Fact Sheet on Occupational Health

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Adjustment of Occupational Exposure Limits for Unusual Work Schedules

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Introduction

Occupational Exposure Limits (OELs) assume a "typical" work regimen of 8 h per day and 40 h per week. Because people sometimes work according to unusual schedules, it can be necessary to adjust the OEL to reflect the difference in either total dose or peak burden associated with the unusual schedule. Such an adjustment can be needed if either the total dose or the peak burden of the contaminant is appreciably greater under the unusual schedule.

In order to determine the need for adjusting an OEL, it is useful to consider the pharmacokinetic relationships between exposure and burden. Single-compartment linear models, which assume constant uptake and first-order elimination, are generally adequate for this purpose. Several investigators, notably Mason and Dershin,[1] Hickey and Reist,[2] and Roach[3] have discussed pharmacokinetic adjustments of OELs. Paustenbach has summarized these and other studies in a comprehensive review.[4]

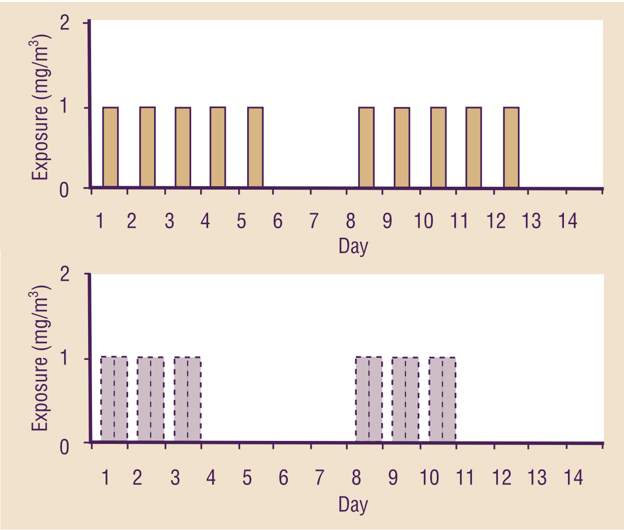

Figure 1.

Exposure to a hypothetical chemical at the level of the OEL = 1 mg/m^3 for two weeks. *Top*: usual schedule of five 8-h exposures per week, *bottom*: unusual schedule of three 16-h schedules per week.

Pharmacokinetic Relationships

Let us assume that a person is exposed to a contaminant at the level of the OEL during each work shift and is unexposed otherwise. The duration of exposure each day and the number of exposures per week are dictated by the work schedule. This is illustrated in Figure 1 for a hypothetical chemical with an OEL of 1 mg/m^3 for the usual schedule of five 8-h shifts per week (top) and an unusual schedule of three 16-h shifts per week (bottom). In both cases, two weeks of exposure at 1 mg/m^3 are shown.

As the worker inhales during the work shift, a portion of the parent chemical is retained in the body and some of this burden is metabolized and excreted. After work, the processes of metabolism and excretion continue until the beginning of the next work shift. Let P_i represent the burden (in mg) of the parent chemical $\{P_i\}$ for i = 1, 2, …, n intervals, each of Δt h. Assuming that the body can be depicted as a single compartment with constant uptake during exposure and first-order elimination of P, then the burden at the end of the i-th interval is given by the following expression:

$$P_i = \frac{k_0}{k_e} X_i \left(1 - e^{-k_e \Delta t}\right) + P_{(i-1)} e^{-k_e \Delta t} , \qquad (1)$$

where X_i represents the exposure concentration during the i-th interval (mg/m^3, as shown in Figure 1), k_0 is the rate of uptake (m^3/h), k_e is the rate of elimination (h^{-1}), and $P_{(i-1)}$ represents the burden at the end of the preceding interval. From

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Equation 1, the values of P_i rise during intervals of exposure and decline during non-exposure until a steady state has been achieved where the pattern is constant each week. Elimination of a chemical is often given in terms of the half time $T_{1/2} = 0.693/k_e$, which is the time required for half of the burden to be removed. Steady state will be achieved after approximately five $T_{1/2}$ have elapsed.

Assuming that the worker is at steady state, then the $\{P_i\}$ assume a characteristic pattern each week. This is shown in Figure 2, for the usual and unusual work schedules illustrated in Figure 1. The figure shows that the burden is relatively unaffected by the work schedule for the rapidly eliminated substance ($T_{1/2}$ = 3 h) because, in this case, the burden approaches steady state within a single shift. Likewise, the burden is not particularly sensitive to the work schedule for the slowly eliminated substance ($T_{1/2}$ = 300 h), due to the accumulation of chemical from week to week.[5] Indeed, only the burden of the substance with an intermediate rate of elimination ($T_{1/2}$ = 30 h) appears to be significantly affected by the work schedule.

Methods of Adjustment

As illustrated in Figure 2, the total dose (area under the burden-time curve) and the peak burden (maximum burden occurring at the end of the last work shift each week) can be predicted for any weekly schedule of exposures. Such relationships offer a convenient means for adjusting the OEL for an unusual work schedule. If the work schedule is erratic, e.g., unusual for only one week in three, then by assuming the same (unusual) schedule each week, any adjustment would be conservative from the viewpoint of health.

Adjustment for total dose. Since the total dose under Equation 1 is strictly proportional to the number of hours worked per week, a longer workweek would result in a total dose that is proportionally greater than the dose obtained under the usual schedule. For example, with the unusual schedule illustrated in Figures 1 & 2 (three 16-h exposures/week), the total dose would be 48/40 = 1.2 or 20% greater than usual. If the OEL is based upon long-term systemic effects or cancer, then the OEL would be reduced by a factor of 40/48 = 0.833 to provide comparable protection for workers in unusual work schedules.

In some cases, the unusual work schedule could involve fewer than 40 h each week and, therefore, would result in lower total doses than under the usual schedule. Although it could be argued that OELs should be adjusted upwards in such cases, I do not advise this.

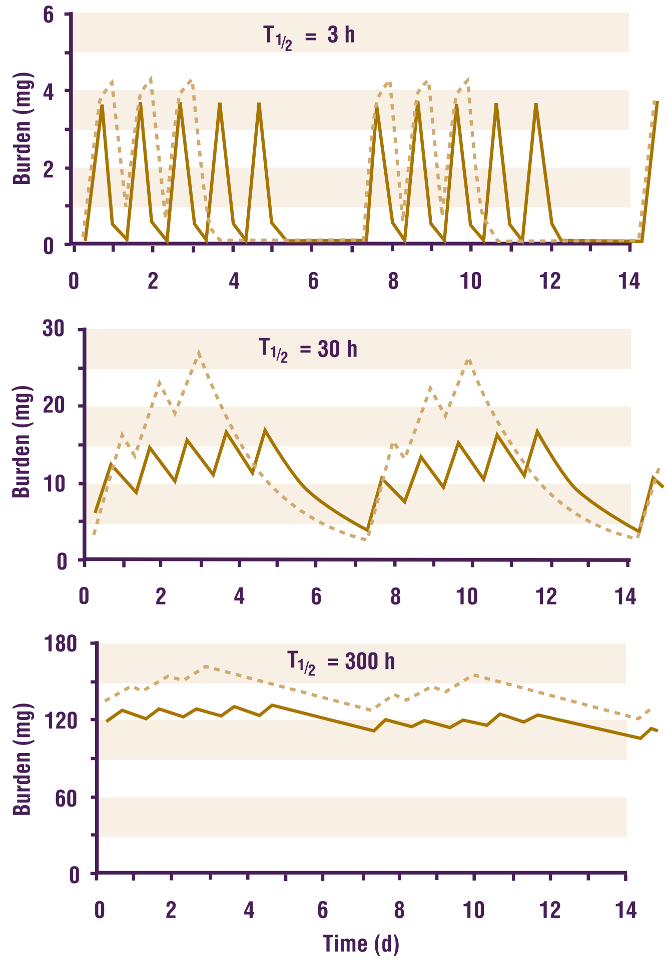

Figure 2.

Burdens arising from exposure according to Figure 1 for three hypothetical contaminants with half times $T_{1/2}$ = 3 h, 30 h, and 300 h. Burdens are predicted by Equation 1, assuming steady state following exposure at the OEL = 1 mg/m^3, uptake rate k_0 = 1 m^3/h and elimination rate $k_e = 0.693/T_{1/2}$. Solid lines represent the usual work schedule (five 8-h exposures per week) and dashed lines represent the unusual schedule (three 16-h exposures per week).

Adjustment for peak burden. The more complex situation involves an increase in the peak burden arising from accumulation of the contaminant from day to day or week to week. For the scenarios depicted in Figure 2, the difference in peak burdens is greater for $T_{1/2}$ = 30 h than for $T_{1/2}$ = 3 or 300 h. Thus, if the OEL were based in part upon dose rate, then a larger adjustment would be needed for a substance with $T_{1/2}$ = 30 h than for substances eliminated either more rapidly or more slowly. More generally, the following relationship can be used to adjust the OEL for any unusual schedule as a function of the elimination rate[2]:

$$F_P = \frac{(1 - e^{-8k_e})(1 - e^{-120k_e})}{(1 - e^{-hk_e})(1 - e^{-24dk_e})} \quad , \qquad (2)$$

where,

F_P = the OEL reduction factor,

k_e = elimination rate of the contaminant (h^{-1}),

h = duration of the daily work shift (h), and

d = number of work shifts per week.

The dimensionless reduction factor F_P varies from zero to one. For the three cases illustrated in Figure 2, $F_P = 0.864$ for $T_{1/2} = 3$ h, $F_P = 0.631$ for $T_{1/2} = 30$ h and $F_P = 0.797$ for $T_{1/2} = 300$ h.

Figure 3 depicts reduction factors over the range of 1 h $\leq T_{1/2} \leq$ 1000 h for three unusual schedules, namely, four 10-h shifts and three 12-h or 16-h shifts per week. The relationships indicate that downward adjustments of OELs in the range of 20 – 40% can be required for substances with 3 h $\leq T_{1/2} \leq$ 300 h. For substances where $T_{1/2} <$ 3 h or $T_{1/2} >$ 300 h, adjustments for peak burden would be less than 10% for a 40-h workweek and, in such cases, would probably not be needed. If the elimination rate of a particular contaminant is not known, Figure 3 suggests that assuming a value of $T_{1/2}$ = 15 h would be conservative from the viewpoint of health.

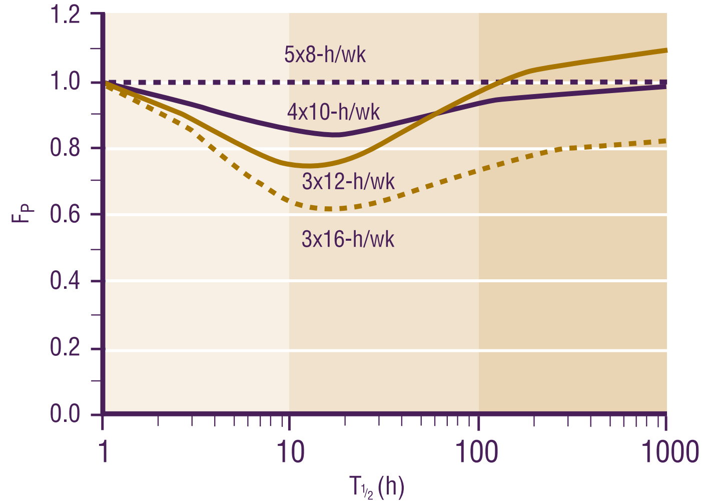

Figure 3.

OEL reduction factors for peak burden predicted by Equation 2 for different work schedules.

Adjustment for substances used in the metals industries. Table 1 categorizes the elimination half times of those substances offered by company representatives in the mining and metals industries. Based upon the above rules of thumb, I do not recommend adjustments of OELs for substances eliminated either rapidly (Category 1) or slowly (Category 3) unless the workweek exceeds 40 h. For substances with intermediate elimination rates (Category 2), or in all cases involving workweeks greater than 40 h, Equation 2 can be used to obtain an adjustment factor. If the elimination half time is not known, then a value of $T_{1/2}$ = 15 h can be used to provide a conservative value of F_P.

Category 1 Rapid Elimination ($T_{1/2} <$ 3 h)	Category 2 Intermediate Elimination (3 $\leq T_{1/2} \leq$ 300 h)	Category 3 Slow Elimination ($T_{1/2} >$ 300 h)
Hydrochloric acid	Cobalt	Silica
NOx	Soluble Ni	Lead
SOx	Solvents	Mercury
Ammonia	Diesel exhaust	Insoluble Ni
Cyanide		Insoluble dusts
Sulfuric acid		

Table 1.

Categories* of Substances for Adjustment of OELs (According to Rates of Elimination).

*Based upon Equation 2.

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About the Author:

Dr. S. M. Rappaport has been a Professor of Occupational Health at the University of North Carolina at Chapel Hill since 1990. Prior to that time he was a professor at the University of California, Berkeley for 14 years. Since 1974, he has been actively engaged in various areas of research involving both environmental and biological monitoring. His current research focuses upon human dosimetry of various chemicals and upon elucidating mechanisms of toxicity of these substances. He has also published extensively in areas related to the assessment of long-term exposures to chemicals for purposes of controlling hazards and investigating exposure–response relationships. This work has motivated Prof. Rappaport to evaluate occupational exposure limits and the interpretation of these limits in assessments of exposure and risks of disease. He has collaborated extensively with investigators throughout the world in his research endeavours.

Fact Sheet on Occupational Health

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