APPENDIX A. ATSDR MINIMAL RISK LEVELS AND WORKSHEETS

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) [42 U.S.C. 9601 et seq.], as amended by the Superfund Amendments and Reauthorization Act (SARA) [Pub. L. 99–499], requires that the Agency for Toxic Substances and Disease Registry (ATSDR) develop jointly with the U.S. Environmental Protection Agency (EPA), in order of priority, a list of hazardous substances most commonly found at facilities on the CERCLA National Priorities List (NPL); prepare toxicological profiles for each substance included on the priority list of hazardous substances; and assure the initiation of a research program to fill identified data needs associated with the substances.

The toxicological profiles include an examination, summary, and interpretation of available toxicological information and epidemiologic evaluations of a hazardous substance. During the development of toxicological profiles, Minimal Risk Levels (MRLs) are derived when reliable and sufficient data exist to identify the target organ(s) of effect or the most sensitive health effect(s) for a specific duration for a given route of exposure. An MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure. MRLs are based on noncancer health effects only and are not based on a consideration of cancer effects. These substance-specific estimates, which are intended to serve as screening levels, are used by ATSDR health assessors to identify contaminants and potential health effects that may be of concern at hazardous waste sites. It is important to note that MRLs are not intended to define clean-up or action levels.

MRLs are derived for hazardous substances using the no-observed-adverse-effect level/uncertainty factor approach. They are below levels that might cause adverse health effects in the people most sensitive to such chemical-induced effects. MRLs are derived for acute (1–14 days), intermediate (15–364 days), and chronic (365 days and longer) durations and for the oral and inhalation routes of exposure. Currently, MRLs for the dermal route of exposure are not derived because ATSDR has not yet identified a method suitable for this route of exposure. MRLs are generally based on the most sensitive chemical-induced end point considered to be of relevance to humans. Serious health effects (such as irreparable damage to the liver or kidneys, or birth defects) are not used as a basis for establishing MRLs. Exposure to a level above the MRL does not mean that adverse health effects will occur.

MRLs are intended only to serve as a screening tool to help public health professionals decide where to look more closely. They may also be viewed as a mechanism to identify those hazardous waste sites that are not expected to cause adverse health effects. Most MRLs contain a degree of uncertainty because of

the lack of precise toxicological information on the people who might be most sensitive (e.g., infants, elderly, nutritionally or immunologically compromised) to the effects of hazardous substances. ATSDR uses a conservative (i.e., protective) approach to address this uncertainty consistent with the public health principle of prevention. Although human data are preferred, MRLs often must be based on animal studies because relevant human studies are lacking. In the absence of evidence to the contrary, ATSDR assumes that humans are more sensitive to the effects of hazardous substance than animals and that certain persons may be particularly sensitive. Thus, the resulting MRL may be as much as 100-fold below levels that have been shown to be nontoxic in laboratory animals.

Proposed MRLs undergo a rigorous review process: Health Effects/MRL Workgroup reviews within the Division of Toxicology and Environmental Medicine, expert panel peer reviews, and agency-wide MRL Workgroup reviews, with participation from other federal agencies and comments from the public. They are subject to change as new information becomes available concomitant with updating the toxicological profiles. Thus, MRLs in the most recent toxicological profiles supersede previously published levels. For additional information regarding MRLs, please contact the Division of Toxicology and Environmental Medicine, Agency for Toxic Substances and Disease Registry, 1600 Clifton Road NE, Mailstop F-32, Atlanta, Georgia 30333.

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

Chemical Name: Acrolein
CAS Number: 107-02-8
Date: July 2007
Profile Status: Post Public, Final
Route: [X] Inhalation [ ] Oral
Duration: [X] Acute [ ] Intermediate [ ] Chronic
Graph Key: 4
Species: Human

Minimal Risk Level: 0.003 [ ] mg/kg/day [X] ppm

Reference: Weber-Tschopp A, Fischer T, Gierer R, et al. 1977. [Experimental irritating effects of acrolein on man.] Int Arch Occup Environ Health 40:117-130. (German)

Experimental design: Forty-six volunteers (21 men, 25 women) were placed into an exposure chamber in groups of 3 and exposed to 0.3 ppm acrolein for 60 minutes. At 5-minute intervals during exposure, participants used a questionnaire to score the level of eye, nose, and throat irritation as 1 (not at all), 2 (a little), 3 (medium), and 4 (strong). In each exposure group, blink rate was observed in two of the three participants, while breathing rate was measured in the third participant. There was no control group or statistical analysis.

In another experiment reported in Weber-Tschopp et al. (1977), volunteers were exposed to a gradually increasing concentration of acrolein for 40 minutes. As acrolein levels rose from 0 to 0.6 ppm over a 35-minute period, participants subjectively scored irritancy at 5-minute intervals as described previously. At the end of 35 minutes, volunteers were exposed for 5 additional minutes at 0.6 ppm. The LOAEL for nose irritation of 0.26 ppm had an average score between 1 and 2 and was statistically significant relative to controls. A NOAEL of 0.17 ppm was identified, which was not statistically different from controls. However, the changing concentrations of acrolein make it difficult to fix the duration or level of exposure that was actually responsible for the onset of noticeable irritation.

Effects noted in study and corresponding doses: Intensity of nose irritation reached a maximum mean score of 2 (a little) at approximately 40 minutes into the exposure, with no change through the remaining 20 minutes. Intensity of throat irritation reached a maximum mean score of between 1 (not at all) and 2 (a little) at approximately 40 minutes into the exposure, with no increase in intensity scores for the remaining 20 minutes. Intensity of nose and throat irritation was scored significantly higher than pre-exposure values beginning at 10 minutes. A 20% decrease in respiratory rate was also observed, compared to pre-exposure values. Controls from the dynamic concentration experiment reported mean scores that were very close to 1 (not at all) for the entire 40-minute test.

Dose and end point used for MRL derivation: LOAEL of 0.3 ppm; decrease in respiratory rate, nose and throat irritation.

[ ] NOAEL [X] LOAEL

Uncertainty Factors used in MRL derivation:

[X] 10 for use of a LOAEL
[ ] 10 for extrapolation from animals to humans
[X] 10 for human variability

Was a conversion used from ppm in food or water to a mg/body weight dose? No.

If an inhalation study in animals, list the conversion factors used in determining human equivalent dose: Not applicable.

Other additional studies or pertinent information which lend support to this MRL: Cassee et al. (1996) exposed 5–6 rats to acrolein vapor levels of 0.25, 0.67, and 1.4 ppm, 6 hours/day for 3 consecutive days. The most sensitive response was mild necrosis, dysplasia, and desquamation of nasal epithelium in rats exposed to 0.25 ppm. Statistically significant cellular proliferation was also observed at 0.25 ppm. Aranyi et al. (1986) reported reduced bactericidal activity of the respiratory tract in mice following acute acrolein inhalation exposures. Significantly lower alveolar macrophagic clearance of a 3-hour *Klebsiella. pneumoniae* infection was observed following a 5-day exposure to 0.1 ppm acrolein in mice. This exposure represents the lowest LOAEL identified for inhalation exposure to acrolein. Treated mice removed 77% of bacteria from their lungs, while controls removed 84%. Though statistically significant, it is not clear what, if any, significance for pathogenicity this difference has on secondary bacterial infections following acrolein exposures. No difference was observed in rats for this same exposure/ infection protocol (Sherwood et al. 1986). The Cassee et al. (1996) study provides a clinically objective measure of nasal irritation in rats; however, the derived LOAEL (0.25 ppm) was very similar to the human LOAEL (0.3 ppm) from Weber-Tschopp et al. (1977). This being the case, the human-derived data are preferable for the basis for the MRL, eliminating the introduction of uncertainty from inter-species extrapolation.

Agency Contacts (Chemical Managers): Nickolette Roney, Jessilynn Taylor, and Annette Ashizawa

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

Chemical Name: Acrolein
CAS Number: 107-02-8
Date: July 2007
Profile Status: Post Public, Final
Route: [X] Inhalation [ ] Oral
Duration: [ ] Acute [X] Intermediate [ ] Chronic
Graph Key: 31
Species: Rat

Minimal Risk Level: 0.00004 [ ] mg/kg/day [X] ppm

Reference: Feron VJ, Kruysse A, Til HP, et al. 1978. Repeated exposure to acrolein vapour: Subacute studies in hamsters, rats and rabbits. Toxicology 9:47-58.

Experimental design: Groups of 12 rats, 20 hamsters, and 4 rabbits were exposed to 0, 0.4, 1.4, and 4.9 ppm acrolein, 6 hours/day, 5 days/week for 13 weeks. General clinical observations were made daily. Body weights and food consumption was recorded weekly. Hematological and serum chemistry measurements were taken at week 12. After euthanasia of animals, organs were removed, weighed, and fixed for histological analysis.

Effects noted in study and corresponding doses: Nasal metaplasia occurred in rats at 0.4 ppm. At 1.4 ppm, rats exhibited squamous epithelia metaplasia, rabbits exhibited decreases in body weight gains, and hamsters exhibited nasal inflammation. At 4.9 ppm, all species exhibited necrotizing rhinitis. Rats exhibited increased heart and kidney weight, tracheal and bronchiolar metaplasia, and lung edema and hemorrhage, and death. Hamsters exhibited increased kidney and heart weight.

Dose and end point used for MRL derivation: LOAEL of 0.4 ppm; nasal epithelial metaplasia in rats. In Feron et al. (1978), the authors did not report incidence data for inhalation effects. Therefore, benchmark dose analysis could not be performed.

[ ] NOAEL [X] LOAEL

Uncertainty Factors used in MRL derivation:

[X] 10 for use of a LOAEL
[X] 3 for extrapolation from animals to humans using dosimetric adjustments
[X] 10 for human variability

Was a conversion used from ppm in food or water to a mg/body weight dose? No.

If an inhalation study in animals, list the conversion factors used in determining human equivalent dose:

Duration adjusted LOAEL ($LOAEL_{ADJ}$) = 0.4 ppm x 6/24 hours x 5/7 days = 0.071 ppm

Regional gas dose ratio for the extrathoracic region ($RGDR_{ER}$) for a category 1 gas =

$$RGDR_{ET} = \frac{\left[\frac{\dot{V}_E}{SA_{ET}}\right]_R}{\left[\frac{\dot{V}_E}{SA_{ET}}\right]_H} = 0.17$$

Where:

Ve is the minute volume and SAET is the surface area of the extrathoracic (ET) region of the respiratory tract.

Minute volume (V_e)

Human: 13.8 L/minute (EPA 1994b)
Rat: 0.16 L/minute; calculated using the following EPA (1994b), reference erroneously uses common logarithm in calculations) equation:

$\ln(V_e) = b_0 + b_1\ln(BW)$

For rats, b_0 equals -0.578 and b_1 equals 0.821 and a body weight of 0.217 kg (EPA 1988b).

EPA (1994b) rat and human respiratory surface area reference values:

Extrathoracic 15.0 cm^2 (rat) 200 cm^2 (human)

$LOAEL_{HEC} = LOAEL_{ADJ}$ x RGDR = 0.071 ppm x 0.17 = 0.012 ppm

Other additional studies or pertinent information which lend support to this MRL: In Feron et al. (1978), the rat appeared to be the most sensitive species, exhibiting more severe histological changes across the respiratory tract than the other species. In other studies, exposures to acrolein concentrations between 0.4 and 5.0 ppm for up to 180 days caused a continuum of histological alterations, inflammation, and severe tissue destruction across the entire respiratory tract of rats, rabbits, guinea pigs, and monkeys. Several similar effects were observed throughout the respiratory tract and across species in the 1–2-ppm exposure level, including nasal epithelial inflammation in hamsters (Feron et al. 1978), tracheal hyperplasia in monkeys (Lyon et al. 1970), bronchiolar inflammation in rats (Kutzman et al. 1985), and lung hyperplasia and inflammation in rats (Costa et al. 1986; Lyon et al. 1970). Effects in the deeper respiratory tract became more severe at the 3–5-ppm exposure levels. Effects included tracheal epithelial metaplasia in hamsters (Feron et al. 1978), epithelial dysplasia in rats (Leach et al. 1987), squamous lung epithelial metaplasia in rats (Kutzman et al. 1985), tracheal metaplasia and bronchial necrosis in rats (Feron et al. 1978; Kutzman et al. 1985), pulmonary edema in rats (Costa et al. 1986), and lung hemorrhage in monkeys (Lyon et al. 1970). The Feron et al. (1978) study was chosen as the critical study since it provided the lowest LOAEL of 0.4 ppm for nasal epithelial metaplasia, the most sensitive effect.

Agency Contacts (Chemical Managers): Nickolette Roney, Jessilynn Taylor, and Annette Ashizawa

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

Chemical Name: Acrolein
CAS Number: 107-02-8
Date: July 2007
Profile Status: Post Public, Final
Route: [ ] Inhalation [X] Oral
Duration: [ ] Acute [X] Intermediate [ ] Chronic
Graph Key: 16
Species: Mouse

Minimal Risk Level: 0.004 [X] mg/kg/day [ ] ppm

Reference: NTP. 2006. NTP technical report on the comparative toxicity studies of allyl acetate, allyl alcohol, and acrolein administered by gavage to F344/N rats and B6C3F1 mice (Tox report #48). National Toxicology Program.

Experimental design: Groups of 10 rats/sex/dose were administered 0.75, 1.25, 2.5, 5, and 10 mg/kg/day by gavage for 14 weeks, while groups of 10 mice/sex/dose were given 1.25, 2.5, 5, 10, and 20 mg/kg for the same duration. Dose volumes were 5 mL/kg for rats and 10 mL/kg for mice.

Effects noted in study and corresponding doses: Common high-dose effects were observed for both species, including hemorrhage and necrosis, and forestomach and glandular stomach lesions. Rats receiving 10 mg/kg/day exhibited abnormal breathing, nasal discharge, and death. The lowest LOAEL observed was 2.5 mg/kg/day for forestomach squamous epithelial hyperplasia in male mice and female rats and mice, with an associated NOAEL of 1.25 mg/kg/day. In male rats, the lowest LOAEL observed was 5 mg/kg/day with an associated NOAEL of 2.5 mg/kg/day. Mice exhibited no clinical signs of toxicity. Glandular stomach lesions appeared in rats and mice given 10 and 20 mg/kg/day, respectively. Liver weights were significantly increased in female rats and male mice given 5 and 10 mg/kg/day, respectively.

Squamous epithelial hyperplasia of the forestomach was the most sensitive end point observed in both rats and mice. However, the lowest LOAEL for this end point in rats was identified only in females, whereas the same LOAEL for this end point was identified in both sexes of mice. Combining the male and female mouse incidence data provided increased statistical sensitivity for data analysis. The incidences of this end point in mice (NTP 2006) are shown in Table A-1.

Table A-1. Incidences of Forestomach Squamous Epithelial Hyperplasia in Male and Female Mice Given Daily Doses of Acrolein by Oral Gavage for 14 Weeks

Sex	Daily gavage doses (mg/kg/day)					
	Control	1.25	2.5	5	10	20
Mice						
Male	0/10	2/10	6/10[a]	7/10[a]	10/10[a]	0/10
Female	0/10	0/10	4/10[b]	7/10[a]	8/10[a]	2/10
Rats						
Female	1/10	3/10	5/10[a]	8/10[a]	10/10[a]	–[c]

[a]Significantly different from controls (p≤0.01) by Fisher exact test.
[b]Significantly different from controls (p≤0.05) by Fisher exact test.
[c]– = Not available

Source: NTP 2006

All dichotomous models in the Benchmark Dose Software (BMDS version 1.3.2) were fit to the combined incidence data for squamous epithelial hyperplasia in the forestomach of male and female mice and female rats. The highest dose (20 mg/kg/day) was dropped from the analysis of lesion incidences in mice in order to achieve an adequate fit of the models to the data. Exclusion of the 20 mg/kg/day group from the BMD analysis is appropriate, since all of the animals exhibited frank glandular stomach toxicity and died during the first week of exposure. The lower 95% confidence limit ($BMDL_{10}$) of a 10% extra risk (BMD_{10}) for forestomach squamous epithelial hyperplasia was selected as the benchmark response for the point of departure. For female rats, the Quantal Quadratic model provided the best fit as assessed by a chi-square goodness-of-fit test and the Akaike's Information Criteria (AIC), giving a $BMDL_{10}$ of 0.88 mg/kg/day (Table A-2, Figure A-1). For mice, the Quantal Linear model provided the best fit (Table A-3), providing a $BMDL_{10}$ of 0.36 mg/kg/day (Table A-3, Figure A-2). Forestomach hyperplasia in mice was chosen as the critical effect instead of the same effect in female rats because both sexes of mice exhibited significantly higher incidences of this lesion, compared to controls, and because the $BMDL_{10}$ for mice was lower than that of female rats, thus being more health protective. The $BMDL_{10}$ value of 0.36 mg/kg/day, derived from the Quantal Linear model, was selected as the point of departure for calculating an intermediate-duration oral MRL.

Table A-2. BMD Modeling of the Incidence of Squamous Epithelial Hyperplasia of the Forestomach in Female F-344/N Rats Exposed to Acrolein via Gavage for 14 Weeks: Goodness-of-fit Criteria for Applied Models

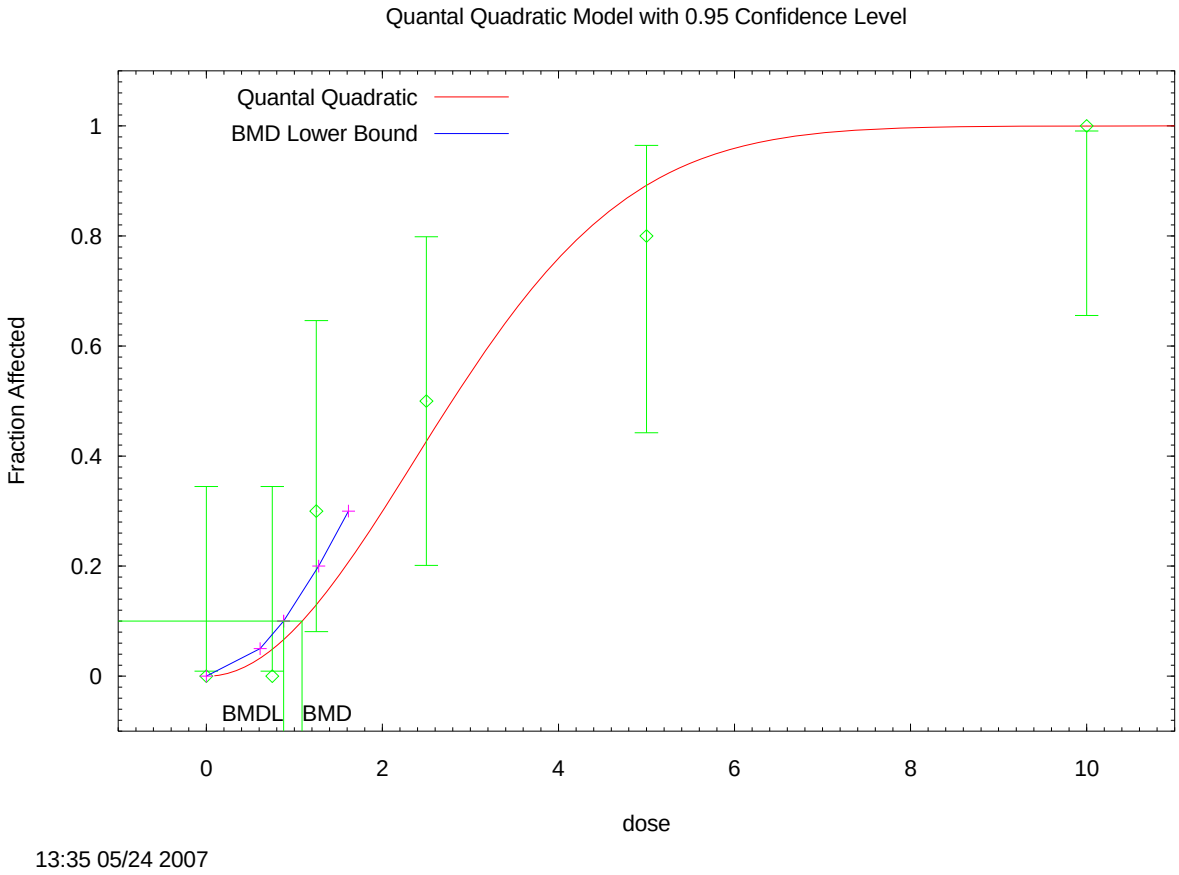
Model	AIC	p[a]	BMD_{10}	$BMDL_{10}$
Gamma	42.7965	0.7397	0.8675	0.3596
Logistic	45.6249	0.3914	1.1363	0.7697
Log-Logistic	43.1105	0.6959	0.9318	0.4954
Multistage	43.1919	0.7116	0.7244	0.3043
Probit	45.2424	0.4178	1.0874	0.7478
Log-probit	42.6336	0.7483	0.9531	0.5409
Quantal-linear	43.6493	0.6863	0.3652	0.2551
Quantal-quadratic	**42.0101**	**0.5245**	**1.0881**	**0.8778**
Weibull	42.941	0.7375	0.7963	0.3440

[a]Values <0.1 fail to meet conventional goodness-of-fit criteria.

AIC = Akaike's Information Criteria; BMD = benchmark dose; BMDL = lower confidence limit (95%) on the benchmark dose; NA = not applicable; p = p value from the Chi-squared test;

Source: NTP 2006

Figure A-1. Benchmark Dose Model Results for the Incidences of Squamous Epithelial Hyperplasia in the Forestomach of Female F344/N Rats Given Daily Gavage Doses of Acrolein for 14 Weeks



Source: NTP 2006

Table A-3. BMD Modeling of the Incidence of Squamous Epithelial Hyperplasia of the Forestomach in Male and Female B6C3F1 Mice Exposed to Acrolein via Gavage for 14 Weeks: Goodness-of-fit Criteria for Applied Models

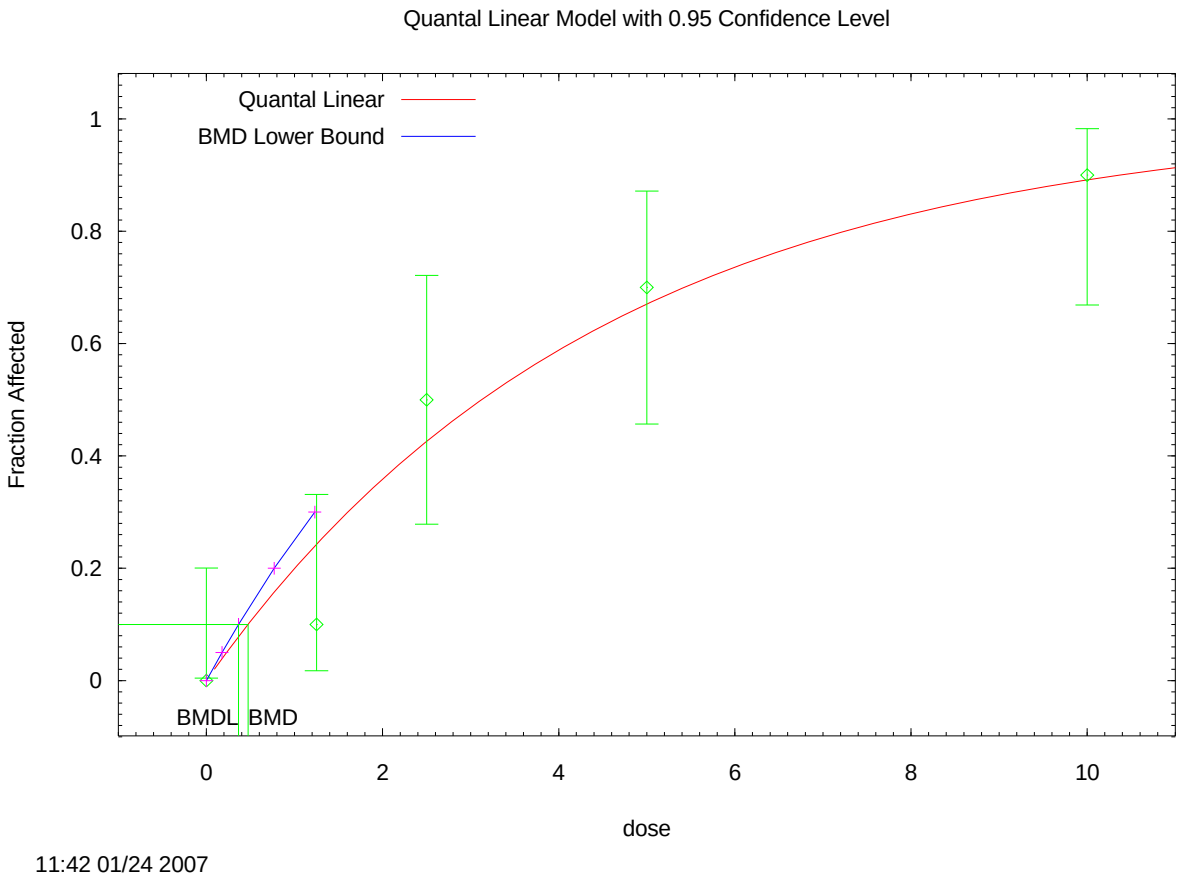
Model	AIC	p[a]	BMD_{10}	$BMDL_{10}$
Gamma	84.4571	0.5301	0.7791	0.3813
Logistic	92.7143	0.0224	NA	NA
Log-Logistic	83.4164	0.7490	0.9800	0.5061
Multistage	85.1092	0.4483	0.5470	0.3680
Probit	93.2507	0.0193	NA	NA
Log-probit	83.3748	0.7575	1.0151	0.6617
Quantal-linear	**83.3634**	**0.6011**	**0.4736**	**0.3635**
Quantal-quadratic	93.4813	0.0017	NA	NA
Weibull	84.6961	0.4978	0.6851	0.3761

[a]Values <0.1 fail to meet conventional goodness-of-fit criteria.

AIC = Akaike's Information Criteria; BMD = benchmark dose; BMDL = lower confidence limit (95%) on the benchmark dose; NA = not applicable; p = p value from the Chi-squared test

Source: NTP 2006

Figure A-2. Benchmark Dose Model Results for the Combined Incidences of Squamous Epithelial Hyperplasia in the Forestomach of Male and Female B6C3F1 Mice Given Daily Gavage Doses of Acrolein for 14 Weeks



Source: NTP 2006

Dose and end point used for MRL derivation: $BMDL_{10}$ of 0.36 mg/kg/day; forestomach squamous epithelial hyperplasia in mice.

[ ] NOAEL [ ] LOAEL [X] $BMDL_{10}$

Uncertainty Factors used in MRL derivation:

[ ] 10 for use of a LOAEL
[X] 10 for extrapolation from animals to humans
[X] 10 for human variability

Was a conversion used from ppm in food or water to a mg/body weight dose? No.

If an inhalation study in animals, list the conversion factors used in determining human equivalent dose: Not applicable.

Other additional studies or pertinent information which lend support to this MRL: Gastric ulceration was observed in rats given an acute gavage doses of 25 mg/kg (Sakata et al. 1989) and in rabbits given 4 mg/kg/day for 12 days (Parent et al. 1993). Gastric ulceration was also seen in rats given intermediate-duration doses of 5.4 mg/kg/day for 115 days (King 1984). Vomiting was also observed in a chronic gavage study in which dogs were given 0.1 mg/kg/day (Parent et al. 1992b). Epithelial hyperplasia is a sensitive end point for nasal effects of acrolein inhalation as seen in rats receiving 1.4 ppm for 62 days (Costa et al. 1986) and in dogs exposed to 3.7 ppm for 6 weeks (Lyon et al. 1970). Forestomach squamous epithelial hyperplasia represented the lowest identified LOAEL in a well-designed study.

Agency Contacts (Chemical Managers): Nickolette Roney, Jessilynn Taylor, and Annette Ashizawa

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APPENDIX B. USER'S GUIDE

Chapter 1

Public Health Statement

This chapter of the profile is a health effects summary written in non-technical language. Its intended audience is the general public, especially people living in the vicinity of a hazardous waste site or chemical release. If the Public Health Statement were removed from the rest of the document, it would still communicate to the lay public essential information about the chemical.

The major headings in the Public Health Statement are useful to find specific topics of concern. The topics are written in a question and answer format. The answer to each question includes a sentence that will direct the reader to chapters in the profile that will provide more information on the given topic.

Chapter 2

Relevance to Public Health

This chapter provides a health effects summary based on evaluations of existing toxicologic, epidemiologic, and toxicokinetic information. This summary is designed to present interpretive, weight-of-evidence discussions for human health end points by addressing the following questions:

1. What effects are known to occur in humans?

2. What effects observed in animals are likely to be of concern to humans?

3. What exposure conditions are likely to be of concern to humans, especially around hazardous waste sites?

The chapter covers end points in the same order that they appear within the Discussion of Health Effects by Route of Exposure section, by route (inhalation, oral, and dermal) and within route by effect. Human data are presented first, then animal data. Both are organized by duration (acute, intermediate, chronic). *In vitro* data and data from parenteral routes (intramuscular, intravenous, subcutaneous, etc.) are also considered in this chapter.

The carcinogenic potential of the profiled substance is qualitatively evaluated, when appropriate, using existing toxicokinetic, genotoxic, and carcinogenic data. ATSDR does not currently assess cancer potency or perform cancer risk assessments. Minimal Risk Levels (MRLs) for noncancer end points (if derived) and the end points from which they were derived are indicated and discussed.

Limitations to existing scientific literature that prevent a satisfactory evaluation of the relevance to public health are identified in the Chapter 3 Data Needs section.

Interpretation of Minimal Risk Levels

Where sufficient toxicologic information is available, ATSDR has derived MRLs for inhalation and oral routes of entry at each duration of exposure (acute, intermediate, and chronic). These MRLs are not meant to support regulatory action, but to acquaint health professionals with exposure levels at which adverse health effects are not expected to occur in humans.

MRLs should help physicians and public health officials determine the safety of a community living near a chemical emission, given the concentration of a contaminant in air or the estimated daily dose in water. MRLs are based largely on toxicological studies in animals and on reports of human occupational exposure.

MRL users should be familiar with the toxicologic information on which the number is based. Chapter 2, "Relevance to Public Health," contains basic information known about the substance. Other sections such as Chapter 3 Section 3.9, "Interactions with Other Substances," and Section 3.10, "Populations that are Unusually Susceptible" provide important supplemental information.

MRL users should also understand the MRL derivation methodology. MRLs are derived using a modified version of the risk assessment methodology that the Environmental Protection Agency (EPA) provides (Barnes and Dourson 1988) to determine reference doses (RfDs) for lifetime exposure.

To derive an MRL, ATSDR generally selects the most sensitive end point which, in its best judgement, represents the most sensitive human health effect for a given exposure route and duration. ATSDR cannot make this judgement or derive an MRL unless information (quantitative or qualitative) is available for all potential systemic, neurological, and developmental effects. If this information and reliable quantitative data on the chosen end point are available, ATSDR derives an MRL using the most sensitive species (when information from multiple species is available) with the highest no-observed-adverse-effect level (NOAEL) that does not exceed any adverse effect levels. When a NOAEL is not available, a lowest-observed-adverse-effect level (LOAEL) can be used to derive an MRL, and an uncertainty factor (UF) of 10 must be employed. Additional uncertainty factors of 10 must be used both for human variability to protect sensitive subpopulations (people who are most susceptible to the health effects caused by the substance) and for interspecies variability (extrapolation from animals to humans). In deriving an MRL, these individual uncertainty factors are multiplied together. The product is then divided into the inhalation concentration or oral dosage selected from the study. Uncertainty factors used in developing a substance-specific MRL are provided in the footnotes of the levels of significant exposure (LSE) tables.

Chapter 3

Health Effects

Tables and Figures for Levels of Significant Exposure (LSE)

Tables and figures are used to summarize health effects and illustrate graphically levels of exposure associated with those effects. These levels cover health effects observed at increasing dose concentrations and durations, differences in response by species, MRLs to humans for noncancer end points, and EPA's estimated range associated with an upper- bound individual lifetime cancer risk of 1 in 10,000 to 1 in 10,000,000. Use the LSE tables and figures for a quick review of the health effects and to locate data for a specific exposure scenario. The LSE tables and figures should always be used in conjunction with the text. All entries in these tables and figures represent studies that provide reliable, quantitative estimates of NOAELs, LOAELs, or Cancer Effect Levels (CELs).

The legends presented below demonstrate the application of these tables and figures. Representative examples of LSE Table 3-1 and Figure 3-1 are shown. The numbers in the left column of the legends correspond to the numbers in the example table and figure.

LEGEND

See Sample LSE Table 3-1 (page B-6)

(1) Route of Exposure. One of the first considerations when reviewing the toxicity of a substance using these tables and figures should be the relevant and appropriate route of exposure. Typically when sufficient data exist, three LSE tables and two LSE figures are presented in the document. The three LSE tables present data on the three principal routes of exposure, i.e., inhalation, oral, and dermal (LSE Tables 3-1, 3-2, and 3-3, respectively). LSE figures are limited to the inhalation (LSE Figure 3-1) and oral (LSE Figure 3-2) routes. Not all substances will have data on each route of exposure and will not, therefore, have all five of the tables and figures.

(2) Exposure Period. Three exposure periods—acute (less than 15 days), intermediate (15–364 days), and chronic (365 days or more)—are presented within each relevant route of exposure. In this example, an inhalation study of intermediate exposure duration is reported. For quick reference to health effects occurring from a known length of exposure, locate the applicable exposure period within the LSE table and figure.

(3) Health Effect. The major categories of health effects included in LSE tables and figures are death, systemic, immunological, neurological, developmental, reproductive, and cancer. NOAELs and LOAELs can be reported in the tables and figures for all effects but cancer. Systemic effects are further defined in the "System" column of the LSE table (see key number 18).

(4) Key to Figure. Each key number in the LSE table links study information to one or more data points using the same key number in the corresponding LSE figure. In this example, the study represented by key number 18 has been used to derive a NOAEL and a Less Serious LOAEL (also see the two "18r" data points in sample Figure 3-1).

(5) Species. The test species, whether animal or human, are identified in this column. Chapter 2, "Relevance to Public Health," covers the relevance of animal data to human toxicity and Section 3.4, "Toxicokinetics," contains any available information on comparative toxicokinetics. Although NOAELs and LOAELs are species specific, the levels are extrapolated to equivalent human doses to derive an MRL.

(6) Exposure Frequency/Duration. The duration of the study and the weekly and daily exposure regimens are provided in this column. This permits comparison of NOAELs and LOAELs from different studies. In this case (key number 18), rats were exposed to “Chemical x” via inhalation for 6 hours/day, 5 days/week, for 13 weeks. For a more complete review of the dosing regimen, refer to the appropriate sections of the text or the original reference paper (i.e., Nitschke et al. 1981).

(7) System. This column further defines the systemic effects. These systems include respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, and dermal/ocular. "Other" refers to any systemic effect (e.g., a decrease in body weight) not covered in these systems. In the example of key number 18, one systemic effect (respiratory) was investigated.

(8) NOAEL. A NOAEL is the highest exposure level at which no harmful effects were seen in the organ system studied. Key number 18 reports a NOAEL of 3 ppm for the respiratory system, which was used to derive an intermediate exposure, inhalation MRL of 0.005 ppm (see footnote "b").

(9) LOAEL. A LOAEL is the lowest dose used in the study that caused a harmful health effect. LOAELs have been classified into "Less Serious" and "Serious" effects. These distinctions help readers identify the levels of exposure at which adverse health effects first appear and the gradation of effects with increasing dose. A brief description of the specific end point used to quantify the adverse effect accompanies the LOAEL. The respiratory effect reported in key number 18 (hyperplasia) is a Less Serious LOAEL of 10 ppm. MRLs are not derived from Serious LOAELs.

(10) Reference. The complete reference citation is given in Chapter 9 of the profile.

(11) CEL. A CEL is the lowest exposure level associated with the onset of carcinogenesis in experimental or epidemiologic studies. CELs are always considered serious effects. The LSE tables and figures do not contain NOAELs for cancer, but the text may report doses not causing measurable cancer increases.

(12) Footnotes. Explanations of abbreviations or reference notes for data in the LSE tables are found in the footnotes. Footnote "b" indicates that the NOAEL of 3 ppm in key number 18 was used to derive an MRL of 0.005 ppm.

LEGEND

See Sample Figure 3-1 (page B-7)

LSE figures graphically illustrate the data presented in the corresponding LSE tables. Figures help the reader quickly compare health effects according to exposure concentrations for particular exposure periods.

(13) Exposure Period. The same exposure periods appear as in the LSE table. In this example, health effects observed within the acute and intermediate exposure periods are illustrated.

(14) Health Effect. These are the categories of health effects for which reliable quantitative data exists. The same health effects appear in the LSE table.

(15) Levels of Exposure. Concentrations or doses for each health effect in the LSE tables are graphically displayed in the LSE figures. Exposure concentration or dose is measured on the log scale "y" axis. Inhalation exposure is reported in mg/m^3 or ppm and oral exposure is reported in mg/kg/day.

(16) NOAEL. In this example, the open circle designated 18r identifies a NOAEL critical end point in the rat upon which an intermediate inhalation exposure MRL is based. The key number 18 corresponds to the entry in the LSE table. The dashed descending arrow indicates the extrapolation from the exposure level of 3 ppm (see entry 18 in the table) to the MRL of 0.005 ppm (see footnote "b" in the LSE table).

(17) CEL. Key number 38m is one of three studies for which CELs were derived. The diamond symbol refers to a CEL for the test species-mouse. The number 38 corresponds to the entry in the LSE table.

(18) Estimated Upper-Bound Human Cancer Risk Levels. This is the range associated with the upper-bound for lifetime cancer risk of 1 in 10,000 to 1 in 10,000,000. These risk levels are derived from the EPA's Human Health Assessment Group's upper-bound estimates of the slope of the cancer dose response curve at low dose levels (q_1*).

(19) Key to LSE Figure. The Key explains the abbreviations and symbols used in the figure.

SAMPLE

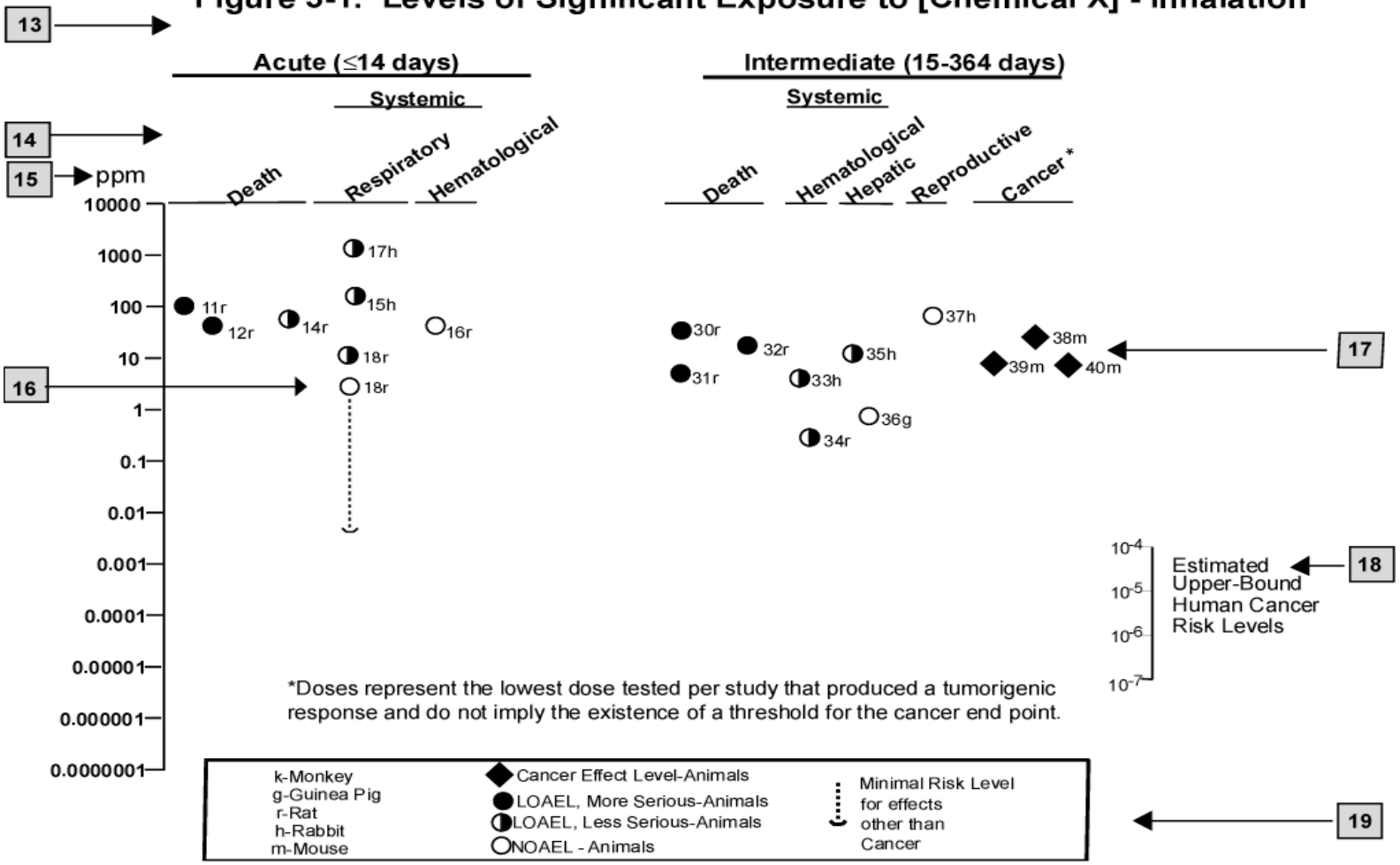
1 → **Table 3-1. Levels of Significant Exposure to [Chemical x] – Inhalation**

	Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	Serious (ppm)	Reference
2 →	INTERMEDIATE EXPOSURE							
		5	6	7	8	9		10
3 →	Systemic	↓	↓	↓	↓	↓		↓
4 →	18	Rat	13 wk 5 d/wk 6 hr/d	Resp	3[b]	10 (hyperplasia)		Nitschke et al. 1981
	CHRONIC EXPOSURE							
	Cancer					11 ↓		
	38	Rat	18 mo 5 d/wk 7 hr/d			20	(CEL, multiple organs)	Wong et al. 1982
	39	Rat	89–104 wk 5 d/wk 6 hr/d			10	(CEL, lung tumors, nasal tumors)	NTP 1982
	40	Mouse	79–103 wk 5 d/wk 6 hr/d			10	(CEL, lung tumors, hemangiosarcomas)	NTP 1982

12 → [a] The number corresponds to entries in Figure 3-1.
[b] Used to derive an intermediate inhalation Minimal Risk Level (MRL) of $5x10^{-3}$ ppm; dose adjusted for intermittent exposure and divided by an uncertainty factor of 100 (10 for extrapolation from animal to humans, 10 for human variability).

SAMPLE

Figure 3-1. Levels of Significant Exposure to [Chemical X] - Inhalation



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APPENDIX C. ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ACGIH	American Conference of Governmental Industrial Hygienists
ACOEM	American College of Occupational and Environmental Medicine
ADI	acceptable daily intake
ADME	absorption, distribution, metabolism, and excretion
AED	atomic emission detection
AFID	alkali flame ionization detector
AFOSH	Air Force Office of Safety and Health
ALT	alanine aminotransferase
AML	acute myeloid leukemia
AOAC	Association of Official Analytical Chemists
AOEC	Association of Occupational and Environmental Clinics
AP	alkaline phosphatase
APHA	American Public Health Association
AST	aspartate aminotransferase
atm	atmosphere
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
BAT	best available technology
BCF	bioconcentration factor
BEI	Biological Exposure Index
BMD	benchmark dose
BMR	benchmark response
BSC	Board of Scientific Counselors
C	centigrade
CAA	Clean Air Act
CAG	Cancer Assessment Group of the U.S. Environmental Protection Agency
CAS	Chemical Abstract Services
CDC	Centers for Disease Control and Prevention
CEL	cancer effect level
CELDS	Computer-Environmental Legislative Data System
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ci	curie
CI	confidence interval
CL	ceiling limit value
CLP	Contract Laboratory Program
cm	centimeter
CML	chronic myeloid leukemia
CPSC	Consumer Products Safety Commission
CWA	Clean Water Act
DHEW	Department of Health, Education, and Welfare
DHHS	Department of Health and Human Services
DNA	deoxyribonucleic acid
DOD	Department of Defense
DOE	Department of Energy
DOL	Department of Labor
DOT	Department of Transportation
DOT/UN/ NA/IMCO	Department of Transportation/United Nations/ North America/Intergovernmental Maritime Dangerous Goods Code

DWEL	drinking water exposure level
ECD	electron capture detection
ECG/EKG	electrocardiogram
EEG	electroencephalogram
EEGL	Emergency Exposure Guidance Level
EPA	Environmental Protection Agency
F	Fahrenheit
F_1	first-filial generation
FAO	Food and Agricultural Organization of the United Nations
FDA	Food and Drug Administration
FEMA	Federal Emergency Management Agency
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FPD	flame photometric detection
fpm	feet per minute
FR	Federal Register
FSH	follicle stimulating hormone
g	gram
GC	gas chromatography
gd	gestational day
GLC	gas liquid chromatography
GPC	gel permeation chromatography
HPLC	high-performance liquid chromatography
HRGC	high resolution gas chromatography
HSDB	Hazardous Substance Data Bank
IARC	International Agency for Research on Cancer
IDLH	immediately dangerous to life and health
ILO	International Labor Organization
IRIS	Integrated Risk Information System
Kd	adsorption ratio
kg	kilogram
kkg	metric ton
K_{oc}	organic carbon partition coefficient
K_{ow}	octanol-water partition coefficient
L	liter
LC	liquid chromatography
LC_{50}	lethal concentration, 50% kill
LC_{Lo}	lethal concentration, low
LD_{50}	lethal dose, 50% kill
LD_{Lo}	lethal dose, low
LDH	lactic dehydrogenase
LH	luteinizing hormone
LOAEL	lowest-observed-adverse-effect level
LSE	Levels of Significant Exposure
LT_{50}	lethal time, 50% kill
m	meter
MA	*trans,trans*-muconic acid
MAL	maximum allowable level
mCi	millicurie
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF	modifying factor

MFO	mixed function oxidase
mg	milligram
mL	milliliter
mm	millimeter
mmHg	millimeters of mercury
mmol	millimole
mppcf	millions of particles per cubic foot
MRL	Minimal Risk Level
MS	mass spectrometry
NAAQS	National Ambient Air Quality Standard
NAS	National Academy of Science
NATICH	National Air Toxics Information Clearinghouse
NATO	North Atlantic Treaty Organization
NCE	normochromatic erythrocytes
NCEH	National Center for Environmental Health
NCI	National Cancer Institute
ND	not detected
NFPA	National Fire Protection Association
ng	nanogram
NHANES	National Health and Nutrition Examination Survey
NIEHS	National Institute of Environmental Health Sciences
NIOSH	National Institute for Occupational Safety and Health
NIOSHTIC	NIOSH's Computerized Information Retrieval System
NLM	National Library of Medicine
nm	nanometer
nmol	nanomole
NOAEL	no-observed-adverse-effect level
NOES	National Occupational Exposure Survey
NOHS	National Occupational Hazard Survey
NPD	nitrogen phosphorus detection
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
NR	not reported
NRC	National Research Council
NS	not specified
NSPS	New Source Performance Standards
NTIS	National Technical Information Service
NTP	National Toxicology Program
ODW	Office of Drinking Water, EPA
OERR	Office of Emergency and Remedial Response, EPA
OHM/TADS	Oil and Hazardous Materials/Technical Assistance Data System
OPP	Office of Pesticide Programs, EPA
OPPT	Office of Pollution Prevention and Toxics, EPA
OPPTS	Office of Prevention, Pesticides and Toxic Substances, EPA
OR	odds ratio
OSHA	Occupational Safety and Health Administration
OSW	Office of Solid Waste, EPA
OTS	Office of Toxic Substances
OW	Office of Water
OWRS	Office of Water Regulations and Standards, EPA
PAH	polycyclic aromatic hydrocarbon

PBPD	physiologically based pharmacodynamic
PBPK	physiologically based pharmacokinetic
PCE	polychromatic erythrocytes
PEL	permissible exposure limit
pg	picogram
PHS	Public Health Service
PID	photo ionization detector
pmol	picomole
PMR	proportionate mortality ratio
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
PSNS	pretreatment standards for new sources
RBC	red blood cell
REL	recommended exposure level/limit
RfC	reference concentration
RfD	reference dose
RNA	ribonucleic acid
RQ	reportable quantity
RTECS	Registry of Toxic Effects of Chemical Substances
SARA	Superfund Amendments and Reauthorization Act
SCE	sister chromatid exchange
SGOT	serum glutamic oxaloacetic transaminase
SGPT	serum glutamic pyruvic transaminase
SIC	standard industrial classification
SIM	selected ion monitoring
SMCL	secondary maximum contaminant level
SMR	standardized mortality ratio
SNARL	suggested no adverse response level
SPEGL	Short-Term Public Emergency Guidance Level
STEL	short term exposure limit
STORET	Storage and Retrieval
TD_{50}	toxic dose, 50% specific toxic effect
TLV	threshold limit value
TOC	total organic carbon
TPQ	threshold planning quantity
TRI	Toxics Release Inventory
TSCA	Toxic Substances Control Act
TWA	time-weighted average
UF	uncertainty factor
U.S.	United States
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VOC	volatile organic compound
WBC	white blood cell
WHO	World Health Organization

>	greater than
≥	greater than or equal to
=	equal to
<	less than
≤	less than or equal to
%	percent
α	alpha
β	beta
γ	gamma
δ	delta
μm	micrometer
μg	microgram
q_1^*	cancer slope factor
–	negative
+	positive
(+)	weakly positive result
(–)	weakly negative result

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APPENDIX D. INDEX

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