ADJUSTMENTS FOR UNUSUAL WORK SCHEDULES

Authors

John Elias, MPH, CIH, ROH, CRSP. President, Elias Occupational Hygiene Consulting Inc. (jelias@mts.net)
Alison Reineke, BSc, B.HEc, CIH, CRSP. Director, Elias Occupational Hygiene Consulting Inc. (Alison@eliasconsulting.ca)

Introduction

TLVs are guidelines to be used by professional occupational hygienists. TLVs will not protect all workers under all conditions. One of the conditions that must be addressed by the occupational hygienist is the work schedule. The work schedule that was assumed when developing the TLVs was a normal 8-hour day and 40-hour week. Any variation from this must be taken into account, and the occupational hygienist must provide equivalent protection for workers employed on different work schedules.

It should be noted that other guidelines such as NIOSH's RELs may use a different definition of a normal work schedule. In the case of NIOSH it is up to a 10 hour day during a 40 hour week. When using an exposure limit with a different definition of a normal work schedule, that definition should be applied to the following material.

It should also be noted that unusual work schedules are not defined the same as shift work where work is done outside of the normal working hours such as at night. Issues surrounding shift work are discussed under Shift Work.

Toxicology Background – Biological Half–Life

Our objective is to keep the concentration of workplace chemicals in target organs below the level where harmful effects would be observed.

When workers are exposed to workplace chemicals, the chemicals are absorbed into the body. The amount absorbed, or dose, depends on the concentration of chemical and the length of time the exposure takes place. It also depends on how quickly the chemical is removed from the body. This is a dynamic process where chemicals are absorbed and eliminated at the same time. If the chemical is absorbed faster than it can be eliminated, the material will accumulate in the target organs.

The rate that a material is eliminated from the body is called the half-life. The half-life is the length of time it takes for the body to eliminate half of the material. Some materials are eliminated almost as fast as they are absorbed (hydrogen sulfide has a half-life <10 min). These materials are less likely to accumulate in target organs. Other materials take much longer to be eliminated (lead has a half-life ≈900 hours). These materials can

quickly accumulate in target organs as the exposure time increases. It is also likely that a person will be re-exposed before all of the original chemical has been eliminated.

If the length of the workday is increased, there is more time for the chemical to accumulate, and less time for it to be eliminated. It is assumed that the time away from work will be contamination free. Ideally, the concentration of material remaining in the body should be zero at the start of the next day's work. The aim is to keep the chemical concentrations in the target organs from exceeding the levels determined by the TLVs (8 hr day, 5 day week) regardless of the shift length[1,2,3,4].

Models for Adjusting TLVs

The following are four models that are in use at this time to adjust TLVs for different shift lengths:

Brief and Scala;
OSHA;
Quebec (IRSST); and
Pharmacokinetic.

None of these models should be used to increase the TLV-TWA if the day or week is shorter than the normal work hours.

Brief and Scala Model

The Brief and Scala method, developed in 1975, was one of the first models used for adjusting for unusual work schedules. It provided an adjustment component for both the longer workday and the corresponding shorter recovery period. The method applies to all chemicals regardless of their half-lives and consists of two parts:

Daily adjustment:

Adjusted TLV = TLV x Daily Reduction Factor

$$\text{Adjusted TLV} = TLV \times \left\{\frac{8}{h_d}\right\} \times \left\{\frac{24 - h_d}{16}\right\}$$

Where h_d = hours worked per day

Weekly Adjustment:

Adjusted TLV = TLV x Weekly Reduction Factor

$$\text{Adjusted TLV} = TLV \times \left\{\frac{40}{h_w}\right\} \times \left\{\frac{168 - h_w}{128}\right\}$$

Where h_W = hours worked per week

Both the daily and weekly adjustment factor should be calculated, and the worst case should be used.

It should be noted that adjustments are not to be made for chemicals whose TLV is based on irritation since this TLV is determined by concentration and is not necessarily affected by hours of exposure[4].

Example of Calculation

A workplace is working five 10-hour shifts each week. The TLV-TWA for the chemical used is 100 ppm. What exposure limit should they use?

Daily adjustment:

$$TLV_{adj} = 100 \times \left(\frac{8}{10}\right) \times \left(\frac{24-10}{16}\right) = 70ppm$$

Weekly adjustment:

$$TLV_{adj} = 100 \times \left(\frac{40}{50}\right) \times \left(\frac{168-50}{128}\right) = 73ppm$$

The daily adjustment of 70ppm is greater, and should be the exposure limit used for the chemical in this workplace.

This is a conservative value. It takes into account both the longer exposure time, and the shorter recovery time. It does not require research to find hard to find data such as the half-life of the chemical and therefore it is easy to use.

OSHA Model

In 1979 OSHA developed a model for adjusting PELs to take into account the effect of chemical exposures over longer than normal (8 hr) work shifts. This model is no longer in use, except for lead[4,5]. Although OSHA no longer uses it, it will be addressed here since it is felt to be a useful tool for the protection of workers.

Like the Brief and Scala method it has an adjustment for both daily and weekly exposures.

Acute (short term effects) adjustment:

$$TLV_{adj} = TLV \times \frac{8\ hr}{hours\ of\ exposure\ per\ day}$$

Chronic (long term effects) adjustment:

$$TLV_{adj} = TLV \times \frac{40\ hr}{hours\ of\ exposure\ per\ week}$$

Unlike the Brief and Scala Model, the OSHA Model only addresses the extended work day, and does not include the effect of the reduced recovery period. The rationale was that if the amount of chemical absorbed during the extended shift was equal to the amount absorbed during a normal (8 hr) shift, the protection would be the same.

Instead of using the straight day or week to determine the adjustment factor, the OSHA Model classifies chemicals by acute and chronic effects. Whether an effect is acute or

chronic takes into account the biological half-life (if it is known) and the rationale for the exposure limit itself. Table 1 shows the health effects that the rationale is based on.

Table 2 gives the category classifications for adjustment of exposure limits as defined by OSHA. It will be noted that materials falling in the first category (1A, 1B, and 1C) require no adjustment. These a ceiling values or materials causing irritation, and thus can have immediate effects regardless of shift length, or call for best practice controls (as low as reasonably practicable).

Table 1: OSHA Health Effects and Health Code.

Health Code	Health Effect
1	Cancer
2	Chronic toxicity – suspected carcinogen or mutagen
3	Chronic toxicity – long term organ toxicity other than nervous, respiratory, hematologic, or reproductive
4	Acute toxicity – short term high hazard effects
5	Reproductive hazards –fertility impairment or teratogenesis
6	Nervous system disturbances – cholinesterase inhibition
7	Nervous system disturbances – nervous system effects other than narcosis
8	Nervous system disturbances – narcosis
9	Respiratory effects other than irritation – respiratory sensitization, asthma
10	Respiratory effects other than irritation – cumulative lung damage
11	Respiratory effects – acute lung damage / edema
12	Hematologic disturbances – anemias
13	Hematologic disturbances – methaemoglobinaemia
14	Irritation – eye, nose, throat, skin – Marked
15	Irritation – eye, nose, throat, skin – Moderate
16	Irritation – eye, nose, throat, skin – Mild
17	Asphyxiants, anoxiants
18	Explosive, flammable, safety (no adverse effects encountered when good housekeeping practices are followed).
19	Generally low risk health effects – nuisance particulates, vapors gases
20	Generally low risk health effects – odors

Category 2 is for acute effects, which would be effects that take place a short time after exposure. The adjustment is calculated with the Acute (short term) formula.

Category 3 is for chronic effects, which would be effects that take place over a longer period of time with multiple exposures. The adjustment is calculated with the Chronic (long term effects) formula.

Category 4 is used when there are both acute and chronic effects. In this case, both the Acute and Chronic adjustments are calculated and the most restrictive one (worst case) is applied similar to the Brief and Scala Model.

To determine which category a chemical falls into, use Table 1 above, along with the current Documetation of the Threshold Limit Values by the ACGIH to determine the Health Effect Code. Table 3 provides a general guide to what Health Effect Code corresponds to what Category. It should be noted that some Health Effect Codes correspond to more than one classidication. This may depend on how quickly the the health effects become noticable. The Documentation should be consulted to make the best selection of Category.

Table 2: OSHA Adjustment Criteria.

Category	Classification	Adjustment Criteria	Rationale
1A	Ceiling Standard	None	Ceiling level should not be exceeded for even short times. No change needed
1B	Irritants	None	This is a short term effect without accumulation. No change needed
1C	Technological Limitations	None	Limits are based on technological feasibility or good practice. No change needed.
2	Acute Toxicants	Hours/day	Short term effects and does not accumulate. Short half-life.
3	Chronic Toxicants	Hours/week	Long term effects and can accumulate. Long half-life.
4	Both Acute and Chronic	Hours/day and/or Hours/week	Has both short and long term effects.

Table 3: OSHA Category and the Corresponding Health Effect Code.

Category	Health Effect Code#
1A	11, 14
1B	11, 14, 15, 16, 20
1C	1, 17, 18, 19
2	3, 4, 8, 9, 11, 12, 13, 14, 16
3	2, 3, 4, 5, 6, 7, 9, 10, 12, 13, 15
4	Both 2 and 3

In order to get the correct Category and Classification you must understand the basis for TLV. Use the Documentation and professional judgement to get it right. The easy route is to make everything a class 4. This can impose unnecessary costs on the employer without any significant benefit to the worker.

Example of Calculation

Malathion is used during a 10 hour shift, 5 days a week. What adjustment must be made to the TLV of 1 mg/m^3?

The TLV is based on cholinesterase inhibition as reported in the TLV Booklet, Column 6. The Documentation suggests that a single dose at the TLV-TWA is unlikely to have an adverse effect. The Health Effect Code would be #6 (Nervous system disturbances – cholinesterase inhibition), a chronic effect. The calculation for a chronic effect is:

$$TLV_{adj} = 1\,mg/m^3 \times \frac{40\ hrs}{50\ hrs\ exposure\ per\ week} = 0.8\,mg/m^3$$

This is a less conservative value than what would be provided by the Brief and Scala method. It does not take into account the shorter recovery time. It requires more information about the toxicity of the material and the toxicological basis for the exposure limit. However, it does eliminate certain classes of materials that do not require adjustment, so as to not impose unnecessary controls and expenses.

Quebec (IRSST) Model

The Quebec model is essentially based on the OSHA model. It uses the same categories and formulas for calculating the adjustment factor as shown in Table 4 from the Quebec Technical Guide T-22[6, 7].

Table 4: Quebec adjustment categories.

Ad	Adjustment classification	Type of adjustment
I-a	Substances regulated by a ceiling value	**No** adjustment
I-b	Irritating or malodorous substances	
I-c	Simple asphyxiants, substances presenting a safety risk or a very low health risk, whose half-life is less than 4 hours. Technological limitations	
II	Substances that produce effects following *short-term* exposure	**Daily** adjustment
III	Substances that produce effects following *long-term* exposure	**Weekly** adjustment
IV	Substances that produce effects following a *short-* or *long-term* exposure	Daily or weekly adjustment **the most conservative of the two**

Like the OSHA method it has an adjustment for both daily and weekly exposures.

Daily adjustment:

$$Adjustment_{daily} = \frac{8}{daily\ exposure\ duration}$$

Weekly adjustment:

$$Adjustment_{weekly} = \frac{40}{weekly\ exposure\ duration}$$

When calculating the weekly exposure duration, the Technical Guide T-22 offers the following useful definitions.

Repetitive work cycle: the calendar period during which the work schedule (work shift) is exactly repeated on a daily and weekly basis.

> For example, a conventional schedule of 8h/d (Monday to Friday) and 5d/wk is a *repetitive calendar – week work cycle*; a schedule of 10 h/d (Tuesday to Friday) is also a *repetitive calendar – week work cycle.* However, a schedule of 12 h/d for 7 consecutive days, followed by 7 days off, would be a 14-day *repetitive cycle*. If this same schedule consists of alternating weeks of day and night shifts, it would *then be a 28-day repetitive cycle*.

Average exposure duration in hours per week based on a repetitive work cycle: the arithmetic mean in hours (H_W) of the weekly total (7 days) of the work shifts during the repetitive work cycle.

> For example, a schedule of 8 h/d (Monday to Friday), 5 d/wk, gives an average exposure duration in hours per week based on a repetitive work cycle of 40 h/wk; a schedule of 10 h/d, 4 d/wk (Tuesday to Friday) also represents an average exposure duration in hours per week based on a repetitive work cycle of 40 h/wk. However, a schedule of 12 h/d for 7 consecutive days, followed by 7 days off, corresponds to an average exposure duration in hours per week based on a repetitive work cycle of 42 h/wk.

Appendix IV of Technical Guide T-22 is a table containing the adjustment category for over 700 chemicals. There is also an Excel spreadsheet that contains the adjustment categories for the chemicals and performs the calculations. It is available at:
http://www.irsst.qc.ca/en/-tool-utility-for-the-adjustment-of-twa.html

Like the OSHA Model, this is a less conservative method than provided by the Brief and Scala method. It does not take into account the shorter recovery time. It requires more information about the toxicity of the material, and the toxicological basis for the exposure limit, however it provides these in the Technical guide T-22 and in the related Excel spreadsheet. Also like the OSHA Model, it does eliminate certain classes of materials that do not require adjustment, so as to not impose unnecessary controls and expenses.

Pharmacokinetic Model

Pharmacokinetic adjustment models are based around the concept of body burden. The toxic effects of workplace chemicals are more closely related to the concentration of chemicals in the body than in the air. The pharmacokinetic model is a mathematical

model that predicts peak concentrations in the body. It is assumed that if the peak body burden for the unusual work shift is the same as for the normal work shift then the effects will be the same.[4, 6, 8, 9]

The most common pharmacokinetic model is the single compartment model where the body is treated as a single homogeneous entity where the chemical is absorbed, distributed through the body, metabolized, and excreted. The model that demonstrates this best is the one developed by Hickey and Reist[10]. Armstrong, Caldwell, and Verma[8] created an Excel spreadsheet program to do the lengthy calculations. The program contains three worksheets:

1. Spreadsheet Documentation
2. Known T half (known biological half-life)
3. Unknown T half (MAHL) (unknown biological half-life)

Worksheet #3 calculates the maximum adjustment half-life (MAHL) where there is no know half-life for a chemical. This worksheet finds the worst-case half-life for the scenario that is presented to it. That is, knowing the half-life is not necessary to use the program. Table 5 shows the difference between the adjustment factors calculated with and without a half-life ($T_{1/2}$). There is very little difference between the adjustment factors. When there is a difference between the two, the adjustment factor calculated without the known half-life is the worst case condition, and therefore is the more conservative of the two.

Table 5: Comparison of adjustment factors for different chemicals calculated with and without known half-lives.

Chemical	Half-life (hrs)	Daily Exposure	Weekly Exposure	Pharmacokinetic Work Cycle	
				Known $T_{1/2}$	Unknown $T_{1/2}$
Ethyl alcohol	1.5	8	48	1	0.9
MEK	4	10	60	0.9	0.8
Perchloroethylene	96	11	55	0.7	0.7
Acrylamide	196	12	36	1.0	0.9
Pentachlorophenol	700	12	60	0.7	0.7

The authors/creators of the spreadsheet make it available to users without charge or warranty. Thus, users assume responsibility for determining its suitability for their specific application and for any modifications they may make, purposefully or accidentally. The calculations are quite complex, and the authors[8] are thanked for their contribution to the science of occupational hygiene.

Appendix A contains a list of half-lives for some common chemicals. There is some variation in the reported half-lives when found under test conditions. It should also be remembered that there would also be variations between individuals.

The Pharmacokinetic Model takes into account both the exposure and recovery time as does the Brief and Scala Model. However, the Pharmacokinetic Model requires more

technical input, such as the half-life, and therefore may not always be the preferred method.

Summary

Unusual work shifts are one of the workplace conditions that must be taken into account when assessing risk to workers. The four models described above are useful tools for making these adjustments. Each has its own strengths and weaknesses, and it is up to the user to apply professional judgment as to which one to use. As shown in Tables 6 and 7 there are differences between the models. These differences should not be an excuse to hesitate in the application of a model during a risk assessment. Frequently the hesitation revolves around not making an adjustment to the exposure limit and making any adjustment. Not making an adjustment is always biased against the worker's health.

Table 6: Comparison of adjustment factors calculated by the different models for different chemicals under the same working conditions.

Chemical	Half Life (hrs)	Daily exposure	Weekly exposure	Adjustment factors				
				Brief and Scala		OSHA/Quebec		Pharmacokinetic
				Day	Week	Classification	Adjustment	Work Cycle
Ethyl alcohol	1.5	10	50	0.70	0.74	1B	0	0.98
MEK	4	10	50	0.70	0.74	1B	0	0.91
Perchloroethylene	96	10	50	0.70	0.74	4	0.8	0.81
Acrylamide	196	10	50	0.70	0.74	3	0.8	0.80
Pentachlorophenol	700	10	50	0.70	0.74	3	0.8	0.80

Table 7: Comparison of adjustment factors calculated by the different models for the same chemical under different working conditions.

Chemical	Half Life (hrs)	Daily exposure	Weekly exposure	Adjustment factors				
				Brief and Scala		OSHA/Quebec		Pharmacokinetic
				Day	Week	Classification	Adjustment	Work Cycle
Perchloroethylene	96	12	36	0.50	1.15	4	0.67	0.97
Perchloroethylene	96	12	48	0.50	0.78	4	0.67	0.78
Perchloroethylene	96	12	60	0.50	0.56	4	0.67	0.68

References

1. ACGIH, TLVs and BEIs Threshold limit values & biological exposure indices, 2013.

2. Ottoboni, M.A., The Dose makes the poison, 2nd ed, Van Nostrand Reinhold, New York, 1991.

3. Loomis, T.A. Essentials of toxicology, 2nd ed, Henry Kimpton Publishers, London. 1976.

4. Paustenbach, D.J. Occupational exposure limits, pharmacokinetics, and unusual work schedules. in Patty's Industrial Hygiene and Toxicology, 3rd ed, Volume 3, Part A, Harris, R.L., Cralley, L.J., and Cralley, L.V., editors; John Wiley & Sons, Inc., 1994.

5. Kindley, M., Adjusting occupational exposure limits for extended work shifts, http://www.workplace-hygiene.com/articles/OEL-extended-work.html, 2014.

6. Steer, C., and Irving, G., Workplace exposure standards – How do we adjust for extended work shifts? AIOH2009 Conference, 5 – 9 December, Canberra, ACT, Australia, 2009.

7. Drolet D., Technical Guide T-22: Guide for the adjustment of permissible exposure values (pevs) for unusual work schedules, 3rd ed, IRSST Montreal. 2008.

8. Armstrong T.W., Caldwell D.J., Verma D.K., Occupational exposure limits: an approach and calculation aid for extended work schedule adjustments, J Occup Environ Hyg. 2005, 2(11):600-7.

9. Tiernan, G., and Van Zanten, D., Development of an extended shift exposure limit adjustment factor for coal mine dusts, Queensland Mining Industry Health and Safety Conference Proceedings, 1998.

10. Hickey, J.L., and Reist, P.C., Application of occupational exposure limits to unusual work schedules. Am Ind Hyg Assoc J 1977, 38:613–621.

APPENDIX A - Biological Half–Life (Hours)

CHEMICAL	Determinant Timing	Half-Life (hours)
Acetaldehyde	in blood	0.25
Acetone	in blood	3-4
Acrylamide		192
Alumium	in serum	4-6
	in urine	20-400 days
Ammonia		<0.3
Analine	in urine	2.9-4
Arazine		20
Arsenic	blood	60
Benomyl	in urine	10
Benzene	in urine	5.7-12
	exhaled air	30
	in blood	3-5
Benzidene	in urine	5.3
Beryllium	pulmonary soluble	20 days
	pulmonary insoluble	1 year
Biphenyl		1-3
1,3-Butadiene	In urine	4.6–5.6
2-Butoxyethanol	In urine	5.7
tert-Butyltoluene		24
Cadmium	in urine	20 years
	in blood	2400
Carbon Disulfide	end of shift	0.9-5
Carbon Monoxide	in blood	5
	exhaled air	1.5-5
Carbon tetrachloride	exhaled air	0.3-3
Chlorine		<0.3
Chlorobenzene	in urine	8-15
o-Chlorobenzylidene malononitrile	in blood	0.002
Chloroform		0.4-0.5
Chlorflurocarbon	varies for different CFCs	7min-29 hrs
Chromium VI	in urine	15-41
Chromium III		12 hrs-12 months
Cobalt		Days-years
Cyclohexane		11-115 min
Cyclohexanol	in urine	1.5
-metabolites	in urine	14-18
Cyclohexanone	in urine	1.5
-metabolites	in urine	16-18
DDT		1-3 Years
Dichlorodifluoromethane	in blood	10 min
Dichlorofluoromethane	in blood	0.16
Dichloromethane	in blood	5-40 min

CHEMICAL	Determinant Timing	Half-Life (hours)
	in richly perfused tissue	50-60 min
	in muscle	50-80 min
	in adipose tissue	240-400 min
1,3 Dichloropropene	in urine	5
Dinethylamine	in plasma	1.3
	in urine	1.5-7
Dimethylamine-N-oxide	in plasma	3
	in urine	1.5-8
Dimethyl formamide	in urine	3-12
Dioxane	in urine	1
Endrin (in rats)		72 (male) 96 (female)
Ethyl Acetate	exhaled air	2
Ethyl Alcohol	exhaled air	1.5-10
Ethyl Benzene	in urine	4.5
	exhaled air	48
Ethylene glycol monoethyl ether	in urine	21-24
Ethylene glycol monobutyl ether	in blood	4
Endrin	in blood	24
	in urine	55-75
Fluoride	in plasma	5.8
Fonofos		5
Furfural		2-2.5
Halothane	in blood	50-70
Hexachlorobenzene	in blood	2 years
Hexane isomers	in breath	3
n-Hexane	in urine	15
	exhaled air	0.25-3
Hydrogen sulfide		<0.3
Iron		12
Isocyanates	in urine	1.2
Isopropanol	in blood	2.5-6.4
Lead	in blood	900
	in urine	700
	zinc protoporphyrine in blood	500
Lindane	in blood	20
Manganese	in blood	very short
Mercury	in blood	72
	in kidney	2 months
Mercury (methyl)	in blood	45-70 days
Methanol	in blood	1.5 - 2
	in urine	7
Methyl chloride		1-1.5
Methylene Chloride	in blood	2.4-6
Methyl Chloroform	exhaled air	32

CHEMICAL	Determinant Timing	Half-Life (hours)
	trichloracetic acid in urine	72
	trichloroethanol in urine	12
	trichloroethanol in blood	12
Methyl Ethyl Ketone	in urine	4
	in blood	0.5-1.5
Methyl isobutyl ketone	in blood	0.2-1.2
Mineral dust	in lung	>6 months
Monochlorobenzene	in urine	2.2-12
Monochloromethane	in urine	<16
Nickel	in urine/blood	24
Nickel particles	in lung	3.5 years
Nitrobenzene	in urine	86
p-Nitrophenol	in urine	1
Nitrogen dioxide		1
Organophosphorus Cholinesterase Inhibitors	in blood	700
Parathion	in urine	7
Pentachlorophenol	in urine	700
	in plasma	700
Perchloroethylene	exhaled air	96
	in blood	96
	trichloroacetic acid in urine	80
p-Nitrophenol	in urine	1
Phenol	in urine	3.5
Phenoxy acid herbacide	in urine	12-22
Polychlorinated biphenyl	highly chlorinated in blood	33-34 months
	less chlorinated in blood	6-7 months
Polychloro dibenzo-p-dioxin (PCDD)	in fat and blood	2-7 years
Polycyclic aromatic hydrocarbons (PAHs)	in urine	6-35
Phenoxy acid herbicide	in urine	12-22
2-Propanol	In blood	3-4
Silica (crystalline)		>6 months
Styrene	in urine	0.5-8
	exhaled air	20
	penylglyoxylic acid in urine	7
Sulfur dioxide		<0.3
Tetrachloroethylene	exhaled air	70
Tetrahydrofuran	exhaled air	0.5
Thallium	in urine	15-30 days
Toluene	in urine	1.5-12
	in venous blood	0.5
	exhaled air	0.5
1,1,1- Trichloroethane	in urine	8.7
Trichloroethylene	in urine	75
	in blood	12

CHEMICAL	Determinant Timing	Half-Life (hours)
	exhaled air	0.5-30
Trichlorofluorethane	in blood	0.25
Vanadium	in urine	20-40
Vinyl chloride		3
Welding fume	in lung	3.5 years
Xylenes	in urine	3.6