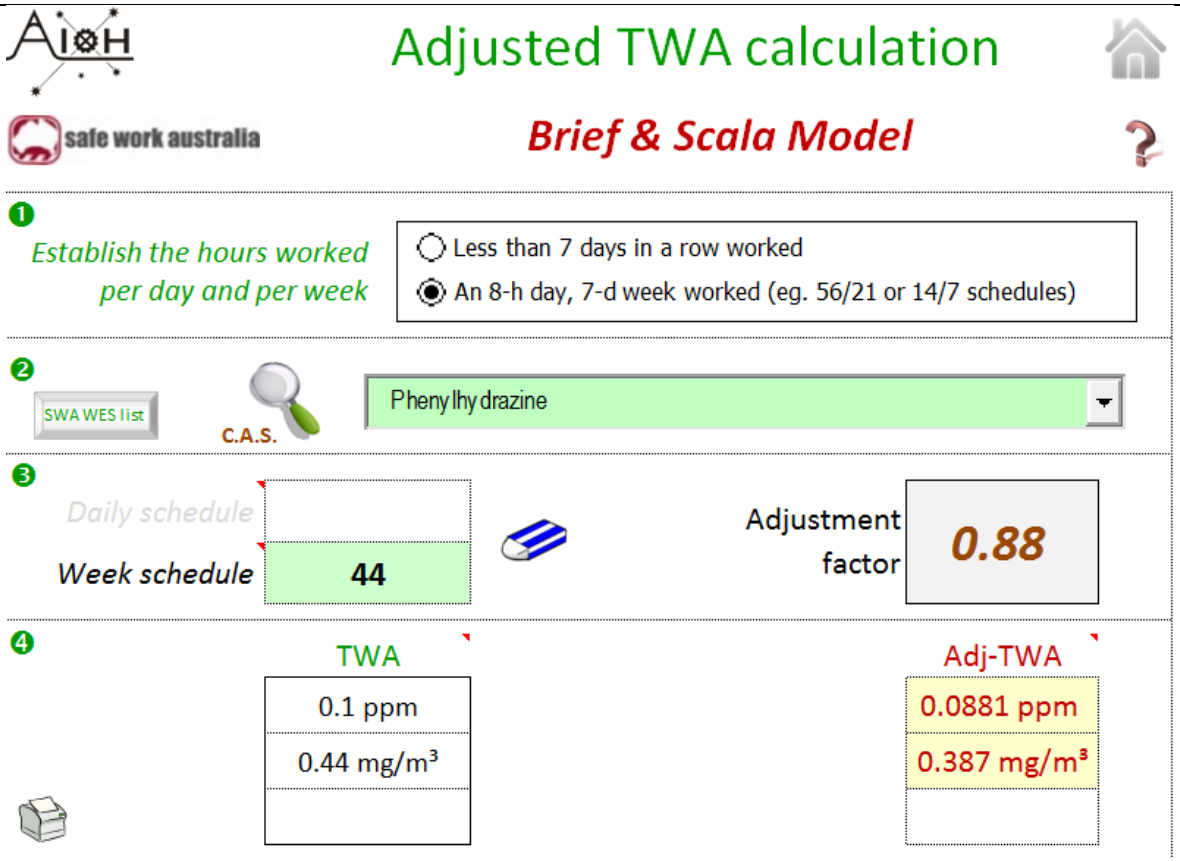


Figure 4: Working pages to the AIOH / SWA tool





Concluding Comments

The AIOH Exposure Standards Committee considers that this Excel-based tool will provide an appropriate and accessible methodology to adjust exposure standards for extended work shifts. Its use should therefore provide more consistent and informed advice for affected workers. The tool is feely available on the AIOH web site, however we recommend that the workplace monitoring strategy should at least have been reviewed by appropriately qualified and experienced persons (eg. a certified occupational hygienist).

The Committee also regards updating of the WESs to be of vital importance for protecting the health of the Australian workforce. We look forward to participating further with SWA in their updating.

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Appendix 1: Substances for which the WES adjustment (Adj) category was changed from the IRSST one.

Substance	CAS No.	IRSST Adj	AIOH Adj	Health Effect	Decision Reason
Acetaldehyde	75-07-0	1A	1B	Eye & upper respiratory tract (URT) irritation	A
Acetic anhydride	108-24-7	1B	1A	Eye & URT irr (plus burns)	A
Acrylic acid	79-10-7	1B	4	URT & eye irr; pulmonary function effect; skin notation	D
Acrylonitrile (Vinyl cyanide)	107-13-1	3	4	CNS impairment; LRT irr; skin & sensitiser notation; Carc. 1B	B, C & D
Allyl alcohol	107-18-6	1B	2	Eye & URT irr; skin notation	D
Allyl chloride (3-Chloro-1-propene)	107-05-1	3	4	Eye & URT irr; liver & kidney damage; Carc. 2	D
Allyl glycidyl ether (AGE)	106-92-3	1B	4	URT irr; dermatitis; eye & skin irr; skin & sensitiser notation; Carc. 2	C & D
Aniline & homologues	62-53-3	1C	4	MeHb-emia; skin & sensitiser notation; Carc. 2	C & D
Anisidine (o-, p- isomers)	29191-52-4	2	4	MeHb-emia; skin notation; Carc. 1B	B
Benomyl (Benlate)	17804-35-2	1C	4	URT irr; male repro & testicular damage; embryo/foetal damage; sensitiser	C & D
Biphenyl (Diphenyl)	92-52-4	1B	3	Pulmonary function	D
Bitumen fumes (Asphalt)	8052-42-4	3	4	Eye & URT irr	D
2-Butoxyethanol	111-76-2	3	1B	Eye & URT irr (sk notation no longer recommended by ACGIH®)	D
n-Butyl acrylate (Acrylic acid)	141-32-2	1B	4	Skin, eye & URT irr; sensitiser	C
Captafol (Difolatan)	2425-06-1	3	4	Skin irr & dermatitis; skin & sensitiser notation; Carc. 1B	B, C & D
Captan	133-06-2	3	4	Skin irr; skin & sensitiser notation; Carc. 2	C & D
Chlorine	7782-50-5	1C	1B	URT & eye irr	D
Copper, dusts & mists (as Cu)	7440-50-8	1B	2	Irr; GI; (metal fume fever)	D
Cyanamide	420-04-2	1B	4	Skin & eye irr; sensitiser	C
Cyclohexane	110-82-7	1B	2	CNS impairment	D

Dibutyl phthalate	84-74-2	1B	4	Testicular damage; eye & URT irr; Repr. 1B	D
o-Dichlorobenzene	95-50-1	1A	1B	URT & eye irr; liver damage (in rats)	A & D
Dichlorofluoromethane (Freon 21)	75-43-4	4	3	Liver damage	D
Diethanolamine	111-42-2	1B	4	Liver & kidney damage (also irritative effects)	D
Diethyl phthalate	84-66-2	3	1B	URT irr	D
Diethylene triamine	111-40-0	3	4	URT & eye irr; skin & sensitiser notation	C
Dimethyl sulphate	77-78-1	3	4	Eye & skin irr; skin & sensitiser notation; Carc. 1B	B, C & D
Dioxathion (Delnav)	78-34-2	3	4	Cholinesterase inhib; skin notation	D
Substance	**CAS No.**	**IRSST Adj**	**AIOH Adj**	**Health Effect**	**Decision Reason**
Ethyl acrylate	140-88-5	3	4	URT, eye & GI irr; CNS impair; skin sens	C & D
Ethyl benzene	100-41-4	3	4	URT irr; kidney damage (nephropathy); cochlear impair	D
Ethylene glycol (particulate)	107-21-1	1A	1B	URT & eye irr; skin notation	A
Ethylene glycol (vapour)	107-21-1	1A	1B	URT & eye irr (headaches, vasodilation?); skin notation	A
Ethylene glycol dinitrate (EGDN)	628-96-6	1A	2	Vasodilation; headache; skin notation	A & D
Ferbam	14484-64-1	1B	3	CNS impairment; body weight effect; spleen damage	D
Formaldehyde	50-00-0	1A	4	URT & eye irr, but an A2 carcinogen & sensitiser	C & D
Glutaraldehyde	111-30-8	1A	4	URT, skin & eye irr; CNS impair; sensitiser	C & D
Glycidol (2,3-Epoxy-1-propanol)	556-52-5	1B	4	URT, eye & skin irr; cancer & genotoxicity; Carc. 1B	B
2-Hydroxypropyl acrylate	999-61-1	1B	4	Eye & URT irr; skin notation & sensitiser	C & D
Indene	95-13-6	1B	4	Liver damage	D
Manganese, fume (as Mn) (Manganese tetroxide)	7439-96-5	4	3	CNS impairment - TWA= 0.02 mg/m3 (R) & 0.1 mg/m3 (I)	D

Man-Made Vitreous (Silicate) Fibres - Glass wool		1C	1B	URT, skin & eye irr	D
Methoxychlor (DMDT)	72-43-5	4	3	Liver damage; CNS impairment (based on animal studies; no mention of CNS in documentation)	D
4-Methoxyphenol	150-76-5	1B	4	Eye irr; skin damage; sensitiser	C
Methyl 2-cyanoacrylate	137-05-3	3	1B	URT & eye irr	D
Methyl hydrazine	60-34-4	1A	4	URT & eye irr; lung cancer; liver damage; skin notation	D
Methyl methacrylate	80-62-6	1B	4	URT & eye irr; body weight effects; pulmonary oedema; sensitiser	C & D
Naphthalene	91-20-3	1B	4	Haematological effect; URT & eye irr; eye damage; skin notation; Carc. 2; (NIC is to URT irr only)	D
Nitroglycerin	55-63-0	1A	2	Vasodilation; skin notation	A & D
2-Nitrotoluene	88-72-2	2	4	MeHb-emia; skin notation; Carc. 1B	B
Pentachlorophenol	87-86-5	3	4	URT & eye irr; CNS & cardiac impairment; skin notation; Carc. 2	D
Phenylhydrazine	100-63-0	3	4	Anemia; URT & skin irr; skin & sensitiser notation; Carc. 1B	D
beta-Propiolactone	57-57-8	3	4	Skin cancer (Carc. 1B); URT irr	D
Propylene oxide	75-56-9	3	4	Eye & URT irr; Carc. 1B	B

Substance	**CAS No.**	**IRSST Adj**	**AIOH Adj**	**Health Effect**	**Decision Reason**
Rhodium, insoluble compounds (as Rh)	7440-16-6	3	1B	LRT irr	D
Subtilisins (Proteolytic enzymes as 100% pure crystalline enzyme)	1395-21-7	1C	4	Skin, URT & LRT irr; asthma; sensitiser	D
Tetraethyl lead (as Pb)	78-00-2	3	2	CNS impairment; skin notation	D
Tetrahydrofuran	109-99-9	1B	4	URT irr; CNS impairment; kidney damage; skin notation	D

Tributyl phosphate	126-73-8	1B	4	Bladder, eye & URT irr; Carc. 2	D
1,2,4-Trichlorobenzene	120-82-1	1B	1A	Eye & URT irr	A
Trichloroethylene	79-01-6	2	4	CNS impairment; cognitive decrements; renal toxicity; skin notation; Carc. 1B	B
1,2,3-Trichloropropane	96-18-4	3	4	Liver & kidney damage; eye & URT irr; skin notation; Carc. 1B	B
Triorthocresyl phosphate	78-30-8	3	4	Cholinesterase inhib; skin notation	D
Turpentine (wood)	8006-64-2	1B	4	URT & skin irr; CNS impair; lung damage; sensitiser	C & D