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 Human Health Sciences, 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 Human Health Sciences, Agency for Toxic Substances and Disease Registry, 1600 Clifton Road NE, Mailstop F-57, Atlanta, Georgia 30329-4027.

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

Chemical Name: Nitrate
CAS Numbers: 14797-55-8
Date: September 2015
Profile Status: Draft for Public Comment
Route: [ ] Inhalation [x] Oral
Duration: [x] Acute [x] Intermediate [x] Chronic
Graph Key: 3 (Acute), 15 (Intermediate), 49 (Chronic)
Species: Human

Minimal Risk Level: 4 [x] mg/kg/day [ ] ppm

Reference: Walton G. 1951. Survey of literature relating to infant methemoglobinemia due to nitrate-contaminated water. Am J Public Health 41:986-996.

Experimental design: Walton (1951) reviewed available literature and found 278 reported cases of infant methemoglobinemia in a total of 14 U.S. states from which information was available. Cases were grouped by state according to ranges of nitrate levels in drinking water sources.

Effect noted in study and corresponding doses: Among methemoglobinemia cases for which nitrate levels in water sources used to prepare infant formula were available, 173 cases were associated with >50 mg nitrate-nitrogen/L (220 mg nitrate/L), 36 cases with 21–50 mg nitrate-nitrogen/L (92–220 mg nitrate/L), and 5 cases with 11–20 mg nitrate-nitrogen (48–88 mg nitrate/L). None of the methemoglobinemia cases were associated with drinking water sources measuring <10 mg nitrate-nitrogen/L (<44 mg nitrate/L). Limitations of the contributing studies include lack of information regarding the actual ages of the infants, total nitrate doses, and other water source contaminants (e.g., bacterial levels).

Following ingestion of relatively large amounts of nitrate by healthy normal individuals, blood methemoglobin levels increase rapidly, followed by a return to normal within several hours following intake. Repeated ingestion for intermediate- or chronic-duration time periods would be expected to result in changes in methemoglobin levels similar to those elicited from a single exposure. Therefore, the acute-, intermediate-, and chronic-duration oral MRL values are equivalent.

Dose and end point used for MRL derivation: 4.33 mg nitrate/kg/day

[x] NOAEL [ ] LOAEL

Uncertainty Factors used in MRL derivation:

[ ] 10 for use of a LOAEL
[ ] 10 for extrapolation from animals to humans
[x] 1 for human variability

A total uncertainty factor of 1 is justified because the point of departure is a NOAEL for nitrate-induced effects on methemoglobin in a particularly sensitive human subpopulation (i.e., <3-month-old infants, which in many cases may have been at increased risk of methemoglobinemia due to microbial contamination and associated gastrointestinal infection).

Was a conversion factor used from ppm in food or water to a mg/body weight dose? Nitrate may be expressed in terms of ionic concentration (i.e., mg nitrate/L), or elemental concentration (i.e., mg nitrate-nitrogen/L or mg nitrogen as nitrate/L). A concentration of nitrate expressed in elemental concentration (mg nitrogen per liter from nitrate source) can be converted to its ionic concentration (mg NO_3^-) according to the following relationship: 1 mg nitrate-nitrogen = 4.4 mg nitrate (i.e., the proportion of N in NO_3^- is 14 [atomic mass of N] ÷ 62 [molecular mass of NO_3^-] = 0.226).
Table A-1 presents estimated nitrate doses to infants (birth–<3 months of age) calculated using estimated mean values for drinking water ingestion rates (Kahn and Stralka 2009) and body weight (EPA 2008) and assuming a drinking water level of 44 mg nitrate/L as a concentration not expected to cause methemoglobinemia; the calculated doses of 4.31–4.34 mg nitrate/kg/day represent NOAELs for the age ranges. The TWA-based calculated dose of 4.33 mg nitrate/kg/day for the age range of birth–<3 months is selected as the point of departure for deriving acute-, intermediate-, and chronic-duration oral MRLs for nitrate.

Table A-1. Estimated Nitrate Dose to Infants of Selected Age Ranges Assuming a Drinking Water Level of 44 mg Nitrate/L[a]

Age range	Water intake (L/day)[b]	Body weight (kg)[c]	Nitrate dose (mg/kg/day)[d]
Birth–<1 month	0.470	4.8	4.31
1–<3 months	0.552	5.6	4.34
Birth–<3 months	0.525[e]	5.33[e]	4.33

[a]Considered a no-adverse-effect concentration for nitrate intake by infants up to 6 months of age, based on weight-of-evidence analysis of available human data.
[b]Estimated mean water intake (combined direct intake [ingested largely as a beverage] and indirect intake [added in preparation of food or beverages]) from community water; data from Table 3-14 of EPA (2008) and Table 2 of Kahn and Stralka (2009).
[c]Estimated mean body weight; data from Table 8-1 of EPA (2008).
[d]Nitrate dose = 44 mg nitrate/L (NOAEL) x water intake (L/day) / body weight (kg).
[e]Calculated TWA for birth–<1 month and 1–<3 months (e.g., TWA water intake for birth–<3 months = (0.470 L/day x 1 month) + (0.552 L/day x 2 months)/3 months = 0.525 L/day.

EPA = Environmental Protection Agency; NOAEL = no-observed-adverse-effect level; TWA = time-weighted average

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

Was a conversion used from intermittent to continuous exposure? Not applicable.

Other additional studies or pertinent information that lend support to this MRL: Methemoglobinemia is a condition in which increased methemoglobin as a percentage of total hemoglobin results in the expression of clinical signs that increase in severity with increasing percent methemoglobin (Agency for Toxic Substances and Disease Registry 2013; Bloom et al. 2013; Denshaw-Burke et al. 2013; Haymond et al. 2005). In normal healthy individuals, methemoglobin levels are <1% of total hemoglobin. Discoloration (e.g., pale, gray blue) of the skin is often observed at methemoglobin levels in the range of 3–15%; most patients tolerate methemoglobin levels <10%. Tachycardia, weakness, and other signs of tissue hypoxia may be observed at 10–20% methemoglobin levels. Effects on the central nervous system (e.g., headache, dizziness, fatigue) and dyspnea and nausea appear at >20% methemoglobin; the severity of symptoms increases with increasing methemoglobin level. High risk of mortality occurs at levels >70% methemoglobin.

Proposed explanations for increased susceptibility of infants to methemoglobinemia following ingestion of nitrate include: (1) increased reduction of nitrate to nitrite in the newborn, (2) increased tendency for nitrite-induced methemoglobin formation by fetal hemoglobin compared to adult hemoglobin, (3) lower levels of NADH-dependent methemoglobin reductase (the major enzyme responsible for reduction of methemoglobin to normal hemoglobin; also termed NADH-diaphorase, a soluble form of cytochrome-b5 reductase) in the newborn compared to older infants and adults, and (4) incompletely developed hepatic microsomal enzyme system in the infant and consequent lower rate of hepatic reduction of circulating nitrite compared to that of older children and adults. A portion of ingested nitrate is reduced to nitrite by commensal bacteria in the mouth; however, the acid environment of the normal stomach does not support the growth of such bacteria and most of the nitrate that reaches the stomach passes to the small intestine from which it is nearly completely absorbed into the blood. Although Kanady et al. (2012) reported little or no bacterial conversion of nitrate to nitrite in the saliva of a group of 10 infants during the first 2 postnatal months (considered mainly due to lower numbers of major nitrate-reducing oral bacteria than adults), a higher pH in the stomach of the newborn may favor growth of nitrate-reducing bacteria, resulting in increased reduction of nitrate to nitrite and increased plasma methemoglobin. Most hemoglobin in the newborn is in the form of fetal hemoglobin, which appears to be more readily oxidized to methemoglobin than adult hemoglobin; fetal hemoglobin is replaced by adult hemoglobin during early postnatal life. Levels of NADH-dependent methemoglobin reductase in the newborn increase approximately 2-fold during the first 4 months of postnatal life to reach adult levels. During the period of relatively lower methemoglobin reductase levels, methemoglobin would not be expected to be as readily reduced, resulting in increased susceptibility to methemoglobinemia. In apparent contrast, Ibrahim et al. (2012) reported that blood nitrite levels in newborns approximately 1–2 days of age were 35–55% lower than that of adults. However, one study that evaluated reduction rates of methemoglobin in human adult blood and cord blood from term newborns estimated methemoglobin half-lives of 162 and 210 minutes, respectively, indicating that methemoglobin reduction occurs more slowly in newborns than adults (Power et al. 2007). Although specific mechanisms have not been elucidated, the increased susceptibility to nitrite-induced methemoglobinemia in infants is well-documented.

Bosch et al. (1950) evaluated 139 reported cases of cyanosis among infants in Minnesota (90% were <2 months of age; range 8 days to 5 months). Samples from 129 wells that served as water sources to the cases revealed nitrate-nitrogen concentrations >100 mg/L (>440 mg nitrate/L) in 49 wells, 50–100 mg/L (220–440 mg nitrate/L) in 53 wells, 21–50 mg/L (92–220 mg nitrate/L) in 25 wells, and 10–20 mg/L (44–88 mg nitrate/L) in the other 2 wells. A major limitation of this study was the detection of coliform organisms in 45 of 51 well water samples tested for bacterial contamination.

A nested case-control study included 26 cases of infants diagnosed with methemoglobinemia at ≤2 months of age and 45 age-matched controls (Zeman et al. 2002). Nitrate exposure levels were categorized as low (<0.5 ppm), medium (1–10 ppm), or high (>10 ppm) according to estimated nitrate levels reconstructed from parental responses to dietary questionnaires and environmental sampling. Numbers of methemoglobinemia cases in the low, medium, and high exposure categories were 0/26, 4/26, and 22/26, respectively, and estimated dietary nitrate intake ranged from 2.83 to 451.20 mg/kg/day (mean 103.6 mg nitrate/kg/day). Diarrheal disease was reported for 14/26 methemoglobinemia cases. Numbers of controls in the low, medium, and high exposure categories were 21/45, 11/45, and 13/45, respectively, and estimated dietary nitrate intake ranged from 0 to 182 mg/kg/day (mean 11.2 mg nitrate/kg/day) for the controls; diarrheal disease was reported for 13/45 controls. Univariate and multifactorial analysis of risk factors for methemoglobinemia indicated that methemoglobinemia was most strongly associated with dietary exposure to nitrate/nitrite ($p=0.0318$), but also significantly associated with diarrheal disease ($p=0.0376$). Controls in the high exposure category were less likely than high exposure methemoglobinemia cases to have experienced severe diarrhea and were more likely to have been breastfed for >2 weeks. Major limitations to the study include the collection of information contributing

to the exposure estimates several years following the occurrences of methemoglobinemia and reliance on parental recollection of infant nutritional intake.

Results from other studies suggest an association between nitrate in drinking water sources and elevated methemoglobin among infants. Average methemoglobin levels of 1.0, 1.3, and 2.9% during the first postnatal trimester (0–3 months of age) were reported among groups healthy infants with water sources that were nitrate-free or contained 50–100 mg nitrate/L or >100 mg nitrate/L, respectively (Simon et al. 1964). At the end of the second trimester (6 months), methemoglobin averaged 0.7–0.8% for each group. Super et al. (1981) reported mean methemoglobin levels of 1.54% among infants ingesting ≤2.93 mg nitrate/kg/day and 3.03% among infants ingesting >2.93 mg nitrate/kg/day.

Limited data are available regarding administration of controlled amounts of nitrate and methemoglobin levels. Cornblath and Hartmann (1948) administered sodium nitrate in the formula fed to four infants (ages 11 days to 11 months) for 2–18 days at a concentration resulting in a dose of 50 mg nitrate/kg/day. The highest observed level of methemoglobin was 5.3% of total hemoglobin; there was no evidence of cyanosis. Among four other infants (ages 2 days to 6 months) similarly treated at 100 mg nitrate/kg/day for 6–9 days, the only reported effect was that of 7.5% methemoglobin in a 10-day-old infant following 8 days of treatment in the absence of clinical cyanosis. Gruener and Toeplitz (1975) fed 104 infants (1 week to 10 months of age) for 1 day with formula prepared using water containing 15 mg nitrate/L (~0.8–1.5 mg nitrate/kg, based on age-specific values for water consumption [Kahn and Stralka 2009] and body weight [EPA 2008]), increased to 108 mg nitrate/L for the next 3 days (~5.5–10.6 mg nitrate/kg/day, based on age-specific values for water consumption [Kahn and Stralka 2009] and body weight [EPA 2008], and returned to 15 mg nitrate/L for 1 additional day. Mean methemoglobin levels were 0.89% after the first day of feeding, 1.3, 0.91, and 0.93% after days 2, 3, and 4, and dropped to 0.8% on the fifth day. Among three of these infants (ages not specified), methemoglobin levels reached 6.9, 13.9, and 15.9% during the high-dose days. Limitations of this study include the use of a wide range of ages and the fact that only 57 of the 104 infants supplied blood samples on all 5 treatment days.

Agency Contacts (Chemical Managers): Carolyn Harper, Ph.D.

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

Chemical Name: Nitrite
CAS Numbers: 14797-65-0
Date: September 2015
Profile Status: Draft for Public Comment
Route: [ ] Inhalation [x] Oral
Duration: [x] Acute [x] Intermediate [x] Chronic
Graph Key: 4 (Acute), 16 (Intermediate), 50 (Chronic)
Species: Human

Minimal Risk Level: 0.1 [x] mg/kg/day [ ] ppm

Reference: Walton G. 1951. Survey of literature relating to infant methemoglobinemia due to nitrate-contaminated water. Am J Public Health 41:986-996.

Experimental design: Walton (1951) reviewed available literature and found 278 reported cases of infant methemoglobinemia in a total of 14 U.S. states from which information was available. Cases were grouped by state according to ranges of nitrate levels in drinking water sources.

Effect noted in study and corresponding doses: Among methemoglobinemia cases for which nitrate levels in water sources used to prepare infant formula were available, 173 cases were associated with >50 mg nitrate-nitrogen/L (220 mg nitrate/L), 36 cases with 21–50 mg nitrate-nitrogen/L (92–220 mg nitrate/L), and 5 cases with 11–20 mg nitrate-nitrogen (48–88 mg nitrate/L). None of the methemoglobinemia cases were associated with drinking water sources measuring <10 mg nitrate-nitrogen/L (<44 mg nitrate/L). Limitations of the contributing studies include lack of information regarding the actual ages of the infants, total nitrate doses, and other water source contaminants (e.g., bacterial levels).

Following ingestion of relatively large amounts of nitrate by healthy normal individuals, blood methemoglobin levels increase rapidly, followed by a return to normal within several hours following intake. Repeated ingestion of nitrate or nitrite for intermediate- or chronic-duration time periods would be expected to result in changes in methemoglobin levels similar to those elicited from a single exposure. Therefore, the acute-, intermediate-, and chronic-duration oral MRL values are equivalent.

Dose and end point used for MRL derivation: 0.2 mg nitrite/kg/day. The ingestion of nitrate results in the formation of nitrite, which is the moiety responsible for methemoglobinemia. On average, approximately 25% of an ingested dose of nitrate enters the saliva of an adult where a portion (ca. 20% g/g) is reduced by commensal bacteria to nitrite (i.e., approximately 5% g/g of ingested nitrate is reduced to nitrite in the saliva of an adult (Spiegelhalder et al. 1976); most salivary nitrite is absorbed into the blood in the small intestine. Therefore, the ingestion of 0.2 mg nitrite/kg/day by an adult would be expected to result in a nitrite blood level similar to that achieved following ingestion of 4 mg nitrate/kg/day, based on essentially 100% absorption of the ingested dose of nitrite (i.e., 0.2 mg nitrite/kg/day is 5% of an oral dose of nitrate at the oral MRL of 4 mg nitrate/kg/day).

[x] NOAEL [ ] LOAEL

Uncertainty Factors used in MRL derivation:

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

[x] 1 for human variability

A total uncertainty factor of 1 is justified because the point of departure is a NOAEL for nitrate-induced effects on methemoglobin in a particularly sensitive human subpopulation (i.e., <3-month-old infants, which in many cases may have been at increased risk of methemoglobinemia due to microbial contamination and associated gastrointestinal infection).

Modifying factor used in MRL derivation:

[x] 2 because young infants exhibit increased susceptibility to methemoglobinemia following nitrate ingestion; the modifying factor assumes that the effective methemoglobin level from a given intake of nitrate by an infant is up to twice that of an adult; however, quantitative data regarding conversion of nitrate to nitrite in the infant are lacking.

Was a conversion factor used from ppm in food or water to a mg/body weight dose? Nitrate may be expressed in terms of ionic concentration (i.e., mg nitrate/L), or elemental concentration (i.e., mg nitrate-nitrogen/L or mg nitrogen as nitrate/L). A concentration of nitrate expressed in elemental concentration (mg nitrogen per liter from nitrate source) can be converted to its ionic concentration (mg NO_3^-) according to the following relationship: 1 mg nitrate-nitrogen = 4.4 mg nitrate (i.e., the proportion of N in NO_3^- is 14 [atomic mass of N] ÷ 62 [molecular mass of NO_3^-] = 0.226).

A concentration of 44 mg nitrate/L (10 mg nitrate-nitrogen/L) in drinking water used to prepare infant formula represents a NOAEC for infants <3 months of age. Table A-1 presents estimated nitrate doses to infants (birth–<3 months of age) calculated using estimated mean values for drinking water ingestion rates (Kahn and Stralka 2009) and body weight (EPA 2008) and assuming a drinking water level of 44 mg nitrate/L as a concentration not expected to cause methemoglobinemia; the calculated doses of 4.31–4.34 mg nitrate/kg/day represent NOAELs for the age ranges. The TWA-based calculated dose of 4.33 mg nitrate/kg/day for the age range of birth–<3 months is selected as the point of departure for deriving acute-, intermediate-, and chronic-duration oral MRLs for nitrite.

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

Was a conversion used from intermittent to continuous exposure? Not applicable.

Other additional studies or pertinent information that lend support to this MRL: Methemoglobinemia is a condition in which increased methemoglobin as a percentage of total hemoglobin results in the expression of clinical signs that increase in severity with increasing percent methemoglobin (Agency for Toxic Substances and Disease Registry 2013; Bloom et al. 2013; Denshaw-Burke et al. 2013; Haymond et al. 2005). In normal healthy individuals, methemoglobin levels are <1% of total hemoglobin. Discoloration (e.g., pale, gray blue) of the skin is often observed at methemoglobin levels in the range of 3–15%; most patients tolerate methemoglobin levels <10%. Tachycardia, weakness, and other signs of tissue hypoxia may be observed at 10–20% methemoglobin levels. Effects on the central nervous system (e.g., headache, dizziness, fatigue) and dyspnea and nausea appear at >20% methemoglobin; the severity of symptoms increases with increasing methemoglobin level. High risk of mortality occurs at levels >70% methemoglobin.

Proposed explanations for increased susceptibility of infants to methemoglobinemia following ingestion of nitrate include: (1) increased reduction of nitrate to nitrite in the newborn, (2) increased tendency for nitrite-induced methemoglobin formation by fetal hemoglobin compared to adult hemoglobin, (3) lower levels of NADH-dependent methemoglobin reductase (the major enzyme responsible for reduction of

methemoglobin to normal hemoglobin; also termed NADH-diaphorase, a soluble form of cytochrome-b5 reductase) in the newborn compared to older infants and adults, and (4) incompletely developed hepatic microsomal enzyme system in the infant and consequent lower rate of hepatic reduction of circulating nitrite compared to that of older children and adults. A portion of ingested nitrate is reduced to nitrite by commensal bacteria in the mouth; however, the acid environment of the normal stomach does not support the growth of such bacteria and most of the nitrate that reaches the stomach passes to the small intestine from which it is nearly completely absorbed into the blood. Although Kanady et al. (2012) reported little or no bacterial conversion of nitrate to nitrite in the saliva of a group of 10 infants during the first 2 postnatal months (considered mainly due to lower numbers of major nitrate-reducing oral bacteria than adults), a higher pH in the stomach of the newborn may favor growth of nitrate-reducing bacteria, resulting in increased reduction of nitrate to nitrite and increased plasma methemoglobin. Most hemoglobin in the newborn is in the form of fetal hemoglobin, which appears to be more readily oxidized to methemoglobin than adult hemoglobin; fetal hemoglobin is replaced by adult hemoglobin during early postnatal life. Levels of NADH-dependent methemoglobin reductase in the newborn increase approximately 2-fold during the first 4 months of postnatal life to reach adult levels. During the period of relatively lower methemoglobin reductase levels, methemoglobin would not be expected to be as readily reduced, resulting in increased susceptibility to methemoglobinemia. In apparent contrast, Ibrahim et al. (2012) reported that blood nitrite levels in newborns approximately 1–2 days of age were 35–55% lower than that of adults. However, one study that evaluated reduction rates of methemoglobin in human adult blood and cord blood from term newborns estimated methemoglobin half-lives of 162 and 210 minutes, respectively, indicating that methemoglobin reduction occurs more slowly in newborns than adults (Power et al. 2007). Although specific mechanisms have not been elucidated, the increased susceptibility to nitrite-induced methemoglobinemia in infants is well-documented.

Bosch et al. (1950) evaluated 139 reported cases of cyanosis among infants in Minnesota (90% were <2 months of age; range 8 days to 5 months). Samples from 129 wells that served as water sources to the cases revealed nitrate-nitrogen concentrations >100 mg/L (>440 mg nitrate/L) in 49 wells, 50–100 mg/L (220–440 mg nitrate/L) in 53 wells, 21–50 mg/L (92–220 mg nitrate/L) in 25 wells, and 10–20 mg/L (44–88 mg nitrate/L) in the other 2 wells. A major limitation of this study was the detection of coliform organisms in 45 of 51 well water samples tested for bacterial contamination.

A nested case-control study included 26 cases of infants diagnosed with methemoglobinemia at ≤2 months of age and 45 age-matched controls (Zeman et al. 2002). Nitrate exposure levels were categorized as low (<0.5 ppm), medium (1–10 ppm), or high (>10 ppm) according to estimated nitrate levels reconstructed from parental responses to dietary questionnaires and environmental sampling. Numbers of methemoglobinemia cases in the low, medium, and high exposure categories were 0/26, 4/26, and 22/26, respectively, and estimated dietary nitrate intake ranged from 2.83 to 451.20 mg/kg/day (mean 103.6 mg nitrate/kg/day). Diarrheal disease was reported for 14/26 methemoglobinemia cases. Numbers of controls in the low, medium, and high exposure categories were 21/45, 11/45, and 13/45, respectively, and estimated dietary nitrate intake ranged from 0 to 182 mg/kg/day (mean 11.2 mg nitrate/kg/day) for the controls; diarrheal disease was reported for 13/45 controls. Univariate and multifactorial analysis of risk factors for methemoglobinemia indicated that methemoglobinemia was most strongly associated with dietary exposure to nitrate/nitrite ($p=0.0318$), but also significantly associated with diarrheal disease ($p=0.0376$). Controls in the high exposure category were less likely than high exposure methemoglobinemia cases to have experienced severe diarrhea and were more likely to have been breastfed for >2 weeks. Major limitations to the study include the collection of information contributing to the exposure estimates several years following the occurrences of methemoglobinemia and reliance on parental recollection of infant nutritional intake.

Results from other studies suggest an association between nitrate in drinking water sources and elevated methemoglobin among infants. Average methemoglobin levels of 1.0, 1.3, and 2.9% during the first

postnatal trimester (0–3 months of age) were reported among groups healthy infants with water sources that were nitrate-free or contained 50–100 mg nitrate/L or >100 mg nitrate/L, respectively (Simon et al. 1964). At the end of the second trimester (6 months), methemoglobin averaged 0.7–0.8% for each group. Super et al. (1981) reported mean methemoglobin levels of 1.54% among infants ingesting ≤2.93mg nitrate/kg/day and 3.03% among infants ingesting >2.93 mg nitrate/kg/day.

Limited data are available regarding administration of controlled amounts of nitrate and methemoglobin levels. Cornblath and Hartmann (1948) administered sodium nitrate in the formula fed to four infants (ages 11 days to 11 months) for 2–18 days at a concentration resulting in a dose of 50 mg nitrate/kg/day. The highest observed level of methemoglobin was 5.3% of total hemoglobin; there was no evidence of cyanosis. Among four other infants (ages 2 days to 6 months) similarly treated at 100 mg nitrate/kg/day for 6–9 days, the only reported effect was that of 7.5% methemoglobin in a 10-day-old infant following 8 days of treatment in the absence of clinical cyanosis. Gruener and Toeplitz (1975) fed 104 infants (1 week to 10 months of age) for 1 day with formula prepared using water containing 15 mg nitrate/L (~0.8–1.5 mg nitrate/kg, based on age-specific values for water consumption [Kahn and Stralka 2009] and body weight [EPA 2008]), increased to 108 mg nitrate/L for the next 3 days (~5.5–10.6 mg nitrate/kg/day, based on age-specific values for water consumption [Kahn and Stralka 2009] and body weight [EPA 2008], and returned to 15 mg nitrate/L for 1 additional day. Mean methemoglobin levels were 0.89% after the first day of feeding, 1.3, 0.91, and 0.93% after days 2, 3, and 4, and dropped to 0.8% on the fifth day. Among three of these infants (ages not specified), methemoglobin levels reached 6.9, 13.9, and 15.9% during the high-dose days. Limitations of this study include the use of a wide range of ages and the fact that only 57 of the 104 infants supplied blood samples on all 5 treatment days.

In a study designed to evaluate the oral bioavailability of sodium nitrite in healthy volunteers (seven females and two males; mean age 22.9 years), ingestion of ~2.2–2.7 mg sodium nitrite/kg (1.5–1.8 mg nitrite/kg) resulted in maximum methemoglobin concentrations ranging from 3.4 to 4.5% of total hemoglobin at approximately 0.70 hours following ingestion (Kortboyer et al. 1997b). At a higher intake (~4.4–5.4 mg sodium nitrite/kg, or 2.9–3.6 mg nitrite/kg), the maximum methemoglobin concentrations ranged from 7.7 to 10.9% of total hemoglobin at approximately 1.14 hours following ingestion.

Agency Contacts (Chemical Managers): Carolyn Harper, Ph.D.

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

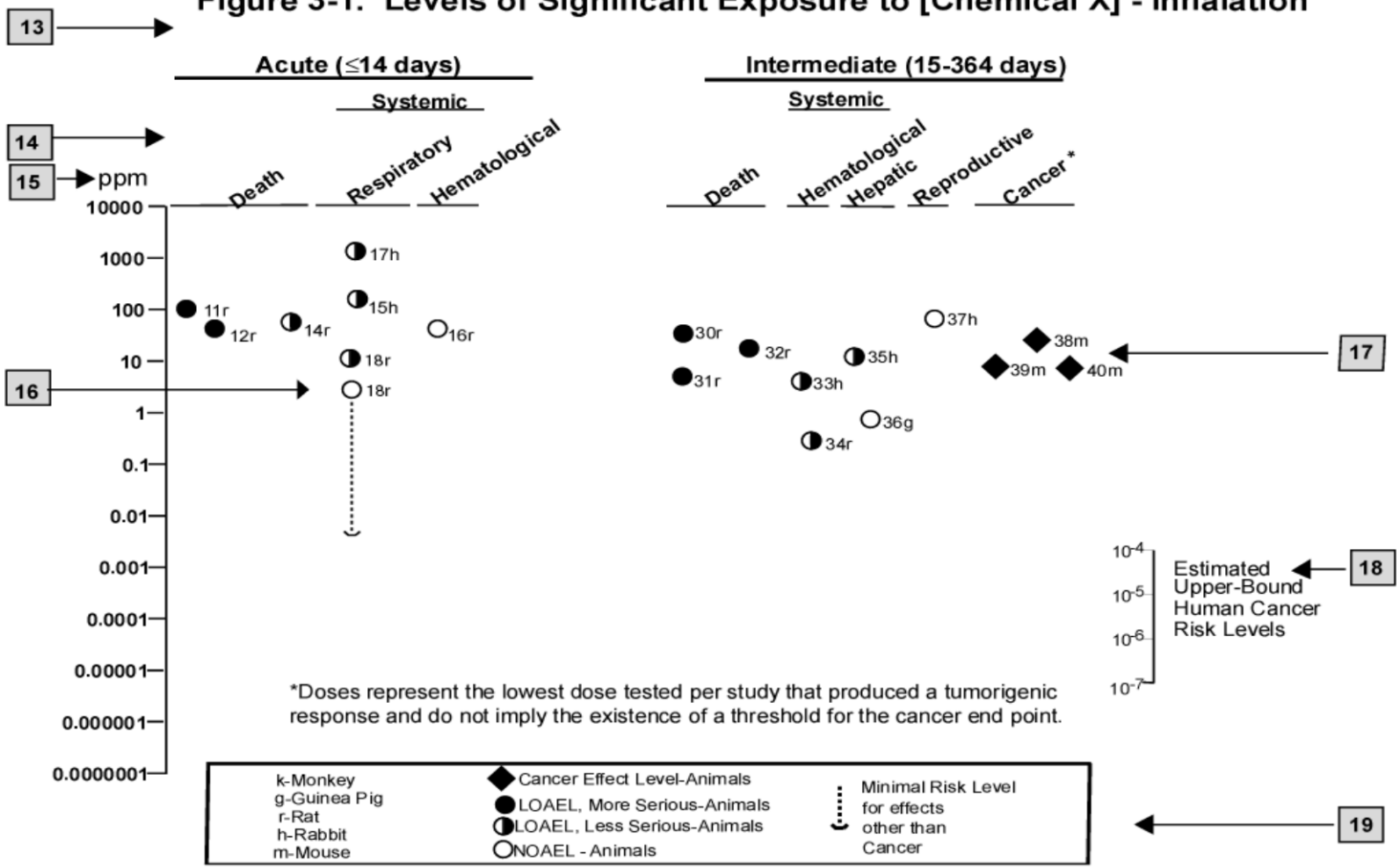
1 → **Table 3-1. Levels of Significant Exposure to [Chemical x] – Inhalation**

	Key to figure[a]	Species	Exposure frequency/ duration	System	NOAEL (ppm)	LOAEL (effect) Less serious (ppm)	LOAEL (effect) 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 5×10^{-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/C	benchmark dose or benchmark concentration
BMD_X	dose that produces a X% change in response rate of an adverse effect
$BMDL_X$	95% lower confidence limit on the BMD_X
BMDS	Benchmark Dose Software
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/IMDG	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