INTRODUCTORY MATERIAL

The Toxicology Section (TS) of the Chief Engineer's Office of the Texas Commission on Environmental Quality (TCEQ) has prepared a Development Support Document that outlines the hazard assessment and dose-response processes used to derive Effects Screening Levels (ESLs, Reference Values (ReV), and Unit Risk Factors (URFs) for 1,3-butadiene (Cas. No. 106-99-0). The toxicity values were developed using TCEQ Publication RG-442 *Guidelines to Develop Effects Screening Levels, Reference Values, and Unit Risk Factors* (TCEQ 2006) (hereafter referred to as RG-442 ESL Guidelines). ESLs are chemical-specific air concentrations set to protect human health and welfare. Short-term ESLs are based on data concerning acute health effects, odor potential, and vegetative effects, while long-term ESLs are generally based on data concerning chronic noncarcinogenic and/or carcinogenic health effects and vegetative effects. ESLs are used in the evaluation of air permit applications as well as proposed rules and regulation (e.g. Permits by Rule). ReVs and URFs, used as the basis of ESLs, are used in the evaluation of air monitoring data and may be used in the development of Protective Concentration Levels for remediation sites.

ESL Development Support Document (DSD)

The purpose of the DSD is to provide a summary of information on the ESL development process and the key toxicity studies/information used to derive toxicity factors. It is not a criteria document in that it does not review or discuss all articles published since USEPA (2002) and it does not reproduce work done by USEPA (2002). The butadiene DSD is approximately 161 pages long, although 96 pages are appendices that provide supporting information on statistical analyses, benchmark dose modeling, etc. The DSD is a technical guide written and used by TS staff. Although the butadiene DSD is primarily written for TS staff, it also documents (largely by reference) the processes used to develop ESLs, ReVs, and URFs for any interested person who is familiar with RG-442 ESL Guidelines and has training in inhalation toxicology and risk assessment.

First, several summary tables of key information are provided followed by a brief summary of sources and use of the chemical. The following analytical approach was used to derive toxicity factors for BD:

- review essential data including physical/chemical properties and select key studies;
- conduct a mode of action (MOA) analysis;
- choose the appropriate dose metric;
- determine the point of departure (POD) for each key study;
- conduct appropriate dosimetric modeling; and
- extrapolate from the adjusted POD to lower exposures based on MOA analysis and select critical effect.

Each one of these steps is discussed in the DSD. Finally, a section entitled "Other Relevant Information" is included and contains additional information pertinent to an understanding of the toxicity of butadiene. At the end of the DSD, there are two separate reference sections: a list of the references of key studies discussed in the DSD and a list of references of other studies that were reviewed and considered by the TS staff but were not discussed in the DSD.

Since the DSD is a summary document, the following sections, which are brief summaries of RG-442 ESL Guidelines, are provided as introductory material for the convenience of the peer reviewers:

- Legal Authority and Regulatory Use
- Specific Risk Management Objectives and TCEQ Policy Decisions
- Published Toxicity Factors Considered by TS Staff
- ReVs and URFs
- ReVs for Nonlinear Dose-Response Effects
- URFs for Linear Dose-Response Effects
- ESLs
- Health-Based ESLs
- Calculation of ESLs for Nonlinear Effects
- Calculation of ESLs for Linear Effects
- Odor-Based ESLs
- Vegetation-Based ESLs
- Determination of Short-Term and Long-Term ESLs

The following material is also provided for the convenience of the peer-reviewers:

- List of Acronyms and Abbreviations Used in the Butadiene Development Support Document
- List of Butadiene Toxicity Studies

Legal Authority and Regulatory Use

The Texas Clean Air Act (Chapter 382 of the Texas Health and Safety Code (THSC)) authorizes the TCEQ to prevent and remedy conditions of air pollution. Section 382.003 of the THSC defines air pollution as

> *the presence in the atmosphere of one or more air contaminants or combination of air contaminants in such concentration and of such duration that:*
>
> > *(a) are or may tend to be injurious to or to adversely affect human health or welfare, animal life, vegetation, or property; or*
> > *(b) interfere with the normal use and enjoyment of animal life, vegetation, or property.*

Sections 382.0518 and 382.085 of the THSC specifically mandate the TCEQ to conduct air permit reviews of all new and modified facilities to ensure that the operation of a proposed facility will not cause or contribute to a condition of air pollution. Air permit reviews typically involve evaluations of best available control technology and predicted air concentrations related to proposed emissions from the new or modified facility. In the review of proposed emissions, federal/state standards and chemical-specific Effects Screening Levels (ESLs) are used, respectively, for criteria and non-criteria pollutants. Because of the comprehensiveness of the language in the THSC, ESLs are developed for as many air contaminants as possible, even for chemicals with limited toxicity data.

Air contaminants may cause both direct and indirect effects. Direct effects are those that result from direct inhalation and dermal exposures to chemicals in air. Deposition of contaminants on

soil and water—and subsequent uptake by plants and animals—may cause indirect effects in humans who consume those plants and animals. However, the THSC authorizes the prevention and remedy of air pollution based on effects and interference from contaminants *present in the atmosphere*, i.e., direct effects. Therefore, during the air permitting process, the TCEQ does not set air emission limits to restrict, or perform analysis to determine, the impacts emissions may have, by themselves or in combination with other contaminants or pathways, after being deposited on land or water or incorporated into the food chain.

The TCEQ also relies upon this authority to evaluate air monitoring data. Texas has the largest ambient air toxics monitoring network in the country, receiving monitoring data for up to 186 air toxics at approximately 57 different locations throughout the state. Reference Values (ReVs) and Unit Risk Factors (URFs) are used to evaluate measured air toxics concentrations for their potential to cause health effects and odor- and vegetative-based ESLs are used to evaluate welfare effects, as well as to help the agency prioritize its resources in the areas of permitting, compliance, and enforcement.

Specific Risk Management Objectives and TCEQ Policy Decisions

The following are TCEQ policy decisions. Peer reviewers are asked not to comment on policy decisions. In order to ensure consistent protection of human health, chemical-specific ReVs and ESLs are based on a defined risk management objective of no significant risk.

The no significant risk level for a ReV for an individual chemical with a nonlinear dose-response assessment is defined as the concentration associated with a hazard quotient (HQ) of 1. In consideration of cumulative and aggregate exposure when reviewing air permits, the Toxicology Section (TS) uses an HQ of 0.3 to calculate short-term and long-term health-based ESLs for chemicals with a nonlinear (threshold) dose-response assessment (i.e., health-based ESLs = 0.3 x ReV). The TS uses a risk management goal of 1×10^{-5} to calculate long-term ESLs for individual chemicals with a linear (nonthreshold) dose-response assessment. This theoretical excess lifetime cancer risk level is consistent with the State of California's No Significant Risk Level (22 CCR §12703). Further adjustment of this no significant risk level is not necessary for air permit reviews since few chemicals with a linear dose-response assessment are routinely permitted in Texas. These risk management goals were approved by the Commissioners and Executive Director of the TCEQ and are consistent with other TCEQ programs. ESLs developed in accordance with these no significant risk levels are intended to prevent adverse effects potentially associated with cumulative and aggregate exposures as defined in Section 1.2 of RG-442 ESL Guidelines (TCEQ 2006).

Air concentrations calculated at a theoretical excess lifetime cancer risk of one in 100,000 (1×10^{-5}) are based on a lifetime exposure of 70 years, the default used by TCEQ for exposure analysis.

Published Toxicity Factors Considered by TS Staff

When toxicity factors or guideline levels are identified in the scientific literature or databases, they are reviewed to determine whether the approach used to develop these toxicity factors is similar to the procedures used by the TS to develop ReVs or URFs based on RG-442 ESL Guidelines. Many published toxicity factors are not appropriate to be used as ReVs or URFs because it is likely that procedures other than those recommended in RG-442 ESL Guidelines were used to derive these values. Due to time and resource constraints, the TS considers the published values and their respective key studies as a starting place for gathering toxicity

information. However, because the toxicity factors may be outdated, the TS also evaluates peer-reviewed studies available after the date these toxicity factors were published to ensure that the latest data are considered prior to developing a toxicity factor. The TS considers adoption of a published toxicity factor when the risk assessment procedures used are similar to those described in RG-442 ESL Guidelines. Preference is given to values that have undergone external peer review and public involvement.

USEPA published *Health Assessment of 1,3-Butadiene* (EPA/600/P-98/001F) in October 2002 that provided detailed information on the following topics: overview of exposure to 1,3-butadiene, pharmacokinetics, mutagenicity, reproductive and developmental effects, toxicity in animals, epidemiological studies of carcinogenicity, hazard characterization, pharmacokinetic modeling, quantitative risk assessment for 1,3-butadiene, and dose-response characterization. USEPA (2002) derived the following toxicity values:

- an acute reference concentration (RfC) of 3.2 $\mu g/m^3$ (7 ppb) representative for a 24-h exposure duration based on reduced fetal body weight observed in a reproductive/developmental toxicity study in mice (Hackett et al. 1987b);
- a chronic RfC of 0.88 ppb based on ovarian atrophy in mice evaluated in a 2-year bioassay conducted by the National Toxicology Program (NTP 1993); and
- a URF of 0.08/ppm based on an occupational epidemiological study of synthetic rubber production workers exposed to BD in a retrospective cohort mortality study conducted by Delzell et al. (1995; 1996).

TS staff have reviewed the toxicity values derived by USEPA (2002) and determined they have undergone an extensive external peer and public involvement review. USEPA (2002) included data from the scientific literature from July 1, 1985 through January 31, 2000. TS staff also conducted an extensive literature search to identify any studies available after January 2000 that were not considered by USEPA (2002). The processes that the TS used to conduct a literature search and to update information in USEPA (2002) are discussed in the RG-442 ESL Guidelines (Section 2.3.2 *Review Essential Data*).

A literature search conducted from January 2000 through 2007 revealed no new acute or chronic toxicity studies that could be used to develop acute or chronic ReVs based on a threshold dose-response assessment. Therefore, the TCEQ has developed acute and chronic ReVs based on the same acute and chronic animal toxicity studies used by USEPA (2002) to derive their acute and chronic RfCs (i.e., Hackett et al. 1987b for the acute threshold dose-response assessment and the NTP 1993 study for the chronic threshold dose-response assessment). The TS found some information that was not considered by USEPA in their 2002 health assessment and there were differences in the procedures in RG-442 ESL Guidelines and procedures used by USEPA (2002). The TS has incorporated new findings and updated analyses not available to USEPA (2002):

- For the acute assessment, a correct statistical analysis has been conducted on the Hackett et al. (1987b) data. Reduction in maternal extragestational weight gain is used as the critical effect, not reduced fetal body weight. In addition, an acute ReV protective of a one-hour exposure duration was developed (TCEQ 2006), not a 24-hour exposure duration. In addition, there were differences in the uncertainty factors used based on procedures recommended in RG-442 ESL Guidelines.
- For the chronic ReV, a $BMCL_{05}$ based on ovarian atrophy in mice (NTP 1993) using a Weibull time-to-response model was calculated and used as the point of departure instead of a $BMCL_{10}$. In addition, there were differences in the uncertainty factors used based on procedures recommended in RG-442 ESL Guidelines. The diepoxide metabolite of BD

has been shown to be responsible for ovarian atrophy in mice and recent data on a hemoglobin adduct specific for the diepoxide metabolite demonstrate that humans produce 78 times lower levels of the diepoxide when compared to mice (Swenberg 2007). Therefore, this mode-of-action information was used to reduce the animal-to-human toxicodynamic uncertainty factor to one.

The retrospective cohort mortality study reported by Delzell et al. in 1995 and 1996 which was used by USEPA (2002) to develop their URF based on leukemia mortality in styrene-butadiene rubber workers has been updated to include more up-to-date information:

- The UAB butadiene exposure estimates were updated and estimates for styrene and dimethyldithiocarbamate (DMDTC) were calculated (DMDTC is an immune system depressant) (Macaluso et al. 2004);
- The UAB epidemiology study and analysis of leukemia data was updated (Sathiakumar et al. 2005; Graff et al. 2005); and
- Dr. Delzell and associates finalized a Health Effects Institute (HEI) report that discussed the updated exposure estimates and analysis of leukemia mortality data. Additional analyses requested by the Health Effects Review committee were included in the HEI report (HEI 2006).

The Health Review Committee (HEI 2006) reviewed Delzell's findings and concluded "An analysis of butadiene that controlled for the possibly carcinogenic coexposures to styrene and DMDTC produced the most important result of the investigation: the clear and consistent exposure-response relation observed between cumulative exposure to butadiene and mortality from leukemia. . . . and support the presence of a linear increase in the relative rate of leukemia mortality with increasing cumulative exposures to butadiene."

After the HEI report was finalized, an exposure estimate validation study was conducted on the updated UAB butadiene exposure estimates (Sathiakumar et al. 2007) and dose-response modeling was conducted and potency estimates were determined based on the updated studies (Cheng et al. 2007; Sielken et al. 2007). These new, updated studies were used by the TS to update the USEPA (2002) assessment. A review of the scientific literature indicated there were no other epidemiology studies (e.g., Alder et al. 2006) that would be appropriate to evaluate human cancer risk from BD exposure.

In addition, the TS has evaluated acute odor potential and acute and chronic vegetative effects (i.e. welfare effects) for butadiene.

ReVs and URFs

ReVs and URFs are the health-based toxicity values used in the evaluation of ambient air monitoring data and in the calculation of health-based ESLs and source media cleanup levels. This section introduces several toxicological concepts necessary for derivation of ReVs and URFs. The method by which ReVs and URFs are used in the calculation of health-based ESLs is also described.

Derivation of ReV and URF values begins with a toxicity assessment involving hazard identification and dose-response assessment based on a chemical's MOA. For each hazard (i.e., adverse health effect) this assessment determines whether the dose-response relationship is (or is presumed to be) linear or nonlinear in the low dose region, depending on the MOA. The low dose region is generally defined as the dose range below the experimental doses. If a chemical's dose-

response relationship is nonlinear, it has an effects threshold, meaning that there exists a concentration and resulting dose of that chemical below which exposure is not expected to cause adverse effects. Conversely, if a chemical's dose-response relationship is linear, it is presumed to be non-threshold, meaning that any dose, no matter how small, causes an effect.

ReVs are derived for hazards associated with nonlinear (threshold) dose-response relationships. URFs are derived for hazards associated with linear (non-threshold) dose-response relationships. In other words, the derivation of a ReV or URF is dependent on whether the adverse effect is associated with a linear or non-linear dose-response relationship, not with the classification of the effect as carcinogenic or noncarcinogenic.

ReVs for Nonlinear Dose-Response Effects

For acute and chronic adverse effects determined to be associated with nonlinear dose-response relationships in the low-dose region, the TS adopts or derives ReVs. This determination is based on data or science policy default assumptions. These effects are assumed to exhibit a threshold, a dose below which no effect is observed. Typically, the effects associated with such nonlinear dose-response relationships are noncarcinogenic. However, some carcinogenic effects, such as those of formaldehyde and possibly other chemicals, are understood to exhibit a nonlinear dose-response. The TS derives or adopts inhalation ReVs for both noncarcinogenic and carcinogenic effects which are associated with nonlinear dose-response relationships based on their MOAs (Chapters 2-4 of RG-442 ESL Guidelines).

Acute ReVs are health-based exposure concentrations used in assessing health risks of short-term chemical exposures. They are derived from acute or subacute human or animal studies, or from developmental toxicity studies conducted on animals. Acute ReVs are typically derived for a 1-h exposure duration, although those based on reproductive/developmental effects may be derived for exposure durations other than 1 h.

Chronic ReVs are health-based exposure concentrations used in assessing health risks of long-term (i.e., lifetime) chemical exposures. Chronic ReVs are derived from chronic human epidemiology studies, chronic animal studies, or well-conducted subchronic human or animal studies. Chronic ReVs are derived for lifetime inhalation exposure duration. A chronic ReV is analogous to a reference concentration (RfC) which is developed by USEPA.

An inhalation ReV is defined as an estimate of an inhalation exposure concentration for a given duration to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse effects. ReVs are based on the most sensitive adverse health effect relevant for humans reported in the literature. ReVs are derived by adjusting an appropriate point of departure (POD) with uncertainty/variability factors to reflect data limitations. Examples of PODs include benchmark concentration lower confidence limit (BMCL) and no-observed-adverse-effect-level (NOAEL).

ReVs are designed to protect the most sensitive individuals in a population by inclusion of uncertainty/variability factors (UFs). UFs account for differences between study animal and human species, variability within the human species, and uncertainties related to the applicability and completeness of the available data. Since UFs are incorporated to address data gaps, variability, and other uncertainties, exceeding the ReV does not automatically indicate that an adverse health effect would occur.

URFs for Linear Dose-Response Effects

For chronic adverse effects determined to be associated with linear dose-response relationships in the low-dose region, the TS adopts or derives URFs. This determination is based on data or science policy default assumptions. Typically, the effects associated with linear dose-response relationships are carcinogenic and are from chronic exposures. The TS recognizes that the dose-response relationship for some noncarcinogenic effects, such as those of lead, may also be best described as linear. For adverse effects associated with a linear dose-response, it is assumed that an effects threshold does not exist. Therefore, a linear extrapolation from the POD to the origin of the inhalation dose-response curve is performed to estimate excess lifetime risk at lower doses. The slope of the line from this linear extrapolation is the inhalation URF, which is defined as the upper-bound excess risk estimated to result from continuous lifetime exposure to an agent at a concentration of 1 $\mu g/m^3$ in air (i.e., risk estimate per $\mu g/m^3$). While guidance for this process has been explicit for carcinogenic effects (USEPA 2005a), URFs could also be developed for chronic noncarcinogenic effects which exhibit a linear dose-response relationship.

ESLs

ESLs are chemical-specific air concentrations set to protect human health and welfare. Exposure to an air concentration at or below the ESL is not likely to cause an adverse health effect in the general public, including sensitive subgroups such as children, the elderly, pregnant women, and people with preexisting health conditions. However, ESLs may not protect individuals who exhibit idiosyncratic responses which cannot be predicted based on health effects studies. ESLs are used in the air permitting process to assess the protectiveness of substance-specific emission rate limits for facilities undergoing air permit reviews. Evaluations of modeled worst-case ground-level air concentrations are conducted to determine the potential for adverse effects to occur due to the operation of a proposed facility. They are comparison levels, not ambient air standards. If predicted airborne levels of a chemical exceed its ESL, adverse health or welfare effects would not necessarily be expected to result, but a more in-depth review would be triggered, as described in *Modeling and Effects Review Applicability: How to Determine the Scope of Modeling and Effects Review for Air Permits* (TCEQ 2001) (http://www.tceq.state.tx.us/assets/public/permitting/air/Guidance/NewSourceReview/mera.pdf).

The exposure duration generally associated with short-term ESLs is 1 h, although exposure may occur on an intermittent basis. This duration is consistent with TCEQ air permits modeling. Short-term ESLs for exposure durations other than 1 h may be needed based on reproductive/developmental toxicity. Long-term ESLs are associated with a lifetime exposure duration which is commonly assumed to be 70 years. For application in air permitting, long-term ESLs are used to evaluate modeled 1-year average concentrations.

Short-term ESLs are based on data concerning acute health effects, odor potential, and acute vegetation effects, while long-term ESLs are based on data concerning chronic health or vegetation effects. Therefore, before a short-term or long-term ESL can be selected, available information on each of these health and welfare effects is obtained as described in RG-442 ESL Guidelines.

Health-Based ESLs

Health-based ESLs are calculated from ReVs and URFs as described in the following sections using the risk management objectives stated previously and in Section 1.4 of RG-442 ESL Guidelines

Calculation of ESLs for Nonlinear Effects

An HQ is defined as the ratio of the exposure level (E) to the reference value (ReV):

$$HQ = \frac{E}{ReV}$$

The E and ReV are expressed in the same units ($\mu g/m^3$) and represent the same exposure period (i.e., acute or chronic). This equation can be rearranged to solve for the exposure concentration that corresponds to a risk management-specified HQ for a specified exposure period:

$$E = HQ \times ReV$$

For nonlinear effects, ESLs that correspond to an HQ of 0.3 for an acute or chronic exposure period are calculated as follows:

$$^{acute}ESL = HQ \times \text{acute ReV}$$
$$= 0.3 \times \text{acute ReV}$$

$$^{chronic}ESL_{nonlinear(c)} \text{ or } ^{chronic}ESL_{nonlinear(nc)} = HQ \times \text{chronic ReV}$$
$$= 0.3 \times \text{chronic ReV}$$

Calculation of ESLs for Linear Effects

Risk Level = E x URF

The URF is expressed in reciprocal units to E (i.e., $\mu g/m^3$ and $(\mu g/m^3)^{-1}$, respectively) and both represent a chronic exposure. This equation can be rearranged to solve for E ($\mu g/m^3$) for a chronic exposure period that corresponds to a specified no significant risk level:

$$E = \frac{\text{No Significant Risk Level}}{URF}$$

For linear effects, the continuous lifetime exposure concentration of a chemical that corresponds to TCEQ's no significant risk level of 1 x 10^{-5} ($^{chronic}ESL_{linear}$) is calculated as follows:

$$^{chronic}ESL_{linear(c)} \text{ or } ^{chronic}ESL_{linear(nc)} = \frac{1 \times 10^{-5}}{URF}$$

However, when the linear effect is cancer mediated through a mutagenic MOA, consideration of early life exposure (see Chapter 4 Section 4.5.4; USEPA 2005b) results in the following chronic ESL calculation:

$$^{chronic}ESL_{linear(c)} = \frac{6 \times 10^{-6}}{URF}$$

Odor-Based ESLs

Odor-based ESLs ($^{acute}ESL_{odor}$) are set at a chemical's odor threshold as described in pages 7-9 of RG-442 ESL Guidelines.

Vegetation-Based ESLs

Vegetation-based ESLs ($^{acute}ESL_{veg}$ and $^{chronic}ESL_{veg}$) are set at the threshold concentration for adverse effects (page 9 of RG-442 ESL Guidelines). If available plant toxicity data indicate that a chemical's adverse effect threshold concentration in plants is substantially higher than its odor threshold or adverse effect levels in humans, the plant toxicity information is presented in the DSD, but a vegetation-based ESL is not developed.

Determination of Short-Term and Long-Term ESLs

The preceding sections introduce the derivation of health-based ReVs and URFs and describe the development of odor- and vegetation-based ESLs. A short-term ESL is determined by choosing the lowest value of the following health- and welfare-based ESLs (as available) (Figure 1-1, TCEQ 2006):

$^{acute}ESL_{generic}$ or $^{acute}ESL$

$^{acute}ESL_{odor}$

$^{acute}ESL_{veg}$

A long-term ESL is determined by choosing the lowest value of the following health- and welfare-based ESLs (as available) (Figure 1-2, TCEQ 2006)::

$^{chronic}ESL_{linear(c)}$

$^{chronic}ESL_{linear(nc)}$

$^{chronic}ESL_{nonlinear(c)}$

$^{chronic}ESL_{nonlinear(nc)}$

$^{chronic}ESL_{veg}$

List of Acronyms and Abbreviations Used in the Butadiene Development Support Document

ACGIH	American Conference of Governmental Industrial Hygienists
ADAF	age-dependent default adjustment factors
β	Beta
BD	1,3-butadiene
BMC	benchmark concentration
BMCL	benchmark concentration lower confidence limit
BMD	benchmark dose
BMDL	benchmark dose lower confidence limit
BMDS	benchmark dose software
BMR	benchmark response
C	Concentration
D	exposure duration, hour per day
DSD	development support document
E	exposure level or concentration
EC	effective concentration
ESL	Effects Screening Level
$^{acute}ESL$	acute health-based Effects Screening Level for chemicals meeting minimum database requirements
$^{acute}ESL_{generic}$	acute health-based Effects Screening Level for chemicals not meeting minimum database requirements
$^{acute}ESL_{odor}$	acute odor-based Effects Screening Level
$^{acute}ESL_{veg}$	acute vegetation-based Effects Screening Level
$^{chronic}ESL_{linear(c)}$	chronic health-based Effects Screening Level for linear dose response cancer effect
$^{chronic}ESL_{linear(nc)}$	chronic health-based Effects Screening Level for linear dose response noncancer effects
$^{chronic}ESL_{nonlinear(c)}$	chronic health-based Effects Screening Level for nonlinear dose response cancer effects
$^{chronic}ESL_{nonlinear(nc)}$	chronic health-based Effects Screening Level for nonlinear dose response noncancer effects
$^{chronic}ESL_{veg}$	chronic vegetation-based Effects Screening Level
F	exposure frequency, days per week
h	hour
$H_{b/g}$	blood:gas partition coefficient

HEC	human equivalent concentration
HITs	high intensity tasks
HQ	hazard quotient
IARC	International Agency for Research on Cancer
IRIS	Integrated Risk Information System
K	constant level or severity of response
LEC	lowest effective concentration
LOAEL	lowest-observed-adverse-effect-level
m	meter
MW	molecular weight
µg	microgram
MLE	Maximum Likelihood Estimate
min	minute
MOA	mode of action
NAC	National Advisory Committee
NIOSH	National Institute for Occupational Safety and Health
NOAEL	no-observed-adverse-effect-level
NRC	National Research Council
OEHHA	Office of Environmental Health Hazard Assessment
OSHA	Occupational Safety and Health Administration
PBPK	physiologically-based pharmacokinetic model
POD	point of departure
POD_{ADJ}	point of departure adjusted for exposure duration
POD_{HEC}	point of departure adjusted for human equivalent concentration
ppbv	parts per billion by volume
ppm	parts per million
ReV	Reference Value
RfC	Reference Concentration
RGDR	regional gas dose ratio
SD	standard deviation
SE	standard error
STEL	Short-term Exposure Level
T	time or exposure duration
TCEQ	Texas Commission on Environmental Quality
TLV	Threshold Limit Value
TS	Toxicology Section

TWA	Time-Weighted Average
TWA-TLV	Time-Weighted Average Threshold Limit Value
UAB	University of Alabama at Birmingham
UF	uncertainty factor
UF_H	interindividual or intraspecies human uncertainty factor
UF_A	animal to human uncertainty factor
UF_{Sub}	subchronic to chronic exposure uncertainty factor
UF_L	LOAEL to NOAEL uncertainty factor
UF_D	incomplete database uncertainty factor
URF	Unit Risk Factor
USEPA	United States Environmental Protection Agency
VE	minute ventilation
VE_{ho}	default occupational ventilation rate for an eight-hour day
VE_h	default non-occupational ventilation rate for a 24-h day