APPENDIX A. ATSDR MINIMAL RISK LEVEL WORKSHEETS

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 route and duration of exposure. MRLs are based on noncancer health effects only; cancer effects are not considered. 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 NOAEL/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) 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 substance-induced endpoint considered to be of relevance to humans. LOAELs for serious health effects (such as irreparable damage to the liver or kidneys, or serious 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.

APPENDIX A

Proposed MRLs undergo a rigorous review process: Health Effects/MRL Workgroup reviews within the Office of Innovation and Analytics, Toxicology Section, 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 MRLs. For additional information regarding MRLs, please contact the Office of Innovation and Analytics, Toxicology Section, Agency for Toxic Substances and Disease Registry, 1600 Clifton Road NE, Mailstop S106-5, Atlanta, Georgia 30329-4027.

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

***Chemical Name*:** Thallium compounds
CAS Numbers: Various CAS numbers
Date: October 2024
Profile Status: Draft for Public Comment
Route: Inhalation
Duration: Acute

MRL Summary: An acute-duration inhalation MRL was not derived for thallium due to the lack of acute-duration inhalation studies.

Rationale for Not Deriving an MRL: No acute-duration inhalation studies were identified for thallium.

Agency Contact (Chemical Manager): Fahim Atif

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

***Chemical Name*:** Thallium compounds
CAS Numbers: Various CAS numbers
Date: October 2024
Profile Status: Draft for Public Comment
Route: Inhalation
Duration: Intermediate

MRL Summary: An intermediate-duration inhalation MRL was not derived for thallium due to the lack of intermediate-duration inhalation studies.

Rationale for Not Deriving an MRL: No intermediate-duration inhalation studies were identified for thallium.

Agency Contact (Chemical Manager): Fahim Atif

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

***Chemical Name*:** Thallium compounds
CAS Numbers: Various CAS numbers
Date: October 2024
Profile Status: Draft for Public Comment
Route: Inhalation
Duration: Chronic

MRL Summary: A chronic-duration inhalation MRL was not derived for thallium due to the limitations in the small number of chronic-duration exposure studies.

Rationale for Not Deriving an MRL: Several studies have evaluated the toxicity of airborne thallium in humans (Ludolph et al. 1986; Marcus 1985; Peng et al. 2022; Qiu et al. 2022). A study in workers reported paresthesia (Ludolph et al. 1986); another study found no cardiovascular effects and a lower incidence of gastrointestinal effects (Marcus 1985). In studies examining the relationship between the thallium content of $PM_{2.5}$ and adverse health effects, alterations in parameters of renal function (Peng et al. 2022) or no effect on thyroid hormone levels (Qiu et al. 2022) were reported. None of the available studies evaluated a wide range of potential health effects and poorly characterized exposure characteristics. Therefore, studies were not considered suitable for MRL derivation. No chronic-duration inhalation studies in animals were identified for thallium.

Agency Contact (Chemical Manager): Fahim Atif

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

***Chemical Name*:** Thallium compounds
CAS Numbers: Various CAS numbers
Date: October 2024
Profile Status: Draft for Public Comment
Route: Oral
Duration: Acute

MRL Summary: The available database was considered inadequate for derivation of an acute-duration oral MRL for thallium. Studies on the acute oral toxicity of thallium in humans are limited to case reports, most of which did not report doses. A small number of limited-scope acute oral studies in animals have been identified; however, these studies do not allow for identification of sensitive targets of toxicity and the lowest dose tested resulted in increases in mortality.

Rationale for Not Deriving an MRL: Information on the toxicity of thallium following acute oral exposure comes from numerous case reports of intentional or accidental poisonings and a small number of animal studies. Although a wide variety of effects have been reported in individuals acutely ingesting thallium, the most consistently reported effects are cardiovascular (e.g., tachycardia, hypertension, EKG alterations), gastrointestinal (e.g., abdominal pain, nausea/vomiting, constipation), dermal (e.g., alopecia), and neurological (peripheral neuropathy resulting in paresthesia, hyperalgesia, and weakness) effects. In a small number of case reports, dose information was provided; however, case reports are not considered suitable for derivation of an MRL because they typically only involve one person and there is no control group.

A small number of studies in animals have evaluated the acute oral toxicity. Increases in lethality were observed in rats at ≥15 mg thallium/kg following a single-dose exposure (Downs et al. 1960; Leloux et al. 1987) and at 0.77 mg thallium/kg/day following a 4-day exposure (Leloux et al. 1987). In mice and rabbits, deaths were observed at 2.5 and 61 mg thallium/kg, respectively (Grunfeld et al. 1963; Rao et al. 1993). Other observed effects include body weight decreases, diarrhea, alopecia, and decreases in spontaneous activity. Effects observed at doses that did not cause deaths in the study are summarized in Table A-1. In addition to the effects listed in Table A-1, there is some evidence of neurodevelopmental and hepatic effects. Bornhausen and Hagen (1984) reported impaired performance on an operant behavior test in the offspring of rat dams administered thallium I sulfate on GDs 6–9. However, poor reporting of the methods and results precludes an independent evaluation of the study. Li et al. (2022a) reported hepatic sinus congestion and necrosis in mice exposed to thallium I nitrate (1.2 mg thallium/kg/day) or thallium III nitrate (0.7 mg thallium/kg/day) for 2 weeks; however, no incidence data were provided to evaluate whether the incidence was significantly different from controls. The study also reported alterations in the levels of hepatic fatty acids in mice exposed to 1.2 mg thallium/kg/day as thallium I nitrate or to 0.7 mg thallium/kg/day as thallium III nitrate (Li et al. 2022a). However, the toxicological significance of these alterations is not known.

Table A-1. Summary of NOAEL and LOAEL Values in Animals Following Acute Oral Exposure to Thallium

Species, duration	Effect	Compound	NOAEL (mg Tl/kg/day)	LOAEL (mg Tl/kg/day)	Reference
Mouse, 2 weeks	Decreased terminal body weight (11–16%)	Thallium I sulfate	0.4 (M) 0.7 (F)	0.9 (M) 1.5 (F)	Shipkowski et al. 2023

Table A-1. Summary of NOAEL and LOAEL Values in Animals Following Acute Oral Exposure to Thallium

Species, duration	Effect	Compound	NOAEL (mg Tl/kg/day)	LOAEL (mg Tl/kg/day)	Reference
Mouse, 1 week	Decreased terminal body weight (21%)	Thallium I nitrate		8 (serious LOAEL)	Li et al. 2023a
Mouse, 1 week	Decreased relative thymus weight, decreased B cell frequency in bone marrow, blood, and spleen	Thallium I nitrate		8	Li et al. 2023a
Rat, 1 day	Diarrhea	Thallium I sulfate		18.2	Rusyniak et al. 2003
Rat, 1 day	Alopecia	Thallium I sulfate		18.2	Rusyniak et al. 2003
Rat, 1 day	Decreased spontaneous activity	Thallium I sulfate		18.2	Rusyniak et al. 2003

LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect level

None of the available studies identified a reliable LOAEL that was lower than the lowest dose associated with lethality (0.77 mg thallium/kg/day as thallium I nitrate). Thus, an acute-duration oral MRL is not derived.

Agency Contact (Chemical Manager): Fahim Atif

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

***Chemical Name*:** Thallium compounds
CAS Numbers: Various CAS numbers
Date: October 2024
Profile Status: Draft for Public Comment
Route: Oral
Duration: Intermediate

MRL Summary: The database was not considered adequate for derivation of an intermediate-duration oral MRL for thallium due to uncertainty of whether the alopecia observed at the lowest LOAEL was related to thallium exposure.

Rationale for Not Deriving an MRL: No human studies have evaluated the toxicity of thallium following intermediate-duration oral exposure; nine animal studies have been identified, the results of these studies are summarized in Table A-2. Alopecia is the most consistently reported effect reported in intermediate-duration oral studies. Alopecia is also commonly reported in humans acutely exposed to thallium and typically occurs 1–3 weeks after exposure.

Table A-2. Summary of NOAEL and LOAEL Values in Animals Following Intermediate Oral Exposure to Thallium

Species, duration	Effect	Compound	NOAEL (mg Tl/kg/day)	LOAEL (mg Tl/kg/day)	Reference
Rat, 90 days	Alopecia	Thallium I sulfate		0.2[a]	EPA 1986
Rat, 9–15 weeks	Alopecia	Thallium I acetate	0.4	1.1	Downs et al. 1960
Rat, 30 or 60 days	Irritability	Thallium I sulfate		1.2	Gregotti et al. 1985
Rat, 60 days	Decreased sperm motility	Thallium I sulfate		1.3	Formigli et al. 1986
Rat, 36 weeks	Alopecia	Thallium I sulfate		1.5[b]	Manzo et al. 1983
Rat, 36 weeks	Decreased motor and sensory action potentials	Thallium I sulfate		1.5[b]	Manzo et al. 1983
Rat, 9–15 weeks	Alopecia	Thallium I oxide		1.6	Downs et al. 1960
Rat, 21 weeks	Alopecia	Thallium I acetate		2[b]	Gross et al. 1948
Rat, GD 6–PND 28	Alopecia in dams and pups	Thallium I sulfate	1	2.2	Shipkowski et al. 2023

Table A-2. Summary of NOAEL and LOAEL Values in Animals Following Intermediate Oral Exposure to Thallium

Species, duration	Effect	Compound	NOAEL (mg Tl/kg/day)	LOAEL (mg Tl/kg/day)	Reference
Rat, GD 6–PND 28	Decreased pup body weight	Thallium I sulfate	1	2.2	Shipkowski et al. 2023

[a]There is uncertainty whether this dose is a LOAEL, see text for additional information.
[b]Increased mortality was also observed at this dose level.

GD = gestation day; LOAEL = lowest-observed-adverse-effect level; NOAEL = no-observed-adverse-effect level; PND = postnatal day

The lowest dose associated with an adverse effect is 0.20 mg thallium/kg/day reported in the EPA (1986) rat study. The incidence of alopecia in this study (as presented in EPA 2009a) was observed in 2/20, 1/20, 4/20, 9/20, and 4/20 male rats and 4/20, 1/20, 4/20, 9/20, and 12/20 female rats in the untreated controls, vehicle controls, and 0.008, 0.04, and 0.20 mg thallium/kg/day groups, respectively. However, some of the alopecia was attributed to barbering behavior (defined as abnormal whisker or fur plucking behavior). In the 0.20 mg thallium/kg/day female rats, five instances of alopecia were not attributed to barbering behavior; this incidence is significantly higher than controls. Atrophy of hair follicles was also observed in two of the females in the 0.20 mg thallium/kg/day group with alopecia; this effect was not observed in the males at this dose level or in the male or female vehicle controls. The study investigators did not consider the alopecia to be toxicologically significant and attributed it to the cyclic pattern of hair growth in rats. Although there is some uncertainty, ATSDR considered alopecia to be a thallium-related and adverse effect. This consideration is supported by the findings of alopecia in several other intermediate-duration animal studies (Downs et al. 1960; Manzo et al. 1983; Shipkowski et al. 2023) and in humans acutely exposed to thallium (for example, Al Hammouri et al. 2011; Almassri and Sekkarie 2018; Desenclos et al. 1992; Sun et al. 2012; Villanueva et al. 1990; Wang et al. 2007; Zavaliy et al. 2021; Zhang et al. 2014). However, the uncertainty of the interpretation of the EPA (1986) findings precludes identifying a LOAEL and using the study as the basis of an intermediate-duration oral MRL. The Downs et al. (1960) study of thallium I acetate was not considered suitable for MRL derivation due to the high mortality in the control group (two of five males and two of five females died after 12 and 8 weeks of exposure, respectively) and the uncertainty in whether basing an MRL of a NOAEL of 0.4 mg thallium/kg/day would be protective for alopecia given the possible LOAEL of 0.2 mg thallium/kg/day identified in the EPA (1986) study.

Agency Contact (Chemical Manager): Fahim Atif

APPENDIX A

MINIMAL RISK LEVEL (MRL) WORKSHEET

***Chemical Name*:** Thallium compounds
CAS Numbers: Various CAS numbers
Date: October 2024
Profile Status: Draft for Public Comment
Route: Oral
Duration: Chronic

MRL Summary: The database was considered inadequate for derivation of a chronic-duration oral MRL for thallium. Although a number of epidemiological studies have been identified, they were not considered suitable for MRL derivation due to inconsistent or unsupported findings and lack of a pharmacokinetic model to convert urinary (or blood) thallium levels to intakes.

Rationale for Not Deriving an MRL: A number of epidemiological studies have evaluated possible associations between thallium exposure and adverse effects; the majority of the studies were cross-sectional in design and were conducted in the general population with no known source of elevated thallium exposure. Interpretation of the results of these studies is limited by the lack of consistent findings. In addition, many outcomes were only examined in one or two studies. Another limitation of the epidemiological studies is that none of the studies reported external doses; exposure was assessed using biomarkers of exposure, typically urinary thallium levels or blood thallium levels, or did not provide exposure information. However, pharmacokinetic models relating urinary or blood thallium levels to thallium intake have not been identified. The lack of consistent or supported findings and the lack of pharmacokinetic models to estimate doses preclude using the epidemiological studies as the basis of an MRL. No chronic-duration oral animal studies were identified.

Agency Contact (Chemical Manager): Fahim Atif

APPENDIX B. LITERATURE SEARCH FRAMEWORK FOR THALLIUM

The objective of the toxicological profile is to evaluate the potential for human exposure and the potential health hazards associated with inhalation, oral, or dermal/ocular exposure to thallium.

B.1 LITERATURE SEARCH AND SCREEN

A literature search and screen were conducted to identify studies examining health effects, toxicokinetics, mechanisms of action, susceptible populations, biomarkers, chemical interactions, physical and chemical properties, production, use, environmental fate, environmental releases, and environmental and biological monitoring data for thallium. ATSDR primarily focused on peer-reviewed articles without publication date or language restrictions. Foreign language studies are reviewed based on available English-language abstracts and/or tables (or summaries in regulatory assessments, such as International Agency for Research on Cancer [IARC] documents). If the study appears critical for hazard identification or MRL derivation, translation into English is requested. Non-peer-reviewed studies that were considered relevant to the assessment of the health effects of thallium have undergone peer review by at least three ATSDR-selected experts who have been screened for conflict of interest. The inclusion criteria used to identify relevant studies examining the health effects of thallium are presented in Table B-1.

Table B-1. Inclusion Criteria for the Literature Search and Screen

Health Effects
Species
Human
Laboratory mammals
Route of exposure
Inhalation
Oral
Dermal (or ocular)
Parenteral (these studies will be considered supporting data)
Health outcome
Death
Systemic effects
Body weight effects
Respiratory effects
Cardiovascular effects
Gastrointestinal effects
Hematological effects
Musculoskeletal effects
Hepatic effects
Renal effects
Dermal effects
Ocular effects
Endocrine effects
Immunological effects
Neurological effects
Reproductive effects

Table B-1. Inclusion Criteria for the Literature Search and Screen

Developmental effects
Other noncancer effects
Cancer
Toxicokinetics
Absorption
Distribution
Metabolism
Excretion
PBPK models
Biomarkers
Biomarkers of exposure
Biomarkers of effect
Interactions with other chemicals
Potential for human exposure
Releases to the environment
Air
Water
Soil
Environmental fate
Transport and partitioning
Transformation and degradation
Environmental monitoring
Air
Water
Sediment and soil
Other media
Biomonitoring
General populations
Occupation populations

B.1.1 Literature Search

The current literature search was intended to update the 1992 toxicological profile for thallium; thus, the literature search was restricted to studies published between January 1990 and July 2023. The following main databases were searched in July 2023:

- PubMed
- National Technical Reports Library (NTRL)
- Scientific and Technical Information Network's TOXCENTER

The search strategy used the chemical names, Chemical Abstracts Service (CAS) numbers, synonyms, Medical Subject Headings (MeSH) headings, and keywords for thallium. The query strings used for the literature search are presented in Table B-2.

The search was augmented by searching the Toxic Substances Control Act Test Submissions (TSCATS), NTP website, and National Institute of Health Research Portfolio Online Reporting Tools Expenditures and Results (NIH RePORTER) databases using the queries presented in Table B-3. Additional databases were searched in the creation of various tables and figures, such as the TRI Explorer, the Substance Priority List (SPL) resource page, and other items as needed. Regulations applicable to thallium were identified by searching international and U.S. agency websites and documents.

Review articles were identified and used for the purpose of providing background information and identifying additional references. ATSDR also identified reports from the grey literature, which included unpublished research reports, technical reports from government agencies, conference proceedings and abstracts, and theses and dissertations.

Table B-2. Database Query Strings

Database search date	Query string
PubMed	
07/2023	((("Thallium/toxicity"[mh] OR "Thallium/adverse effects"[mh] OR "Thallium/poisoning"[mh] OR "Thallium/pharmacokinetics"[mh]) OR ("Thallium"[mh] AND ("environmental exposure"[mh] OR ci[sh])) OR ("Thallium"[mh] AND toxicokinetics[mh:noexp]) OR ("Thallium/blood"[mh] OR "Thallium/cerebrospinal fluid"[mh] OR "Thallium/urine"[mh]) OR ("Thallium"[mh] AND ("endocrine system"[mh] OR "hormones, hormone substitutes, and hormone antagonists"[mh] OR "endocrine disruptors"[mh])) OR ("Thallium"[mh] AND ("computational biology"[mh] OR "medical informatics"[mh] OR genomics[mh] OR genome[mh] OR proteomics[mh] OR proteome[mh] OR metabolomics[mh] OR metabolome[mh] OR genes[mh] OR "gene expression"[mh] OR phenotype[mh] OR genetics[mh] OR genotype[mh] OR transcriptome[mh] OR ("systems biology"[mh] AND ("environmental exposure"[mh] OR "epidemiological monitoring"[mh] OR analysis[sh])) OR "transcription, genetic "[mh] OR "reverse transcription"[mh] OR "transcriptional activation"[mh] OR "transcription factors"[mh] OR ("biosynthesis"[sh] AND (RNA[mh] OR DNA[mh])) OR "RNA, messenger"[mh] OR "RNA, transfer"[mh] OR "peptide biosynthesis"[mh] OR "protein biosynthesis"[mh] OR "reverse transcriptase polymerase chain reaction"[mh] OR "base sequence"[mh] OR "trans-activators"[mh] OR "gene expression profiling"[mh])) OR ("Thallium/antagonists and inhibitors"[mh]) OR ("Thallium/metabolism"[mh] AND ("humans"[mh] OR "animals"[mh])) OR ("Thallium/pharmacology"[majr])) OR ("Thallium"[mh] AND ("Neoplasms"[mh] OR "Carcinogens"[mh] OR "Lymphoproliferative disorders"[mh] OR "Myeloproliferative disorders"[mh] OR "Toxicity Tests"[mh] OR ((cancer*[tiab] OR carcinogen*[tiab]) AND (risk*[tiab] OR health[tiab]) AND assessment*[tiab]) OR "Mutagens"[mh] OR "Mutagenicity Tests"[mh] OR "Chromosome Aberrations"[mh] OR "DNA Damage"[mh] OR "DNA Repair"[mh] OR "DNA Replication/drug effects"[mh] OR "DNA/drug effects"[mh] OR "DNA/metabolism"[mh] OR "Genomic Instability"[mh] OR "Salmonella typhimurium/drug effects"[mh] OR "Salmonella typhimurium/genetics"[mh] OR "Sister Chromatid Exchange"[mh] OR strand-break*[tiab])) OR "thallium acetate"[nm] OR ("Bithallium trisulfate"[tw] OR "Dithallium oxide"[tw] OR "dithallium trioxide"[tw] OR "Dithallium tris(sulphate)"[tw] OR "Dithalloxane-1,3-dione"[tw] OR "KRS-5"[tw] OR "Nitric acid, thallium salt"[tw] OR "Nitric acid, thallium(3+) salt"[tw] OR "Sulfuric acid, thallium(2+) salt"[tw] OR "Sulfuric acid, thallium(3+) salt"[tw] OR "Thallic nitrate"[tw] OR "Thallic oxide"[tw] OR "Thallic sulfate"[tw] OR "thallium bromide"[tw] OR "Thallium fluoride"[tw] OR "Thallium iodide"[tw] OR "Thallium monobromide"[tw] OR "Thallium monofluoride"[tw] OR "thallium monoiodide"[tw] OR "Thallium oxide"[tw] OR "Thallium peroxide"[tw] OR "Thallium sesquioxide"[tw] OR "Thallium tribromide"[tw] OR "Thallium trichloride"[tw] OR "Thallium trifluoride"[tw] OR "Thallium triiodide"[tw] OR "Thallium trinitrate"[tw] OR "Thallium

Table B-2. Database Query Strings

Database search date	Query string
	trioxide"[tw] OR "Thallium(1+) bromide"[tw] OR "Thallium(1+) iodide"[tw] OR "Thallium(1+) lambda 1 -thallanolate"[tw] OR "Thallium(1+) oxide"[tw] OR "Thallium(1+) thallium(3+) sulfate"[tw] OR "Thallium(3+) oxide"[tw] OR "Thallium(3+) sulfate"[tw] OR "Thallium(3+) tribromide"[tw] OR "Thallium(3+) trichloride"[tw] OR "Thallium(3+) trifluoride"[tw] OR "Thallium(3+) triiodide"[tw] OR "Thallium(3+) trinitrate"[tw] OR "Thallium(I) bromide"[tw] OR "Thallium(I) fluoride"[tw] OR "Thallium(I) iodide"[tw] OR "Thallium(I) oxide"[tw] OR "Thallium(II) sulfate"[tw] OR "Thallium(III) bromide"[tw] OR "Thallium(III) chloride"[tw] OR "Thallium(III) iodide"[tw] OR "Thallium(III) oxide"[tw] OR "Thallium(III) sulfate"[tw] OR "Thallous bromide"[tw] OR "Thallous fluoride"[tw] OR "Thallous iodide"[tw] OR "Thallous oxide"[tw]) OR (("thallium"[tw] OR "dithallium"[tw] OR "thallic"[tw] OR "thallous"[tw] OR "Bithallium trisulfate"[tw] OR "Bonide antzix"[tw] OR "Carbonic acid, dithallium(1+) salt"[tw] OR "Dithalloxane-1,3-dione"[tw] OR "Eccothal"[tw] OR "KRS-5"[tw] OR "Ramor"[tw] OR "Ratox"[tw] OR "Tharattin"[tw] OR "Th-Universal"[tw] OR "Triacetatothallium(III)"[tw] OR "Tris(acetato)thallium"[tw] OR "Zelio"[tw] OR "thallium208"[tw] OR "208thallium"[tw] OR "tl-208"[tw] OR "tl208"[tw] OR "208tl"[tw] OR "208-tl"[tw] OR "thallium201"[tw] OR "201thallium"[tw] OR "tl-201"[tw] OR "tl201"[tw] OR "201tl"[tw] OR "201-tl"[tw] OR "thallium199"[tw] OR "199thallium"[tw] OR "tl-199"[tw] OR "tl199"[tw] OR "199tl"[tw] OR "199-tl"[tw] OR "thallium200"[tw] OR "200thallium"[tw] OR "tl-200"[tw] OR "tl200"[tw] OR "200tl"[tw] OR "200-tl"[tw] OR "thallium202"[tw] OR "202thallium"[tw] OR "tl-202"[tw] OR "tl202"[tw] OR "202tl"[tw] OR "202-tl"[tw] OR "thallium204"[tw] OR "204thallium"[tw] OR "tl-204"[tw] OR "tl204"[tw] OR "204tl"[tw] OR "204-tl"[tw] OR "thallium210"[tw] OR "210thallium"[tw] OR "tl-210"[tw] OR "tl210"[tw] OR "210tl"[tw] OR "210-tl"[tw]) NOT medline[sb]) OR ("Thallium Radioisotopes/toxicity"[mh] OR "Thallium Radioisotopes/adverse effects"[mh] OR "Thallium Radioisotopes/poisoning"[mh] OR "Thallium Radioisotopes/pharmacokinetics"[mh]) OR ("Thallium Radioisotopes"[mh] AND ("environmental exposure"[mh] OR ci[sh])) OR ("Thallium Radioisotopes"[mh] AND toxicokinetics[mh:noexp]) OR ("Thallium Radioisotopes/blood"[mh] OR "Thallium Radioisotopes/cerebrospinal fluid"[mh] OR "Thallium Radioisotopes/urine"[mh]) OR ("Thallium Radioisotopes"[mh] AND ("endocrine system"[mh] OR "hormones, hormone substitutes, and hormone antagonists"[mh] OR "endocrine disruptors"[mh])) OR ("Thallium Radioisotopes"[mh] AND ("computational biology"[mh] OR "medical informatics"[mh] OR genomics[mh] OR genome[mh] OR proteomics[mh] OR proteome[mh] OR metabolomics[mh] OR metabolome[mh] OR genes[mh] OR "gene expression"[mh] OR phenotype[mh] OR genetics[mh] OR genotype[mh] OR transcriptome[mh] OR ("systems biology"[mh] AND ("environmental exposure"[mh] OR "epidemiological monitoring"[mh] OR analysis[sh])) OR "transcription, genetic "[mh] OR "reverse transcription"[mh] OR "transcriptional activation"[mh] OR "transcription factors"[mh] OR ("biosynthesis"[sh] AND (RNA[mh] OR DNA[mh])) OR "RNA, messenger"[mh] OR "RNA, transfer"[mh] OR "peptide biosynthesis"[mh] OR "protein biosynthesis"[mh] OR "reverse transcriptase polymerase chain reaction"[mh] OR "base sequence"[mh] OR "trans-activators"[mh] OR "gene expression profiling"[mh])) OR ("Thallium Radioisotopes/antagonists and inhibitors"[mh]) OR ("Thallium Radioisotopes/metabolism"[mh] AND ("humans"[mh] OR "animals"[mh])) OR ("Thallium Radioisotopes/pharmacology"[majr]) OR ("Thallium Radioisotopes"[mh] AND ("Neoplasms"[mh] OR "Carcinogens"[mh] OR "Lymphoproliferative disorders"[mh] OR "Myeloproliferative disorders"[mh] OR "Toxicity Tests"[mh] OR ((cancer*[tiab] OR carcinogen*[tiab]) AND (risk*[tiab] OR health[tiab]) AND assessment*[tiab]) OR "Mutagens"[mh] OR "Mutagenicity Tests"[mh] OR "Chromosome Aberrations"[mh] OR "DNA Damage"[mh] OR "DNA Repair"[mh] OR "DNA Replication/drug effects"[mh] OR "DNA/drug effects"[mh] OR "DNA/metabolism"[mh] OR "Genomic Instability"[mh] OR "Salmonella typhimurium/drug effects"[mh] OR "Salmonella typhimurium/genetics"[mh] OR

Table B-2. Database Query Strings

Database search date	Query string
	"Sister Chromatid Exchange"[mh] OR strand-break*[tiab])) OR (("Thallium"[mh] OR "Thallium Radioisotopes"[mh]) AND (indexingmethod_automated OR indexingmethod_curated) AND ("RNA"[mh] OR "DNA"[mh] OR "DNA Replication"[mh] OR "Salmonella typhimurium"[mh] OR antagonist*[tw] OR inhibitor*[tw] OR "blood"[tw] OR "serum"[tw] OR pharmacokinetic*[tw] OR toxicokinetic*[tw] OR "pbpk"[tw] OR "poisoned"[tw] OR "poisoning"[tw] OR "urine"[tw] OR "urinary"[tw] OR "toxicity"[sh] OR "occupational diseases"[mh] OR "hazardous substances"[mh] OR "epidemiology"[sh] OR "epidemiologic studies"[mh]))) AND (2020/10/01:3000[mhda] OR 2020/10/01:3000[edat] OR 2020/10/01:3000[crdat])
11/2020	(((((("Thallium/toxicity"[mh] OR "Thallium/adverse effects"[mh] OR "Thallium/poisoning"[mh] OR "Thallium/pharmacokinetics"[mh]) OR ("Thallium"[mh] AND ("environmental exposure"[mh] OR ci[sh])) OR ("Thallium"[mh] AND toxicokinetics[mh:noexp]) OR ("Thallium/blood"[mh] OR "Thallium/cerebrospinal fluid"[mh] OR "Thallium/urine"[mh]) OR ("Thallium"[mh] AND ("endocrine system"[mh] OR "hormones, hormone substitutes, and hormone antagonists"[mh] OR "endocrine disruptors"[mh])) OR ("Thallium"[mh] AND ("computational biology"[mh] OR "medical informatics"[mh] OR genomics[mh] OR genome[mh] OR proteomics[mh] OR proteome[mh] OR metabolomics[mh] OR metabolome[mh] OR genes[mh] OR "gene expression"[mh] OR phenotype[mh] OR genetics[mh] OR genotype[mh] OR transcriptome[mh] OR ("systems biology"[mh] AND ("environmental exposure"[mh] OR "epidemiological monitoring"[mh] OR analysis[sh])) OR "transcription, genetic "[mh] OR "reverse transcription"[mh] OR "transcriptional activation"[mh] OR "transcription factors"[mh] OR ("biosynthesis"[sh] AND (RNA[mh] OR DNA[mh])) OR "RNA, messenger"[mh] OR "RNA, transfer"[mh] OR "peptide biosynthesis"[mh] OR "protein biosynthesis"[mh] OR "reverse transcriptase polymerase chain reaction"[mh] OR "base sequence"[mh] OR "trans-activators"[mh] OR "gene expression profiling"[mh])) OR ("Thallium/antagonists and inhibitors"[mh]) OR ("Thallium/metabolism"[mh] AND ("humans"[mh] OR "animals"[mh])) OR ("Thallium"[mh] AND cancer[sb]) OR ("Thallium/pharmacology"[majr]))) OR ("thallium acetate"[nm]) OR (("Bithallium trisulfate"[tw] OR "Dithallium oxide"[tw] OR "dithallium trioxide"[tw] OR "Dithallium tris(sulphate)"[tw] OR "Dithalloxane-1,3-dione"[tw] OR "KRS-5"[tw] OR "Nitric acid, thallium salt"[tw] OR "Nitric acid, thallium(3+) salt"[tw] OR "Sulfuric acid, thallium(2+) salt"[tw] OR "Sulfuric acid, thallium(3+) salt"[tw] OR "Thallic nitrate"[tw] OR "Thallic oxide"[tw] OR "Thallic sulfate"[tw] OR "thallium bromide"[tw] OR "Thallium fluoride"[tw] OR "Thallium iodide"[tw] OR "Thallium monobromide"[tw] OR "Thallium monofluoride"[tw] OR "thallium monoiodide"[tw] OR "Thallium oxide"[tw] OR "Thallium peroxide"[tw] OR "Thallium sesquioxide"[tw] OR "Thallium tribromide"[tw] OR "Thallium trichloride"[tw] OR "Thallium trifluoride"[tw] OR "Thallium triiodide"[tw] OR "Thallium trinitrate"[tw] OR "Thallium trioxide"[tw] OR "Thallium(1+) bromide"[tw] OR "Thallium(1+) iodide"[tw] OR "Thallium(1+) lambda 1 -thallanolate"[tw] OR "Thallium(1+) oxide"[tw] OR "Thallium(1+) thallium(3+) sulfate"[tw] OR "Thallium(3+) oxide"[tw] OR "Thallium(3+) sulfate"[tw] OR "Thallium(3+) tribromide"[tw] OR "Thallium(3+) trichloride"[tw] OR "Thallium(3+) trifluoride"[tw] OR "Thallium(3+) triiodide"[tw] OR "Thallium(3+) trinitrate"[tw] OR "Thallium(I) bromide"[tw] OR "Thallium(I) fluoride"[tw] OR "Thallium(I) iodide"[tw] OR "Thallium(I) oxide"[tw] OR "Thallium(II) sulfate"[tw] OR "Thallium(III) bromide"[tw] OR "Thallium(III) chloride"[tw] OR "Thallium(III) iodide"[tw] OR "Thallium(III) oxide"[tw] OR "Thallium(III) sulfate"[tw] OR "Thallous bromide"[tw] OR "Thallous fluoride"[tw] OR "Thallous iodide"[tw] OR "Thallous oxide"[tw])) OR ((thallium OR dithallium OR thallic OR thallous OR "Bithallium trisulfate"[tw] OR "Bonide antzix"[tw] OR "Carbonic acid, dithallium(1+) salt"[tw] OR "Dithalloxane-1,3-dione"[tw] OR "Eccothal"[tw] OR "KRS-5"[tw] OR "Ramor"[tw] OR "Ratox"[tw] OR "Tharattin"[tw] OR "Th-Universal"[tw] OR

Table B-2. Database Query Strings

Database search date	Query string
	"Triacetatothallium(III)"[tw] OR "Tris(acetato)thallium"[tw] OR "Zelio"[tw] OR "thallium208"[tw] OR "208thallium"[tw] OR "tl-208"[tw] OR "tl208"[tw] OR "208tl"[tw] OR "208-tl"[tw] OR "thallium201"[tw] OR "201thallium"[tw] OR "tl-201"[tw] OR "tl201"[tw] OR "201tl"[tw] OR "201-tl"[tw] OR "thallium199"[tw] OR "199thallium"[tw] OR "tl-199"[tw] OR "tl199"[tw] OR "199tl"[tw] OR "199-tl"[tw] OR "thallium200"[tw] OR "200thallium"[tw] OR "tl-200"[tw] OR "tl200"[tw] OR "200tl"[tw] OR "200-tl"[tw] OR "thallium202"[tw] OR "202thallium"[tw] OR "tl-202"[tw] OR "tl202"[tw] OR "202tl"[tw] OR "202-tl"[tw] OR "thallium204"[tw] OR "204thallium"[tw] OR "tl-204"[tw] OR "tl204"[tw] OR "204tl"[tw] OR "204-tl"[tw] OR "thallium210"[tw] OR "210thallium"[tw] OR "tl-210"[tw] OR "tl210"[tw] OR "210tl"[tw] OR "210-tl"[tw]) NOT medline[sb]) OR ((("Thallium Radioisotopes/toxicity"[mh] OR "Thallium Radioisotopes/adverse effects"[mh] OR "Thallium Radioisotopes/poisoning"[mh] OR "Thallium Radioisotopes/pharmacokinetics"[mh]) OR ("Thallium Radioisotopes"[mh] AND ("environmental exposure"[mh] OR ci[sh])) OR ("Thallium Radioisotopes"[mh] AND toxicokinetics[mh:noexp]) OR ("Thallium Radioisotopes/blood"[mh] OR "Thallium Radioisotopes/cerebrospinal fluid"[mh] OR "Thallium Radioisotopes/urine"[mh]) OR ("Thallium Radioisotopes"[mh] AND ("endocrine system"[mh] OR "hormones, hormone substitutes, and hormone antagonists"[mh] OR "endocrine disruptors"[mh])) OR ("Thallium Radioisotopes"[mh] AND ("computational biology"[mh] OR "medical informatics"[mh] OR genomics[mh] OR genome[mh] OR proteomics[mh] OR proteome[mh] OR metabolomics[mh] OR metabolome[mh] OR genes[mh] OR "gene expression"[mh] OR phenotype[mh] OR genetics[mh] OR genotype[mh] OR transcriptome[mh] OR ("systems biology"[mh] AND ("environmental exposure"[mh] OR "epidemiological monitoring"[mh] OR analysis[sh])) OR "transcription, genetic "[mh] OR "reverse transcription"[mh] OR "transcriptional activation"[mh] OR "transcription factors"[mh] OR ("biosynthesis"[sh] AND (RNA[mh] OR DNA[mh])) OR "RNA, messenger"[mh] OR "RNA, transfer"[mh] OR "peptide biosynthesis"[mh] OR "protein biosynthesis"[mh] OR "reverse transcriptase polymerase chain reaction"[mh] OR "base sequence"[mh] OR "trans-activators"[mh] OR "gene expression profiling"[mh])) OR ("Thallium Radioisotopes/antagonists and inhibitors"[mh]) OR ("Thallium Radioisotopes/metabolism"[mh] AND ("humans"[mh] OR "animals"[mh])) OR ("Thallium Radioisotopes"[mh] AND cancer[sb]) OR ("Thallium Radioisotopes/pharmacology"[majr]))))) AND (1990:3000[dp] OR 1990:3000[mhda] OR 1990:3000[crdt] OR 1990:3000[edat]))
NTRL	
07/2023	Date Published 1990 to 2023 "thallium" OR "dithallium" OR "thallic" OR "thallous" OR "Bithallium trisulfate" OR "Bonide antzix" OR "Carbonic acid, dithallium(1+) salt" OR "Dithalloxane-1,3-dione" OR "Eccothal" OR "KRS-5" OR "Ramor" OR "Ratox" OR "Tharattin" OR "Th-Universal" OR "Triacetatothallium(III)" OR "Tris(acetato)thallium" OR "Zelio" OR "thallium208" OR "208thallium" OR "tl-208" OR "tl208" OR "208tl" OR "208-tl" OR "thallium201" OR "201thallium" OR "tl-201" OR "tl201" OR "201tl" OR "201-tl" OR "thallium199" OR "199thallium" OR "tl-199" OR "tl199" OR "199tl" OR "199-tl" OR "thallium200" OR "200thallium" OR "tl-200" OR "tl200" OR "200tl" OR "200-tl" OR "thallium202" OR "202thallium" OR "tl-202" OR "tl202" OR "202tl" OR "202-tl" OR "thallium204" OR "204thallium" OR "tl-204" OR "tl204" OR "204tl" OR "204-tl" OR "thallium210" OR "210thallium" OR "tl-210" OR "tl210" OR "210tl" OR "210-tl"
Toxcenter	
07/2023	FILE 'TOXCENTER' ENTERED AT 10:46:34 ON 03 JUL 2023 L1 12931 SEA FILE=TOXCENTER 7440-28-0 OR 563-68-8 OR 2570-63-0 OR 15843-14-8 OR 13453-32-2 OR 7791-12-0 OR 10102-45-1 OR

Table B-2. Database Query Strings

Database search date	Query string
	1314-32-5 OR 1314-12-1 OR 7446-18-6 OR 10031-59-1 OR 6533-73-9 OR 29809-42-5 OR 7789-40-4 OR 7790-30-9 OR 7789-27-
	L2 373 SEA FILE=TOXCENTER 15230-71-4 OR 13746-98-0 OR 16901-76-1 OR 16222-66-5 OR 37475-01-7 OR 13701-90-1 OR 57232-83-4 OR 13453-37-7 OR 7783-57-5 OR 14627-67-9 OR 22537-56-0
	L3 1178 SEA FILE=TOXCENTER 14913-50-9 OR 15064-65-0 OR 15064-66-1 OR 15720-55-5 OR 15720-57-7 OR 13968-51-9 OR 13966-01-3
	L4 0 SEA FILE=TOXCENTER 55172â□□29â□□7
	L5 14345 SEA FILE=TOXCENTER L1 OR L2 OR L3
	L6 1582 SEA FILE=TOXCENTER L5 AND ED>=20201001
	L7 1582 SEA FILE=TOXCENTER L6 NOT TSCATS/FS
	L8 1395 SEA FILE=TOXCENTER L7 NOT PATENT/DT
	ACT TOXQUERY/Q

	L9 QUE (CHRONIC OR IMMUNOTOX? OR NEUROTOX? OR TOXICOKIN? OR BIOMARKER? OR NEUROLOG?)
	L10 QUE (PHARMACOKIN? OR SUBCHRONIC OR PBPK OR EPIDEMIOLOGY/ST,CT, IT)
	L11 QUE (ACUTE OR SUBACUTE OR LD50# OR LD(W)50 OR LC50# OR LC(W)50)
	L12 QUE (TOXICITY OR ADVERSE OR POISONING)/ST,CT,IT
	L13 QUE (INHAL? OR PULMON? OR NASAL? OR LUNG? OR RESPIR?)
	L14 QUE ((OCCUPATION? OR WORKPLACE? OR WORKER?) AND EXPOS?)
	L15 QUE (ORAL OR ORALLY OR INGEST? OR GAVAGE? OR DIET OR DIETS OR DIETARY OR DRINKING(W)WATER?)
	L16 QUE (MAXIMUM AND CONCENTRATION? AND (ALLOWABLE OR PERMISSIBLE))
	L17 QUE (ABORT? OR ABNORMALIT? OR EMBRYO? OR CLEFT? OR FETUS?)
	L18 QUE (FOETUS? OR FETAL? OR FOETAL? OR FERTIL? OR MALFORM? OR OVUM?)
	L19 QUE (OVA OR OVARY OR PLACENTA? OR PREGNAN? OR PRENATAL?)
	L20 QUE (PERINATAL? OR POSTNATAL? OR REPRODUC? OR STERIL? OR TERATOGEN?)
	L21 QUE (SPERM OR SPERMAC? OR SPERMAG? OR SPERMATI? OR SPERMAS? OR SPERMATOB? OR SPERMATOC? OR SPERMATOG?)
	L22 QUE (SPERMATOI? OR SPERMATOL? OR SPERMATOR? OR SPERMATOX? OR SPERMATOZ? OR SPERMATU? OR SPERMI? OR SPERMO?)
	L23 QUE (NEONAT? OR NEWBORN? OR DEVELOPMENT OR DEVELOPMENTAL?)
	L24 QUE (ENDOCRIN? AND DISRUPT?)
	L25 QUE (ZYGOTE? OR CHILD OR CHILDREN OR ADOLESCEN? OR INFANT?)
	L26 QUE (WEAN? OR OFFSPRING OR AGE(W)FACTOR?)
	L27 QUE (DERMAL? OR DERMIS OR SKIN OR EPIDERM? OR CUTANEOUS?)

Table B-2. Database Query Strings

Database search date	Query string
	L28 QUE (CARCINOG? OR COCARCINOG? OR CANCER? OR PRECANCER? OR NEOPLAS?)
	L29 QUE (TUMOR? OR TUMOUR? OR ONCOGEN? OR LYMPHOMA? OR CARCINOM?)
	L30 QUE (GENETOX? OR GENOTOX? OR MUTAGEN? OR GENETIC(W)TOXIC?)
	L31 QUE (NEPHROTOX? OR HEPATOTOX?)
	L32 QUE (ENDOCRIN? OR ESTROGEN? OR ANDROGEN? OR HORMON?)
	L33 QUE (OCCUPATION? OR WORKER? OR WORKPLACE? OR EPIDEM?)
	L34 QUE L9 OR L10 OR L11 OR L12 OR L13 OR L14 OR L15 OR L16 OR L17 OR L18 OR L19 OR L20 OR L21 OR L22 OR L23 OR L24 OR L25 OR L26 OR L27 OR L28 OR L29 OR L30 OR L31 OR L32 OR L33
	L35 QUE (RAT OR RATS OR MOUSE OR MICE OR GUINEA(W)PIG? OR MURIDAE OR DOG OR DOGS OR RABBIT? OR HAMSTER? OR PIG OR PIGS OR SWINE OR PORCINE OR MONKEY? OR MACAQUE?)
	L36 QUE (MARMOSET? OR FERRET? OR GERBIL? OR RODENT? OR LAGOMORPHA OR BABOON? OR CANINE OR CAT OR CATS OR FELINE OR MURINE)
	L37 QUE L34 OR L35 OR L36
	L38 QUE (NONHUMAN MAMMALS)/ORGN
	L39 QUE L37 OR L38
	L40 QUE (HUMAN OR HUMANS OR HOMINIDAE OR MAMMALS OR MAMMAL? OR PRIMATES OR PRIMATE?)
	L41 QUE L39 OR L40

	L42 819 SEA FILE=TOXCENTER L8 AND L41
	L43 97 SEA FILE=TOXCENTER L42 AND MEDLINE/FS
	L44 722 SEA FILE=TOXCENTER L42 NOT MEDLINE/FS
	L45 703 DUP REM L43 L44 (116 DUPLICATES REMOVED)
	L*** DEL 97 S L42 AND MEDLINE/FS
	L*** DEL 97 S L42 AND MEDLINE/FS
	L46 97 SEA FILE=TOXCENTER L45
	L*** DEL 722 S L42 NOT MEDLINE/FS
	L*** DEL 722 S L42 NOT MEDLINE/FS
	L47 606 SEA FILE=TOXCENTER L45
	L48 606 SEA FILE=TOXCENTER (L46 OR L47) NOT MEDLINE/FS D SCAN L48
	L49 0 SEA "55172â□□29â□□7"
11/2020	FILE 'TOXCENTER' ENTERED AT 13:47:07 ON 05 NOV 2020
	L1 11321 SEA FILE=TOXCENTER 7440-28-0 OR 563-68-8 OR 2570-63-0 OR 15843-14-8 OR 13453-32-2 OR 7791-12-0 OR 10102-45-1 OR 1314-32-5 OR 1314-12-1 OR 7446-18-6 OR 10031-59-1 OR 6533-73-9 OR 29809-42-5 OR 7789-40-4 OR 7790-30-9 OR 7789-27-7
	L2 332 SEA FILE=TOXCENTER 15230-71-4 OR 13746-98-0 OR 16901-76-1 OR 16222-66-5 OR 37475-01-7 OR 13701-90-1 OR 57232-83-4 OR 13453-37-7 OR 7783-57-5 OR 14627-67-9 OR 22537-56-0

Table B-2. Database Query Strings

Database search date	Query string
	L4 1082 SEA FILE=TOXCENTER 14913-50-9 OR 15064-65-0 OR 15064-66-1 OR 15720-55-5 OR 15720-57-7 OR 13968-51-9 OR 13966-01-3 OR 55172&#8208
	L5 12614 SEA FILE=TOXCENTER L1 OR L2 OR L4
	L6 8889 SEA FILE=TOXCENTER L5 AND PY>1989
	L8 8889 SEA FILE=TOXCENTER L6 NOT TSCATS/FS
	L9 7764 SEA FILE=TOXCENTER L8 NOT PATENT/DT
	ACT TOXQUERY/Q

	L10 QUE (CHRONIC OR IMMUNOTOX? OR NEUROTOX? OR TOXICOKIN? OR BIOMARKER? OR NEUROLOG?)
	L11 QUE (PHARMACOKIN? OR SUBCHRONIC OR PBPK OR EPIDEMIOLOGY/ST,CT, IT)
	L12 QUE (ACUTE OR SUBACUTE OR LD50# OR LD(W)50 OR LC50# OR LC(W)50)
	L13 QUE (TOXICITY OR ADVERSE OR POISONING)/ST,CT,IT
	L14 QUE (INHAL? OR PULMON? OR NASAL? OR LUNG? OR RESPIR?)
	L15 QUE ((OCCUPATION? OR WORKPLACE? OR WORKER?) AND EXPOS?)
	L16 QUE (ORAL OR ORALLY OR INGEST? OR GAVAGE? OR DIET OR DIETS OR DIETARY OR DRINKING(W)WATER?)
	L17 QUE (MAXIMUM AND CONCENTRATION? AND (ALLOWABLE OR PERMISSIBLE))
	L18 QUE (ABORT? OR ABNORMALIT? OR EMBRYO? OR CLEFT? OR FETUS?)
	L19 QUE (FOETUS? OR FETAL? OR FOETAL? OR FERTIL? OR MALFORM? OR OVUM?)
	L20 QUE (OVA OR OVARY OR PLACENTA? OR PREGNAN? OR PRENATAL?)
	L21 QUE (PERINATAL? OR POSTNATAL? OR REPRODUC? OR STERIL? OR TERATOGEN?)
	L22 QUE (SPERM OR SPERMAC? OR SPERMAG? OR SPERMATI? OR SPERMAS? OR SPERMATOB? OR SPERMATOC? OR SPERMATOG?)
	L23 QUE (SPERMATOI? OR SPERMATOL? OR SPERMATOR? OR SPERMATOX? OR SPERMATOZ? OR SPERMATU? OR SPERMI? OR SPERMO?)
	L24 QUE (NEONAT? OR NEWBORN? OR DEVELOPMENT OR DEVELOPMENTAL?)
	L25 QUE (ENDOCRIN? AND DISRUPT?)
	L26 QUE (ZYGOTE? OR CHILD OR CHILDREN OR ADOLESCEN? OR INFANT?)
	L27 QUE (WEAN? OR OFFSPRING OR AGE(W)FACTOR?)
	L28 QUE (DERMAL? OR DERMIS OR SKIN OR EPIDERM? OR CUTANEOUS?)
	L29 QUE (CARCINOG? OR COCARCINOG? OR CANCER? OR PRECANCER? OR NEOPLAS?)
	L30 QUE (TUMOR? OR TUMOUR? OR ONCOGEN? OR LYMPHOMA? OR CARCINOM?)

Table B-2. Database Query Strings

Database search date	Query string
	L31 QUE (GENETOX? OR GENOTOX? OR MUTAGEN? OR GENETIC(W)TOXIC?) L32 QUE (NEPHROTOX? OR HEPATOTOX?) L33 QUE (ENDOCRIN? OR ESTROGEN? OR ANDROGEN? OR HORMON?) L34 QUE (OCCUPATION? OR WORKER? OR WORKPLACE? OR EPIDEM?) L35 QUE L10 OR L11 OR L12 OR L13 OR L14 OR L15 OR L16 OR L17 OR L18 OR L19 OR L20 OR L21 OR L22 OR L23 OR L24 OR L25 OR L26 OR L27 OR L28 OR L29 OR L30 OR L31 OR L32 OR L33 OR L34 L36 QUE (RAT OR RATS OR MOUSE OR MICE OR GUINEA(W)PIG? OR MURIDAE OR DOG OR DOGS OR RABBIT? OR HAMSTER? OR PIG OR PIGS OR SWINE OR PORCINE OR MONKEY? OR MACAQUE?) L37 QUE (MARMOSET? OR FERRET? OR GERBIL? OR RODENT? OR LAGOMORPHA OR BABOON? OR CANINE OR CAT OR CATS OR FELINE OR MURINE) L38 QUE L35 OR L36 OR L37 L39 QUE (HUMAN OR HUMANS OR HOMINIDAE OR MAMMALS OR MAMMAL? OR PRIMATES OR PRIMATE?) L40 QUE L38 OR L39 --------- L41 3673 SEA FILE=TOXCENTER L9 AND L40 L42 505 SEA FILE=TOXCENTER L41 AND MEDLINE/FS L43 3168 SEA FILE=TOXCENTER L41 NOT MEDLINE/FS L44 3157 DUP REM L42 L41 (1021 DUPLICATES REMOVED) ANSWERS '1-3157' FROM FILE TOXCENTER L*** DEL 3673 S L9 AND L40 L*** DEL 3673 S L9 AND L40 L45 2652 SEA FILE=TOXCENTER L44 L*** DEL 505 S L41 AND MEDLINE/FS L*** DEL 505 S L41 AND MEDLINE/FS L46 505 SEA FILE=TOXCENTER L44 L47 2652 SEA FILE=TOXCENTER (L45 OR L46) NOT MEDLINE/FS

Table B-3. Strategies to Augment the Literature Search

Source	Query and number screened when available
TSCATS via ChemView	
07/2023	Compounds searched: 7440-28-0; 563-68-8; 2570-63-0; 15843-14-8; 13453-32-2; 7791-12-0; 15230-71-4; 10102-45-1; 13746-98-0; 16901-76-1; 1314-32-5; 1314-12-1; 7446-18-6; 10031-59-1; 16222-66-5; 37475-01-7; 6533-73-9; 29809-42-5; 7789-40-4; 13701-90-1; 7790-30-9; 57232-83-4; 13453-37-7; 7789-27-7; 7783-57-5; 14627-67-9; 22537-56-0; 14913-50-9; 15064-65-0; 15064-66-1; 15720-55-5; 15720-57-7; 13968-51-9; 13966-01-3; 55172-29-7

Table B-3. Strategies to Augment the Literature Search

Source	Query and number screened when available
NTP	
07/2023	7440-28-0 563-68-8 2570-63-0 15843-14-8 13453-32-2 7791-12-0 15230-71-4 10102-45-1 13746-98-0 16901-76-1 1314-32-5 1314-12-1 7446-18-6 10031-59-1 16222-66-5 37475-01-7 6533-73-9 29809-42-5 7789-40-4 13701-90-1 7790-30-9 57232-83-4 13453-37-7 7789-27-7 7783-57-5 14627-67-9 22537-56-0 14913-50-9 15064-65-0 15064-66-1 15720-55-5 15720-57-7 13968-51-9 13966-01-3 55172-29-7 "thallium" "dithallium" "thallic" "thallous" "bithallium" "Ramor" "Ratox" "Zelio" "Eccothal" "Tharattin" "Triacetatothallium" "Tris(acetato)thallium" "thallium208" "208thallium" "tl-208" "tl208" "208tl" "208-tl" "thallium201" "201thallium" "tl-201" "tl201" "201tl" "201-tl" "thallium199" "199thallium" "tl-199" "tl199" "199tl" "199-tl" "thallium200" "200thallium" "tl-200" "tl200" "200tl" "200-tl" "thallium202" "202thallium" "tl-202" "tl202" "202tl" "202-tl" "thallium204" "204thallium" "tl-204" "tl204" "204tl" "204-tl" "thallium210" "210thallium" "tl-210" "tl210" "210tl" "210-tl"

Table B-3. Strategies to Augment the Literature Search

Source	Query and number screened when available
Regulations.gov	
07/2023	Limited to Notices, 1990-present "7440-28-0" "563-68-8" "2570-63-0" "15843-14-8" "13453-32-2" "7791-12-0" "15230-71-4" "10102-45-1" "13746-98-0" "16901-76-1" "1314-32-5" "1314-12-1" "7446-18-6" "10031-59-1" "16222-66-5" "37475-01-7" "6533-73-9" "29809-42-5" "7789-40-4" "13701-90-1" "7790-30-9" "57232-83-4" "13453-37-7" "7789-27-7" "7783-57-5" "14627-67-9 " "22537-56-0" "14913-50-9" "15064-65-0" "15064-66-1" "15720-55-5" "15720-57-7" "13968-51-9" "13966-01-3" "55172-29-7" thallium dithallium bithallium thallic thallous triacetatothallium
NIH RePORTER	
01/2024	Search Criteria Fiscal Year: Active Projects Text Search: "thallium" OR "dithallium" OR "thallic" OR "thallous" OR "Bithallium trisulfate" OR "Bonide antzix" OR "Carbonic acid, dithallium(1+) salt" OR "Dithalloxane-1,3-dione" OR "Eccothal" OR "KRS-5" OR "Ramor" OR "Ratox" OR "Tharattin" OR "Th-Universal" OR "Triacetatothallium(III)" OR "Tris(acetato)thallium" OR "Zelio" OR "thallium208" OR "208thallium" OR "tl-208" OR "tl208" OR "208tl" OR "208-tl" OR "thallium201" OR "201thallium" OR "tl-201" OR

Table B-3. Strategies to Augment the Literature Search

Source	Query and number screened when available
	"tl201" OR "201tl" OR "201-tl" OR "thallium199" OR "199thallium" OR "tl-199" OR "tl199" OR "199tl" OR "199-tl" OR "thallium200" OR "200thallium" OR "tl-200" OR "tl200" OR "200tl" OR "200-tl" OR "thallium202" OR "202thallium" OR "tl-202" OR "tl202" OR "202tl" OR "202-tl" OR "thallium204" OR "204thallium" OR "tl-204" OR "tl204" OR "204tl" OR "204-tl" OR "thallium210" OR "210thallium" OR "tl-210" OR "tl210" OR "210tl" OR "210-tl" OR "Bithallium trisulfate" OR "Dithallium oxide" OR "dithallium trioxide" OR "Dithallium tris(sulphate)" OR "Dithalloxane-1,3-dione" OR "KRS-5" OR "Nitric acid, thallium salt" OR "Nitric acid, thallium(3+) salt" OR "Sulfuric acid, thallium(2+) salt" OR "Sulfuric acid, thallium(3+) salt" OR "Thallic nitrate" OR "Thallic oxide" OR "Thallic sulfate" OR "thallium bromide" OR "Thallium fluoride" OR "Thallium iodide" OR "Thallium monobromide" OR "Thallium monofluoride" OR "thallium monoiodide" OR "Thallium oxide" OR "Thallium peroxide" OR "Thallium sesquioxide" OR "Thallium tribromide" OR "Thallium trichloride" OR "Thallium trifluoride" OR "Thallium triiodide" OR "Thallium trinitrate" OR "Thallium trioxide" OR "Thallium(1+) bromide" OR "Thallium(1+) iodide" OR "Thallium(1+) lambda 1 - thallanolate" OR "Thallium(1+) oxide" OR "Thallium(1+) thallium(3+) sulfate" OR "Thallium(3+) oxide" OR "Thallium(3+) sulfate" OR "Thallium(3+) tribromide" OR "Thallium(3+) trichloride" OR "Thallium(3+) trifluoride" OR "Thallium(3+) triiodide" OR "Thallium(3+) trinitrate" OR "Thallium(I) bromide" OR "Thallium(I) fluoride" OR "Thallium(I) iodide" OR "Thallium(I) oxide" OR "Thallium(II) sulfate" OR "Thallium(III) bromide" OR "Thallium(III) chloride" OR "Thallium(III) iodide" OR "Thallium(III) oxide" OR "Thallium(III) sulfate" OR "Thallous bromide" OR "Thallous fluoride" OR "Thallous iodide" OR "Thallous oxide" (advanced) Limit to: Project Title, Project Terms, Project Abstracts
Other	Identified throughout the assessment process

The 2023 results were:

- Number of records identified from PubMed, NTRL, and TOXCENTER (after duplicate removal): 6,525
- Number of records identified from other strategies: 100
- Total number of records to undergo literature screening: 6,625

B.1.2 Literature Screening

A two-step process was used to screen the literature search to identify relevant studies on thallium:

- Title and abstract screen
- Full text screen

Title and Abstract Screen. Within the reference library, titles and abstracts were screened manually for relevance. Studies that were considered relevant (see Table B-1 for inclusion criteria) were moved to the second step of the literature screening process. Studies were excluded when the title and abstract clearly indicated that the study was not relevant to the toxicological profile.

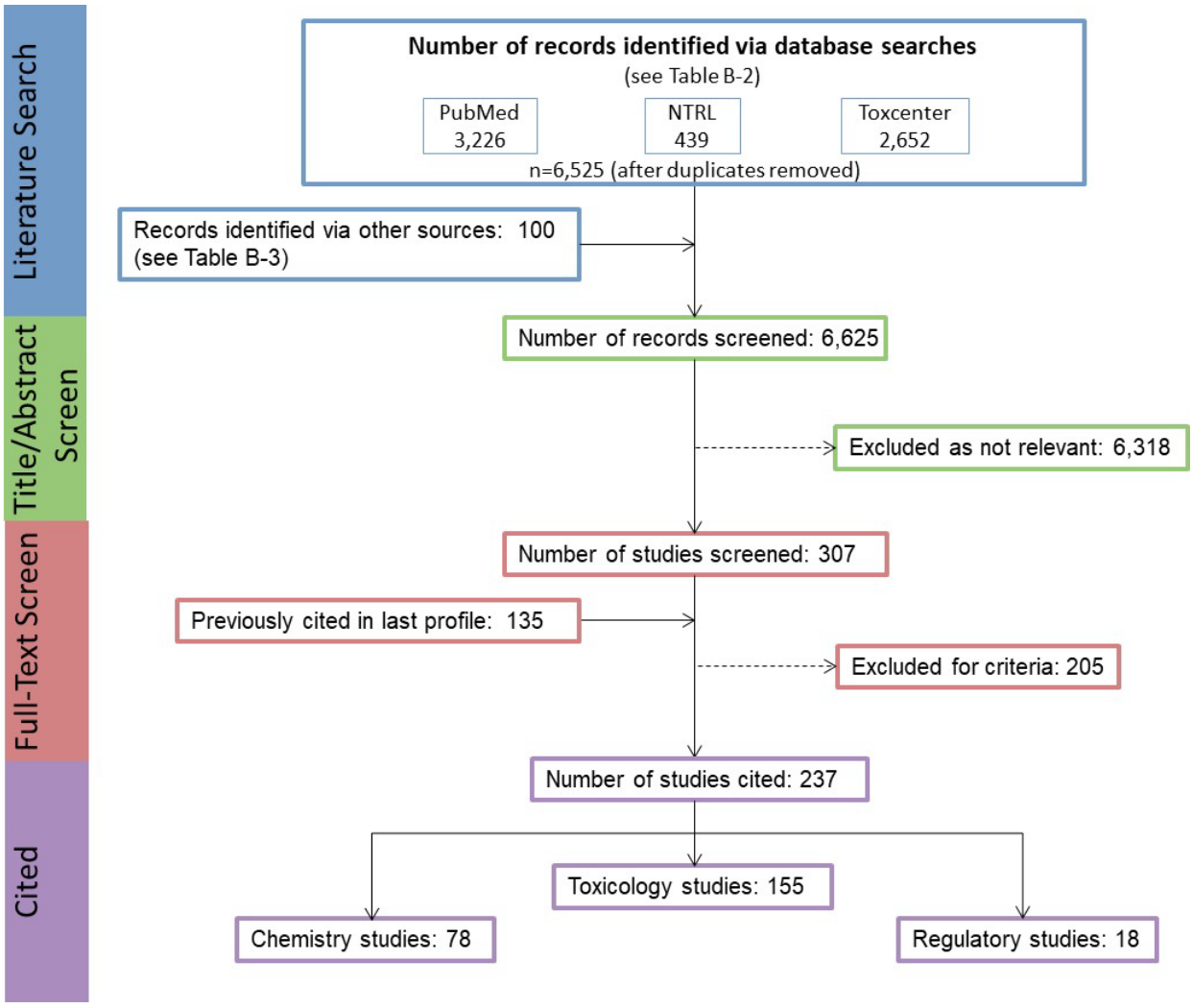
- Number of titles and abstracts screened: 6,625
- Number of studies considered relevant and moved to the next step: 307

Full Text Screen. The second step in the literature screening process was a full text review of individual studies considered relevant in the title and abstract screen step. Each study was reviewed to determine whether it was relevant for inclusion in the toxicological profile.

- Number of studies undergoing full text review: 307
- Number of studies cited in the pre-public draft of the toxicological profile: 135
- Total number of studies cited in the profile: 237

A summary of the results of the literature search and screening is presented in Figure B-1.

Figure B-1. July 2023 Literature Search Results and Screen for Thallium



APPENDIX C. FRAMEWORK FOR ATSDR'S SYSTEMATIC REVIEW OF HEALTH EFFECTS DATA FOR THALLIUM

To increase the transparency of ATSDR's process of identifying, evaluating, synthesizing, and interpreting the scientific evidence on the health effects associated with exposure to thallium, ATSDR utilized a slight modification of NTP's Office of Health Assessment and Translation (OHAT) systematic review methodology (NTP 2013, 2015; Rooney et al. 2014). ATSDR's framework is an eight-step process for systematic review with the goal of identifying the potential health hazards of exposure to thallium:

- Step 1. Problem Formulation
- Step 2. Literature Search and Screen for Health Effects Studies
- Step 3. Extract Data from Health Effects Studies
- Step 4. Identify Potential Health Effect Outcomes of Concern
- Step 5. Assess the Risk of Bias for Individual Studies
- Step 6. Rate the Confidence in the Body of Evidence for Each Relevant Outcome
- Step 7. Translate Confidence Rating into Level of Evidence of Health Effects
- Step 8. Integrate Evidence to Develop Hazard Identification Conclusions

C.1 PROBLEM FORMULATION

The objective of the toxicological profile and this systematic review was to identify the potential health hazards associated with inhalation, oral, or dermal/ocular exposure to thallium. The inclusion criteria used to identify relevant studies examining the health effects of thallium are presented in Table C-1.

Data from human and laboratory animal studies were considered relevant for addressing this objective. Human studies were divided into two broad categories: observational epidemiology studies and controlled exposure studies. The observational epidemiology studies were further divided: cohort studies (retrospective and prospective studies), population studies (with individual data or aggregate data), and case-control studies.

Table C-1. Inclusion Criteria for Identifying Health Effects Studies

Species
Human
Laboratory mammals
Route of exposure
Inhalation
Oral
Dermal (or ocular)
Parenteral (these studies will be considered supporting data)
Health outcome
Death
Systemic effects
Body weight effects
Respiratory effects
Cardiovascular effects

Table C-1. Inclusion Criteria for Identifying Health Effects Studies

Gastrointestinal effects
Hematological effects
Musculoskeletal effects
Hepatic effects
Renal effects
Dermal effects
Ocular effects
Endocrine effects
Immunological effects
Neurological effects
Reproductive effects
Developmental effects
Other noncancer effects
Cancer

C.2 LITERATURE SEARCH AND SCREEN FOR HEALTH EFFECTS STUDIES

A literature search and screen were conducted to identify studies examining the health effects of thallium. The literature search framework for the toxicological profile is discussed in detail in Appendix B.

C.2.1 Literature Search

As noted in Appendix B, the current literature search was intended to update the 1992 toxicological profile for thallium; thus, the literature search was restricted to studies published between January 1990 and July 2023. See Appendix B for the databases searched and the search strategy.

A total of 6,625 records relevant to all sections of the toxicological profile were identified (after duplicate removal).

C.2.2 Literature Screening

As described in Appendix B, a two-step process was used to screen the literature search to identify relevant studies examining the health effects of thallium.

Title and Abstract Screen. In the Title and Abstract Screen step, 6,625 records were reviewed; 81 documents were considered to meet the health effects inclusion criteria in Table C-1 and were moved to the next step in the process.

Full Text Screen. In the second step in the literature screening process for the systematic review, a full text review of 99 health effect documents (documents identified in the updated literature search and documents cited in older versions of the profile) was performed. From those 99 documents (101 studies), 6 documents (7 studies) were included in the qualitative review.

C.3 EXTRACT DATA FROM HEALTH EFFECTS STUDIES

Relevant data extracted from the individual studies selected for inclusion in the systematic review were collected in customized data forms. A summary of the type of data extracted from each study is presented in Table C-2. For references that included more than one experiment or species, data extraction records were created for each experiment or species.

Table C-2. Data Extracted From Individual Studies

Citation
Chemical form
Route of exposure (e.g., inhalation, oral, dermal)
Specific route (e.g., gavage in oil, drinking water)
Species
Strain
Exposure duration category (e.g., acute, intermediate, chronic)
Exposure duration
Frequency of exposure (e.g., 6 hours/day, 5 days/week)
Exposure length
Number of animals or subjects per sex per group
Dose/exposure levels
Parameters monitored
Description of the study design and method
Summary of calculations used to estimate doses (if applicable)
Summary of the study results
Reviewer's comments on the study
Outcome summary (one entry for each examined outcome)
No-observed-adverse-effect level (NOAEL) value
Lowest-observed-adverse-effect level (LOAEL) value
Effect observed at the LOAEL value

A summary of the extracted data for each study is presented in the Supplemental Document for Thallium and overviews of the results of oral exposure studies (no inhalation or dermal exposure animals studies were identified) are presented in Sections 2.2–2.18 of the profile and in the Levels Significant Exposures tables in Section 2.1 of the profile (Table 2-2).

C.4 IDENTIFY POTENTIAL HEALTH EFFECT OUTCOMES OF CONCERN

Overviews of the potential health effect outcomes for thallium identified in human and animal studies are presented in Tables C-3 and C-4, respectively. Available human studies include numerous case studies and case series reports, a small number of occupational exposure studies and studies of people living near a thallium point source, and general population studies evaluating possible associations between a biomarker of thallium exposure and adverse health outcomes. The general population studies provide limited information on health outcomes of concern due to the inconsistency of the findings and co-exposure to other compounds. When evaluated together, the case reports and case series reports suggest that the cardiovascular system, gastrointestinal system, skin, and peripheral nervous system are sensitive targets of thallium toxicity. A small number of animal studies have evaluated health outcomes following

acute- or intermediate-duration oral exposure. Alopecia was considered a sensitive outcome. Case studies and case-series reports were not included in the formal systematic review due to inherent high risk of bias and low confidence based on study design. However, consistent findings from numerous case studies were considered during the adjustment of the confidence rating. Animal studies have not adequately evaluated cardiovascular, gastrointestinal, or neurological endpoints (typically only examined in one study or did not evaluate function). Studies examining alopecia were carried through to Steps 4–8 of the systematic review. There were 7 studies (published in 6 documents) examining these potential outcomes carried through to Steps 4–8 of the systematic review.

APPENDIX C

Table C-3. Overview of the Health Outcomes for Thallium Evaluated In Human Studies

	Body weight	Respiratory	Cardiovascular	Gastrointestinal	Hematological	Musculoskeletal	Hepatic	Renal	Dermal	Ocular	Endocrine	Immunological	Neurological	Reproductive	Developmental	Other Noncancer	Caner
Inhalation studies																	
Cohort			1 0	1 0									1 1				
Case control																	
Population																	
Case series																	
Oral studies																	
Cohort								1 1			1 1						
Case control																	
Population		1															
Case series		3 3	10 10	11 11		1 1	2 2	2 2	18 18	3 3			21 21		1 1		
Dermal studies																	
Cohort																	
Case control																	
Population																	
Case series																	

Number of studies examining endpoint	0	1	2	3	4	5–9	≥10	
Number of studies reporting outcome	0	1	2	3	4	5–9	≥10	

Table C-4. Overview of the Health Outcomes for Thallium Evaluated in Experimental Animal Studies

	Body weight	Respiratory	Cardiovascular	Gastrointestinal	Hematological	Musculoskeletal	Hepatic	Renal	Dermal	Ocular	Endocrine	Immunological[a]	Neurological[a]	Reproductive[a]	Developmental	Other Noncancer	Caner
Inhalation studies																	
Acute-duration																	
Intermediate-duration																	
Chronic-duration																	
Oral studies																	
Acute-duration	5		1	1		1	3		1			1	3		1		
	3		1	1		0	2		1			1	3		1		
Intermediate-duration	6	3	3	1	1	1	3	3	6	1	1		3	4	2		
	3	0	0	0	0	0	0	0	6	0	0		2	1	2		
Chronic-duration																	
Dermal studies																	
Acute-duration																	
Intermediate-duration																	
Chronic-duration																	

Number of studies examining endpoint	0	1	2	3	4	5–9	≥10	
Number of studies reporting outcome	0	1	2	3	4	5–9	≥10	

[a]Number of studies examining endpoint includes study evaluating histopathology, but not evaluating function.

C.5 ASSESS THE RISK OF BIAS FOR INDIVIDUAL STUDIES

C.5.1 Risk of Bias Assessment

The risk of bias of individual studies was assessed using OHAT's Risk of Bias Tool (NTP 2015). The risk of bias questions for observational epidemiology studies, human-controlled exposure studies, and animal experimental studies are presented in Tables C-5, C-6, and C-7, respectively. Each risk of bias question was answered on a four-point scale:

- **Definitely low risk of bias (++)**
- **Probably low risk of bias (+)**
- **Probably high risk of bias (-)**
- **Definitely high risk of bias (– –)**

In general, "definitely low risk of bias" or "definitely high risk of bias" were used if the question could be answered with information explicitly stated in the study report. If the response to the question could be inferred, then "probably low risk of bias" or "probably high risk of bias" responses were typically used.

Table C-5. Risk of Bias Questionnaire for Observational Epidemiology Studies

Selection bias
Were the comparison groups appropriate?
Confounding bias
Did the study design or analysis account for important confounding and modifying variables?
Attrition/exclusion bias
Were outcome data complete without attrition or exclusion from analysis?
Detection bias
Is there confidence in the exposure characterization?
Is there confidence in outcome assessment?
Selective reporting bias
Were all measured outcomes reported?

Table C-6. Risk of Bias Questionnaire for Human-Controlled Exposure Studies

Selection bias
Was administered dose or exposure level adequately randomized?
Was the allocation to study groups adequately concealed?
Performance bias
Were the research personnel and human subjects blinded to the study group during the study?
Attrition/exclusion bias
Were outcome data complete without attrition or exclusion from analysis?
Detection bias
Is there confidence in the exposure characterization?
Is there confidence in outcome assessment?
Selective reporting bias
Were all measured outcomes reported?

Table C-7. Risk of Bias Questionnaire for Experimental Animal Studies

Selection bias
Was administered dose or exposure level adequately randomized?
Was the allocation to study groups adequately concealed?
Performance bias
Were experimental conditions identical across study groups?
Were the research personnel blinded to the study group during the study?
Attrition/exclusion bias
Were outcome data complete without attrition or exclusion from analysis?
Detection bias
Is there confidence in the exposure characterization?
Is there confidence in outcome assessment?
Selective reporting bias
Were all measured outcomes reported?

After the risk of bias questionnaires were completed for the health effects studies, the studies were assigned to one of three risk of bias tiers based on the responses to the key questions listed below and the responses to the remaining questions.

- Is there confidence in the exposure characterization? (only relevant for observational studies)
- Is there confidence in the outcome assessment?
- Does the study design or analysis account for important confounding and modifying variables? (only relevant for observational studies)

First Tier. Studies placed in the first tier received ratings of "definitely low" or "probably low" risk of bias on the key questions **AND** received a rating of "definitely low" or "probably low" risk of bias on the responses to at least 50% of the other applicable questions.

Second Tier. A study was placed in the second tier if it did not meet the criteria for the first or third tiers.

Third Tier. Studies placed in the third tier received ratings of "definitely high" or "probably high" risk of bias for the key questions **AND** received a rating of "definitely high" or "probably high" risk of bias on the response to at least 50% of the other applicable questions.

The results of the risk of bias assessment for the different types of thallium health effects studies (animal experimental studies) are presented in Table C-8.

Table C-8. Summary of Risk of Bias Assessment for Thallium—Experimental Animal Studies

Reference	Risk of bias criteria and ratings: Selection bias: Was administered dose or exposure level adequately randomized?	Selection bias: Was the allocation to study groups adequately concealed?	Performance bias: Were experimental conditions identical across study groups?	Performance bias: Were the research personnel blinded to the study group during the study?	Attrition/ exclusion bias: Were outcome data complete without attrition or exclusion from analysis?	Detection bias: Is there confidence in the exposure characterization?	Detection bias: Is there confidence in the outcome assessment?*	Selective reporting bias: Were all measured outcomes reported?	Other bias: Did the study design or analysis account for important confounding and modifying variables?	Risk of bias tier
Outcome: Alopecia										
Oral acute-duration exposure										
Rusyniak et al. 2003	–	+	+	+	+	+	+	+	+	First
Oral Intermediate-duration exposure										
Downs et al. 1960 (thallium acetate)	–	+	+	+	+	–	+	+	+	First
Downs et al. 1960 (thallium oxide)	–	+	+	+	+	–	+	+	+	First
Gross et al. 1948	–	+	+	+	+	–	+	+	+	First
Manzo et al. 1983	–	+	–	+	+	–	+	+	+	First
Shipkowski et al. 2023	–	+	+	+	+	–	+	+	+	First
EPA 1986	++	+	+	+	+	++	+	+	++	First

++ = definitely low risk of bias; + = probably low risk of bias; – = probably high risk of bias; – – = definitely high risk of bias; na = not applicable

*Key question used to assign risk of bias tier

C.6 RATE THE CONFIDENCE IN THE BODY OF EVIDENCE FOR EACH RELEVANT OUTCOME

Confidences in the bodies of human and animal evidence were evaluated independently for each potential outcome. ATSDR did not evaluate the confidence in the body of evidence for carcinogenicity; rather, the Agency defaulted to the cancer weight-of-evidence assessment of other agencies including HHS, EPA, and IARC. The confidence in the body of evidence for an association or no association between exposure to thallium and a particular outcome was based on the strengths and weaknesses of individual studies. Four descriptors were used to describe the confidence in the body of evidence for effects or when no effect was found:

- **High confidence:** the true effect is highly likely to be reflected in the apparent relationship
- **Moderate confidence:** the true effect may be reflected in the apparent relationship
- **Low confidence:** the true effect may be different from the apparent relationship
- **Very low confidence:** the true effect is highly likely to be different from the apparent relationship

Confidence in the body of evidence for a particular outcome was rated for each type of study: case-control, case series, cohort, population, human-controlled exposure, and experimental animal. In the absence of data to the contrary, data for a particular outcome were collapsed across animal species, routes of exposure, and exposure durations. If species (or strain), route, or exposure duration differences were noted, then the data were treated as separate outcomes.

C.6.1 Initial Confidence Rating

In ATSDR's modification to the OHAT approach, the body of evidence for an association (or no association) between exposure to thallium and a particular outcome was given an initial confidence rating based on the key features of the individual studies examining that outcome. The presence of these key features of study design was determined for individual studies using four "yes or no" questions, which were customized for epidemiology, human controlled exposure, or experimental animal study designs. Separate questionnaires were completed for each outcome assessed in a study. The key features for observational epidemiology (cohort, population, and case-control) studies, human controlled exposure, and experimental animal studies are presented in Tables C-9, C-10, and C-11, respectively. The initial confidence in the study was determined based on the number of key features present in the study design:

- **High Initial Confidence:** Studies in which the responses to the four questions were "yes".

- **Moderate Initial Confidence:** Studies in which the responses to only three of the questions were "yes".

- **Low Initial Confidence:** Studies in which the responses to only two of the questions were "yes".

- **Very Low Initial Confidence:** Studies in which the response to one or none of the questions was "yes".

Table C-9. Key Features of Study Design for Observational Epidemiology Studies

Exposure was experimentally controlled
Exposure occurred prior to the outcome
Outcome was assessed on individual level rather than at the population level
A comparison group was used

Table C-10. Key Features of Study Design for Human-Controlled Exposure Studies

A comparison group was used or the subjects served as their own control
A sufficient number of subjects were tested
Appropriate methods were used to measure outcomes (i.e., clinically-confirmed outcome versus self-reported)
Appropriate statistical analyses were performed and reported or the data were reported in such a way to allow independent statistical analysis

Table C-11. Key Features of Study Design for Experimental Animal Studies

A concurrent control group was used
A sufficient number of animals per group were tested
Appropriate parameters were used to assess a potential adverse effect
Appropriate statistical analyses were performed and reported or the data were reported in such a way to allow independent statistical analysis

The presence or absence of the key features and the initial confidence levels for studies examining alopecia observed in the animal experimental studies are presented in Table C-12.

Table C-12. Presence of Key Features of Study Design for Thallium—Experimental Animal Studies

	Key feature				
Reference	Concurrent control group	Sufficient number of animals per group	Appropriate parameters to assess potential effect	Adequate data for statistical analysis	Initial study confidence
Outcome: Alopecia					
Oral acute-duration exposure					
Rusyniak et al. 2003	Yes	Yes	Yes	No	Moderate

Table C-12. Presence of Key Features of Study Design for Thallium—Experimental Animal Studies

Reference	Key feature				
	Concurrent control group	Sufficient number of animals per group	Appropriate parameters to assess potential effect	Adequate data for statistical analysis	Initial study confidence
Oral intermediate-duration exposure					
Downs et al. 1960 (thallium acetate)	Yes	Yes	Yes	No	Moderate
Downs et al. 1960 (thallium oxide)	Yes	Yes	Yes	No	Moderate
Gross et al. 1948	No	Yes	Yes	No	Low
Manzo et al. 1983	Yes	Yes	Yes	No	Moderate
Shipkowski et al. 2023	Yes	Yes	Yes	Yes	High
EPA 1986	Yes	Yes	Yes	Yes	High

A summary of the initial confidence ratings for each outcome is presented in Table C-13. If individual studies for a particular outcome and study type had different study quality ratings, then the highest confidence rating for the group of studies was used to determine the initial confidence rating for the body of evidence; any exceptions were noted in Table C-13.

Table C-13. Initial Confidence Rating for Thallium Health Effects Studies

	Initial study confidence	Initial confidence rating
Outcome: Alopecia		
Oral acute-duration		
Animal studies		
Rusyniak et al. 2003	Moderate	Moderate
Oral intermediate-duration		
Animal studies		
Downs et al. 1960 (thallium acetate)	Moderate	High
Downs et al. 1960 (thallium oxide)	Moderate	
Gross et al. 1948	Low	
Manzo et al. 1983	Moderate	
Shipkowski et al. 2023	High	
EPA 1986	High	

C.6.2 Adjustment of the Confidence Rating

The initial confidence rating was then downgraded or upgraded depending on whether there were substantial issues that would decrease or increase confidence in the body of evidence. The nine properties of the body of evidence that were considered are listed below. The summaries of the assessment of the confidence in the body of evidence for alopecia are presented in Table C-14. If the confidence ratings for a particular outcome were based on more than one type of human study, then the highest confidence rating was used for subsequent analyses. An overview of the confidence in the body of evidence for all health effects associated with thallium exposure is presented in Table C-15.

Table C-14. Adjustments to the Initial Confidence in the Body of Evidence

	Initial confidence	Adjustments to the initial confidence rating	Final confidence
Outcome: Alopecia			
Human studies			
Animal studies	High	+1 Consistency of effect	High

Table C-15. Confidence in the Body of Evidence for Thallium

	Confidence in body of evidence	
Outcome	Human studies	Animal studies
Alopecia		High

Five properties of the body of evidence were considered to determine whether the confidence rating should be downgraded:

- **Risk of bias.** Evaluation of whether there is substantial risk of bias across most of the studies examining the outcome. This evaluation used the risk of bias tier groupings for individual studies examining a particular outcome (Tables C-5, C-6, and C-7). Below are the criteria used to determine whether the initial confidence in the body of evidence for each outcome should be downgraded for risk of bias:
    - No downgrade if most studies are in the risk of bias first tier
    - Downgrade one confidence level if most studies are in the risk of bias second tier
    - Downgrade two confidence levels if most studies are in the risk of bias third tier

- **Unexplained inconsistency.** Evaluation of whether there is inconsistency or large variability in the magnitude or direction of estimates of effect across studies that cannot be explained. Below are the criteria used to determine whether the initial confidence in the body of evidence for each outcome should be downgraded for unexplained inconsistency:
    - No downgrade if there is little inconsistency across studies or if only one study evaluated the outcome
    - Downgrade one confidence level if there is variability across studies in the magnitude or direction of the effect
    - Downgrade two confidence levels if there is substantial variability across studies in the magnitude or direct of the effect

- **Indirectness.** Evaluation of four factors that can affect the applicability, generalizability, and relevance of the studies:
    - Relevance of the animal model to human health—unless otherwise indicated, studies in rats, mice, and other mammalian species are considered relevant to humans
    - Directness of the endpoints to the primary health outcome—examples of secondary outcomes or nonspecific outcomes include organ weight in the absence of histopathology or clinical chemistry findings in the absence of target tissue effects
    - Nature of the exposure in human studies and route of administration in animal studies—inhalation, oral, and dermal exposure routes are considered relevant unless there are compelling data to the contrary
    - Duration of treatment in animal studies and length of time between exposure and outcome assessment in animal and prospective human studies—this should be considered on an outcome-specific basis

  Below are the criteria used to determine whether the initial confidence in the body of evidence for each outcome should be downgraded for indirectness:
    - No downgrade if none of the factors are considered indirect
    - Downgrade one confidence level if one of the factors is considered indirect
    - Downgrade two confidence levels if two or more of the factors are considered indirect

- **Imprecision.** Evaluation of the narrowness of the effect size estimates and whether the studies have adequate statistical power. Data are considered imprecise when the ratio of the upper to lower 95% CIs for most studies is ≥10 for tests of ratio measures (e.g., odds ratios) and ≥100 for absolute measures (e.g., percent control response). Adequate statistical power is determined if the study can detect a potentially biologically meaningful difference between groups (20% change from control response for categorical data or risk ratio of 1.5 for continuous data). Below are the criteria used to determine whether the initial confidence in the body of evidence for each outcome should be downgraded for imprecision:
    - No downgrade if there are no serious imprecisions
    - Downgrade one confidence level for serious imprecisions
    - Downgrade two confidence levels for very serious imprecisions

- **Publication bias.** Evaluation of the concern that studies with statistically significant results are more likely to be published than studies without statistically significant results.
    - Downgrade one level of confidence for cases where there is serious concern with publication bias

Four properties of the body of evidence were considered to determine whether the confidence rating should be upgraded:

- **Large magnitude of effect.** Evaluation of whether the magnitude of effect is sufficiently large so that it is unlikely to have occurred as a result of bias from potential confounding factors.
    - Upgrade one confidence level if there is evidence of a large magnitude of effect in a few studies, provided that the studies have an overall low risk of bias and there is no serious unexplained inconsistency among the studies of similar dose or exposure levels; confidence can also be upgraded if there is one study examining the outcome, provided that the study has an overall low risk of bias

- **Dose response.** Evaluation of the dose-response relationships measured within a study and across studies. Below are the criteria used to determine whether the initial confidence in the body of evidence for each outcome should be upgraded:
    - Upgrade one confidence level for evidence of a monotonic dose-response gradient
    - Upgrade one confidence level for evidence of a non-monotonic dose-response gradient where there is prior knowledge that supports a non-monotonic dose-response and a non-monotonic dose-response gradient is observed across studies

- **Plausible confounding or other residual biases.** This factor primarily applies to human studies and is an evaluation of unmeasured determinants of an outcome such as residual bias towards the null (e.g., "healthy worker" effect) or residual bias suggesting a spurious effect (e.g., recall bias). Below is the criterion used to determine whether the initial confidence in the body of evidence for each outcome should be upgraded:
    - Upgrade one confidence level for evidence that residual confounding or bias would underestimate an apparent association or treatment effect (i.e., bias toward the null) or suggest a spurious effect when results suggest no effect

- **Consistency in the body of evidence.** Evaluation of consistency across animal models and species, consistency across independent studies of different human populations and exposure scenarios, and consistency across human study types. Below is the criterion used to determine whether the initial confidence in the body of evidence for each outcome should be upgraded:
    - Upgrade one confidence level if there is a high degree of consistency in the database

C.7 TRANSLATE CONFIDENCE RATING INTO LEVEL OF EVIDENCE OF HEALTH EFFECTS

In the seventh step of the systematic review of the health effects data for thallium, the confidence in the body of evidence for specific outcomes was translated to a level of evidence rating. The level of evidence rating reflected the confidence in the body of evidence and the direction of the effect (i.e., toxicity or no toxicity); route-specific differences were noted. The level of evidence for health effects was rated on a five-point scale:

- **High level of evidence:** High confidence in the body of evidence for an association between exposure to the substance and the health outcome
- **Moderate level of evidence:** Moderate confidence in the body of evidence for an association between exposure to the substance and the health outcome
- **Low level of evidence:** Low confidence in the body of evidence for an association between exposure to the substance and the health outcome
- **Evidence of no health effect:** High confidence in the body of evidence that exposure to the substance is not associated with the health outcome
- **Inadequate evidence:** Low or moderate confidence in the body of evidence that exposure to the substance is not associated with the health outcome OR very low confidence in the body of evidence for an association between exposure to the substance and the health outcome

A summary of the level of evidence of health effects for thallium is presented in Table C-16.

Table C-16. Level of Evidence of Health Effects for Thallium

Outcome	Confidence in body of evidence	Direction of health effect	Level of evidence for health effect
Animal studies			
Alopecia	High	Effect	High

C.8 INTEGRATE EVIDENCE TO DEVELOP HAZARD IDENTIFICATION CONCLUSIONS

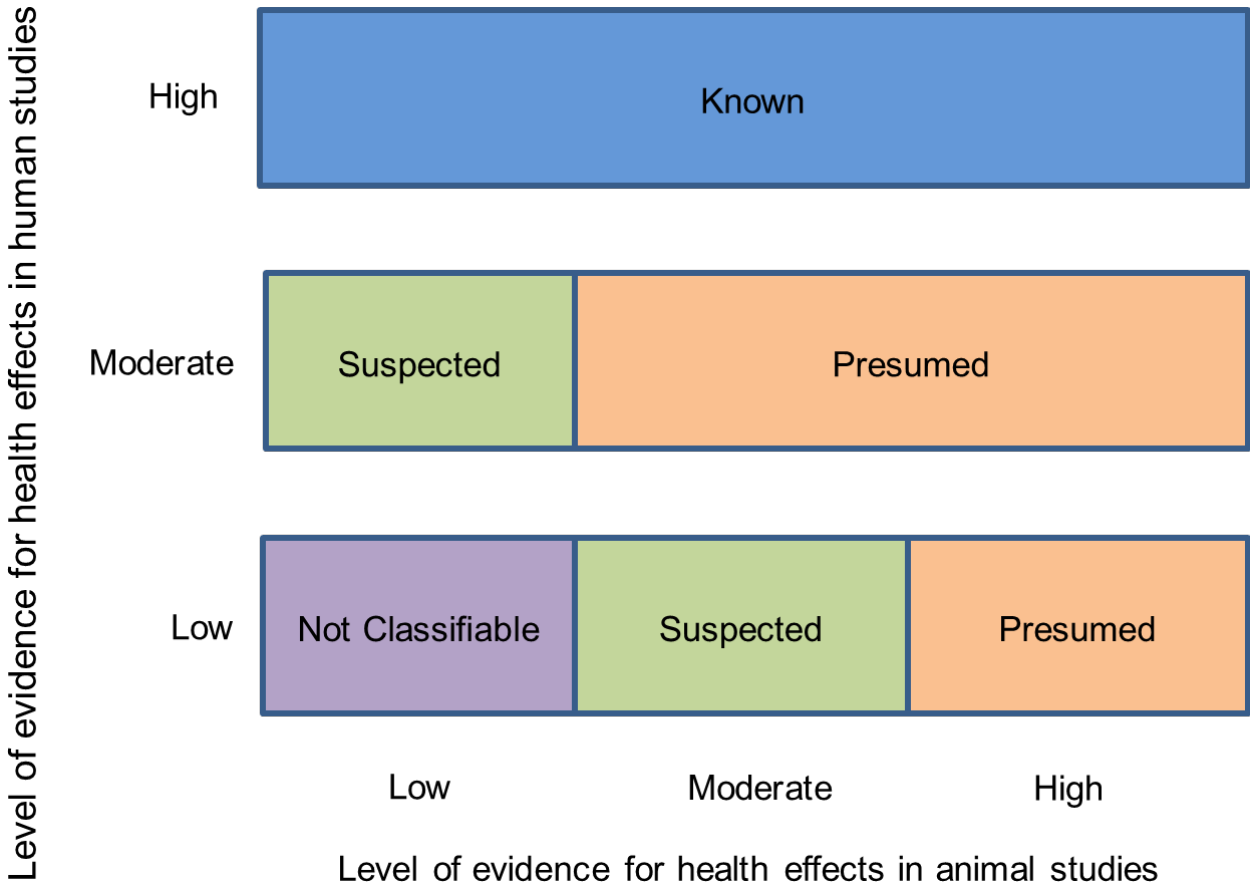
The final step involved the integration of the evidence streams for the human studies and animal studies to allow for a determination of hazard identification conclusions. For health effects, there were four hazard identification conclusion categories:

- **Known** to be a hazard to humans
- **Presumed** to be a hazard to humans
- **Suspected** to be a hazard to humans
- **Not classifiable** as to the hazard to humans

The initial hazard identification was based on the highest level of evidence in the human studies and the level of evidence in the animal studies; if there were no data for one evidence stream (human or animal), then the hazard identification was based on the one data stream (equivalent to treating the missing evidence stream as having low level of evidence). The hazard identification scheme is presented in Figure C-1 and described below:

- **Known:** A health effect in this category would have:
  - High level of evidence for health effects in human studies **AND** a high, moderate, or low level of evidence in animal studies.
- **Presumed:** A health effect in this category would have:
  - Moderate level of evidence in human studies **AND** high or moderate level of evidence in animal studies **OR**
  - Low level of evidence in human studies **AND** high level of evidence in animal studies
- **Suspected:** A health effect in this category would have:
  - Moderate level of evidence in human studies **AND** low level of evidence in animal studies **OR**
  - Low level of evidence in human studies **AND** moderate level of evidence in animal studies
- **Not classifiable:** A health effect in this category would have:
  - Low level of evidence in human studies **AND** low level of evidence in animal studies

Figure C-1. Hazard Identification Scheme



Other relevant data such as mechanistic or mode-of-action data were considered to raise or lower the level of the hazard identification conclusion by providing information that supported or opposed biological plausibility.

Two hazard identification conclusion categories were used when the data indicated that there may be no health effect in humans:

- **Not identified** to be a hazard in humans
- **Inadequate** to determine hazard to humans

If the human level of evidence conclusion of no health effect was supported by the animal evidence of no health effect, then the hazard identification conclusion category of "not identified" was used. If the human or animal level of evidence was considered inadequate, then a hazard identification conclusion category of "inadequate" was used. As with the hazard identification for health effects, the impact of other relevant data was also considered for no health effect data.

The hazard identification conclusions for thallium are listed below and summarized in Table C-17.

Presumed Health Effects

- Alopecia
  - No experimental or reliable epidemiological studies evaluating alopecia in humans were identified.
  - High level of evidence in animals following acute- or intermediate-duration oral exposure (Downs et al. 1960; EPA 1986; Gross et al. 1948; Manzo et al. 1983; Rusyniak et al. 2003; Shipkowski et al. 2023).
  - Studies evaluating alopecia in humans are limited to case studies or case series reports. These studies provide consistent evidence of alopecia in humans following acute-duration oral exposure to thallium (for example, Al Hammouri et al. 2011; Almassri and Sekkarie 2018; Desenclos et al. 1992; Gastel 1978; Grunfeld and Hinostroza 1964; Lu et al. 2007; Meggs et al. 1994; Rayisyan et al. 2021; Sojáková et al. 2015; Sun et al. 2012; Villanueva et al. 1990; Wang et al. 2007, 2021; Zavaliy et al. 2021; Zhang et al. 2014; Zhao et al. 2008).

Table C-17. Hazard Identification Conclusions for Thallium

Outcome	Hazard identification
Alopecia	Presumed health effect

APPENDIX D. USER'S GUIDE

Chapter 1. Relevance to Public Health

This chapter provides an overview of U.S. exposures, a summary of health effects based on evaluations of existing toxicologic, epidemiologic, and toxicokinetic information, and an overview of the minimal risk levels. This is designed to present interpretive, weight-of-evidence discussions for human health endpoints 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?

Minimal Risk Levels (MRLs)

Where sufficient toxicologic information is available, ATSDR derives 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 hazardous substance 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. Section 1.2, Summary of Health Effects, contains basic information known about the substance. Other sections, such as Section 3.2 Children and Other Populations that are Unusually Susceptible and Section 3.4 Interactions with Other Substances, 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 endpoint 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 endpoint 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 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 that are provided in Chapter 2. Detailed discussions of the MRLs are presented in Appendix A.

Chapter 2. 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 and MRLs to humans for noncancer endpoints. The LSE tables and figures can be used 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 tables and figures follow. The numbers in the left column of the legends correspond to the numbers in the example table and figure.

TABLE LEGEND

See Sample LSE Table (page D-5)

(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 figures are limited to the inhalation and oral routes. Not all substances will have data on each route of exposure and will not, therefore, have all five of the tables and figures. Profiles with more than one chemical may have more LSE tables and figures.

(2) Exposure period. Three exposure periods—acute (<15 days), intermediate (15–364 days), and chronic (≥365 days)—are presented within each relevant route of exposure. In this example, two oral studies of chronic-duration exposure are 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) Figure key. 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 51 identified NOAELs and less serious LOAELs (also see the three "51R" data points in sample LSE Figure 2-X).

(4) Species (strain) No./group. The test species (and strain), whether animal or human, are identified in this column. The column also contains information on the number of subjects and sex per group. Chapter 1, Relevance to Public Health, covers the relevance of animal data to human toxicity and Section 3.1, 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.

(5) Exposure parameters/doses. The duration of the study and exposure regimens are provided in these columns. This permits comparison of NOAELs and LOAELs from different studies. In this case (key number 51), rats were orally exposed to “Chemical X” via feed for 2 years. For a

more complete review of the dosing regimen, refer to the appropriate sections of the text or the original reference paper (i.e., Aida et al. 1992).

(6) Parameters monitored. This column lists the parameters used to assess health effects. Parameters monitored could include serum (blood) chemistry (BC), biochemical changes (BI), body weight (BW), clinical signs (CS), developmental toxicity (DX), food intake (FI), gross necropsy (GN), hematology (HE), histopathology (HP), immune function (IX), lethality (LE), neurological function (NX), organ function (OF), ophthalmology (OP), organ weight (OW), reproductive function (RX), urinalysis (UR), and water intake (WI).

(7) Endpoint. This column lists the endpoint examined. The major categories of health endpoints included in LSE tables and figures are death, body weight, respiratory, cardiovascular, gastrointestinal, hematological, musculoskeletal, hepatic, renal, dermal, ocular, endocrine, immunological, neurological, reproductive, developmental, other noncancer, and cancer. "Other noncancer" refers to any effect (e.g., alterations in blood glucose levels) not covered in these systems. In the example of key number 51, three endpoints (body weight, hematological, and hepatic) were investigated.

(8) NOAEL. A NOAEL is the highest exposure level at which no adverse effects were seen in the organ system studied. The body weight effect reported in key number 51 is a NOAEL at 25.5 mg/kg/day. NOAELs are not reported for cancer and death; with the exception of these two endpoints, this field is left blank if no NOAEL was identified in the study.

(9) LOAEL. A LOAEL is the lowest dose used in the study that caused an adverse 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 endpoint used to quantify the adverse effect accompanies the LOAEL. Key number 51 reports a less serious LOAEL of 6.1 mg/kg/day for the hepatic system, which was used to derive a chronic exposure, oral MRL of 0.008 mg/kg/day (see footnote "c"). MRLs are not derived from serious LOAELs. A cancer effect level (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. If no LOAEL/CEL values were identified in the study, this field is left blank.

(10) Reference. The complete reference citation is provided in Chapter 8 of the profile.

(11) Footnotes. Explanations of abbreviations or reference notes for data in the LSE tables are found in the footnotes. For example, footnote "c" indicates that the LOAEL of 6.1 mg/kg/day in key number 51 was used to derive an oral MRL of 0.008 mg/kg/day.

FIGURE LEGEND

See Sample LSE Figure (page D-6)

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.

(12) Exposure period. The same exposure periods appear as in the LSE table. In this example, health effects observed within the chronic exposure period are illustrated.

(13) Endpoint. These are the categories of health effects for which reliable quantitative data exist. The same health effect endpoints appear in the LSE table.

(14) 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.

(15) LOAEL. In this example, the half-shaded circle that is designated 51R identifies a LOAEL critical endpoint in the rat upon which a chronic oral exposure MRL is based. The key number 51 corresponds to the entry in the LSE table. The dashed descending arrow indicates the extrapolation from the exposure level of 6.1 mg/kg/day (see entry 51 in the sample LSE table) to the MRL of 0.008 mg/kg/day (see footnote "c" in the sample LSE table).

(16) CEL. Key number 59R is one of studies for which CELs were derived. The diamond symbol refers to a CEL for the test species (rat). The number 59 corresponds to the entry in the LSE table.

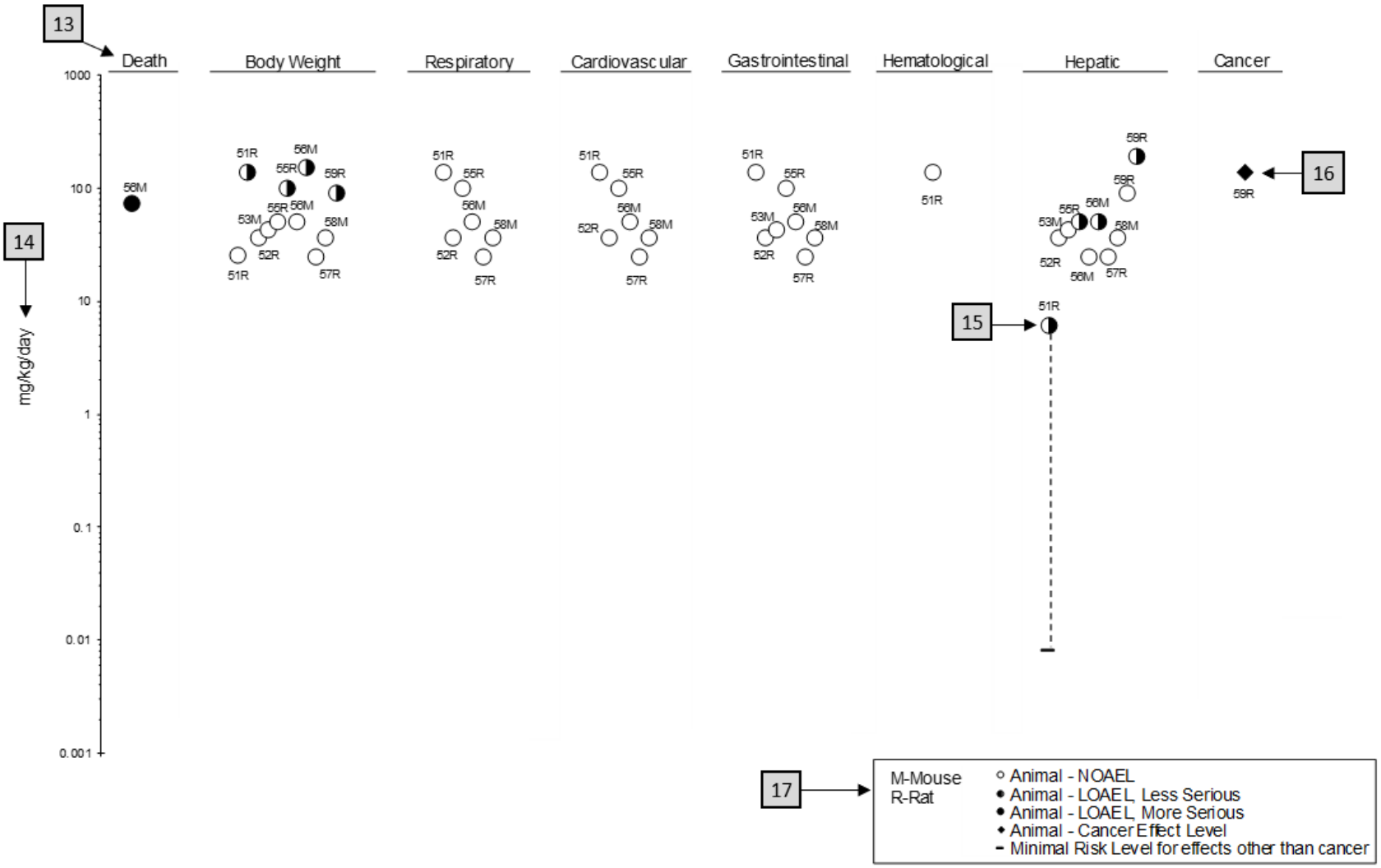
(17) Key to LSE figure. The key provides the abbreviations and symbols used in the figure.

Table 2-X. Levels of Significant Exposure to [Chemical X] – Oral

Figure key[a]	Species (strain) No./group	Exposure parameters	Doses (mg/kg/day)	Parameters monitored	Endpoint	NOAEL (mg/kg/day)	Less serious LOAEL (mg/kg/day)	Serious LOAEL (mg/kg/day)	Effect
CHRONIC EXPOSURE									
51	Rat (Wistar) 40 M, 40 F	2 years (F)	M: 0, 6.1, 25.5, 138.0 F: 0, 8.0, 31.7, 168.4	CS, WI, BW, OW, HE, BC, HP	Bd wt	25.5	138.0		Decreased body weight gain in males (23–25%) and females (31–39%)
					Hemato	138.0			
					Hepatic		6.1[c]		Increases in absolute and relative weights at ≥6.1/8.0 mg/kg/day after 12 months of exposure; fatty generation at ≥6.1 mg/kg/day in males and at ≥31.7 mg/kg/day in females, and granulomas in females at 31.7 and 168.4 mg/kg/day after 12, 18, or 24 months of exposure and in males at ≥6.1 mg/kg/day only after 24 months of exposure
Aida et al. 1992									
52	Rat (F344) 78 M	104 weeks (W)	0, 3.9, 20.6, 36.3	CS, BW, FI, BC, OW, HP	Hepatic	36.3			
					Renal	20.6	36.3		Increased incidence of renal tubular cell hyperplasia
					Endocr	36.3			
George et al. 2002									
59	Rat (Wistar) 58M, 58F	Lifetime (W)	M: 0, 90 F: 0, 190	BW, HP	Cancer		190 F		Increased incidence of hepatic neoplastic nodules in females only; no additional description of the tumors was provided
Tumasonis et al. 1985									

[a]The number corresponds to entries in Figure 2-x.
[b]Used to derive an acute-duration oral minimal risk level (MRL) of 0.1 mg/kg/day based on the $BMDL_{05}$ of 10 mg/kg/day and an uncertainty factor of 100 (10 for extrapolation from animals to humans and 10 for human variability).
[c]Used to derive a chronic-duration oral MRL of 0.008 mg/kg/day based on the $BMDL_{10}$ of 0.78 mg/kg/day and an uncertainty factor of 100 (10 for extrapolation from animals to humans and 10 for human variability).

Figure 2-X. Levels of Significant Exposure to [Chemical X] - Oral



APPENDIX E. QUICK REFERENCE FOR HEALTH CARE PROVIDERS

Toxicological Profiles are a unique compilation of toxicological information on a given hazardous substance. Each profile reflects a comprehensive and extensive evaluation, summary, and interpretation of available toxicologic and epidemiologic information on a substance. Health care providers treating patients potentially exposed to hazardous substances may find the following information helpful for fast answers to often-asked questions.

Primary Chapters/Sections of Interest

Chapter 1: Relevance to Public Health: The Relevance to Public Health Section provides an overview of exposure and health effects and evaluates, interprets, and assesses the significance of toxicity data to human health. A table listing minimal risk levels (MRLs) is also included in this chapter.

Chapter 2: Health Effects: Specific health effects identified in both human and animal studies are reported by type of health effect (e.g., death, hepatic, renal, immune, reproductive), route of exposure (e.g., inhalation, oral, dermal), and length of exposure (e.g., acute, intermediate, and chronic).
NOTE: Not all health effects reported in this section are necessarily observed in the clinical setting.

Pediatrics:
Section 3.2 Children and Other Populations that are Unusually Susceptible
Section 3.3 Biomarkers of Exposure and Effect

ATSDR Information Center

Phone: 1-800-CDC-INFO (800-232-4636) or 1-888-232-6348 (TTY)
Internet: http://www.atsdr.cdc.gov

ATSDR develops educational and informational materials for health care providers categorized by hazardous substance, clinical condition, and/or by susceptible population. The following additional materials are available online:

Clinician Briefs and Overviews discuss health effects and approaches to patient management in a brief/factsheet style. They are narrated PowerPoint presentations with Continuing Education credit available (see https://www.atsdr.cdc.gov/emes/health_professionals/clinician-briefs-overviews.html).

Managing Hazardous Materials Incidents is a set of recommendations for on-scene (prehospital) and hospital medical management of patients exposed during a hazardous materials incident (see https://www.atsdr.cdc.gov/MHMI/index.html).

Fact Sheets (ToxFAQs™) provide answers to frequently asked questions about toxic substances (see https://www.atsdr.cdc.gov/toxfaqs/Index.asp).

Other Agencies and Organizations

The National Center for Environmental Health (NCEH) focuses on preventing or controlling disease, injury, and disability related to the interactions between people and their environment outside the workplace. Contact: NCEH, Mailstop F-29, 4770 Buford Highway, NE, Atlanta, GA 30341-3724 • Phone: 770-488-7000 • FAX: 770-488-7015 • Web Page: https://www.cdc.gov/nceh/.

The National Institute for Occupational Safety and Health (NIOSH) conducts research on occupational diseases and injuries, responds to requests for assistance by investigating problems of health and safety in the workplace, recommends standards to the Occupational Safety and Health Administration (OSHA) and the Mine Safety and Health Administration (MSHA), and trains professionals in occupational safety and health. Contact: NIOSH, 400 7th Street, S.W., Suite 5W, Washington, DC 20024 • Phone: 202-245-0625 or 1-800-CDC-INFO (800-232-4636) • Web Page: https://www.cdc.gov/niosh/.

The National Institute of Environmental Health Sciences (NIEHS) is the principal federal agency for biomedical research on the effects of chemical, physical, and biologic environmental agents on human health and well-being. Contact: NIEHS, PO Box 12233, 104 T.W. Alexander Drive, Research Triangle Park, NC 27709 • Phone: 919-541-3212 • Web Page: https://www.niehs.nih.gov/.

Clinical Resources (Publicly Available Information)

The Association of Occupational and Environmental Clinics (AOEC) has developed a network of clinics in the United States to provide expertise in occupational and environmental issues. Contact: AOEC, 1010 Vermont Avenue, NW, #513, Washington, DC 20005 • Phone: 202-347-4976 • FAX: 202-347-4950 • e-mail: AOEC@AOEC.ORG • Web Page: http://www.aoec.org/.

The American College of Occupational and Environmental Medicine (ACOEM) is an association of physicians and other health care providers specializing in the field of occupational and environmental medicine. Contact: ACOEM, 25 Northwest Point Boulevard, Suite 700, Elk Grove Village, IL 60007-1030 • Phone: 847-818-1800 • FAX: 847-818-9266 • Web Page: http://www.acoem.org/.

The American College of Medical Toxicology (ACMT) is a nonprofit association of physicians with recognized expertise in medical toxicology. Contact: ACMT, 10645 North Tatum Boulevard, Suite 200-111, Phoenix AZ 85028 • Phone: 844-226-8333 • FAX: 844-226-8333 • Web Page: http://www.acmt.net.

The Pediatric Environmental Health Specialty Units (PEHSUs) is an interconnected system of specialists who respond to questions from public health professionals, clinicians, policy makers, and the public about the impact of environmental factors on the health of children and reproductive-aged adults. Contact information for regional centers can be found at http://pehsu.net/findhelp.html.

The American Association of Poison Control Centers (AAPCC) provide support on the prevention and treatment of poison exposures. Contact: AAPCC, 515 King Street, Suite 510, Alexandria VA 22314 • Phone: 701-894-1858 • Poison Help Line: 1-800-222-1222 • Web Page: http://www.aapcc.org/.

APPENDIX F. GLOSSARY

Absorption—The process by which a substance crosses biological membranes and enters systemic circulation. Absorption can also refer to the taking up of liquids by solids, or of gases by solids or liquids.

Acute Exposure—Exposure to a chemical for a duration of ≤14 days, as specified in the Toxicological Profiles.

Adsorption—The adhesion in an extremely thin layer of molecules (as of gases, solutes, or liquids) to the surfaces of solid bodies or liquids with which they are in contact.

Adsorption Coefficient (K_{oc})—The ratio of the amount of a chemical adsorbed per unit weight of organic carbon in the soil or sediment to the concentration of the chemical in solution at equilibrium.

Adsorption Ratio (Kd)—The amount of a chemical adsorbed by sediment or soil (i.e., the solid phase) divided by the amount of chemical in the solution phase, which is in equilibrium with the solid phase, at a fixed solid/solution ratio. It is generally expressed in micrograms of chemical sorbed per gram of soil or sediment.

Benchmark Dose (BMD) or Benchmark Concentration (BMC)—is the dose/concentration corresponding to a specific response level estimate using a statistical dose-response model applied to either experimental toxicology or epidemiology data. For example, a BMD_{10} would be the dose corresponding to a 10% benchmark response (BMR). The BMD is determined by modeling the dose-response curve in the region of the dose-response relationship where biologically observable data are feasible. The BMDL or BMCL is the 95% lower confidence limit on the BMD or BMC.

Bioconcentration Factor (BCF)—The quotient of the concentration of a chemical in aquatic organisms at a specific time or during a discrete time period of exposure divided by the concentration in the surrounding water at the same time or during the same period.

Biomarkers—Indicators signaling events in biologic systems or samples, typically classified as markers of exposure, effect, and susceptibility.

Cancer Effect Level (CEL)—The lowest dose of a chemical in a study, or group of studies, that produces significant increases in the incidence of cancer (or malignant tumors) between the exposed population and its appropriate control.

Carcinogen—A chemical capable of inducing cancer.

Case-Control Study—A type of epidemiological study that examines the relationship between a particular outcome (disease or condition) and a variety of potential causative agents (such as toxic chemicals). In a case-control study, a group of people with a specified and well-defined outcome is identified and compared to a similar group of people without the outcome.

Case Report—A report that describes a single individual with a particular disease or exposure. These reports may suggest some potential topics for scientific research, but are not actual research studies.

Case Series—Reports that describe the experience of a small number of individuals with the same disease or exposure. These reports may suggest potential topics for scientific research, but are not actual research studies.

Ceiling Value—A concentration that must not be exceeded.

Chronic Exposure—Exposure to a chemical for ≥365 days, as specified in the Toxicological Profiles.

Clastogen—A substance that causes breaks in chromosomes resulting in addition, deletion, or rearrangement of parts of the chromosome.

Cohort Study—A type of epidemiological study of a specific group or groups of people who have had a common insult (e.g., exposure to an agent suspected of causing disease or a common disease) and are followed forward from exposure to outcome, and who are disease-free at start of follow-up. Often, at least one exposed group is compared to one unexposed group, while in other cohorts, exposure is a continuous variable and analyses are directed towards analyzing an exposure-response coefficient.

Cross-sectional Study—A type of epidemiological study of a group or groups of people that examines the relationship between exposure and outcome to a chemical or to chemicals at a specific point in time.

Data Needs—Substance-specific informational needs that, if met, would reduce the uncertainties of human health risk assessment.

Developmental Toxicity—The occurrence of adverse effects on the developing organism that may result from exposure to a chemical prior to conception (either parent), during prenatal development, or postnatally to the time of sexual maturation. Adverse developmental effects may be detected at any point in the life span of the organism.

Dose-Response Relationship—The quantitative relationship between the amount of exposure to a toxicant and the incidence of the response or amount of the response.

Embryotoxicity and Fetotoxicity—Any toxic effect on the conceptus as a result of prenatal exposure to a chemical; the distinguishing feature between the two terms is the stage of development during which the effect occurs. Effects include malformations and variations, altered growth, and *in utero* death.

Epidemiology—The investigation of factors that determine the frequency and distribution of disease or other health-related conditions within a defined human population during a specified period.

Excretion—The process by which metabolic waste products are removed from the body.

Genotoxicity—A specific adverse effect on the genome of living cells that, upon the duplication of affected cells, can be expressed as a mutagenic, clastogenic, or carcinogenic event because of specific alteration of the molecular structure of the genome.

Half-life—A measure of rate for the time required to eliminate one-half of a quantity of a chemical from the body or environmental media.

Health Advisory—An estimate of acceptable drinking water levels for a chemical substance derived by EPA and based on health effects information. A health advisory is not a legally enforceable federal standard, but serves as technical guidance to assist federal, state, and local officials.

Immediately Dangerous to Life or Health (IDLH)—A condition that poses a threat of life or health, or conditions that pose an immediate threat of severe exposure to contaminants that are likely to have adverse cumulative or delayed effects on health.

Immunotoxicity—Adverse effect on the functioning of the immune system that may result from exposure to chemical substances.

Incidence—The ratio of new cases of individuals in a population who develop a specified condition to the total number of individuals in that population who could have developed that condition in a specified time period.

Intermediate Exposure—Exposure to a chemical for a duration of 15–364 days, as specified in the Toxicological Profiles.

***In Vitro*—**Isolated from the living organism and artificially maintained, as in a test tube.

***In Vivo*—**Occurring within the living organism.

Lethal Concentration$_{(LO)}$ (LC_{LO})—The lowest concentration of a chemical in air that has been reported to have caused death in humans or animals.

Lethal Concentration$_{(50)}$ (LC_{50})—A calculated concentration of a chemical in air to which exposure for a specific length of time is expected to cause death in 50% of a defined experimental animal population.

Lethal Dose$_{(LO)}$ (LD_{Lo})—The lowest dose of a chemical introduced by a route other than inhalation that has been reported to have caused death in humans or animals.

Lethal Dose$_{(50)}$ (LD_{50})—The dose of a chemical that has been calculated to cause death in 50% of a defined experimental animal population.

Lethal Time$_{(50)}$ (LT_{50})—A calculated period of time within which a specific concentration of a chemical is expected to cause death in 50% of a defined experimental animal population.

Lowest-Observed-Adverse-Effect Level (LOAEL)—The lowest exposure level of chemical in a study, or group of studies, that produces statistically or biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control.

Lymphoreticular Effects—Represent morphological effects involving lymphatic tissues such as the lymph nodes, spleen, and thymus.

Malformations—Permanent structural changes that may adversely affect survival, development, or function.

Minimal LOAEL—Indicates a minimal adverse effect or a reduced capacity of an organ or system to absorb additional toxic stress that does not necessarily lead to the inability of the organ or system to function normally.

Metabolism—Process in which chemical substances are biotransformed in the body that could result in less toxic and/or readily excreted compounds or produce a biologically active intermediate.

Minimal Risk Level (MRL)—An estimate of daily human exposure to a hazardous substance that is likely to be without an appreciable risk of adverse noncancer health effects over a specified route and duration of exposure.

Modifying Factor (MF)—A value (greater than zero) that is applied to the derivation of a Minimal Risk Level (MRL) to reflect additional concerns about the database that are not covered by the uncertainty factors. The default value for a MF is 1.

Morbidity—The state of being diseased; the morbidity rate is the incidence or prevalence of a disease in a specific population.

Mortality—Death; the mortality rate is a measure of the number of deaths in a population during a specified interval of time.

Mutagen—A substance that causes mutations, which are changes in the DNA sequence of a cell's DNA. Mutations can lead to birth defects, miscarriages, or cancer.

Necropsy—The gross examination of the organs and tissues of a dead body to determine the cause of death or pathological conditions.

Neurotoxicity—The occurrence of adverse effects on the nervous system following exposure to a hazardous substance.

No-Observed-Adverse-Effect Level (NOAEL)—The exposure level of a chemical at which there were no statistically or biologically significant increases in frequency or severity of adverse effects seen between the exposed population and its appropriate control. Although effects may be produced at this exposure level, they are not considered to be adverse.

Octanol-Water Partition Coefficient (K_{ow})—The equilibrium ratio of the concentrations of a chemical in *n*-octanol and water, in dilute solution.

Odds Ratio (OR)—A means of measuring the association between an exposure (such as toxic substances and a disease or condition) that represents the best estimate of relative risk (risk as a ratio of the incidence among subjects exposed to a particular risk factor divided by the incidence among subjects who were not exposed to the risk factor). An odds ratio that is greater than 1 is considered to indicate greater risk of disease in the exposed group compared to the unexposed group.

Permissible Exposure Limit (PEL)—An Occupational Safety and Health Administration (OSHA) regulatory limit on the amount or concentration of a substance not to be exceeded in workplace air averaged over any 8-hour work shift of a 40-hour workweek.

Pesticide—General classification of chemicals specifically developed and produced for use in the control of agricultural and public health pests (insects or other organisms harmful to cultivated plants or animals).

Pharmacokinetics—The dynamic behavior of a material in the body, used to predict the fate (disposition) of an exogenous substance in an organism. Utilizing computational techniques, it provides the means of studying the absorption, distribution, metabolism, and excretion of chemicals by the body.

Pharmacokinetic Model—A set of equations that can be used to describe the time course of a parent chemical or metabolite in an animal system. There are two types of pharmacokinetic models: data-based and physiologically-based. A data-based model divides the animal system into a series of compartments, which, in general, do not represent real, identifiable anatomic regions of the body, whereas the physiologically-based model compartments represent real anatomic regions of the body.

Physiologically Based Pharmacodynamic (PBPD) Model—A type of physiologically based dose-response model that quantitatively describes the relationship between target tissue dose and toxic endpoints. These models advance the importance of physiologically based models in that they clearly describe the biological effect (response) produced by the system following exposure to an exogenous substance.

Physiologically Based Pharmacokinetic (PBPK) Model—A type of physiologically based dose-response model that is comprised of a series of compartments representing organs or tissue groups with realistic weights and blood flows. These models require a variety of physiological information, including tissue volumes, blood flow rates to tissues, cardiac output, alveolar ventilation rates, and possibly membrane permeabilities. The models also utilize biochemical information, such as blood:air partition coefficients, and metabolic parameters. PBPK models are also called biologically based tissue dosimetry models.

Prevalence—The number of cases of a disease or condition in a population at one point in time.

Prospective Study—A type of cohort study in which a group is followed over time and the pertinent observations are made on events occurring after the start of the study.

Recommended Exposure Limit (REL)—A National Institute for Occupational Safety and Health (NIOSH) time-weighted average (TWA) concentration for up to a 10-hour workday during a 40-hour workweek.

Reference Concentration (RfC)—An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious noncancer health effects during a lifetime. The inhalation RfC is expressed in units of mg/m^3 or ppm.

Reference Dose (RfD)—An estimate (with uncertainty spanning perhaps an order of magnitude) of the daily oral exposure of the human population to a potential hazard that is likely to be without risk of deleterious noncancer health effects during a lifetime. The oral RfD is expressed in units of mg/kg/day.

Reportable Quantity (RQ)—The quantity of a hazardous substance that is considered reportable under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). RQs are (1) ≥1 pound or (2) for selected substances, an amount established by regulation either under CERCLA or under Section 311 of the Clean Water Act. Quantities are measured over a 24-hour period.

Reproductive Toxicity—The occurrence of adverse effects on the reproductive system that may result from exposure to a hazardous substance. The toxicity may be directed to the reproductive organs and/or the related endocrine system. The manifestation of such toxicity may be noted as alterations in sexual behavior, fertility, pregnancy outcomes, or modifications in other functions that are dependent on the integrity of this system.

Retrospective Study—A type of cohort study based on a group of persons known to have been exposed at some time in the past. Data are collected from routinely recorded events, up to the time the study is undertaken. Retrospective studies are limited to causal factors that can be ascertained from existing records and/or examining survivors of the cohort.

Risk—The possibility or chance that some adverse effect will result from a given exposure to a hazardous substance.

Risk Factor—An aspect of personal behavior or lifestyle, an environmental exposure, existing health condition, or an inborn or inherited characteristic that is associated with an increased occurrence of disease or other health-related event or condition.

Risk Ratio/Relative Risk—The ratio of the risk among persons with specific risk factors compared to the risk among persons without risk factors. A risk ratio that is greater than 1 indicates greater risk of disease in the exposed group compared to the unexposed group.

Serious LOAEL—A dose that evokes failure in a biological system and can lead to morbidity or mortality.

Short-Term Exposure Limit (STEL)—A STEL is a 15-minute TWA exposure that should not be exceeded at any time during a workday.

Standardized Mortality Ratio (SMR)—A ratio of the observed number of deaths and the expected number of deaths in a specific standard population.

Target Organ Toxicity—This term covers a broad range of adverse effects on target organs or physiological systems (e.g., renal, cardiovascular) extending from those arising through a single limited exposure to those assumed over a lifetime of exposure to a chemical.

Teratogen—A chemical that causes structural defects that affect the development of an organism.

Threshold Limit Value (TLV)—An American Conference of Governmental Industrial Hygienists (ACGIH) concentration of a substance to which it is believed that nearly all workers may be repeatedly exposed, day after day, for a working lifetime without adverse effect. The TLV may be expressed as a Time-Weighted Average (TLV-TWA), as a Short-Term Exposure Limit (TLV-STEL), or as a ceiling limit (TLV-C).

Time-Weighted Average (TWA)—An average exposure within a given time period.

Toxicokinetic—The absorption, distribution, metabolism, and elimination of toxic compounds in the living organism.

Toxics Release Inventory (TRI)—The TRI is an EPA program that tracks toxic chemical releases and pollution prevention activities reported by industrial and federal facilities.

Uncertainty Factor (UF)—A factor used in operationally deriving the Minimal Risk Level (MRL), Reference Dose (RfD), or Reference Concentration (RfC) from experimental data. UFs are intended to account for (1) the variation in sensitivity among the members of the human population, (2) the uncertainty in extrapolating animal data to the case of human, (3) the uncertainty in extrapolating from data obtained in a study that is of less than lifetime exposure, and (4) the uncertainty in using lowest-observed-adverse-effect level (LOAEL) data rather than no-observed-adverse-effect level (NOAEL) data. A default for each individual UF is 10; if complete certainty in data exists, a value of 1 can be used; however, a reduced UF of 3 may be used on a case-by-case basis (3 being the approximate logarithmic average of 10 and 1).

Xenobiotic—Any substance that is foreign to the biological system.

APPENDIX G. ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AAPCC	American Association of Poison Control Centers
ACGIH	American Conference of Governmental Industrial Hygienists
ACOEM	American College of Occupational and Environmental Medicine
ACMT	American College of Medical Toxicology
ADI	acceptable daily intake
ADME	absorption, distribution, metabolism, and excretion
AEGL	Acute Exposure Guideline Level
AIC	Akaike's information criterion
AIHA	American Industrial Hygiene Association
ALT	alanine aminotransferase
AOEC	Association of Occupational and Environmental Clinics
AP	alkaline phosphatase
AST	aspartate aminotransferase
atm	atmosphere
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
BCF	bioconcentration factor
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
BUN	blood urea nitrogen
C	centigrade
CAA	Clean Air Act
CAS	Chemical Abstract Services
CDC	Centers for Disease Control and Prevention
CEL	cancer effect level
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
Ci	curie
CI	confidence interval
cm	centimeter
CPSC	Consumer Products Safety Commission
CWA	Clean Water Act
DNA	deoxyribonucleic acid
DOD	Department of Defense
DOE	Department of Energy
DWEL	drinking water exposure level
EAFUS	Everything Added to Food in the United States
ECG/EKG	electrocardiogram
EEG	electroencephalogram
EPA	Environmental Protection Agency
ERPG	emergency response planning guidelines
F	Fahrenheit
F1	first-filial generation
FDA	Food and Drug Administration
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FR	Federal Register

FSH	follicle stimulating hormone
g	gram
GC	gas chromatography
gd	gestational day
GGT	γ-glutamyl transferase
GRAS	generally recognized as safe
HEC	human equivalent concentration
HED	human equivalent dose
HHS	Department of Health and Human Services
HPLC	high-performance liquid chromatography
HSDB	Hazardous Substances Data Bank
IARC	International Agency for Research on Cancer
IDLH	immediately dangerous to life and health
IRIS	Integrated Risk Information System
Kd	adsorption ratio
kg	kilogram
kkg	kilokilogram; 1 kilokilogram is equivalent to 1,000 kilograms and 1 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	lactate dehydrogenase
LH	luteinizing hormone
LOAEL	lowest-observed-adverse-effect level
LSE	Level of Significant Exposure
LT_{50}	lethal time, 50% kill
m	meter
mCi	millicurie
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MF	modifying factor
mg	milligram
mL	milliliter
mm	millimeter
mmHg	millimeters of mercury
mmol	millimole
MRL	Minimal Risk Level
MS	mass spectrometry
MSHA	Mine Safety and Health Administration
Mt	metric ton
NAAQS	National Ambient Air Quality Standard
NAS	National Academy of Science
NCEH	National Center for Environmental Health
ND	not detected
ng	nanogram
NHANES	National Health and Nutrition Examination Survey
NIEHS	National Institute of Environmental Health Sciences

NIOSH	National Institute for Occupational Safety and Health
NLM	National Library of Medicine
nm	nanometer
nmol	nanomole
NOAEL	no-observed-adverse-effect level
NPL	National Priorities List
NR	not reported
NRC	National Research Council
NS	not specified
NTP	National Toxicology Program
OR	odds ratio
OSHA	Occupational Safety and Health Administration
PAC	Protective Action Criteria
PAH	polycyclic aromatic hydrocarbon
PBPD	physiologically based pharmacodynamic
PBPK	physiologically based pharmacokinetic
PEHSU	Pediatric Environmental Health Specialty Unit
PEL	permissible exposure limit
PEL-C	permissible exposure limit-ceiling value
pg	picogram
PND	postnatal day
POD	point of departure
ppb	parts per billion
ppbv	parts per billion by volume
ppm	parts per million
ppt	parts per trillion
REL	recommended exposure limit
REL-C	recommended exposure limit-ceiling value
RfC	reference concentration
RfD	reference dose
RNA	ribonucleic acid
SARA	Superfund Amendments and Reauthorization Act
SCE	sister chromatid exchange
SD	standard deviation
SE	standard error
SGOT	serum glutamic oxaloacetic transaminase (same as aspartate aminotransferase or AST)
SGPT	serum glutamic pyruvic transaminase (same as alanine aminotransferase or ALT)
SIC	standard industrial classification
SMR	standardized mortality ratio
sRBC	sheep red blood cell
STEL	short term exposure limit
TLV	threshold limit value
TLV-C	threshold limit value-ceiling value
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
USNRC	U.S. Nuclear Regulatory Commission

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