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DOE-HDBK-1046-2008
August 2008

DOE HANDBOOK

TEMPORARY EMERGENCY EXPOSURE LIMITS FOR CHEMICALS: METHODS AND PRACTICE



U.S. Department of Energy
Washington, D.C. 20585

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FOREWORD

In 2005, the Office of Emergency Management and Policy (NA-41) within the National Nuclear Security Administration (NNSA), U.S. Department of Energy (DOE), issued DOE O 151.1C, *Comprehensive Emergency Management System*. This order, and its Guides issued in 2007, reference Acute Exposure Guideline Levels (AEGLs) and Emergency Response Planning Guidelines (ERPGs) as the emergency exposure limits of choice. They also provide for the use of Temporary Emergency Exposure Limits (TEELs) for chemicals for which no AEGLs or ERPGs are available.

This document describes why TEELs are needed, their role in emergency planning in DOE, the history of their development, and the methods by which they are developed.

Constructive comments, recommendations, additions, deletions, and any pertinent data that may improve this document are welcome. Please send these to:

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ACRONYMS

ABR	Animal breathing rate
ABW	Animal body weight
ACGIH	American Conference of Governmental Industrial Hygienists
AEGL	Acute Exposure Guideline Level
AIHA	American Industrial Hygiene Association
ALC	Animal lethal concentration
ALC₅₀	Animal lethal concentration 50%
ALC_{LO}	Animal lethal concentration lowest
ALD	Animal lethal dose
ALD₅₀	Animal lethal dose 50%
ALD_{LO}	Animal lethal dose lowest
ANSI	American National Standards Institute
C	Ceiling
CAS	Chemical Abstracts Service
CAS RN	Chemical Abstracts Service Registry Number
CEGL	Continuous Exposure Guidance Level
CF	Conversion factor
CFR	Code of Federal Regulations
CMM	Chemical Mixture Methodology
CSE	Confined space entry
DFG	Deutsche Forschungsgemeinschaft (German Research Foundation)
DOE	Department of Energy
DOT	Department of Transportation
EEGL	Emergency Exposure Guidance Level
EPA	Environmental Protection Agency
EPHA	Emergency Planning Hazard Assessment
EPZ	Emergency Planning Zone
ERPG	Emergency Response Planning Guideline
HBR	Human breathing rate
HBW	Human body weight
HCN	Health Code Number
HHR	Health Hazard Rating
HLC	Human-equivalent lethal concentration
HLC₅₀	Human-equivalent lethal concentration 50%
HLC_{LO}	Human-equivalent lethal concentration lowest
HSDB	Hazardous Substances Data Bank
HTC	Human-equivalent toxic concentration
HTC₅₀	Human-equivalent toxic concentration 50%
HTC_{LO}	Human-equivalent toxic concentration lowest
IDLH	Immediately Dangerous to Life or Health
LOC	Level of Concern
LC₅₀	Lethal concentration 50%
LC_{LO}	Lethal concentration lowest
LD₅₀	Lethal dose 50%

LD_{Lo}	Lethal dose lowest
LEL	Lower Explosive Limit
MAK	Maximale Arbeitsplatz-Konzentration (maximum workplace concentration) from the German Research Foundation
NAS	National Academy of Sciences
NIOSH	National Institute for Occupational Safety and Health
NNSA	National Nuclear Security Administration
NRC	National Research Council
OEM	Office of Emergency Management (DOE)
OSHA	Occupational Safety and Health Administration
PAC	Protective Action Criterion
PEL	Permissible Exposure Limit
PNOS	Particles not otherwise specified
ppm	Parts per million (See also Glossary)
RAF	Route Adjustment Factor
RecTEEL	Recommended TEEL
REL	Recommended Exposure Limit
RTECS	Registry of Toxic Effects of Chemical Substances
SAR	Structure activity relationship
SCAPA	Subcommittee on Consequence Assessment and Protective Action
STEL	Short-Term Exposure Limit
TAG	TEEL Advisory Group
TC_{Lo}	Toxic concentration lowest
TD	Toxic dose
TD_{Lo}	Toxic dose lowest
TEEL	Temporary Emergency Exposure Limit
TLV	Threshold Limit Value
TWA	Time-Weighted Average
WEEL	Workplace Environmental Exposure Level

GLOSSARY

Animal Breathing Rate (ABR)	Breathing rate used to calculate human equivalent dose.
Animal Body Weight (ABW)	Body weight used to calculate human equivalent dose.
American Conference of Governmental Industrial Hygienists (ACGIH)	Professional association of industrial hygienists.
Acute Exposure Guideline Levels (AEGLs)	PAC established by EPA and NAS.
American Industrial Hygiene Association (AIHA)	Professional association of industrial hygienists.
American National Standards Institute (ANSI)	A non-governmental consensus standards-setting organization.
Biological Exposure Index (BEI)	The upper limit of chemicals or their metabolites in body tissue recommended by the ACGIH.
Ceiling (C)	The upper limit of chemicals in workplace air not to be exceeded at any time.
Chemical Abstracts Service (CAS)	The organization that assigns CAS RNs to chemicals, among other matters.
Emergency Planning Hazards Assessment (EPHA)	The application of rigorous hazard analysis techniques that provide sufficient detail to assess a broad spectrum of postulated events or conditions involving the potential onsite release of hazardous materials and to analyze the resulting consequences.
Emergency Response Planning Guidelines (ERPGs)	PAC recommended by AIHA.
Hazardous Substances Data Bank (HSDB)	A peer-reviewed database on toxic effects to humans managed by the National Library of Medicine.
Immediately Dangerous to Life or Health (IDLH)	The concentration of a chemical in air which, if exposed, a person should leave immediately.
Lethal Concentration, 50% (LC₅₀)	Concentration that is lethal to 50% of a test species.
Lethal Concentration, lowest (LC_{LO})	Lowest concentration that is lethal to a test species.
Lethal Dose, 50% (LD₅₀)	Dose that is lethal to 50% of a test species.
Lethal Dose, lowest (LD_{LO})	Lowest dose that is lethal to a test species.

Maximale Arbeitsplatz-Konzentration (MAK) (maximum workplace concentration)	Occupational exposure limit adopted by the German Research Foundation.
“N” Chemicals	Chemicals whose toxic effects are dose-depend (considering both concentration and duration of exposure) and causing only chronic health effects.
Protective Action Criteria (PAC)	Threshold concentration of a chemical in air at which protective action is required (set by DOE).
Permissible Exposure Limits (PELs)	A legally enforceable occupational exposure limit set by OSHA.
Particles Not Otherwise Specified (PNOS)	Short-hand term applied to particles not characterized in some other way.
parts per million (ppm)	A conventional measure of concentration of a chemical in air, by volume.
Route Adjustment Factor (RAF)	A unitless parameter to adjust exposure for different absorption efficiencies by different routes (e.g., inhalation, ingestion, etc.).
Recommended Exposure Limits (RELs)	Occupational exposure limits recommended by NIOSH.
Registry of Toxic Effects of Chemical Substances (RTECS)	A compendium of results of toxicological experiments published by NIOSH.
Structure Activity Relationship (SAR)	A procedure for predicting a chemical’s effects from its chemical structure.
N. Irving Sax (Sax)	The original editor of <i>Dangerous Properties of Industrial Materials</i> .
Short-Term Exposure Limits (STELs)	A time-weighted average exposure limit for short time periods (usually 15 minutes).
Temporary Emergency Exposure Limits (TEEL)	Chemical exposure guidelines to use for emergency planning (if no AEGL or ERPG is available).
TEEL Advisory Group (TAG)	An advisory group of DOE that provides advice and oversight on TEELs.
Toxic Concentration, 50% (TC₅₀)	Concentration that is toxic to 50% of a test species.
Toxic Concentration, lowest (TC_{LO})	Lowest concentration causing toxic effects.
Threshold Limit Values (TLVs)	An occupational exposure limit set by ACGIH.

Time-Weighted Average (TWA)	The average concentration of a chemical in air for a specified time period, commonly, 8 hours.
Workplace Environmental Exposure Levels (WEELs)	Health-based occupational exposure limits for chemicals that lack PELs, TLVs, or RELs.
“Y” Chemicals	Chemicals whose toxic effects are concentration-dependent, causing acute health effects.

1.0 INTRODUCTION

Emergency exposure limits are essential components of planning for the uncontrolled release of hazardous chemicals. These limits, combined with estimates of exposure, provide the information necessary to identify and evaluate accidents for the purpose of taking appropriate protective actions. During an emergency response to an uncontrolled release, these limits may be used to evaluate the severity of the event, to identify potential outcomes, and to decide what protective actions should be taken. In anticipation of an uncontrolled release, these limits may also be used to estimate the consequences of an uncontrolled release and to plan emergency responses.

The U.S. Department of Energy (DOE) issued its latest Emergency Management Order in 2005 (DOE O 151.1C, 2005) for managing chemical emergencies. In DOE O 151.1C, DOE uses Acute Exposure Guideline Levels (AEGLs) and Emergency Response Planning Guidelines (ERPGs) as the emergency exposure limits of choice. Recognizing that such guidelines exist only for a limited number of individual chemicals, DOE also commissioned the development of Temporary Emergency Exposure Limits (TEELs) so that DOE facilities could conduct Emergency Planning Hazard Assessments (EPHAs) and consequence assessments during response for chemicals lacking AEGLs or ERPGs. As the “T” in TEELs indicates, TEELs are *temporary* limits for chemicals until AEGLs or ERPGs are developed, at which time the TEELs should no longer be used and the AEGLs or ERPGs should be used exclusively.

The objectives of this document are to present the following information associated with TEELs:

- The need for emergency exposure limits in general and for TEELs in particular (Section 2)
- The methods used to derive TEEL values for hazardous chemicals based on exposure limits, toxicity parameters, and other information (Section 3)
- Sample calculations showing how TEELs are derived (Section 4)
- Quality assurance and control measures used to ensure that TEELs are appropriately derived following approved methods (Section 5)

2.0 FRAMEWORK FOR DEVELOPMENT AND APPLICATION OF TEELS

2.1 Planning for Chemical Emergencies

Chemical emergencies can occur as a result of either an accidental or intentional release. Fires, explosions, equipment malfunctions or failures, vehicle crashes, and similar incidents are possible accidental events. Persons immediately affected by these incidents could include those at the scene (e.g., at a workplace or involved in a vehicular crash), first responders (e.g., incident commander) and other emergency personnel, and nearby workers and members of the public downwind of the incident. Intentional releases, such as terrorist attacks or chemical warfare, create similar problems but have some important differences. Chemicals used in an intentional release are usually designed and selected with the intent of inflicting injury and are usually released in a way designed to increase that potential (e.g., inflicted on a large population in a confined space). For either an accidental or intentional release scenario, however, it is important to prepare for such emergencies to allow for the selection of protective actions that are the most effective for minimizing disease and injury.

Response planning actions include evaluating exposure, acquiring equipment, training first responders, developing methods to determine the potential area (i.e., footprint) affected by the release of hazardous material, identifying populations at risk, and planning and selecting appropriate protective actions. This document is concerned with evaluating exposure; other aspects are beyond the scope of this document.

To aid such evaluations, the Environmental Protection Agency (EPA), with the assistance of the National Academy of Sciences (NAS), develops AEGLs as concentration limits designed to aid planning for chemical emergencies (EPA, 2007; National Research Council (NRC), 1985, 1993). The American Industrial Hygiene Association (AIHA) develops ERPGs for similar purposes (AIHA, 2007a).

DOE and the National Nuclear Security Administration (NNSA) use AEGLs, ERPGs, and TEELs as protective action criteria (PACs), in that order (See Section 2.8.) PACs are the concentrations of airborne hazardous materials at which protective actions are needed. Planning for emergencies at DOE and NNSA sites and facilities includes selecting or developing these criteria for protective action decision making. Emergency procedures for classifying Operational Emergencies and for implementing or recommending protective actions also incorporate these criteria.

The planning process identifies hazards and the potential consequences from unplanned releases of (or loss of control over) hazardous chemicals using accepted assessment techniques based on PACs assigned to the hazardous chemicals identified. An emergency planning zone (EPZ) is developed based on the area where PAC values would be exceeded. The planning process may identify the consequences of projected accidents so that additional inventory or process controls may be implemented to reduce the risk. Field measurements based on these exposure guidelines may be used to refine the area affected by a hazardous material release and to adjust protective actions as appropriate.

2.2 Exposure Assessment and Risk Assessment

An essential aspect of protective actions is evaluating real or potential exposure to chemicals. To do so, it is important to acquire, to the extent feasible, the following information:

- The identities of the chemicals
- The amount released
- Their concentration in air
- The potential duration of exposure (e.g., continuous or puff)
- Characteristics of the population exposed
- The determinants of exposure (i.e., any circumstances that could alter exposure, such as the weather or the physical environment)

This information constitutes the raw material for assessing and managing the consequences in a specific incident. Translating this information into an estimate of injury also requires knowledge of the safe levels of exposure. Emergency exposure limits—AEGLs, ERPGs, and TEELs—are the key additional ingredients for assessing the consequences of injury.

2.3 Need for TEEL Values

AEGLs and ERPGs are developed by a painstaking process of reviewing the primary scientific literature, proposing limits, having proposals subject to peer review by subject matter experts in the field, and revising the AEGLs and ERPGs accordingly (NRC, 2001; AIHA 2007a). Although the specific processes for AEGL and ERPG value development differ significantly, both processes result in limits with a solid scientific foundation. By the end of 2006, however, there were only 89 chemicals with final or interim AEGLs and only 125 chemicals with ERPGs. Yet thousands of chemicals are used every day at DOE facilities and throughout the United States. The risk of accidental release of chemicals without AEGLs or ERPGs remains, as does the need for DOE to set emergency exposure limits.

TEELs, first referred to as Alternative Guidelines Limits, serve this purpose. The principal difference between TEELs and AEGLs and ERPGs is that the method for developing TEELs (described below) requires far less time than do the methods for deriving AEGLs or ERPGs. The first TEEL list was released in October 1992 and included values for approximately 65 chemicals without AEGLs or ERPGs (Craig, 1992). By Revision 21, published in October 2005, the TEEL database included values for 2,945 chemicals. The database includes the more common chemicals used by DOE and NNSA.

2.4 Protective Action Criteria and Risk Management

Risk management occurs in anticipation of and during chemical emergencies. PACs (i.e., AEGLs, ERPGs, and TEELs) define the concentration of airborne chemicals at which protective actions are required. They are the basis for consequence assessment for chemical emergencies and are used by DOE and NNSA in Emergency Preparedness procedures and for Operational Emergencies.

Risk management can consist of actions in anticipation of an accidental release or during and after a release to mitigate the release to reduce the magnitude of injury. Preventive measures include reducing the quantity of chemicals in storage, securing storage or transport from accidental release, removing chemicals (or reducing their quantities) from proximity to sensitive populations, providing for emergency response services, and, if used at a worksite, using less toxic chemicals. In all such procedures, PACs are an essential input to risk management and to planning. Actions during a release can include containing the release; removing injured persons and others at risk; providing first aid, triage, and other medical treatment; and initiating follow-up actions to mitigate injury and illness.

2.5 Populations at Risk

Virtually any member of any population can be exposed to toxic chemicals as a result of an accidental release, including persons who are members of susceptible subpopulations, such as infants, children, the elderly, persons with asthma, and those with other illnesses. Most exposure limits and toxicity parameters, however, are not designed to protect susceptible individuals. As a consequence, some members of the exposed population, including those who may be subject to unique or idiosyncratic responses, may be affected even when exposed at levels below the pertinent limit.

Typically, employed persons are healthy adults exposed during working hours so that limits to protect the general public for longer than a typical work shift should be more stringent. TEEL-0 limits, for example, which assume a 15-minute time-weighted average (TWA) concentration, are determined using the 8-hour TWA Permissible Exposure Limit (PEL) value designed for occupational exposure. This value is conservative because the exposure time is short compared with the 8-hour workday. Similar considerations are addressed in deriving AEGLs, ERPGs, and other TEEL levels to make them relevant to the general public in an emergency situation. However, none of these PACs are designed to protect hypersensitive individuals.

2.6 Nature and Severity of Toxic Effects

The nature and severity of toxic effects depend on the specific chemical, its concentration, the duration of exposure, the exposure rate, and the route of exposure. (All emergency exposure limits to which this document refers assume exposure by inhalation because it is the limiting pathway for acute exposures. However, some airborne chemicals can also be absorbed through the skin.) Emergency exposure limits are designed to prevent illness and injury graded by the exposure's severity. For ERPG values, the duration of exposure is assumed to be up to 1 hour. AEGL values are being developed for 1 hour and for longer and shorter time intervals as well. For TEELs, the recommended duration is 15 minutes. The exposure severity is based on the peak 15-minute TWA concentration. Health effects may be acute, chronic, delayed, localized, systemic, transient and reversible, and irreversible.

The nature and severity of health effects are relevant to the planning process. Chemical exposures with acute effects require prompt action for primary prevention measures. If effects are expected to be localized, short-lived, and self-limiting, then preventive actions can be appropriately limited. Chemicals and exposures that might have chronic effects may require more sustained monitoring, follow-up, and counseling of exposed persons.

2.7 Exposure to Known, Probable, and Possible Carcinogenic Chemicals

Both the ERPG and AEGL approval committees consider carcinogenesis by adopting a procedure described by the NRC (NRC, 1986). If health effects data show the potential of carcinogenicity from exposure to a chemical, a calculation is conducted that consolidates risk estimates derived from low-dose extrapolation in animals or humans into a single 1-hour exposure timeframe and assumes a 1 in 10,000 risk of cancer. Both the ERPG and AEGL committees then consider the results of the calculations in determining ERPG-2 or AEGL-2, respectively, and provide the calculations within technical support documents.

TEELs are based on concentration limits or toxicology parameters. These parameters include a wide variety of health effects, including carcinogenesis. Consequently, whether TEELs are based on carcinogenic effects depends on whether the corresponding concentration limits or the toxicology parameters used to develop the TEELs are based on carcinogenic effects.

2.8 Comparison of AEGLs, ERPGs, and TEELs

AEGLs, ERPGs, and TEELs all serve the same general purpose—to provide PACs to those who are responsible for planning for and responding to chemical emergencies. For each, there are multiple benchmarks for each chemical, and the benchmarks are associated with increasingly severe effects with higher levels of exposure.

The principal differences between AEGLs, ERPGs, and TEELs are how they are developed. There are also some subtle differences in how they are defined. As shown in Table 2.1, AEGLs pertain to the “general population, including susceptible individuals,” but ERPGs and TEELs pertain to “nearly all individuals.” AEGLs are defined as the level “above which” certain health effects are expected, while ERPGs and TEELs are defined as the level “below which” certain health effects are *not* expected. ERPGs refer to an exposure duration of 1 hour (with shorter periods for some chemicals); AEGLs are developed for five time periods; and TEELs are defined for a 15 minute period. For TEELs, the exposure severity is based on a peak 15-minute TWA concentration. Unlike AEGLs and ERPGs, there is a TEEL-0. This is a “no-effect” level that allows planners to conclude that if exposure is less than TEEL-0, there would be minimal or no risk of adverse health effects. For any particular chemical, the PAC concentration limit hierarchy is to use AEGLs first, then ERPGs, and finally TEELs, as illustrated in Figure 2.1. (There is no TEEL if there is an AEGL or an ERPG at a particular level.)

Table 2.1 Comparison of AEGLs, ERPGs, and TEELs: -0, -1, -2, and -3 Values

AEGL*	ERPG*	TEEL*
There is no AEGL-0 value.	There is no ERPG-0 value.	TEEL-0 is the threshold concentration below which most people will experience no appreciable risk of health effects.
AEGL-1 is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic non-sensory effects. However, the effects are not disabling and are transient and reversible on cessation of exposure.	ERPG-1 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odor.	TEEL-1 is the maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odor.
AEGL-2 is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience irreversible or other serious, long-lasting adverse health effects or an impaired ability to escape.	ERPG-2 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing irreversible or other serious health effects or symptoms which could impair an individual's ability to take protective action.	TEEL-2 is the maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing irreversible or other serious health effects or symptoms that could impair their abilities to take protective action.
AEGL-3 is the airborne concentration of a substance above which it is predicted that the general population, including susceptible individuals, could experience life-threatening health effects or death.	ERPG-3 is the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to 1 hour without experiencing or developing life-threatening health effects.	TEEL-3 is the maximum concentration in air below which it is believed nearly all individuals could be exposed without experiencing or developing life-threatening health effects.

*AEGLs are defined for five time periods ranging from 10 minutes to 8 hours. DOE has selected the 60-minute AEGL for use in its Emergency Management System (Thomas and Lu, 2006). ERPGs are defined for up to 1 hour, and TEELs are recommended for a peak 15-minute TWA concentration.

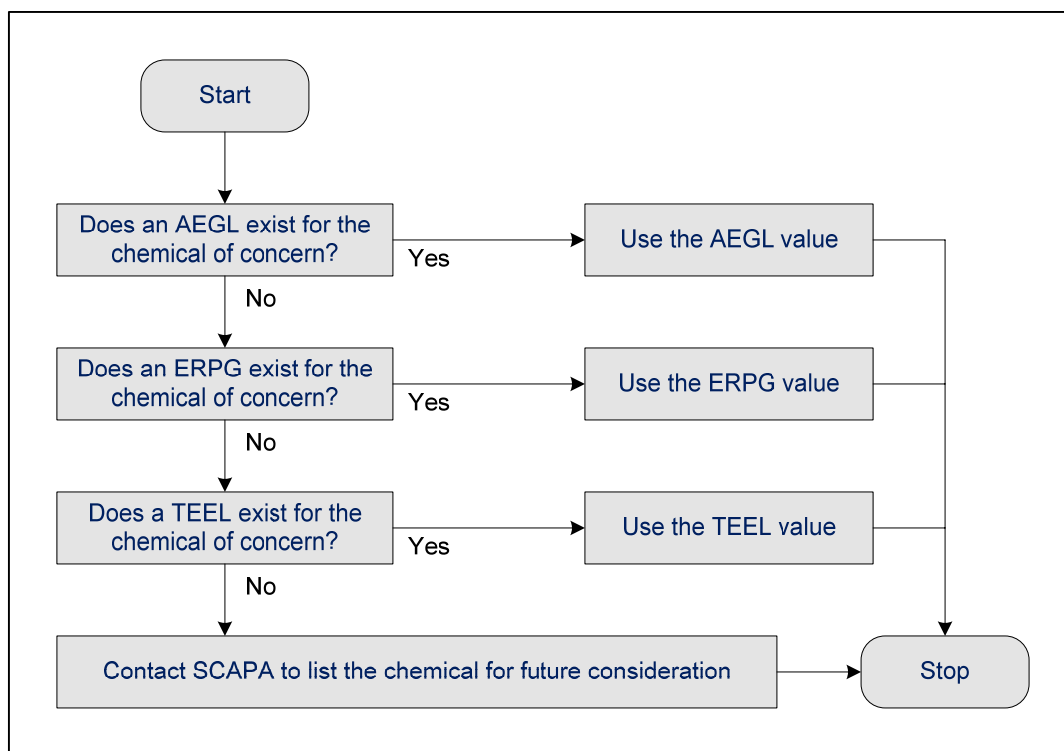


Figure 2.1 PAC Selection Process

2.9 SCAPA and the TEEL Advisory Group

TEEL development is supported directly through the DOE Office of Emergency Management (OEM), which is responsible for developing, maintaining, and testing the Emergency Management System at DOE and NNSA sites and facilities. These responsibilities include, among other activities, providing technical, management, administrative, and outreach support to the Subcommittee on Consequence Assessment and Protective Actions (SCAPA), which provides technical information and recommendations for emergency preparedness to assist in safeguarding the health and safety of workers and the public.

The TEEL Advisory Group (TAG) was established in early 2004 as an offshoot of SCAPA to promote consistency in the calculation and application of TEELs and the Chemical Mixture Methodology (CMM). This task includes oversight of the development of Health Code Numbers (HCNs), which are used with TEELs in the application of the CMM. The TAG provides technical support on TEEL-, CMM-, and HCN-related issues to the OEM. The six TAG members are appointed by the OEM. As stated in its charter, the objectives of the TAG are to:

- Promote consistency in calculation and application of TEEL and HCN values
- Provide quality control of the development of the TEEL- and HCN-related projects
- Provide technical support on TEEL- and HCN-related issues to the OEM
- Promote the understanding and use of TEEL and HCN values within DOE, other government agencies, and private interests

More specifically, the TAG is responsible for overseeing:

- Modifications to the TEEL and CMM
- Calculations of TEEL and HCN values
- Publication of TEEL- and HCN-related technical papers in peer-reviewed journals
- Development and recommendations for approval of TEEL chemical priority lists
- Distribution and publication of approved TEEL and HCN values (DOE 2007a, 2007b; ORISE, 2007)

3.0 TEEL DEVELOPMENT METHODOLOGY

3.1 General Considerations

TEELs originally were derived as temporary exposure limits for chemicals that did not have ERPGs. At that time, no AEGLs existed. TEELs have since been used for chemicals that have neither AEGLs nor ERPGs. Chemicals are selected for deriving TEELs if they are used at DOE facilities and if workers or others may be exposed to them.

TEELs have the same objectives and achieve them in the same way as do AEGLs and ERPGs. AEGLs and ERPGs each have three exposure levels, -1, -2, and -3, associated with increasingly severe health effects. ERPGs and TEELs are applicable to one exposure period, while AEGLs are applicable for five exposure periods. In addition to these three exposure levels, TEEL-0 is developed and defined as the level below which no adverse health effects are expected. (See Table 2.1 for definitions.)

TEELs differ from AEGLs and ERPGs by the methods and the sources of data used to develop them. AEGLs and ERPGs are derived from a rigorous review of primary sources, and the levels for each chemical are individually peer reviewed. (Note: ERPGs use a weight of evidence approach, whereas AEGLs use the results of a key study to derive each level.) These processes are both painstaking and time-consuming. To produce limits in a more timely fashion while maintaining high quality, TEELs are derived from secondary data sources using a peer-reviewed algorithm. These sources are either existing exposure limits designed to prevent adverse effects in humans or experimentally-derived toxicity parameters.

A hierarchy of sources is used for developing TEELs. Because they are designed to prevent adverse health effects in humans, existing exposure limits are the preferred source of information for the development of TEELs. However, there are many chemicals for which there are no exposure limits. For these chemicals, toxicity parameters, such as LD₅₀, LD_{LO}, etc., which have been experimentally derived, are used to set TEELs from mainly animal toxicology studies after making adjustments to extrapolate experimental results from animals to humans.

Thus, in what follows, concentration limit-based TEELs derived from existing exposure limits and toxicity-based TEELs derived from toxicity parameters are discussed. Unfortunately, there still remains a large number of chemicals for which there are no exposure limits, and toxicity parameters are either absent or represent insufficient information. For these chemicals, a default methodology has been developed based on structure activity relationships (SARs) and other available knowledge. (See Section 3.5.) The hierarchy of sources for deriving TEELs is shown in Table 3.1. [The asterisks after TLV-TWA x 5 and TLV-TWA x 3 indicate limitations on their use (see Section 3.5.).]

Table 3.1 PAC Data Selection Hierarchy

PRIMARY PAC	HIERARCHY OF ALTERNATIVE PAC DATA PARAMETERS	SOURCE
AEGL-3 (60 minutes)	ERPG-3 TEEL-3: EEGL (30-min) IDLH LC ₅₀ LC _{LO} LD ₅₀ LD _{LO}	EPA/NAS AIHA DOE-OEM NAS NIOSH RTECS/Sax/HSDB/etc. RTECS/Sax/HSDB/etc. RTECS/Sax/HSDB/etc. RTECS/Sax/HSDB/etc.
AEGL-2 (60 minutes)	ERPG-2 TEEL-2: EEGL (60 minutes) LOC PEL-C TLV-C REL-C WEEL-C TLV-TWA $\times 5 *$ TC _{LO} TD _{LO}	EPA/NAS AIHA DOE-OEM NAS EPA/DOT OSHA ACGIH NIOSH AIHA ACGIH RTECS/Sax/HSDB/etc. RTECS/Sax/HSDB/etc.
AEGL-1 (60 minutes)	ERPG-1 TEEL-1: PEL-STEL TLV-STEL REL-STEL WEEL-STEL OTHER-STEL TLV-TWA $\times 3 *$	EPA/NAS AIHA DOE-OEM OSHA ACGIH NIOSH AIHA OTHER ACGIH
TEEL-0	PEL-TWA TLV-TWA REL-TWA WEEL-TWA MAK-TWA OTHER-TWA CEGL	DOE-OEM OSHA ACGIH NIOSH AIHA DFG OTHER NAS

3.2 Concentration Limit-Based TEELs

The preferred sources for deriving TEELs are published and peer-reviewed exposure limits intended to prevent adverse health effects among humans. These are the preferred sources because in almost all instances, they were derived from primary data sources following a formal, rigorous, and peer-reviewed process. In addition, because they are intended to protect the health and welfare of humans, the uncertainty associated with extrapolating results from other species is eliminated.

The common generic occupational exposure limits are: (1) the TWA, usually measured as the average over an 8-hour shift; (2) the Short-Term Exposure Limit (STEL), designed to prevent acute effects of exposure and measured as the TWA over a 15-minute interval; (3) a ceiling limit (C), measured as the instantaneous level and, in practice, for as short a time interval as is feasible to measure and also designed to prevent acute effects; and (4) the level that is immediately dangerous to life or health (IDLH). The IDLH threshold is designed to alert a worker to escape such an environment immediately. It is also designed to allow such a worker 30 minutes to select the most appropriate choice of respiratory protection and to escape without becoming incapacitated or suffering life-threatening or serious and irreversible health effects.

These exposure limits are analogous to emergency exposure limits. A STEL could be translated into a TEEL-1 (e.g., because both assume an exposure duration of 15 minutes and both are designed to prevent irreversible health effects). Similarly, a C limit could be translated into a TEEL-2 and an IDLH value into a TEEL-3. The TWA designed for an 8-hour work shift is used as a TEEL-0.

However, occupational exposure limits do not fit exactly the needs associated with emergencies. Occupational exposure limits are designed to protect employed adults who are exposed intermittently (i.e., during normal work activities). During emergencies, however, any member of a population could be exposed. Moreover, exposure could be very short, intermittent, or very long. Therefore, deriving TEELs from these limits requires the consideration of these limitations.

3.2.1 Sources of Data

The principal sources of data for concentration-based TEELs are PELs promulgated by the Occupational Safety and Health Administration (OSHA); Threshold Limit Values (TLVs), adopted by the American Conference of Governmental Industrial Hygienists (ACGIH); Recommended Exposure Limits (RELs) and limits that are IDLH, recommended by the National Institute for Occupational Safety and Health (NIOSH); and Workplace Environmental Exposure Levels (WEELs), adopted by the AIHA (AIHA, 2007b).

PELs are legally enforceable occupational exposure limits promulgated by OSHA for the purpose of preventing occupational disease and injury among workers. PELs are published in the Code of Federal Regulations (CFR) at 29 CFR 1910.1000–1018, and 1025–1052 and are set according to provisions in the *Occupational Safety and Health Act*. They are available on the Internet at <http://www.osha.gov/SLTC/pel/standards.html> (OSHA, 2007a).

The ACGIH adopts TLVs as advisories, and these values have been adopted by many jurisdictions in the United States and internationally (ACGIH, 2007a, 2007b). TLVs are revised and published annually, as they have been since 1939. The TLV list is available on the Internet to members of the ACGIH and in a booklet that can be purchased from the ACGIH (ACGIH, 2007a).

RELs and IDLHs are published by NIOSH in the *NIOSH Pocket Guide to Chemical Hazards*, available as a booklet, on CD, and on the Internet at <http://www.cdc.gov/niosh/npg> (CDC, 2005). NIOSH, as advisory to OSHA, bases its RELs on reviews of scientific literature. RELs are usually peer-reviewed before they are made final. As a convenience for users, current OSHA PELs can also be found in the *NIOSH Pocket Guide to Chemical Hazards*.

WEELs are designed as guidance for selected chemicals not otherwise addressed by OSHA, ACGIH, or NIOSH. WEELs are available on the Internet at <http://www.aiha.org/1documents/Committees/WEEL-WEELslevels2007.pdf> (AIHA, 2007b). WEELs are expressed as either TWA concentrations or ceiling values.

These exposure limits are set according to different statutory or other criteria, and consequently, for some chemicals, PELs, RELs, and TLVs differ. All these limits are combined in an ACGIH publication, *2007 Guide to Occupational Exposure Values*, published annually (ACGIH, 2007b). This publication includes not only PELs, TLVs, WEELs, and RELs, but also the Maximale Arbeitsplatz-Konzentration (maximum workplace concentration) (MAK) values from the Deutsche Forschungsgemeinschaft (German Research Foundation). Some concentration limits from other countries are also listed in the *Registry of Toxic Effects of Chemical Substances* (RTECS) (SilverPlatter, 2007).

3.2.2 Particles not Otherwise Specified

Particles not otherwise specified (PNOS) have been assigned a TLV-TWA of 10 mg/m³. This TLV-TWA applies only to solids and non-volatile liquids for which dispersion would be as an aerosol cloud. [See Appendix B of the ACGIH *2007 TLVs and BEIs* booklet (ACGIH, 2007a).]

3.2.3 Concentration or Dose Dependent Toxicity of Chemicals

In the following discussion, reference is made to “Y” and “N” chemicals. The letters “Y” and “N” are used in this section because they are also used in the TEEL database spreadsheets and associated workbook. “Y” means “Yes, the toxic effects of this chemical are concentration-dependent and/or it is a severe or moderate irritant.” “N” means “No, the toxic effects of this chemical are not concentration-dependent but are instead dose-dependent and/or it is a mild irritant.” “Y” chemicals are fast-acting with immediate toxic effects and include sensory irritants and corrosives and chemicals that cause blistering. Chemicals with “STEL” or “C” values by either OSHA or the ACGIH are “Y” chemicals. “N” chemicals are dose-dependent and not concentration-dependent. Effects of “N” chemicals depend, not only on concentration, but also on duration of exposure, breathing rate, and absorption rate. The toxic effects of some chemicals are both concentration-dependent and dose-dependent.

3.2.4 Order of Consideration

The order of consideration for the development of TEELs is described briefly and schematically in Table 3.1. TWA limits are used for TEEL-0, STELs are used for TEEL-1, C limits are used for TEEL-2, and IDLH values are used for TEEL-3. For the more detailed hierarchy at each TEEL level, see Table 3.1.

3.3 Special Considerations

3.3.1 Simple Asphyxiants

Simple asphyxiants are biologically inert gases that can cause injury by displacing oxygen rather than by any inherent toxicity of their own. Simple asphyxiants include the noble gases (i.e., argon, helium, krypton, radon, and xenon) as well as nitrogen and hydrogen. Because risk of harm is associated with displacement of oxygen, the concentration limits for simple asphyxiants are the same and are determined by the level to which they reduce oxygen concentration. Although it is anticipated that response personnel would use direct-reading oxygen instruments to determine oxygen levels rather than attempt to measure the concentration of simple asphyxiants and then calculate oxygen levels, development of TEELs for simple asphyxiants is dependent on the toxicity associated with them and is independent of how their concentrations may be measured in an actual event. In addition, the TEELs for simple asphyxiants may be useful to emergency planners and responders in some situations for estimating their effects in a potential or actual event independent of their correlated oxygen levels. For example, when modeling an actual release of a simple asphyxiant, modeling results could shortcut the time it might take for responders to determine where to make actual confirming real-time direct-reading oxygen measurements by indicating where asphyxiant levels may be lethal, incapacitating, or life-sustaining. This could in turn shortcut the time it would take emergency managers to issue protective action recommendations.

The normal concentration of oxygen in air is 20.9% by volume. The minimum oxygen concentration that OSHA permits for confined space entry (CSE) is 19.5%. If the concentration of a simple asphyxiant reaches approximately 65,000 parts per million (ppm) by volume, it would displace enough air to reduce the oxygen concentration to the OSHA CSE limit. According to both OSHA and the American National Standards Institute (ANSI) in ANSI Z88.2-1992, Respiratory Protection (ANSI, 1992), this level can produce some physiological effects, but they are unnoticeable. Thus, this level corresponds well with the definition of TEEL-0 as “the threshold concentration below which most people will experience no appreciable risk of health effects.” (See Table 2.1.) Therefore, the TEEL-0 is 65,000 ppm for any simple asphyxiant. (Note that all references to ppm in this discussion refer to volumetric measurements.)

Similarly, TEEL-1 is also set at 65,000 ppm, resulting in an oxygen concentration of approximately 19.5%. Although this oxygen concentration level is somewhat higher than the level that would cause decreased ability to work strenuously and therefore is somewhat higher than the definition of TEEL-1 as the threshold for “mild transient adverse health effects” (see Table 2.1), it was set at this level to avoid possible confusion for fire and rescue responders who

are used to the OSHA 19.5% minimum oxygen level for entry into an atmosphere without respiratory protection. However, most fire and rescue personnel that respond to an emergency release are already wearing a self-contained breathing apparatus, further decreasing the possibility of confusion.

TEEL-2 is set at 230,000 ppm. At this concentration, the simple asphyxiant would displace enough air to result in an oxygen concentration of approximately 16%. According to ANSI Z88.2-1992, if the concentration of oxygen drops to 16%, a threshold is reached for the onset of impaired coordination, perception, and judgment, and that would be sufficient to begin to deprive a person of the capability of self-protection and escape (ANSI, 1992). This level corresponds well with the definition of TEEL-2 as the threshold for “developing irreversible or other serious health effects or symptoms that could impair the ability to take protective action.” (See Table 2.1.) TEEL-2 is deliberately set at the 16% oxygen level rather than the OSHA 19.5% level, not only because it fits the TEEL-2 definition, but also because the criteria for an emergency environment as “life preserving” is much different than the criteria for the occupational environment that is not only life preserving but also “health preserving” over a lifetime of working. For example, the 16% oxygen level gives the emergency response decision maker more time to consider and prepare protective action and rescue options for building-sheltered personnel in the path of a potentially lethal asphyxiant plume. As the in-building oxygen level begins to decrease due to infiltration of the asphyxiant, the “life-preserving” 16% TEEL-2 limit offers more time to consider and prepare rescue options. It also gives more time for the outside plume to dissipate without needing to evacuate personnel into a potentially lethal plume, which a 19.5% limit would mandate much earlier.

TEEL-3 is set at 400,000 ppm, resulting in an oxygen concentration of 12.5%, which according to ANSI Z88.2-1992, is the threshold for beginning to cause very poor judgment and coordination with unconsciousness and then death following at lower oxygen levels (ANSI, 1992). It is based on the blood oxygen versus lung alveolar oxygen curve in ANSI Z88.2-1992 that shows the IDLH point on the curve as the beginning of a precipitous slide downward in blood oxygen levels correlated with relatively small changes in percent oxygen, resulting in a significant loss of thought processes and judgment, often without warning properties (ANSI, 1992). This level corresponds well with the definition of TEEL-3 as the threshold for “life-threatening health effects.” (See Table 2.1.)

According to the OSHA rationale in the preamble to its respiratory protection standard (OSHA, 2007b), these values would not need to be reduced for acclimatized people at high altitudes up to 14,000 feet above mean sea level. However, for unacclimatized people, these levels may need to be reduced because of their unacclimatized blood-oxygen carrying capacity compared with those who are acclimatized. The limiting factor producing hypoxia is not the percentage of oxygen in air by volume, but its partial pressure. The volume of oxygen in air remains at a constant 20.9% regardless of altitude, but partial pressure of the earth’s atmosphere decreases with increasing altitude. The human body’s acclimatization processes compensate for the lower abundance of oxygen at altitude by producing more oxygen-carrying red blood cells and other physiological mechanisms. This acclimatization usually takes about 4 weeks’ residence time at a particular altitude to complete. For example, at 5,000 feet above sea level (e.g., the approximate elevation of Denver, Colorado), the partial pressure of oxygen is reduced by about 17%. At 10,000 feet (e.g., the approximate elevation of Leadville, Colorado, the town with the highest elevation of

any incorporated city in the United States), it is reduced by about 29%. However, acclimatized people survive very well at both of these altitudes. At 30,000 feet (e.g., the approximate elevation of Mount Everest and the cruising altitude of some commercial aircraft), the partial pressure of oxygen is reduced by about 70%, which would be lethal for almost all people except the extremely acclimatized.

3.3.2 Radioactive Compounds

Some chemicals for which TEELs have been assigned are also radioactive isotopes. Because the DOE Category 3 radionuclide thresholds are based on radiation dose alone, chemical toxicity may need to be considered when screening values are applied to very low-specific-activity radionuclides or mixtures that are also known to be chemically toxic. For practical purposes, this concern is limited to uranium of low enrichment in the form of compounds that are relatively soluble in body fluids (e.g., carbonates, nitrates, fluorides, and sulfates), but TEELs have also been derived for thorium and some of its compounds. Depending on the exact proportions of the different uranium isotopes, the chemical toxicity concern becomes dominant as the nominal enrichment (U-235 weight percent) decreases through the range from about 16% to 5%.

3.3.3 Compound-to-Element Molecular Weight Ratio Adjustments

Many concentration limits are listed as an element as part of a compound, for example, “zirconium and compounds, as zirconium.” It seems logical to adjust TEELs to account for this practice. For example, zirconium has a molecular weight of 91.22 and chlorine has a molecular weight of 35.45; thus, zirconium chloride (ZrCl_4) has a molecular weight of 233.02 ($91.22 + 4 \times 35.45$). The ratio of these weights is 2.55 and is the factor by which the concentration limits for zirconium compounds (e.g., $\text{PEL-TWA} = 5 \text{ mg/m}^3$) “as zirconium” should be adjusted up for ZrCl_4 by multiplying by the same 2.55. Similar ratio adjustments would need to be made, as the ratio of molecular weights of the element to that of the compound, for exposure limits for similar compounds (e.g., PEL, TLV, REL, MAK, STEL, C, and IDLH). This adjustment is not necessary for toxicity-based TEELs that are already compound-specific.

3.4 Toxicity-Based TEELs

3.4.1 Types of Data

Published concentration limits do not exist for many chemicals. However, existing published toxicity parameters can be used to derive TEELs. For chemicals for which these parameters have been determined, TC_{LO} and TD_{LO} toxic-effect values can be used to estimate TEEL-2 limits, and LC_{50} , LC_{LO} , LD_{50} , and LD_{LO} lethal-effect parameters can be used to derive TEEL-3 limits.

As with concentration limit-based TEELs derived from published concentration limits, a priority order exists to derive TEELs from toxicity parameters. (See Table 3.1.) Data from human exposures are given primary consideration over data from other species; because of their relative abundance, data from rat exposures are preferred over other non-human species. Similarly, because TEELs are concerned primarily with airborne concentration, parameters derived from inhalation experiments are preferred to data from other routes of administration (i.e., skin absorption).

3.4.2 Sources of Data

Toxicity parameters can be obtained from many sources. The three principal sources used for developing TEELs are (1) RTECS, (2) Sax's Dangerous Properties of Industrial Chemicals (Sax), and (3) the Hazardous Substances Data Bank (HSDB) (Silver Platter, 2007; Lewis, 2004; NLM, 2006).

3.4.3 Deriving TEELs from Toxicity Parameters

3.4.3.1 Adjustment Factors for Human-Equivalent Toxicity Data

To adjust human-equivalent toxicity data converted from other toxicity parameters for calculating TEELs, the relationship between ERPGs and human and animal toxicity parameters was evaluated. It was assumed that any model based on ERPGs would also be valid for TEELs. A mathematical model was developed based on the relationship between human and animal toxicity parameters versus existing ERPGs. This model was used to derive adjustment factors that are applied to human-equivalent toxicity data that, in turn, were converted from animal toxicity data, unless the data were human to begin with precluding the animal-to-human conversion step. The adjusted human-equivalent toxicity data are then used for calculating TEELs (Craig et al., 2000).

The adjustment factors resulting from this model are shown in Table 3.2.

Table 3.2 Adjustment Factors to Derive Toxicity-Based TEELs from Human-Equivalent Toxicity Concentration Values

SPECIES	TEEL-3				TEEL-2	
	LC ₅₀	LC _{LO}	LD ₅₀	LD _{LO}	TC _{LO}	TD _{LO}
HUMAN ONLY	-	50	-	1	10	-
RAT ONLY	100	100	2	-	15	1
ALL DATA	100	100	2	1	15	1.5

Source: Craig et al., 2000

3.4.3.2 Parameter Selection

Parameters are selected for deriving TEELs by species, route of administration, the value of the parameter, and time. Data from humans are preferred, followed by data derived from rats, mice, rabbits, guinea pigs, dogs, cats, pigs, and monkeys. Data derived by inhalation are preferred. Oral data are selected next, followed by data from skin, intraperitoneal, intravenous, subcutaneous, intramuscular, or other routes of administration. The lowest value of the selected parameter is chosen. Parameters need to be adjusted by the duration of the experiments, which requires selecting the data for the one nearest to 15 minutes. Although several sets of toxicity data may be selected and entered into the TEEL input sheet for any one TEEL, only one set is actually used by the TEEL development program to derive any TEEL value. The selection of the data to use in TEEL derivation is automatic, calculated with an embedded peer-reviewed algorithm following the selection hierarchy.

3.4.3.3 Adjustment to Human Equivalent Concentration

Extrapolating results from animal experiments to humans requires making adjustments for the many differences. For purposes of deriving TEELs, the most important differences between humans and experimental animals are body weight and breathing rate. (See sample calculations in Section 4.) Default values for mean body weight (kg) and breathing rate (m^3/day) are shown in Table 3.3.

**Table 3.3 Default Mean Body Weight and Breathing Rate
Values for Different Species**

SPECIES	ABBREVIATION FOR SPECIES	MEAN BODY WEIGHT (kg)	MEAN BREATHING RATE (m^3/d)
Bird	brd	0.5	0.525
Bird-type not specified (tns)	brd-t	1	1.05
Bird-wild	brd-w	0.04	0.42
Human/child (1-13 yrs)	chd	20	8.64
Chicken	ckn	0.8	0.85
Cat	ct	2	1.25
Dog	dg	10	3.66
Duck	dck	2.5	2.625
Frog	frg	0.033	1.51
Guinea pig	gp	0.5	0.283
Hamster	ham	0.125	0.1
Human/man	hmn	70	20
Human/infant (0-1 yrs)	inf	5	2.5
Monkey	mo	5	3.94
Mouse	mu	0.025	0.035
Pig	pg	60	20
Quail	quail	1	1.05
Rat	r	0.2	0.153
Rabbit	rb	2	1.3
Human/women	wmn	50	16

Sources: Body weight data are from Sax and other sources. The daily breathing rates are commonly used values for human males, females, children, and infants, as well as laboratory animals. Similar sets of default values for a more limited list of species are from Hayes (2001) and other sources.

3.4.3.4 Time Considerations

All toxic concentration data (LC_{50} , LC_{LO} , TC_{LO}) are reduced to a 15-minute exposure time. If the exposure time is not given, 15 minutes is assumed for concentration-dependent (Y) chemicals and 60 minutes for dose-dependent (N) chemicals. The exponent “n” in the equation used to reduce the data from other exposure times (t_{exp}) to a 15-minute exposure time (t), $[(t_{exp}/t)^n]$ depends on whether the acute toxic effects are Y ($n = 1/2$) or N chemicals ($n = 1.0$). The choice of square root is somewhat arbitrary. The intention is to reduce the influence of exposure time for chemicals whose acute effect is primarily determined by the concentration because exposure time is not the main factor in determining the toxic consequences of Y chemicals (Craig and Lux, 1998).

3.4.3.5 Route Adjustment Factors

The amount of a chemical absorbed varies with the route of administration. For example, intravenous administration is one of the most efficient (i.e., the proportion of the administered chemical that is absorbed systemically is high), and administration on the intact skin is one of the least efficient. Consequently, it is important to adjust the absorbed dose depending on the route of administration.

Route adjustment factors (RAFs) are shown in Table 3.4. These values are estimates. In practice, these values would vary from chemical to chemical, depending on solubility in body fluids, metabolic changes, and other factors. The RAFs for inhaled material are used only when data are given in dose units (i.e., mg/kg) (Lewis, 2004).

**Table 3.4 Routes Adjustment Factors used for
Different Routes of Administration**

ROUTE OF ADMINISTRATION	ABBREVIATION	RAF
Eye	eye	0.20
Implant	imp	0.25
Inhalation	ih	0.50
Inhalation-gas/vapor	ih-g	0.50
Inhalation-particles	ih-p	0.25
Intracerebral	ice	0.50
Intradermal	idr	0.10
Intramuscular	im	0.25
Intraperitoneal	ip	0.25
Intrapleural	ipl	0.50
Intratesticular	itt	0.25
Intratracheal	it	0.25
Intravaginal	ivg	0.25
Intravenous	iv	0.50
Oral	os	0.25
Rectal	rct	0.25
Skin	sk	0.05
Skin-insoluble	sk-i	0.05
Skin-soluble	sk-s	0.10
Subcutaneous	sc	0.10
Unknown	uk	0.25

3.5 TEELs when Exposure Limits and Toxicity Parameters are Missing

3.5.1 DOE Policy Mandate

It is the policy of DOE that TEELs should be developed at all levels (i.e., TEEL-0, -1, -2, and -3) for any chemicals for which emergency planning must be performed. Accordingly, the following rules have been developed for deriving TEELs for which concentration limit-based or hierarchy-based values, toxicity-based TEEL-2s, or toxicity-based TEEL-3s are not known.

To comply with this mandate, TEELs can be derived when other data are missing using default criteria described below. Because of the application of these default criteria, there are no gaps in

the final TEELs, which provide the emergency planner with a full range of consequence values with which to assess the potential impacts of a chemical.

3.5.2 TEELs Derived from Structure-Activity Relationships

If there are no useful concentration limits or toxicology parameters or if a chemical is not listed in any of these databases, a toxicity estimate can be made from other structurally similar chemicals for which there are data (e.g., using SAR).

3.5.3 TEELs Derived from Health Hazard Ratings

If there are no useable data in RTECS or elsewhere sufficient to derive any type of TEEL, but the chemical is listed in Sax, toxicity has been estimated from the Sax Hazard Rating. The National Fire Protection Association Health Hazard Ratings (HHRs) or HHRs from other sources (e.g., Material Safety Data Sheets) have also been used for chemicals not listed in Sax. The Sax Introduction provides definitions for HHR values. These toxicity data have been modified for use in TEEL derivation as follows:

$$\begin{array}{llll} \text{HHR} = 1 & \text{LC}_{50} \text{ rat 240 min} & = & 5000 \text{ ppm, or} \\ & \text{LD}_{50} \text{ rat oral} & = & 20,000 \text{ mg/kg} \end{array}$$

$$\begin{array}{llll} \text{HHR} = 2 & \text{LC}_{50} \text{ rat 240 min} & = & 500 \text{ ppm, or} \\ & \text{LD}_{50} \text{ rat oral} & = & 2000 \text{ mg/kg} \end{array}$$

$$\begin{array}{llll} \text{HHR} = 3 & \text{LC}_{50} \text{ rat 240 min} & = & 100 \text{ ppm, or} \\ & \text{LD}_{50} \text{ rat oral} & = & 400 \text{ mg/kg} \end{array}$$

3.5.4 TEELs Derived from TEELs for Other Levels

If there is information sufficient to derive one level of TEEL (e.g., TEEL-0, -1, -2, or -3), but not for others, recommended TEELs (RecTEELs) can be derived from the others. Thus, for “N” chemicals:

$$\begin{array}{ll} \text{TEEL-1} & = 3 \times \text{TEEL-0 and} \\ \text{TEEL-2} & = 5 \times \text{TEEL-0} \end{array}$$

These values (i.e., $3 \times$, $5 \times$) are taken from the ACGIH TLV booklet (ACGIH, 2007a). They are recommended as acceptable temporary excursions above the TLV. Using these values, one can derive TEEL-1 or TEEL-2 from a TEEL-0, or vice versa, as RecTEELs.

For “Y” chemicals that are concentration-dependent and moderate or severe acute irritants and/or have either STEL or C values:

$$\begin{array}{ll} \text{TEEL-2} & = 7 \times \text{TEEL-1 or} \\ \text{TEEL-1} & = (\text{TEEL-2})/7 \end{array}$$

$$\begin{array}{ll} \text{TEEL-3} & = 5 \times \text{TEEL-2 or} \\ \text{TEEL-2} & = (\text{TEEL-3})/5 \end{array}$$

These values were derived from the mean ratios of ERPG-2 to ERPG-1 (~7) and ERPG-3 to ERPG-2 (~5).

TEEL-0 = (TEEL-1)/3, but as explained earlier, not the inverse for “Y” chemicals.

Thus, in these circumstances, with knowledge of any TEEL for a given chemical, it is possible to derive all the TEELs for that chemical (fulfilling the requirement for having a TEEL -0, -1, -2, and -3).

For all TEELs: $\text{TEEL-0} \leq \text{TEEL-1} \leq \text{TEEL-2} \leq \text{TEEL-3}$.

The multipliers in the discussion above are displayed in Table 3.5.

Table 3.5 Multipliers for Converting TEELs

	TYPE OF CHEMICAL	
	CONCENTRATION-DEPENDENT	NOT CONCENTRATION-DEPENDENT (DOSE-DEPENDENT)
TEEL-3 =	$5 \times \text{TEEL-2}$	$5 \times \text{TEEL-2}$
TEEL-2 =	$(\text{TEEL-3})/5$ $7 \times \text{TEEL-1}$	$5 \times \text{TEEL-0}$ $(\text{TEEL-3})/5$
TEEL-1 =	$(\text{TEEL-2})/7$	$(\text{TEEL-2})/7$ $3 \times \text{TEEL-0}$ $3/5 \times \text{TEEL-2}$
TEEL-0 =	$(\text{TEEL-1})/3$	$(\text{TEEL-1})/3$ $(\text{TEEL-2-not rounded})/21$ $(\text{TEEL-2})/5$ (for conc. limits)

3.6 Default Criteria Summary

Because of the application of these default criteria when data are missing, there are no gaps in the final TEELs. This gives the emergency planner a full range of consequence values with which to assess the potential impacts of a chemical.

3.7 Adjustments

3.7.1 Toxicity-Based to Concentration-Based Ratio Adjustments

Concentration limit-based TEEL-2s are frequently much lower than applicable toxicity data would suggest, in part because they are based on values that sometimes include large built-in safety factors. A partial resolution to this problem is to calculate the ratio of concentration limit-based TEEL-2s to toxicity-based TEEL-2s and then, to use a ratio-based correction factor to adjust the value. If this ratio is between 10 and 100, then set TEEL-2 to concentration limit-based TEEL $\times 10$.

If the ratio is greater than 100, set TEEL-2 to concentration limit-based TEEL $\times 100$.

Hence, applying the ratio removes some of the safety factors, allowing the TEEL value to increase (Craig et al., 2000).

3.7.2 TEEL-3 $\leq$ 500 mg/m³ for Aerosols

TEEL-3 values are restricted to 500 mg/m³ for all chemicals that form aerosol particulates rather than gaseous vapors and for which the original units are in mg/m³. This restriction is based on the extreme instability at high concentrations of aerosol clouds in the respirable size range due to coagulation and subsequent sedimentation (Friedlander, 2000). This restriction does not apply to gases or vapors for which the original units are usually in ppm. Thus:

$$\text{TEEL-3} \leq 500 \text{ mg/m}^3 \text{ for aerosols.}$$

3.7.3 Rounding Guidelines for Final TEELs

Final TEELs are rounded according to the following guidelines. Hierarchy-based values (from existing concentration limits) are presented as given by the original source, but toxicity-based values are rounded down to powers of 10 of the bases 1, 1.25, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, or 7.5 (unless the derived value is within 5% of the limit above it, e.g., 290 is rounded to 300). Where applicable, conversion from ppm to mg/m³ is made before rounding. Adjusted concentration limit-based values are given to not more than three significant figures.

3.8 Other Considerations

3.8.1 Lower Explosive Limits

The Lower Explosive Limit (LEL) values for chemicals can be found in the TEEL database, spreadsheets, and workbook. Note that colors and special fonts are used to alert the user to special precautions. The following special precautions are identified.

- TEELs between 10% and 50% of the LEL are in bold green italics *[bold green italics]*.
- TEELs between 50% and 100% of the LEL are in bold pink italics, underlined *[bold pink italics, underlined]*.
- TEELs exceeding the LEL are in bold bright red italics and double underlined *[bold bright red italics and double underlined]*.

The LEL of chemical substances has not been used to limit TEELs.

4.0 SAMPLE TEEL CALCULATIONS

Sample TEEL calculations/derivations are presented in this section for one chemical in each of the following categories:

1. Chemicals with AEGLs: acrylic acid, Chemical Abstracts Service Registry Number (CAS RN) 79-10-7 (see sample calculation in Section 4.1)
2. Chemicals with ERPGs, but no AEGLs: benzene, CAS RN 71-43-2 (see sample calculation in Section 4.2)
3. Chemicals with concentration limits, but no toxicity data: methyl acetylene-propadiene mixture (MAPP gas), CAS RN 59355-75-8; and lead bromide, CAS RN 10031-22-8 (see sample calculations in Sections 4.3.1 and 4.3.2)
4. Chemicals with both concentration limit and toxicity data: Vinyl Fluoride, CAS RN 75-02-5 (see sample calculation in Section 4.4)
5. Chemicals with toxicity data, but no concentration limits: ricin, CAS RN 9009-86-3 (see sample calculation in Section 4.5)
6. Chemicals with neither concentration limits nor toxicity data:
 - 6.1 Solids and non-volatile liquids: europium, CAS RN 7440-53-1 (see sample calculation in Section 4.6.1)
 - 6.2 Volatile liquids and gases: carbon trifluoride, CAS RN 75-46-7 (see sample calculation in Section 4.6.2)
 - 6.3 Structure activity relationships: bismuth hydroxide, CAS RN 10361-43-0 (see sample calculation in Section 4.6.3)
7. Simple asphyxiants: neon, CAS RN 7440-01-9 (see sample calculation in Section 4.7)

The following abbreviations are used in the calculations below:

ABR	animal breathing rate (m^3/day)
ABW	animal body weight (kg)
CF	conversion factor
HBR	human breathing rate (m^3/day)
HBW	human body weight (kg)
$\text{ALC}_{50, \text{LO}}, \text{ALD}_{50, \text{LO}}$	animal lethal concentration/dose (mg/kg)
$\text{HLC}_{50, \text{LO-eq}}$	human-equivalent lethal concentration (mg/m^3 or ppm)
$\text{HTC}_{\text{LO-eq}}$	human-equivalent toxic concentration (mg/m^3 or ppm)
RAF	route adjustment factor
TD_{LO}	toxic dose (mg/kg)

The information used to calculate and/or derive TEELs for each of the example chemicals is listed after each TEEL value. All concentration limit and toxicity values for each of the examples, including those not used for generating TEELs, may be found on the DOE website.

4.1 Chemicals with AEGLs

Acrylic acid, CAS RN 79-10-7

TEEL-0	=	1.5 ppm, TLV-TWA (hierarchy of alternative guidelines) and TEEL-1 (see discussion below)
TEEL-1	=	1.5 ppm, 60-minute AEGL-1 (primary guideline)
TEEL-2	=	46 ppm, 60-minute AEGL-2 (primary guideline)
TEEL-3	=	180 ppm, 60-minute AEGL-3 (primary guideline)

The initial TEEL-0 value is 2 ppm based on the TLV-TWA. However, because $TEEL-1 \geq TEEL-0$, $TEEL-0 = 1.5$ ppm.

4.2 Chemicals with ERPGs, but No AEGLs

Hydrogen peroxide, CAS RN 7722-84-1

TEEL-0	=	1 ppm, PEL-TWA (primary guideline)
TEEL-1	=	10 ppm, ERPG-1 (alternative guideline)
TEEL-2	=	50 ppm, ERPG-2 (alternative guideline)
TEEL-3	=	100 ppm, ERPG-3 (alternative guideline)

4.3 Chemicals with Concentration Limits, but No Toxicity Data

Two examples of chemicals with concentration limits without toxicity data are provided. One is a simple straightforward example of how concentration limits are used directly to develop TEELs. The other is a more complex example of using a modification of the concentration limits when these are expressed in terms of the element and compounds as the element (e.g., “manganese and inorganic compounds, as Mn”). The adjustment is needed because the element mass is less than the compound mass. The concentration limits are multiplied by the ratio of the compound mass to the element mass.

4.3.1 Straightforward Example: MAPP Gas, CAS RN 59355-75-8

TEEL-0	=	1,000 ppm (PEL-TWA)
TEEL-1	=	1,250 ppm (TLV-STEL)
TEEL-2	=	1,250 ppm ($TEEL-2 \geq TEEL-1$)
TEEL-3	=	3,400 ppm (IDLH)

Since this is a “Y” chemical (i.e., toxicity is concentration dependent), $TEEL-2$ would have been equal to $TEEL-3/5 = 3,400/5 = 680$ ppm. $TEEL-2$ cannot be less than $TEEL-1$, and is therefore increased to 1,250 ppm.

4.3.2 Requiring Calculation: Lead Bromide, CAS RN 10031-22-8

TEEL-0	=	0.0886 mg/m ³ , compound adjusted PEL-TWA (primary guideline)
TEEL-1	=	0.266 mg/m ³ , compound adjusted TLV-TWA × 3 (alternative guideline)
TEEL-2	=	0.443 mg/m ³ , compound adjusted TLV-TWA × 5 (alternative guideline)
TEEL-3	=	177 mg/m ³ , compound adjusted IDLH (alternative guideline)

Concentration limits are sometimes given for an element and compounds, for example, lead (CAS RN 7439-92-1) and inorganic compounds, as Pb. The existing limits are multiplied by an adjustment factor (the ratio of the compound molecular weight to the total element molecular weight) to determine the applicable compound concentration limits. Concentration limit-based TEELs are not rounded.

The following equation determines the adjustment factor:

$$\text{Molecular weight of compound} / (\text{atomic weight of element} \times \# \text{ of element atoms}) \\ = \text{adjustment factor}$$

$$\text{Molecular weight of lead bromide} / (\text{atomic weight of Pb} \times 1) \\ = \text{adjustment factor } 367.01 / (207.2 \times 1) = 1.77$$

The compound concentration limits are used to derive all TEELs for this chemical.

$$\begin{aligned} \text{Given: PEL-TWA for Pb} &= 0.05 \text{ mg/m}^3 \\ \text{TLV-TWA for Pb} &= 0.05 \text{ mg/m}^3 \\ \text{IDLH for Pb} &= 100 \text{ mg/m}^3 \end{aligned}$$

$$\begin{aligned} \text{TEEL-0} &= \text{Element PEL-TWA} \times \text{compound adjustment factor} \\ &= 0.05 \text{ mg/m}^3 \times 1.77 \\ &= 0.0885 \text{ mg/m}^3 \end{aligned}$$

TEEL-1 and TEEL-2 are derived by multiplying the TLV-TWA (i.e., 0.05 mg/m³) by 3 and 5, respectively, as indicated in the hierarchy of alternative guidelines. (See Section 3.5.4 and Table 3.1.)

$$\begin{aligned} \text{TEEL-1} &= \text{Element TLV-TWA} \times 3 \times \text{compound adjustment factor} \\ &= 0.05 \text{ mg/m}^3 \times 3 \times 1.77 \\ &= 0.2655 \text{ mg/m}^3 \end{aligned}$$

$$\begin{aligned} \text{TEEL-2} &= \text{Element TLV-TWA} \times 5 \times \text{compound adjustment factor} \\ &= 0.05 \text{ mg/m}^3 \times 5 \times 1.77 \\ &= 0.4425 \text{ mg/m}^3 \end{aligned}$$

$$\begin{aligned} \text{TEEL-3} &= \text{IDLH} \times \text{compound adjustment factor} \\ &= 100 \text{ mg/m}^3 \times 1.77 \\ &= 177 \text{ mg/m}^3 \end{aligned}$$

4.4 Chemicals with both Concentration Limit and Toxicity Data

Vinyl fluoride CAS RN 75-02-5

$$\begin{aligned}\text{TEEL-0} &= 1.5 \text{ mg/m}^3, \text{ TLV (alternative guideline)} \\ \text{TEEL-1} &= 100 \text{ mg/m}^3, \text{ concentration limit-derived} \\ \text{TEEL-2} &= 750 \text{ mg/m}^3, \text{ REL-C (alternative guideline)} \\ \text{TEEL-3} &= 150,000 \text{ mg/m}^3, \text{ toxicity-based}\end{aligned}$$

Given: LC_{50} = $1.6 \times 10^6 \text{ mg/m}^3$, rat, 240 minutes, “Y” concentration-dependent (All toxic concentration data are reduced to a 15-minute exposure time; See Section 3.4.3.4)

$$\begin{aligned}\text{LC}_{50\text{-eq}} &= \text{LC}_{50} \times (\text{mean HBW/mean ABW}) \times (\text{mean ABR/mean HBR}) \\ \text{LC}_{50\text{-eq}} &= 1.6 \times 10^6 \text{ mg/m}^3 \times (70 \text{ kg}/.2 \text{ kg}) \times (.153 \text{ m}^3/\text{d} / 20 \text{ m}^3/\text{d}) \times 4 = 1.7 \times 10^7 \text{ mg/m}^3\end{aligned}$$

$$\text{TEEL-3} = \text{LC}_{50\text{-eq}}/\text{adjustment factor for “LC}_{50}\text{” “rat only” (See Section 3.4.3.1; Table 3.2)}$$

$$\begin{aligned}\text{TEEL-3} &= 1.7 \times 10^7 \text{ mg/m}^3 / 100 \\ &= 1.7 \times 10^5 \text{ mg/m}^3 \\ &= 150,000 \text{ mg/m}^3 \text{ (see rounding guidelines in Section 3.7.3)}\end{aligned}$$

$$\begin{aligned}\text{TEEL-2} &= \text{REL-C} \\ &= 5 \text{ ppm} \\ &= 5 \text{ ppm} \times 1.88 \text{ (ppm to mg/m}^3 \text{ conversion factor)} \\ &= 9.4 \text{ mg/m}^3 \\ &= 7.5 \text{ mg/m}^3 \text{ (see rounding guidelines in Section 3.7.3)}\end{aligned}$$

The toxicity-based TEEL-2 needs to be derived in order to determine the ratio of the toxicity-based TEEL-2 to the concentration limit-derived TEEL-2.

Given: TC_{LO} = $3.76 \times 10^3 \text{ mg/m}^3$, rat, 360 minutes, concentration-dependent (All toxic concentration data are reduced to a 15-minute exposure time; See Section 3.4.3.4)

$$\begin{aligned}\text{TC}_{\text{LO-eq}} &= \text{TC}_{\text{LO}} \times (\text{mean HBW/mean ABW}) \times (\text{mean ABR/mean HBR}) \\ \text{TC}_{\text{LO-eq}} &= 19.452 \text{ mg/m}^3 \times (70 \text{ kg}/0.2 \text{ kg}) \times (0.153 \text{ m}^3/\text{d} / 20 \text{ m}^3/\text{d}) \times 4.8989 = 49322.2 \text{ mg/m}^3\end{aligned}$$

$$\begin{aligned}\text{TEEL-2} &= \text{LC}_{\text{LO-eq}}/\text{adjustment factor for “TC}_{\text{LO}}\text{,” “rat only”} \\ \text{TEEL-2} &= 49322.2 \text{ mg/m}^3 / 15 \\ &= 3288.14 \text{ mg/m}^3\end{aligned}$$

The concentration limit-derived TEEL-2 is 9.4 mg/m^3 (the converted, but not rounded value shown above).

Ratio of toxicity-derived TEEL-2 to concentration limit-derived TEEL-2 = $3288.14 \text{ mg/m}^3 / 9.4 \text{ mg/m}^3 = 349.8$

Because this value is >100 , the concentration limit-based value is multiplied by 100 to give 750 mg/m^3 . (See Section 3.7.1.)

For chemicals whose toxicity is concentration-dependent, the TEEL-2 is divided by 7 to give TEEL-1. (See Section 3.5.4 and Table 3.5 for explanation.)

$$\begin{aligned}\text{TEEL-1} &= \text{TEEL-2}/7 \\ \text{TEEL-1} &= 750 \text{ mg/m}^3/7 \\ &= 100 \text{ mg/m}^3 \text{ (see rounding guidelines in Section 3.7.3)}\end{aligned}$$

4.5 Chemicals with Toxicity Data, but No Concentration Limits

Ricin, CAS RN 9009-86-3

$$\begin{aligned}\text{TEEL-0} &= 0.025 \text{ mg/m}^3, \text{ procedure-derived} \\ \text{TEEL-1} &= 0.075 \text{ mg/m}^3, \text{ procedure-derived} \\ \text{TEEL-2} &= 0.25 \text{ mg/m}^3, \text{ toxicity-based} \\ \text{TEEL-3} &= 0.25 \text{ mg/m}^3, \text{ toxicity-based}\end{aligned}$$

Because human data are given precedence, LD_{LO} was chosen instead of following the priority order to derive the toxicity-based TEEL-3.

Note: For illustrative purposes, the calculation was carried out as if the available data were from a nonhuman species.

$$\begin{aligned}\text{Given: } \text{LD}_{\text{LO}} &= 0.300 \text{ mg/kg, human, oral} \\ \text{LC}_{\text{LO}} &= \text{LD}_{\text{LO}} \times (\text{mean ABW}/\text{mean ABR}) \times \text{RAF} \\ \text{LC}_{\text{LO}} &= 0.300 \text{ mg/kg/d} \times (70 \text{ kg}/20 \text{ m}^3/\text{d}) \times 0.25 \\ &= 0.2625 \text{ mg/m}^3 \\ \text{LC}_{\text{LO-eq}} &= \text{LC}_{\text{LO}} \times (\text{mean HBW}/\text{mean ABW}) \times (\text{mean ABR}/\text{mean HBR}) \\ \text{LC}_{\text{LO-eq}} &= 0.2625 \text{ mg/m}^3 \times (70 \text{ kg}/70 \text{ kg}) \times (20 \text{ m}^3/\text{d}/20 \text{ m}^3/\text{d}) = 0.2625 \text{ mg/m}^3 \\ \text{TEEL-3} &= \text{LC}_{\text{LO-eq}}/\text{adjustment factor for “LD}_{\text{LO}},” \text{ “human only”} \\ \text{TEEL-3} &= 0.2625 \text{ mg/m}^3/1 \\ &= 0.2625 \text{ mg/m}^3 \\ &= 0.25 \text{ mg/m}^3 \text{ (rounding guidelines)}\end{aligned}$$

Because there are no TC_{LO} data, use TD_{LO} data to estimate TEEL-2.

$$\text{Given: } \text{TD}_{\text{LO}} = 0.9 \text{ mg/kg, human, oral, 1 day.}$$

Note: For illustrative purposes, the calculation was carried out as if the available data were from an animal.

$$\begin{aligned}\text{LC}_{\text{LO}} &= \text{TD}_{\text{LO}} \times (\text{mean ABW}/\text{mean ABR}) \times \text{RAF} \\ \text{LC}_{\text{LO}} &= 0.9 \text{ mg/kg/d} \times (70 \text{ kg}/20 \text{ m}^3/\text{d}) \times 0.25 \\ &= 0.7875 \text{ mg/m}^3\end{aligned}$$

$$\begin{aligned}
 LC_{LO-eq} &= LC_{LO} \times (\text{mean HBW}/\text{mean ABW}) \times (\text{mean ABR}/\text{mean HBR}) \\
 LC_{LO-eq} &= 0.7875 \text{ mg/m}^3 \times (70 \text{ kg}/70 \text{ kg}) \times (20 \text{ m}^3/\text{d}/20 \text{ m}^3/\text{d}) = 0.7875 \text{ mg/m}^3 \\
 TEEL-2 &= LC_{LO-eq}/\text{adjustment factor for "TD}_{LO}\text{" "all data"} \\
 TEEL-2 &= 0.7875 \text{ mg/m}^3/1.5 \\
 &= 0.525 \text{ mg/m}^3 \\
 &= 0.5 \text{ mg/m}^3 \text{ (rounding guidelines)}
 \end{aligned}$$

Because $TEEL-3 = 0.25 \text{ mg/m}^3$ and $TEEL-2$ is equal to or less than a $TEEL-3$, the $TEEL-2 = 0.25 \text{ mg/m}^3$.

For $TEEL-1$ and $TEEL-0$, calculate procedure-derived $TEEL$ estimates from mean ratios of ERPGs as shown below. (See Section 3.2.2 for explanation.)

$$\begin{aligned}
 TEEL-1 &= TEEL-2/7 \text{ for "Y" (concentration-dependent chemicals)} \\
 &= 0.525 \text{ mg/m}^3/7 \\
 &= 0.075 \text{ mg/m}^3 \\
 TEEL-0 &= TEEL-1/3 \text{ for "Y" (concentration-dependent) chemicals and "N" (non-} \\
 &\quad \text{concentration-dependent) chemicals} \\
 &= 0.075 \text{ mg/m}^3/3 \\
 &= 0.025 \text{ mg/m}^3
 \end{aligned}$$

4.6 Chemicals with neither Concentration Limits nor Toxicity Data

4.6.1 Solids and Nonvolatile Liquids: Europium, CAS RN 7440-53-1

$$\begin{aligned}
 TEEL-0 &= 10 \text{ mg/m}^3, \text{ TLV-TWA for PNOS, see below for discussion} \\
 TEEL-1 &= 30 \text{ mg/m}^3, \text{ TLV-TWA} \times 3 \text{ (alternative guideline)} \\
 TEEL-2 &= 50 \text{ mg/m}^3, \text{ TLV-TWA} \times 5 \text{ (alternative guideline)} \\
 TEEL-3 &= 250 \text{ mg/m}^3, \text{ procedure-based}
 \end{aligned}$$

In the absence of concentration limit and toxicity data, other strategies are used to derive $TEEL$ s. A TLV-TWA of 10 mg/m^3 for PNOS for $TEEL-0$ is used where appropriate. (See Section 3.2.2.)

If the toxicity of the chemical is not concentration-dependent or is unknown or is not a moderate or severe irritant, $TEEL-1$ and $TEEL-2$ are derived by multiplying the TLV-TWA (10 mg/m^3) by 3 and 5, respectively, as indicated in the hierarchy of alternative guidelines. (See Section 3.5.4 for explanation.) Hence:

$$TEEL-1 = 30 \text{ mg/m}^3, \text{ and } TEEL-2 = 50 \text{ mg/m}^3.$$

For $TEEL-3$, calculate a procedure-derived $TEEL$ estimate from mean ratios of ERPGs as shown below. (See Section 3.5.4.)

$$\begin{aligned}
 TEEL-3 &= 5 \times TEEL-2 \text{ for "Y" and "N"} \\
 TEEL-3 &= 5 \times 50 \text{ mg/m}^3
 \end{aligned}$$

$$\text{TEEL-3} = 250 \text{ mg/m}^3$$

4.6.2 Volatile Liquids and Gases: Carbon Trifluoride, CAS RN 75-46-7

$$\begin{aligned}\text{TEEL-0} &= 1000 \text{ ppm, procedure-based} \\ \text{TEEL-1} &= 3000 \text{ ppm, procedure-based} \\ \text{TEEL-2} &= 20,000 \text{ ppm, based on information in HSDB HTOX profile} \\ \text{TEEL-3} &= 100,000 \text{ ppm, procedure-based}\end{aligned}$$

Because there are no concentration limit data and no toxicity data, the information in the HSDB HTOX profile was used to derive TC_{LO} , which is used to estimate TEEL-2.

Given: $\text{TC}_{\text{LO}} = 200,000$ ppm, to a human, for a duration of 15 minutes, and an “N” (non-concentration-dependent) chemical.

Note: For illustrative purposes, the calculation was carried out as if the available data were from an animal. (See Section 3.4.3.3.) Further, in the equations below, the exponent for the exposure time for “N” chemicals in this equation is 1. (See Section 3.4.3.4.)

$$\begin{aligned}\text{TC}_{\text{LO-eq}} &= \text{TC}_{\text{LO}} \times (\text{exposure time}/15)^1 \times (\text{mean HBW}/\text{mean ABW}) \times (\text{mean ABR}/\text{mean HBR}) \\ &= 200,000 \text{ ppm} \times (15 \text{ minutes}/15)^1 \times (70 \text{ kg}/70 \text{ kg}) \times (20 \text{ m}^3/\text{d}/20 \text{ m}^3/\text{d}) \\ &= 200,000 \text{ ppm}\end{aligned}$$

$$\begin{aligned}\text{TEEL-2} &= \text{TC}_{\text{LO-eq}} / \text{adjustment factor for “TC}_{\text{LO}}\text{,” “human only”} \\ \text{TEEL-2} &= 200,000 \text{ ppm}/10 \\ \text{TEEL-2} &= 20,000 \text{ ppm}\end{aligned}$$

For TEEL-3, TEEL-0, and TEEL-1, calculate procedure-derived TEEL estimates from mean ratios of ERPGs as shown below. (See Section 3.5.4.)

$$\begin{aligned}\text{TEEL-3} &= 5 \times \text{TEEL-2 for “Y” and “N”} \\ &= 5 \times 20,000 \text{ ppm} \\ &= 100,000 \text{ ppm} \\ \text{TEEL-1} &= \text{TEEL-2}/7 \text{ for “N”} \\ &= 20,000/7 \text{ ppm} \\ &= 3000 \text{ ppm (see rounding guidelines in Section 3.7.3)} \\ \text{TEEL-0} &= \text{TEEL-2}/21 \text{ for “N”} \\ &= 20000 \text{ ppm}/21 \\ &= 1000 \text{ ppm (see rounding guidelines in Section 3.7.3)}\end{aligned}$$

4.6.3 Structure Activity Relationships: Bismuth Hydroxide, CAS RN 10361-43-0

When a chemical does not have concentration limit or toxicity data on which to base TEELs, SARs may be used. Concentration limits are derived from chemicals with similar molecular structures. In this example, sodium/potassium hydroxide concentration limits were used as the

basis for bismuth hydroxide TEELs because bismuth has a rather low toxicity and the toxicity of bismuth hydroxide was considered due more to the hydroxide component rather than the bismuth component. Therefore, because both sodium and potassium also have rather low toxicity and the toxicity of both sodium and potassium hydroxide is primarily due to the hydroxide component, it appeared that sodium and potassium hydroxide would have similar SARs and would make good surrogates. On the other hand, bismuth hydroxide is not soluble in water, unlike either sodium or potassium hydroxide, which generate irritant caustic solutions depending on the concentration. This suggests that the TEELs for bismuth hydroxide are likely conservative.

TEEL-0	=	1 mg/m ³ , SAR-based
TEEL-1	=	1 mg/m ³ , SAR-based
TEEL-2	=	3 mg/m ³ , SAR-based
TEEL-3	=	100 mg/m ³ , SAR-based

4.7 Simple Asphyxiants

Neon; CAS RN 7440-01-9

These TEELs are based on physiological effects resulting from oxygen (O₂) deprivation at different levels. (See Section 3.3.1.)

TEEL-0	=	65,000 ppm resulting in O ₂ % ≈ 19.5%
TEEL-1	=	65,000 ppm resulting in O ₂ % ≈ 19.5%
TEEL-2	=	230,000 ppm resulting in O ₂ % ≈ 16%
TEEL-3	=	400,000 ppm resulting in O ₂ % ≈ 12.5%

5.0 REVIEW PROCESS AND PUBLICATION

5.1 Quality Control and Quality Assurance

TEELs are derived by a published peer-reviewed and automated methodology using established concentration exposure limits, toxicology parameters, and inferences from the analysis of chemical structure and function (Craig et al., 1995, 2000). Although the development of TEELs based on these sources is a reasonable extrapolation, it nevertheless goes beyond their intended purposes. Therefore, it is essential that the sources and the methodology be subject to peer review in order to understand the strengths and limitations of the method and to provide assurance that the outcome is valid and that the procedures are rational and empirical. The peer-review process for the development of TEELs involves a duplicate review by a second independent individual reviewing both the data available for each chemical and its proper entry into the “Input” sheet of the automatically executing TEEL Excel workbook. The computer-based workbook contains the software for the TEEL development methodology (Donoso, 2005).

5.1.1 Sources

An important feature of TEELs is that the sources themselves have been reviewed for their intended purposes. The nature and purpose of review vary from one source to another.

5.1.1.1 Occupational Exposure Limits

OSHA sets PELs according to provisions in *the Occupational Safety and Health Act* of 1970. The pertinent section of this Act is as follows:

The Secretary [of Labor], in promulgating standards dealing with toxic materials or harmful physical agents under this subsection, shall set the standard which most adequately assures, to the extent feasible, on the basis of the best available evidence, that no employee will suffer material impairment of health or functional capacity even if such employee has regular exposure to the hazard dealt with by such standard for the period of his working life. Development of standards under this subsection shall be based upon research, demonstrations, experiments, and such other information as may be appropriate. In addition to the attainment of the highest degree of health and safety protection for the employee, other considerations shall be the latest available scientific data in the field, the feasibility of the standards, and experience gained under this and other health and safety laws. Whenever practicable, the standard promulgated shall be expressed in terms of objective criteria and of the performance desired (Section 6 [b][5]).

When OSHA published its first exposure limits in 1971, it adopted the 1969 TLVs. Since that time, OSHA has promulgated PELs for about 40 chemicals under the language above. Although OSHA has made several efforts to update the remainder of the chemicals listed in 29 CFR 1910.1000, except for its Section 6 Standards, most PELs remain as the 1969 TLVs.

ACGIH has set TLVs since approximately 1939 when the ACGIH was formed for this purpose. The ACGIH was a pioneer in developing both the basic concepts and many exposure limits for occupational exposure. TLVs, as stated in the ACGIH TLV handbook (ACGIH, 2007a):

refer to airborne concentrations of substances and represent conditions under which it is believed that *nearly all* workers may be repeatedly exposed, day after day, over a working lifetime, without adverse health effects.

There will be considerable variation in the level of biological response to a particular chemical substance, regardless of the airborne concentration.... Some individuals may experience discomfort or even more serious adverse health effects when exposed to a chemical substance at the TLV or even at concentrations below the TLV. There are numerous possible reasons for increased susceptibility to a chemical substance, including age, gender, ethnicity, genetic factors (predisposition), lifestyle choices (e.g., diet, smoking, abuse of alcohol and other drugs), medications, and pre-existing medical conditions (e.g., aggravation of asthma or cardiovascular disease).

TLVs are established by committees that review existing published and peer-reviewed literature in various scientific disciplines (e.g., industrial hygiene, toxicology, occupational medicine, and epidemiology).

The ACGIH TLV Committee sets TLVs. The ACGIH TLV Committee is a group of volunteers that reviews and revises selected TLVs annually. The TLV Committee announces chemicals that are considered for revision, solicits comments and information, proposes a revised TLV, solicits additional comments, and usually within 1 year, publishes the revised TLV.

NIOSH has a more general mandate under the *Occupational Safety and Health Act* as follows:

The Institute is authorized to develop and establish recommended occupational safety and health standards (Section 22 [c]).

Although this language is limited and does not describe the nature of the review process that NIOSH must follow, as a matter of U.S. Department of Health and Human Services policy, documents are based on a comprehensive review of the scientific literature, and before they are released, they are subject to peer review both from within the agency and by external reviewers. In most instances, NIOSH recommendations are published in the form of Criteria Documents. In some situations, however, RELs are established in a less formal and rigorous manner, such as in response to an OSHA rulemaking or congressional inquiry or in other forms such as Current Intelligence Bulletins. They are published in the *Pocket Guide to Chemical Hazards*, which is available in hard copy, on CD, and on the Internet (<http://www.cdc.gov/niosh/npg/>) (CDC, 2005).

5.1.1.2 Toxicity Parameters

Toxicity parameters are derived experimentally and usually published in peer-reviewed scientific journals. Toxicity parameters can be obtained from many sources. The three principal sources used for deriving TEELs are the most current versions of: (1) RTECS, (2) Sax's Dangerous Properties of Industrial Chemicals, and (3) the HSDB.

RTECS is a collection of data (referenced but unevaluated) compiled from the open scientific literature and organized in a codified standard format for more than 160,000 chemicals (Silver Platter, 2007).

Sax is a commonly used toxicity text in the field, now in its 11th edition (Lewis, 2004). Sax contains information for approximately 26,000 chemicals. It is available either as a three-volume set or on CD.

The HSDB is a peer-reviewed database with information about health effects on humans for approximately 5,000 chemicals. It is available on the Internet from the National Library of Medicine (<http://toxnet.nlm.nih.gov/cgi-bin/sis/htmlgen?HSDB>) (NLM, 2006).

5.2 TEEL Methodology Review

5.2.1 DOE: SCAPA

SCAPA is an outgrowth of the DOE Subcommittee on Dose Assessment in the OEM. Its mission, as formulated in its charter, is to “support the Office of Emergency Management by developing and disseminating, throughout the DOE/NNSA community, technical guidance, recommendations, and resources to improve emergency preparedness, consequence assessment capabilities, and the formulation of protective actions” (<http://orise.orau.gov/emi/scapa/charter.htm>) (DOE, 2007c). SCAPA is composed of Federal employees and contractors from a wide spectrum of DOE and NNSA facilities. The OEM appoints the chairperson.

“Recognizing that AEGLs and ERPGs exist only for a limited number of chemicals, SCAPA developed TEELs so that DOE facilities can conduct appropriate hazard analyses and consequence assessments for chemicals lacking AEGLs or ERPGs” (<http://orise.orau.gov/emi/scapa/teels.htm>) (DOE, 2007d). SCAPA has a number of working groups, including the Chemical Exposures Working Group and the Chemical Mixtures Working Group. One of the principal tasks of the Chemical Exposures Working Group has been developing TEELs. It has provided peer review and oversight of TEELs since, approximately, 1997.

TEELs were first developed in the early 1990s (Craig, 1992; Craig et al., 1995). Since then, SCAPA has supported the development of TEELs, and updates are presented at most of its meetings. The TEEL methodology was first approved by DOE and was incorporated into its revised Emergency Management Guidelines in 1999 (DOE, 1999). TEELs are incorporated into a key document listing concentration limits for use in emergency situations: “AEGLs, ERPGs and TEELs for Chemicals of Concern, Revision 23,” which is available on the SCAPA TEELS page at <http://orise.orau.gov/emi/scapa/teels.htm> (DOE, 2007d) and on the DOE website at http://www.hss.energy.gov/HealthSafety/WSHP/chem_safety/teel.html (DOE, 2007e).

5.2.2 Peer-Reviewed Publications

The default concentration limit hierarchy for chemicals lacking ERPGs was first published in 1992 (Craig, 1992). This basic concept was submitted for outside peer review and published in 1995 (Craig et al., 1995). This basic concept was revised and expanded, using toxicology parameters (e.g., LC₅₀, LC_{LO}, LD₅₀, and LD_{LO} for TEEL-3, etc.) in the absence of concentration limits. This expanded methodology was published in 1998 as a technical report (Craig and Lux, 1998) and published in a peer-reviewed journal in 2000 (Craig et al., 2000).

5.3 Software Quality Assurance

TEELs are derived using an Excel-based workbook. Users submit the chemical name and its CAS RN. Following a search, selection, and entry of available input parameters, several macros produce the result. Calculations were originally carried out using Excel functions, but starting with Revision 19, these Excel functions were replaced with Visual Basic macros. This software has been used extensively to produce TEELs for approximately 2,950 chemicals (December 2005). An external reviewer examined this software to validate its structure and function (Donoso, 2005). A software quality assurance review of the application, in accordance with DOE O 414.1C, Quality Assurance, is complete.

5.4 Publication of Protective Action Criteria Values

Current PAC values, including values of AEGLs, ERPGs, and TEELs, are published on the Internet at:

<http://orise.orau.gov/emi/scapa/teels.htm> (TEEL table and searchable database) (DOE, 2007d)

http://www.hss.energy.gov/HealthSafety/WSHP/chem_safety/teel.html (TEEL tables) (DOE, 2007e)

REFERENCES

It should be noted that the latest available references are used, e.g., the 2007 handbooks and guides, as soon as they are published. Every effort is made to update the existing TEELs as new AEGLs, ERPGs, PELs, TLVs, WEELs, etc., are published.

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CONCLUDING MATERIAL

Review Activities:

NA
HS
EM
NE
SC
FE

Field Offices:

CH
ID
ORO
RL
SR
KCSO
LSO
LASO
NSO
PSO
SSO
SRSO
YSO
NNSA SC
BSO
CFO
GFO
OFO
PNSO
PPPO
Princeton Site Office
ORP
Stanford Site Office
TJSO

Preparing Activity:

DOE-NA-41

Project Number:

EMER-0001

National Laboratories:

PNNL
INL
LANL
SRS
SNL
ORNL
BNL
ANL
LLNL