HAZARDOUS WASTE TRANSPORTATION RISK ASSESSMENT FOR THE U.S. DEPARTMENT OF ENERGY ENVIRONMENTAL RESTORATION AND WASTE MANAGEMENT PROGRAMMATIC ENVIRONMENTAL IMPACT STATEMENT — HUMAN HEALTH ENDPOINTS*

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ABSTRACT

In this presentation, a quantitative methodology for assessing the risk associated with the transportation of hazardous waste (HW) is proposed. The focus is on identifying air concentrations of HW that correspond to specific human health endpoints.

INTRODUCTION

Although quantitative risk assessment methods for the transportation of radiological materials are well established (1), few methods have been developed for assessing risks associated with the transport of hazardous waste (HW). In this presentation, a quantitative methodology proposed for use in the U.S. Department of Energy (DOE) Environmental Restoration and Waste Management (EM) Programmatic Environmental Impact Statement (PEIS) is discussed. The focus is on identifying air concentrations of HW that correspond to specific human health endpoints (i.e., health criteria concentrations).

The methodology for determining risk from the transportation of HW is similar to the procedure for performing radiological transportation risk calculations (1). The risk to the general public (i.e., number of individuals experiencing an adverse health effect) from transporting a specific HW through a given population zone is estimated. Total risk for a specific chemical and route is computed for each segment of a rural, urban, or suburban population zone that the transportation route of interest passes through. The risk for each chemical and route can be calculated as

$$Risk = \sum_i TAR_i \times P(R|A)_i \times C_i \times D_i \times L_i \quad , \qquad \text{(Eq. 1)}$$

where

$Risk$ = health effects (individuals affected),

TAR_i = truck accident rate per unit of distance traveled in population zone i (accidents/mi),

$P(R|A)_i$ = conditional probability of a HW release in population zone i given an accident involving a truck carrying HW (unitless),

C_i = health consequence area for population zone i (m^2/accident),

D_i = population density in zone i (individuals/m^2), and

L_i = distance traveled in population zone i (mi).

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Important human health risk endpoints with respect to accidental releases of HW include the potential for life-threatening effects, for any adverse effects, and for carcinogenic effects. The Areal Locations of Hazardous Atmospheres (ALOHA) air dispersion model (2) can be used to calculate the health consequence area (C_i in Eq. 1) by predicting the area of the HW plume produced by an accident. To predict the plume area, concentrations corresponding to various health endpoints are required. This presentation focuses on the derivation of appropriate criteria corresponding to (1) potentially life-threatening concentration (PLC) values, (2) any adverse effect concentration (AAEC) values, and (3) increased cancer risk concentration (ICRC) values. Calculated risks will correspond to the endpoint being assessed (i.e., PLC values will be used to estimate the number of individuals in the general population potentially experiencing life-threatening effects; AAEC values will be used to estimate the number of individuals in the general population potentially having any adverse effects; and ICRC values will be used to estimate the number of individuals potentially having an increased risk of cancer).

The goal of the proposed approach for identifying PLC, AAEC, and ICRC values is the estimation of the minimum concentration level that could induce the adverse health effect. This minimum level is used in the ALOHA model to estimate the plume area having an air concentration at that level or higher. The total population exposed is assumed to be at risk for the health effect. Of the population at risk (i.e., within the plume), those exposed to the highest concentrations will have the greatest likelihood of experiencing the health effect. The method identifies the number of individuals in the general population at risk but does not differentiate the risk for individuals within the plume.

CRITERIA DEVELOPMENT FOR ACCIDENTAL RELEASES

The health criteria concentrations required for the analysis of exposures occurring as a result of accidental chemical releases (e.g., from transportation accidents) are criteria applicable for single, brief exposures of individuals in the general public. Prior to the 1984 accidental release of methyl isocyanate in Bhopal, India, which killed over 2,400 people, chemical risk assessment focused primarily on methods for evaluating risks from chronic, low-level exposures due to environmental contamination. In response to the Bhopal catastrophe and other accidental releases in the United States, Title III of the Superfund Amendments and Reauthorization Act of 1986 (also known as the Emergency Planning and Community Right to Know Act or EPCRA) was passed. This act required the U.S. Environmental Protection Agency (EPA) to publish a list of extremely hazardous substances (EHSs) and to develop methods for assessing the lethal hazards of these substances (3). The EPA complied by identifying over 500 EHSs and introducing the Level of Concern (LOC) concept, which is defined as the concentration in air of each EHS above which there may be serious irreversible health effects or death as a result of a single exposure for a relatively short period of time. The EPA published estimated measures of LOC for each EHS on the basis of occupational guideline levels, fractions of lethal concentrations for animals, or modified occupational standards and emphasized that these were preliminary guidelines to be used while more precise measures were being developed (3). Documentation of the LOC derivation for each chemical was never published.

A consortium of chemical firms has developed a protocol for developing community Emergency Response Planning Guidelines (ERPGs), which are reviewed and distributed by the American Industrial Hygiene Association (4). The procedure for the development of ERPGs relies on thorough review of both published and unpublished chemical-specific data. Emergency response planning guidelines are available for about 50 chemicals. For about five chemicals, the National Research Council has developed Short-term Public Exposure Guidance Levels (SPEGLs) intended for application to single, unpredicted short-term exposures of the general public (5).

At the request of the EPA, the National Resource Council Committee on Toxicology (COT) recently prepared a report entitled *Guidelines for Developing Community Emergency Exposure Levels*

(CEELs) for Hazardous Substances (6). This document discusses data sources and appropriate risk assessment methods for deriving emergency response guidelines for the general public; it advocates a chemical-specific approach to the development of CEELs like that used in the development of ERPG values. To date, however, CEEL values have not been developed by federal agencies.

The guidance in the National Research Council CEEL document was implemented whenever possible in developing the health criteria concentrations to be utilized in the HW transportation risk assessment for the EM PEIS. The large number of chemicals transported by DOE waste generators, however, precluded evaluation of the primary literature at the individual chemical level. The proposed approach for deriving criteria concentrations relies on primary toxicity data reported in databases or reference books, and, as such, must be considered a screening level approach. However, implementation of refining features, such as exposure duration adjustment and additional health endpoints (i.e., any adverse effects and increased carcinogenic risk), in addition to careful documentation of criteria derivation, constitutes an improvement on the currently available LOC values.

DERIVATION OF POTENTIALLY LIFE-THREATENING CONCENTRATION VALUES

The probability of life-threatening health effects is assessed for specific HW components designated as "poison inhalation hazards" (PIHs) by the U.S. Department of Transportation (DOT) (*Code of Federal Regulations*, Title 49 Parts 173.115 and 173.132-133). These substances are assigned protective action distances in the DOT *Emergency Response Guidebook* commonly used by hazardous materials incident response personnel (7). Only liquids and gases are designated as PIH substances. Two criteria must be met for designation as a PIH: (1) high toxicity, on the basis of animal 50% lethal concentrations (LC_{50}); and (2) for liquids, medium to high volatility. Potentially life-threatening concentration values have been derived for PIH substances shipped by DOE waste generators in FY 1992, which is considered the baseline case.

Potentially life-threatening concentration values are air concentrations of HW above which exposed persons are at risk of potentially life-threatening health effects when exposed for the associated exposure duration. Potentially life-threatening concentration values are input to the ALOHA code to estimate "PLC-areas at risk" (i.e., areas that equal or exceed the PLC air concentration). In deriving PLC values, three main issues must be addressed: (1) selection of toxicity values, (2) selection of appropriate uncertainty factors, and (3) exposure duration adjustment. These issues are discussed below, and the equations used to derive PLC values are presented.

Toxicity Value Selection

Two possible toxicity values that are often available in the literature for estimating potential human life-threatening health effects are the LC_{50} and the LC_{LO}. The LC_{50} is defined as that concentration of gas or vapor that causes death in half of the animals tested when administered by continuous inhalation. The LC_{50} is obtained only from animal tests; consequently, results must be extrapolated for application to humans. The LC_{LO} is defined as the lowest concentration of gas or vapor that causes death in any exposed species. The LC_{LO} values may be obtained from animal tests or from accidental human exposure occurrences. When obtained from the latter, the lethal concentration measurement may not be accurate.

Because of the limitations of both the human LC_{LO} values and the LC_{50} values, a conservative approach was taken in selecting the chemical-specific toxicity values. The lower of either (1) the lowest available human LC_{LO} value divided by an uncertainty factor of 3 or (2) the LC_{50} value for the most sensitive tested mammalian species divided by an uncertainty factor of 10 was selected as the primary toxicity value for deriving PLCs (uncertainty factor selection is discussed below). Currently, LC_{50} values or human LC_{LO} values are available for 87% of the substances evaluated. For substances for which no LC_{50} or human LC_{LO} value was available, the lowest mammalian

LC_{LO} value was substituted for the LC_{50} value. If none of the above were available, a short-term exposure level (STEL) for occupational exposures was multiplied by 15 to derive the PLC value [based on methods used to derive LOC values (3)].

Uncertainty Factor Selection

The EPA uses uncertainty factors in deriving reference doses for hazardous chemical substances (8). This precedent has been used to support the reduction of human LC_{LO} values by an uncertainty factor of 3 (to correct for variations in susceptibility among individuals in the human population) and LC_{50} or mammalian LC_{LO} values by an uncertainty factor of 10 (3 to correct for interspecies extrapolation and 3 to account for variations in human susceptibility; rounded to 10 for simplicity). The default uncertainty factor generally used by the EPA for each category of uncertainty is 10. However, use of an uncertainty factor of 10 for human LC_{LO} data or 100 for LC_{50} data would, in general, have reduced the estimated human life-threatening level to a concentration that was not life-threatening to humans (compared with other published criteria; see below). The EPA and the National Research Council acknowledge that in certain instances use of uncertainty factors less than 10 is appropriate (6,8). Therefore, an uncertainty factor of 3 (approximate logarithmic mean of 1 and 10) was selected on the basis of limited EPA guidance (8,9).

Exposure Duration Adjustment

The ALOHA code used to estimate the "PLC-areas at risk" for transportation accidents also provides estimated release durations. The release durations provided by ALOHA range from 1 to 60 minutes. Longer durations are reported as "greater than 60 minutes." For the HW transportation risk assessment, it was assumed that control and dispersion of the source limits significant exposures to periods of one hour or less.

Because toxic dose is a function of both exposure level (e.g., air concentration of chemical) and duration of exposure (10), reported LC_{LO} and LC_{50} values are associated with experimental exposure times. The ALOHA-code-estimated release durations are used to scale LC_{LO} or LC_{50} values in the literature from experimental exposure times to the estimated exposure durations. For simplicity, human PLC values were generated for three exposure durations: 15, 30, and 60 minutes. The PLC value for the exposure duration closest to but greater than the ALOHA-estimated release duration is used to generate the area within which exposed persons are at risk of potentially life-threatening effects (e.g., if the release duration is 20 minutes, the PLC for a 30-minute exposure duration is used to estimate the area at risk).

Either a linear or exponential function was assumed in scaling literature-reported toxicity values to the appropriate exposure durations. The linear scaling procedure is based on Haber's Law (10), which in equation form is as follows:

$$PLC = \frac{Toxicity\ Value \times EET}{ED \times UF}\ , \qquad \text{(Eq. 2)}$$

where

PLC = potentially life-threatening concentration (ppm),

$Toxicity\ Value$ = literature-reported LC_{LO} or LC_{50} value (ppm),

EET = experimental exposure time (min),

ED = exposure duration (15, 30, or 60 min), and

UF = uncertainty factor (3 or 10).

The exponential scaling equation is as follows:

$$PLC = \frac{\left[\frac{(ToxicityValue)^n \times EET}{ED}\right]^{1/n}}{UF} \quad \text{(Eq. 3)}$$

The parameters for Eq. 3 are defined in Eq. 2. Wilson (11) discusses use of this scaling equation and gives the appropriate range of values for n in the above equation as 1.5 to 3.5; a factor of 2 was used in calculations for this assessment. The linear scaling procedure results in a lower estimate of the PLC when scaling from an experimental exposure time shorter than the exposure duration (e.g., scaling from a 15-minute experimental exposure time to a 60-minute exposure duration). The exponential scaling procedure results in a lower estimate of the PLC when scaling from an experimental exposure time longer than the exposure duration. In the absence of chemical-specific data, the scaling assumption resulting in the lower PLC value was used.

For this screening level assessment, toxicity data (e.g., LC_{50} values) were obtained from one of two sources: (1) the Registry of Toxic Effects of Chemical Substances (RTECS) database (12) or (2) *Dangerous Properties of Industrial Materials* (13). Uncertainty in the risk estimates could be reduced through verification of the toxicity data by using the primary literature. Also, PLC values should be updated periodically to reflect the most recent toxicity data available.

In calculating accident risks for the potentially life-threatening endpoint, it is assumed that the entire population residing within the PLC area at risk would experience serious health effects from the exposure. This is a conservative assumption since the PLC values have incorporated uncertainty factors to account for sensitive human subpopulations. Table I gives the PLC values for 15-, 30-, and 60-minute exposure durations for representative chemicals transported by DOE waste generators. The literature-reported toxicity value used to derive the PLC for each chemical is also provided.

PLACE TABLE I HERE

Comparison with Other Emergency Planning Criteria

Table I gives two emergency criteria for comparison with PLC values. The ERPG-3 value is defined as "the maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects" (4). In Table I, ERPG-3 values should be compared with PLC values for 60-minute exposure durations. Where available, ERPG-3 values correspond fairly well to the PLC values; in all cases, there was less than an order of magnitude difference.

Table I also provides LOC values developed by the EPA. The LOC values should be compared with 30-minute PLC values. Comparison of the values shows no definite correlation. Of substances with LOC values available, 17% were higher than the corresponding PLC, 45% were within a factor of 10 lower than the PLC, and 38% were more than 10 times lower than the PLC (the factor ranged from 15 to 180 times lower). LOC values were originally derived as one-tenth of Immediately Dangerous to Life and Health (IDLH) values (3). A lack of correlation of IDLH (and thereby LOC) values with primary toxicity values has also been noted in the literature (14) and may be due to the fact that IDLH and LOC values have not been updated to reflect more recent toxicity data since their initial compilation. An additional problem with the use of LOC values is

that documentation of the primary toxicity values used to generate the LOCs has not been published.

DERIVATION OF ANY ADVERSE EFFECT CONCENTRATION VALUES

To estimate the probability of the occurrence of less severe effects, values were also developed to estimate air concentrations of HW above which exposed persons are at risk of any adverse effect (any adverse effect concentration or AAEC values). Any adverse effect concentration values were derived for all PIH substances shipped by DOE waste generators in FY 1992 and for other shipped substances that had inhalation reference doses or concentrations available from the EPA for use as the toxicity value. As in the derivation of PLC values, the derivation of AAEC values requires selection of toxicity values and uncertainty factors and exposure duration adjustment, which are discussed below.

Toxicity Value Selection

Inhalation reference doses developed by the EPA were selected as the most applicable toxicity values for use in deriving AAEC values. An inhalation reference dose is defined as an estimate (with uncertainty spanning perhaps an order of magnitude) of continuous exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious effects (15). Generally, reference concentration (RfC) values are reported in EPA databases; these are transformed to reference dose (RfD) values by using standard conversion factors. When available, subchronic RfC values (applicable to exposure durations of 2 weeks to 7 years) were used in preference to chronic RfC values. The EPA Integrated Risk Information System (IRIS) database and Health Effects Assessment Summary Tables (HEAST) have been utilized to obtain current RfC values (16,17).

Many of the PIH substances did not have available RfC values. For these substances, toxicity values were selected in a hierarchical fashion analogous to that used to estimate PLC values. In the absence of an RfC, the lowest human TC_{LO} value (defined as the lowest concentration causing any adverse effect) was selected as the most appropriate toxicity value for AAEC derivation. When human TC_{LO} values were not available, the following toxicity values from the literature were used (in decreasing order of preference): (1) lowest mammalian TC_{LO} values, (2) lowest human LC_{LO} values, (3) lowest LC_{50} values, (4) lowest mammalian LC_{LO} values, and (5) the STEL value.

Uncertainty Factor Selection

For substances with available RfC values, application of uncertainty factors was not necessary because the appropriate factors are already incorporated into the RfC value (16,17). Where use of other toxicity values was necessary, uncertainty factors were selected following the rationale used by the EPA in deriving reference concentrations (8): (1) human TC_{LO} divided by 10 (for sensitive subpopulations); (2) mammalian TC_{LO} divided by 100 (10 for sensitive subpopulations and 10 for extrapolation from animal data to humans); (3) human LC_{LO} divided by 100 (10 for sensitive human subpopulations and 10 for extrapolation of lethality data to estimate sub-lethal effects); (4) LC_{50} or mammalian LC_{LO} divided by 1,000 (10 for sensitive human subpopulations, 10 for extrapolation from animal data to humans, and 10 for extrapolation of lethality data to estimate sublethal effects); and (5) the STEL value divided by 3 (for sensitive human subpopulations).

Exposure Duration Adjustments

As was done for the assessment of potentially life-threatening effects, AAECs were generated only for assumed exposure durations of 15, 30, and 60 minutes. The AAEC value for the exposure duration closest to but greater than the ALOHA-estimated release duration is used to generate the

area within which exposed persons are at risk of any adverse effects (e.g., for a 20-minute ALOHA-estimated release duration, the 30-minute AAEC value is used).

For substances for which RfC values are available, the equation used to estimate AAEC values was based on EPA methods for estimating inhalation exposures and acceptable air concentrations of noncarcinogenic contaminants (8,18). To ensure that the derived AAEC values are protective, exposure values for a 6-year old child at a moderate breathing rate were modeled rather than standard adult values. Appropriate body weight and inhalation rate values for a child were obtained from the EPA *Exposure Factors Handbook* (19). In addition, because subchronic RfCs were used, the minimum exposure time of 14 days was used as the averaging time. The equation for deriving AAEC values is as follows:

$$AAEC = \frac{HQ \times RfD \times BW \times AT \times 24.5}{IR \times ET \times MW} \quad \text{(Eq. 4)}$$

where

AAEC = any adverse effect concentration (ppm),

HQ = hazard quotient (1),

RfD = reference dose (mg/kg/d) equal to (RfC x 20 m^3/d)/70 kg,

BW = body weight for a 6-year old (21 kg),

AT = averaging time (14 d),

24.5 = factor to convert from mg/m^3 to ppm,

IR = moderate activity inhalation rate for a 6-year old (0.033 m^3/min),

ET = exposure time (min/d, 15, 30, or 60 min), and

MW = molecular weight of substance.

For substances for which no RfC values are available, the exposure duration adjustment is identical to that used in generating PLC values. Namely, the exposure duration adjustment (i.e., linear or exponential) resulting in the lowest AAEC value was used in modifying toxicity values for the derivation of AAECs. Toxicity data for these chemicals (e.g., TC_{LO} values) were obtained from either the RTECS database (12) or *Dangerous Properties of Industrial Materials* (13). The primary literature can be consulted to verify these values and periodically update the AAEC values.

In calculating accident risks for the any adverse effect endpoint, it is assumed that the entire population residing within the AAEC area at risk would experience some adverse effect from the exposure. Again, this is a conservative assumption since the AAEC values have incorporated uncertainty factors to account for sensitive human subpopulations. The AAEC values for representative chemicals are shown in Table II for 15-, 30-, and 60-minute exposure durations. The table also gives the toxicity value used to derive the AAEC for each chemical.

PLACE TABLE II HERE

Comparison with Other Emergency Response Planning Levels

Emergency Response Planning Guideline-1 values are defined as levels "below which exposure for up to 1 hr would not result in any but mild, transient adverse health effects" (4). These values are available for only about 10 of the substances for which AAEC values were derived; these values are provided in Table II and are best compared with the 60-minute AAEC values. Generally, ERPG-1 values are higher than the AAEC values, which suggests that the AAECs will not underestimate risks.

DERIVATION OF INCREASED CANCER RISK CONCENTRATION VALUES

Hazardous chemical waste transported from DOE facilities may also be evaluated for possible increased cancer risk in exposed individuals. Values were developed to estimate the air concentrations of carcinogenic HW components above which exposed persons have an increased carcinogenic risk of one in one million (10^{-6}) or higher (increased cancer risk concentration or ICRC). The 10^{-6} risk level was selected to represent the level below which increased risk is considered negligible. However, regulatory programs generally specify 10^{-4} to 10^{-6} as an acceptable risk range (20,21). For chemicals showing significant risks at the 10^{-6} level, it would be informative to supplement results with risks (e.g., number of people affected) at the 10^{-4} level.

For this assessment, an ICRC value was derived for each gaseous or liquid substance transported by DOE waste generators in FY 1992 and meeting the following criteria: (1) the substance is classified as a known, probable, or possible human carcinogen in the EPA IRIS database (16) or HEAST (17); (2) the substance has an inhalation unit-risk value available from either IRIS or HEAST; and (3) the substance is volatile enough that there is a significant potential for exposure of the general public. Several inorganic and organic substances were not evaluated because they are solids under ambient conditions, or because the potential to volatize is minimal (e.g., polychlorinated biphenyls, lindane, arsenic, beryllium, and cadmium). Only four transported substances classified as carcinogenic did not have inhalation unit-risk values available from IRIS or HEAST. Should inhalation unit-risk values become available for these substances, ICRC values will be derived.

The method used to generate ICRC values is that recommended by the National Research Council (5,6). Because the estimation of increased cancer risk for exposure periods of less than one hour is uncertain, ICRC values were generated only for assumed exposure durations of one hour. Exposures were averaged over a 70-year lifetime. In calculating risks for individual accidents, it was assumed that the entire population residing within the ICRC area at risk would experience an increased cancer risk of 10^{-6} or greater. The following equation was used to estimate the ICRC value:

$$ICRC = \frac{R \times AT \times 24.5}{UR \times ET \times MW \times 1{,}000\ \mu g/mg}, \qquad \text{(Eq. 5)}$$

where

$ICRC$ = increased carcinogenic risk concentration (ppm),

R = assumed risk level (10^{-6}),

AT = averaging time (70 yr x 365 d/yr x 24 h/d),

24.5 = factor to convert from mg/m^3 to ppm,

UR = chemical-specific unit risk $[(\mu g/m^3)^{-1}]$,

ET = exposure time (1 h), and

MW = molecular weight of substance.

A factor of 2 to 6 may be included in the denominator to account for uncertainties related to stage of the carcinogenic process in which the substance has its effect (6). A factor of 2.8 has been used as a default value in deriving military guidelines (5). However, derivation of the default value is not well documented, and the additional conservative factor is considered unwarranted unless chemical-specific data show early stage mechanisms of action. In calculating risks for individual accidents for the increased cancer risk endpoint, it is assumed that the entire population residing within the ICRC area at risk would experience an increased cancer risk of 10^{-6} or greater. Table III provides the ICRC values for representative chemicals.

PLACE TABLE III HERE

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TABLE I Examples of Potentially Life-Threatening Air Concentration (PLC) Values[a]

Substance	CAS No.	Molecular Weight	Toxicity Value (ppm)	Time/Species/Effect Reference[b]	PLC-ppm (15 min)	PLC-ppm (30 min)	PLC-ppm (60 min)	ERPG-3 ppm[c] (60 min)	LOC ppm[d] (30 min)
Acrolein[e]	107-02-8	56	131	30 min/rat	19	13	9.6	3.0	0.44
Allylamine	107-11-9	57	286	4 h/rat/Sax	119	81	57		1.4
Ammonia	7664-41-7	17	5000	5 min/man/LC_{LO}	560	280	140	1,000	50
Arsine	7784-42-1	78	79	10 min/mouse	5.2	2.6	1.3		0.60
Boron trichloride	10294-34-5	117	2541	1 h/rat	510	360	250		2
Boron trifluoride	7637-07-2	68	39	4 h/guinea pig	16	11	8		10
Bromine	7726-95-6	160	750	9 min/mouse	45	23	11	5.0	1.0
Carbon monoxide	630-08-0	28	5000	5 m/man/LC_{LO}	560	280	140		
Chlorine	7782-50-5	71	137	1 h/mouse	27	19	14	20	2.5
Chloropicrin	76-06-2	164	10	4 h/mouse	3.9	2.8	2.0	3.0	
Cyanogen bromide	506-68-3	106	92	10 min/man/LC_{LO}	29	19	5.1		10
Dimethyl sulfate	77-78-1	126	9	4 h/rat	3.5	2.5	1.7		1.0
Hydrogen fluoride[e]			50	30 min/man/LC_{LO}/Sax	24	17	8.3	50	2.0
Hydrogen selenide	7783-07-5	81	0.3	8 h/guinea pig/LC_{LO}	0.17	0.12	0.085		0.20
Hydrogen sulfide	7783-06-4	34	800	5 min/man/LC_{LO}	89	44	22	100	30
Methyl bromide	74-83-9	95	397	2 h/mouse	110	79	56		200
Methyl chloroformate	79-22-1	95	48	2 h/mouse	14	10	7		0.47
Methyl iodide	74-88-4	142	224	4 h/rat	90	63	45	125	
Methyl vinyl ketone	78-94-4	70	3	2 h/mouse	0.79	0.56	0.40		0.024
Methylamine	74-89-5	31	1897	2 h/mouse	540	380	270	500	
Nickel carbonyl[e]	13463-39-3	171	10	30 min/mouse	1.4	1.0	0.50		0.050
Nitric acid (fuming)	7697-37-2	63	67	4 h/rat	27	19	13		10
Nitric oxide	10102-43-9	30	872	4 h/rat	350	250	170		25
Nitrogen dioxide	10102-44-0	46	30	1 h/guinea pig	6.0	4.2	3.0		5.0
Phosgene	75-44-5	99	50	5 min/man/LC_{LO}	5.6	2.8	1.4	1.0	0.20
Phosphine	7803-51-2	34	11	4 h/rat	4.4	3.1	2.2		20
Phosphorous oxychloride	10025-87-3	153	32	4 h/rat	13	9.1	6.4		0.48
Phosphorous trichloride	7719-12-2	137	50	4 h/guinea pig	20	14	10		5.0
Sulfur dioxide	7446-09-5	64	3000	5 min/man/LC_{LO}	330	170	83	15	10
Sulfur trioxide	7446-11-9	80	9	6 h/guinea pig/LC_{LO}	4.5	3.2	2.2		0.92
Sulfuric acid (fuming)	7664-93-9	98	80	2 h/mouse/Sax	23	16	11	30 mg/m^3	2.0
Tellurium hexafluoride	7783-80-4	242	5	1 h/mouse/LC_{LO}	1.0	0.71	0.50	100 mg/m^3	0.10
Titanium tetrachloride	7550-45-0	190	13	2 h/mouse	3.7	2.6	1.8		0.13
Tungsten hexafluoride[f]	7783-82-6	298	0.62	15 min/STEL × 15	12	8.2	3.1		

[a] Data preference hierarchy and linear versus exponential extrapolation detailed in text. Values rounded to two significant figures. To convert toxicity values to ppm, multiply the concentration (mg/m^3) by 24.5 and divide by the molecular weight.

Toxicity value scaled linearly or exponentially to result in lowest PLC value. Linear Scaled PLC = (Toxicity Value × EET/ED × UF; Exponential Scaled $PLC = ((Toxicity\ Value)^2 \times EET/ED)^{1/2}/UF$; UFs: for human LC_{LO}, 3; LC_{50} or mammalian LC_{LO}, 10.

[b] Toxicity value is LC_{50} unless otherwise noted. Data obtained from RTECS database (12), except where Sax (13) is listed.

[c] ERPG-3: Emergency Response Planning Guideline-3 (4).

[d] EPA "Level of Concern" (3).

[e] Exponential scaling used for 15-minute PLC; linear scaling used for 60-minute PLC.

[f] No LC_{50} or LC_{LO} data available for tungsten hexafluoride; used 15-minute STEL value (10 mg(W)/m^3), converted to ppm, × 15. Reference 3 suggests that IDLH Value = 8-hr TWA × 500, and STEL/3 = 8-hr TWA, STEL/3 = TWA; use uncertainty factor of 10 for sensitive human subpopulations; therefore, STEL × 500/10 × 3 = 15.

Abbreviations: CAS = Chemical Abstracts Service, EET = experimental exposure time; ED = exposure duration (15-, 30-, or 60-min); IDLH = immediately dangerous to life and health, LOC = level of concern, RTECS = Registry of Toxic Effects of Chemical Substances, STEL = short-term exposure level, TWA = time-weighted average, and UF = uncertainty factor.

TABLE II Examples of Any Adverse Effect Concentration (AAEC) Values[a]

Substance	CAS No.	Molecular Weight	Subchronic RfC (mg/m^3)	Toxicity Value (ppm)	Time/Species/Effect/Reference[b]	Inhalation RfD mg/kg/d	AAEC-ppm (15 min)	AAEC-ppm (30 min)	AAEC-ppm (60 min)	ERPG-1 ppm[c] (60 min)
Acrolein[d]	107-02-8	56	0.00002	8.7E-06	2 wk-7 yr/human/NOAEL/IRIS or HEAST	5.71E-06	1.5E-03	7.4E-04	3.7E-04	0.1
Allylamine	107-11-9	57		2.5	5 *min/man* TC_{LO}*/eye, resp irrit*		0.08	0.04	0.02	
Ammonia[d]	7664-41-7	17	0.1	1.4E-01	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.86E-02	25	12	6.1	25
Aniline	62-53-3	93.12	0.01	2.6E-03	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.86E-03	0.45	0.22	0.11	
Bromine	7726-95-6	160		750	9 min/mouseE-LC_{50}		0.45	0.23	0.11	0.2
Carbon disulfide[d]	75-15-0	76	0.01	3.2E-03	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.86E-03	0.55	0.27	0.14	
Carbon monoxide	630-08-0	28		525	10 min/man TC_{LO}/headache		35	18	8.8	
Chlorine	7782-50-5	71		500	5 min/human/LC_{LO}		1.7	0.83	0.42	1
Chloroform	67-66-3	119	0.04		2 wk-7 yr/human/NOAEL/SHRTSC	1.14E-02	1.4	0.70	0.35	
Dichlorodifluoromethane	75-71-8	121	2	4.1E-01	2 wk-7 yr/human/NOAEL/IRIS or HEAST	5.71E-01	69	34	17	
Hydrogen fluoride	7664-39-3	20		123	1 min/man TC_{LO}/cough,irrit		0.82	0.41	0.20	5
Hydrogen chloride[d]	7647-01-0	36	0.007	4.7E-03	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.00E-03	0.80	0.40	0.20	
Hydrogen sulfide	7783-06-4	34	0.009	8.5E-03	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.57E-03	1.1	0.55	0.27	0.1
Methyl ethyl ketone[d]	78-93-3	72	1	3.4E-01	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.86E-01	58	29	14	
Methyl iodide	74-88-4	142		224	4 h/rat LC_{50}		0.90	0.63	0.45	25
Methylene chloride[d]	75-09-2	85	3	8.7E-01	2 wk-7 yr/human/NOAEL/IRIS or HEAST	8.57E-01	150	73	37	
n-Hexane[d]	110-54-3	86	0.2	5.7E-02	2 wk-7 yr/human/NOAEL/IRIS or HEAST	5.71E-02	9.6	4.8	2.4	
Nickel carbonyl	13463-39-3	171		8.6	15 min/rat,hamster TC_{LO}/reprod		0.086	0.043	0.021	
Nitric acid (fuming)	7697-37-2	63		67	4 h/rat/LC_{50}		0.27	0.19	0.13	
Nitric oxide	10102-43-9	30		872	4 h/rat/LC_{50}		3.5	2.5	1.7	
Nitrogen dioxide	10102-44-0	46		6.2	10 min/man TC_{LO}/pulmonary changes		0.41	0.21	0.10	
Phosgene	503-38-8	198		445	10 min/mouse LC_{50}		0.30	0.15	0.07	
Phosphine	7803-51-2	34	0.0003	2.2E-04	2 wk-7 yr/human/NOAEL/IRIS or HEAST	8.57E-05	3.7E-02	1.8E-02	9.2E-03	
Propylene glycol monomethyl ether	107-98-2	90	20	5.4E+00	2 wk-7 yr/human/NOAEL/IRIS or HEAST	5.71E+00	920	460	230	
Propylene oxide[d]	75-56-9	58	0.03	1.3E-02	2 wk-7 yr/human/NOAEL/IRIS or HEAST	8.57E-03	2.2	1.1	0.54	
Styrene	100-42-5	104	3	7.1E-01	2 wk-7 yr/human/NOAEL/IRIS or HEAST	8.57E-01	120	60	30	
Sulfur dioxide	7446-09-5	64		12	1 h/human TC_{LO}-resp chgs		2.4	1.7	1.2	0.3
Sulfur trioxide	7446-11-9	80		9.2	6 h/guinea pig LC_{LO}		0.045	0.032	0.022	2 mg/m^3
Sulfuric acid (fuming)[e]	7664-93-9	98	0.07	NA	All durations - units are mg/m^3	NA	0.070	0.070	0.070	2 mg/m^3
Titanium tetrachloride	7550-45-0	190		13	2 h/mouse/LC_{50}		0.037	0.026	0.018	5 mg/m^3
Toluene[d]	108-88-3	92	0.4	1.1E-01	2 wk-7 yr/human/NOAEL/IRIS or HEAST	1.14E-01	18	9.0	4.5	
1,1,1-Trichloroethane[d]	71-55-6	133.42	1	1.8E-01	2 wk-7 yr/human/NOAEL/SHRTSC	2.86E-01	31	16	7.8	
Trichlorofluoromethane	75-69-4	137	7	1.2E+00	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.00E+00	210	106	53	
Triethylamine[d]	121-44-8	101	0.007	1.7E-03	2 wk-7 yr/human/NOAEL/IRIS or HEAST	2.00E-03	0.29	0.14	0.072	
Tungsten hexafluoride[f]	7783-82-6	298		0.82	15 min/man/TLV-STEL/SAX		0.27	0.14	0.070	
Vinyl acetate[d]	108-05-4	86	0.2	5.7E-02	2 wk-7 yr/human/NOAEL/IRIS or HEAST	5.71E-02	9.7	4.8	2.4	

TABLE II (Cont.)

[a] Data preference hierarchy and linear versus exponential scaling detailed in text. For chemicals with RfC values available, inhalation RfD calculated as RfC × 20 m^3/d ÷ 70 kg. AAEC concentrations in ppm calculated as (RfD × BW × AT × 24.5)/(IR × MW × ED), where: RfD = inhalation RfD calculated from RfC (mg/kg/d); BW = body weight for 6-year old, 21 kg (19); AT = averaging time = 14 days for subchronic exposures; 24.5 = factor for converting to ppm; IR = inhalation rate for 6-yr old, 0.033 m^3/min (19); MW = molecular weight; ED = exposure duration = 15, 30, or 60 minutes.

For chemicals with no RfC value available, Linear Scaled AAEC = (Toxicity Value × EET/ED × UF ; Exponential Scaled AAEC = ∜((Toxicity Value)^2 × EET/ED)$^{1/2}$/UF. The toxicity value was scaled linearly or exponentially to result in lowest AAEC value. UFs: for human TC_{LO}, 10; mammalian TC_{LO}, 100; human LC_{LO}, 100; LC_{50} or mammalian LC_{LO}, 1,000. Values rounded to two significant figures. To convert toxicity values to ppm, multiply the concentration (mg/m^3) by 24.5 and divide by the molecular weight.

[b] RfC values obtained from EPA IRIS database (16) or HEAST (17). Other toxicity values obtained from RTECS database (12), except when Sax (13) is listed.

[c] ERPG-1: Emergency Response Planning Guideline-1 (4).

[d] Indicates that chronic RfC was adopted as subchronic RfC; value may be conservative.

[e] HEAST states that portal of entry effects for sulfuric acid make it inappropriate to convert to mg/d; Carson et al. 1981 as cited in HEAST give 0.07 mg/m^3 as an "acceptable" concentration for sulfuric acid.

[f] No TC_{LO}, LC_{50}, or LC_{LO} data available for tungsten hexafluoride; used 15-minute STEL value (10 mg(W)/m^3) divided by 3, converted to ppm.

Abbreviations: CAS = Chemical Abstracts Service, EET = experimental exposure time, ED = exposure duration, HEAST = Health Effects Assessment, Summary Tables, IRIS = Integrated Risk Information System, NOAEL = no observed adverse effect level, RfC = reference concentration, RfD = reference dose, RTECS = Registry of Toxicity Effects of Chemical Substances, UF = uncertainty factor.

TABLE III Examples of Increased Carcinogenic Risk Concentration (ICRC) Values[a]

Chemical Name	CAS No.	Molecular Weight	Carcinogen Class	Inhalation Unit Risk $\mu g/m^3$-1	VSD[b] (10-6) (mg/m^3)	ICRC[c] (60 min) (mg/m^3)	ICRC[d] (60 min) (ppm)
1,1-Dichloroethylene	75-35-4	97	C	5.0E-05	2.0E-05	1.2E+01	3.1
1,1,2-Trichloroethane	79-00-5	133	C	1.6E-05	6.3E-05	3.8E+01	7.0
1,1,2,2-Tetrachloroethane	79-34-5	168	C	5.8E-05	1.7E-05	1.1E+01	1.5
1,2-Dibromoethane	106-93-4	188	B2	2.2E-04	4.5E-06	2.8E+00	0.36
1,2-Dichloroethane	107-06-2	99	B2	2.6E-05	3.8E-05	2.4E+01	5.8
1,3-Butadiene	106-99-0	54	B2	2.8E-04	3.6E-06	2.2E+00	0.99
Acrylonitrile	107-13-1	53	B1	6.8E-05	1.5E-05	9.0E+00	4.2
Benzene	71-43-2	78	A	8.3E-06	1.2E-04	7.4E+01	23
Benzidine	92-87-5	184	A	6.7E-02	1.5E-08	9.2E-03	1.2E-03
Bromoform	75-25-2	253	B2	1.1E-06	9.1E-04	5.6E+02	54
Carbon tetrachloride	56-23-5	154	B2	1.5E-05	6.7E-05	4.1E+01	6.5
Chloroform	67-66-3	119	B2	2.3E-05	4.3E-05	2.7E+01	5.5
Chloromethane[e]	74-87-3	50	C	1.8E-06	5.6E-04	3.4E+02	160
Dichloromethane	75-09-2	85	B2	4.7E-07	2.1E-03	1.3E+03	380
Epichlorohydrin	106-89-8	93	B2	1.2E-06	8.3E-04	5.1E+02	130
Ethylene oxide	75-21-8	44	B1	1.0E-04	1.0E-05	6.1E+00	3.4
Formaldehyde	50-00-0	30	B1	1.3E-05	7.7E-05	4.7E+01	38
Hydrazine/Hydrazine sulfate	302-01-2	32	B2	4.9E-03	2.0E-07	1.3E-01	0.096
N-nitrosodimethylamine	62-75-9	74	B2	1.4E-02	7.1E-08	4.4E-02	0.015
Propylene oxide	75-56-9	58	B2	3.7E-06	2.7E-04	1.7E+02	70
Tetrachloroethene[f]	127-18-4	166	C-B2	5.8E-07	1.7E-03	1.1E+03	160
Trichloroethene[f]	79-01-6	131	C-B2	1.7E-06	5.9E-04	3.6E+02	67
Vinyl chloride[e]	75-01-4	63	A	8.4E-05	1.2E-05	7.3E+00	2.9

[a] Methods for deriving ICRC values detailed in text. Unit-risk values obtained from IRIS (16) unless otherwise noted. Values rounded to two significant figures.

[b] VSD = virtually safe dose = 10-6/(inhalation unit risk × 1,000 µg/mg).

[c] ICRC = VSD × 24 h/d × 365 d/yr × 70 yr (References 5, 6).

[d] ICRC (ppm) = ICRC (mg/m^3) × 24.5/molecular weight.

[e] Data from HEAST (17).

[f] Data from Superfund Health Risk Technical Support Center, Cincinnati, Ohio, 10/92.