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Framework for Inorganic Metals Risk Assessment

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LIST OF ABBREVIATIONS AND ACRONYMS

1CFOK	One-Compartment, First-Order Kinetics Model
ABA	Absolute bioavailability
aBLM	Aquatic Biotic Ligand Model
ACF	Accumulation factor
AEC	Anion exchange capacity
AESOP	Advanced Ecological Systems Operating Program
AI	Adequate intake
ALA	Aminolevulinic acid
ALM	Adult lead methodology
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resources Management Council of Australia and New Zealand
ATSDR	Agency for Toxic Substances and Disease Registry
AUC	Area under the curve
AVS	Acid-volatile sulfide
AWQC	Ambient Water Quality Criteria
BAF	Bioaccumulation factor
BCF	Bioconcentration factor
BF	Bioaccessible fraction
BLM	Biotic Ligand Model
BMD	Benchmark dose
BSAF	Biota/sediment accumulation factor
CAA	Clean Air Act
CATM	Center for Air Toxic Metals
CBR	Critical body residue
CCA	Chromated copper arsenate
CCC	Criterion continuous concentration
CEC	Cation exchange capacity
CHESS	Chemical Equilibria in Soils and Solutions
CHMTRNS	Chemical Transport model
CHNTRN	Channel Transport model
CMAQ	Community Multi-scale Air Quality model
CMC	Criterion maximum concentration

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

CSF	Cancer slope factor
CTAP	Chemical Transport and Analysis Program
CWA	Clean Water Act
DELFT3D	Delft 3-Dimensional model
DEPM	Dietary Exposure Potential Model
DHHS	U.S. Department of Health and Human Services
DJOC	Donald J. O'Connor model
DL	Diffuse Layer model
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DYNTOX	Dynamic Toxics model
EC	Effect concentration
ECOFRAM	Ecological Committee on FIFRA Risk Assessment Methods
ECOM	Estuary, Coastal, Ocean Model
ECOMSED	Estuary, Coastal, Ocean Model (ECOM) updated for sediment transport
EcoSSL	Ecological soil screening level
EERC	Energy and Environmental Research Center (University of North Dakota)
Eh	Redox (reduction-oxidation) potential
EPMA-SEM	Electron probe microanalysis-scanning electron microscopy
EqP	Equilibrium partitioning
ESB	Equilibrium partitioning sediment benchmark
EU	European Union
EUSES	European Union System for the Evaluation of Substances model
EUTRO	Water Quality Analysis Simulation Program (WASP) for Eutrophication
EXAMS	Exposure Analysis Modeling System
f_{OC}	Fraction of organic carbon (mass, for sediment)
FAV	Final acute value
FCV	Final chronic value
FDA	Food and Drug Administration
FETRA	Sediment/Radionuclide Transport Model
FIAM	Free Ion Activity Model
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

FNB	Food and Nutrition Board (NAS)
GI	Gastrointestinal tract
GM	General Motors III model
GMAV	Genus mean acute value
GSIM	Gill Surface Interaction Model
GTLM	Generalized Two-Layer Model
HFO	Hydrous ferric oxide
HLA	Human leukocyte antigens
HOC	Hydrophobic organic compound
HSAB	Hard and soft acid and base
HSP	Hydrologic Simulation Program *(Fortran program also referenced as HSPF)*
HSPF	Hydrologic Simulation Fortran Program
HSRC	Hazardous Substance Research Center
HST3D	3-Dimensional Flow, Heat and Solute Transport model
IBM	Ion Balance Model
ICP-MS	Inductively coupled plasma-mass spectrometry
IEUBK	Integrated Exposure Uptake Biokinetic model
IRIS	Integrated Risk Information System
IWBU	Interstitial Water Benchmark Unit
K_d	Partition distribution coefficient
K_{ow}	Octanol-water partition coefficient
LC_x	Lethal concentration (for x percent of the study population)
LOAEL	Lowest-observed-adverse-effect level
MAP	Metals Action Plan
M:BL	Metal-Biotic Ligand model
MCL	Maximum contaminant level
META4	Metal Exposure and Transformation Assessment model
MEXAMS	Metals Exposure Analysis Modeling Systems
MITE-RN	Metals in the Environment Research Network
MNA	Monitored natural attenuation
MT	Metallothionein
MW	Molecular weight

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

NAS	National Academy of Sciences
NAS/IOM	National Academy of Sciences/Institute of Medicine
NASQAN	National Stream Quality Accounting Network
NIEHS	National Institute of Environmental Health Sciences
NOAEL	No-observed-adverse-effect level
NOM	Natural organic matter
NRC	National Research Council
OAR	Office of Air and Radiation (EPA)
OECD	Organization for Economic Cooperation and Development
OM	Organic matter
OP	Organophosphorous
OPIDN	Organophosphate-induced delayed neurotoxicity
OPP	Office of Pesticide Programs (EPA)
ORD	Office of Research and Development (EPA)
OST	Office of Water, Office of Science and Technology (EPA)
OSWER	Office of Solid Waste and Emergency Response (EPA)
Pawtoxic	Pawtuxent Toxic model
PbL	Blood lead
PBPD	Physiologically based pharmacodynamic
PBPK	Physiologically based pharmacokinetic
PBT	Persistent bioaccumulative toxic
PBTK	Physiologically based toxicokinetic
PDM	Probabilistic Dilution Model
pE	Negative log of electron activity
PEC	Predicted environmental concentration
PNEC	Predicted no-effect concentration
PICT	Pollution-induced community tolerance
PIXE	Particle induced x-ray emission (also μPIXE)
PM	Particulate matter
POC	Particulate organic carbon
QICAR	Quantitative ion character-activity relationship
QSAR	Quantitative structure-activity relationship

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

QWASI	Quantitative Water Air Sediment Interaction model
RAF	Relative absorption factor
RAGS	Risk Assessment Guidance for Superfund
RBA	Relative bioavailability
RCATOX	Row-Column Advanced ecological systems operating program for Toxics model
RCRA	Resource Conservation and Recovery Act
RDA	Recommended dietary allowance
RfC	Reference concentration
RfD	Reference dose
RIVEQLII	River Quality II model
RIVRISK	River Risk model
RTC	Report to Congress
SAB	Science Advisory Board
SCAMP	Surface Chemistry Assemblage Model for Particles
SEM	Simultaneously extracted metals
SERATRA	Sediment Radionuclide Transport model
SHEDS	Stochastic Human Exposure and Dose Simulation model
SIMS	Secondary ion mass spectrometry
SLSA	Simplified Lake and Stream Analysis model
SMAV	Species mean acute value
SPC	Science Policy Council (EPA)
SPM	Suspended particulate matter
SMPTOX	Simplified Method-Program Variable-Complexity Stream Toxics
SPQ	Hydrologic Simulation Program-FORTRAN model
SQG	Sediment quality guideline
SRWG	Science and Research Working Group (SRWG) of the Non-Ferrous Metals Consultative Forum on Sustainable Development
SSD	Species sensitivity distribution
STATSGO	State Soil Geographic Database
STORET	Storage and Retrieval data system
tBLM	Terrestrial Biotic Ligand Model

LIST OF ABBREVIATIONS AND ACRONYMS (continued)

TD	Toxicodynamic
TEF	Toxicity equivalence factor
TIE	Toxicity identification evaluation
TMDL	Total maximum daily load
TRANSPEC	Transport and Speciation model
TRIM	Total Risk Integrated Methodology model
TRIM.FaTE	Total Risk Integrated Methodology Fate, Transport, and Ecological Exposure model
TRV	Toxicity reference value
TSCA	Toxic Substances Control Act
TTD	Target-organ toxicity dose
TTM	Total toxicity of mixture
TU	Toxic unit
U.S. EPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	Volatile organic compound
WASP	Water Quality Analysis Simulation Program
WASTOX	Water Quality Analysis Simulation of Toxics
WER	Water-effect ratio
WHAM	Windermere Humic Aqueous Model
WHO	World Health Organization
WHO/IPCS	World Health Organization/International Programme on Chemical Safety
WOE	Weight of evidence
WQAM	Water Quality Assessment Methodology model
WQC	Water quality criterion
WQG	Water quality guideline
XAS	X-ray absorption spectroscopy
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction

PREFACE

Many U.S. Environmental Protection Agency (EPA or the Agency) programs face decisions on whether and how to regulate metals. These decisions range from setting standards or permitting for environmental releases, to establishing safe levels in different environmental media, to setting priorities for programmatic or voluntary efforts. A fundamental input to the decision-making process for most EPA programs is an assessment of potential risks to human health and the environment.

EPA's Science Policy Council recognizes that metals present unique risk assessment issues and tasked an Agency workgroup, under the auspices of EPA's Risk Assessment Forum, with devising a Metals Action Plan (MAP) to establish a process for ensuring the consistent application of scientific principles to metals risk assessment. The MAP included brief descriptions of the Agency's current activities on metals, identified critical scientific issues that need addressing, and recommended the development of a Metals Risk Assessment Framework. The MAP stated that the framework should offer general guidance to EPA programs for considering the various properties of metals, such as environmental chemistry, bioavailability, and bioaccumulation.

Because of the scientific complexity of metal-specific risk assessment, the Agency recognized the need to include stakeholders and the public in the framework development process and to involve experts throughout the Agency. A stepwise process was initiated, beginning with the MAP and continuing with framework development and review. Workshops and peer-review activities were conducted at multiple intervals during framework production to ensure current and accurate science that supported program applications. To gain additional information, the Agency contracted for the development of issue papers on important topics in metals assessment. These activities, along with input from other federal agencies and review by EPA's Science Advisory Board (SAB), provided additional improvements. Additional details on these activities are provided below.

MAP Stakeholder Input. In February 2002, a meeting was convened to gather stakeholder input to help EPA formulate the plan for developing this framework. EPA solicited input on organization and content and received comments that were adopted to the extent practicable. The meeting report and comments are available on EPA's Web site at http://cfpub2.epa.gov/ncea/raf/recordisplay.cfm?deid=51737 and http://cfpub2.epa.gov/ncea/raf/recordisplay.cfm?deid=51736.

Science Advisory Board Review. In September 2002, EPA's SAB reviewed the MAP and provided comments. Some of the panel's recommendations are summarized below, and all are available in full at http://www.epa.gov/sab/pdf/ecl03001.pdf.

- The panel agreed that inorganic metals should be assessed differently from organic pollutants in a number of contexts. Metals are elements and, although they do not degrade, they have complex environmental chemistry. Moreover, some metals are essential for living organisms, and metals occur naturally in the environment.

- The panel agreed that chemical speciation, bioavailability, bioaccumulation, and toxicity are key issues in assessing the hazards of metals, with some qualifications.

- The panel recommended consideration of stability and environmental residence times, as well as overall environmental chemistry, to determine temporal characteristics of metal hazards.

- The panel recommended greater emphasis on the combined effects of metals, including nutritional and toxicological considerations.

Issue Paper Topics and Science Questions. Issue papers were developed to discuss key scientific topics pertaining to inorganic metals. The issue paper authors were asked to expand on these topics, with focus on decison-making applications, framework-specific uses, and research needs. The papers are available at http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=86119. The topics and primary questions addressed by the papers include the following:

- **Environmental chemistry.** How can environmental chemistry be better incorporated into assessments for inorganic metals?

- **Bioavailability and bioaccumulation of metals.** What methods or tools can be used now to reflect metal bioavailability? What scientifically based approaches can be used to determine metal bioaccumulation?

- **Metal exposure assessment.** What are the relevant exposure pathways for inorganic metals to humans and ecological endpoints?

- **Human health effects.** What populations are most susceptible to effects from inorganic metals? How should toxicity tests be conducted and interpreted, including issues of essential elements, dietary salts, and others?

- **Ecological effects.** What ecological system characteristics promote increased toxicity from metals?

Peer Consultation Workshop. A draft framework was completed in July 2004, and a peer consultation workshop was held on July 27–28 to seek input from scientists expert in the field of metals risk assessment. Scientists participating in the workshop were from academia; industry, state, federal, and Canadian agencies; and various Offices within EPA. Stakeholder comments were also received for consideration. Based on comments received at the workshop, the Agency contracted with a few workshop participants to expand on several gaps and issues identified in the human health and environmental chemistry discussions. The document was revised, and the revised report was made available for inter-Agency review.

Inter-Agency Review. Based on comments received, the framework was revised.

SAB Review and Public Comment. Pending.

AUTHORS, CONTRIBUTORS, AND REVIEWERS

CO-CHAIRS

Anne Fairbrother, U.S. EPA, Office of Research and Development, National Health and Environmental Effects Laboratory, Corvallis, OR

Randy Wentsel, U.S. EPA, Office of Water, Washington, DC

STEERING COMMITTEE

Marilyn Brower, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Risk Assessment Forum, Washington, DC

Stephen Devito, U.S. EPA, Office of Environmental Information, Washington, DC

Alexander McBride, U.S. EPA, Office of Solid Waste and Emergency Response, Washington, DC (Retired)

David Mount, U.S. EPA, Office of Research and Development, National Health and Environmental Effects Laboratory, Duluth, MN

Pamela Noyes, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Risk Assessment Forum, Washington, DC

Keith Sappington, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Washington, DC

William Wood, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Risk Assessment Forum, Washington, DC

CONTRIBUTORS

Environmental Chemistry:

Kim Anderson, Oregon State University, Corvallis, OR

Rufus Chaney, U.S. Department of Agriculture, Beltsville, MD[1]

Paul Chrostowski, CPF Associates, Inc., Takoma Park, MD[1]

Miriam L. Diamond, University of Toronto, Toronto, ON, Canada

Robert Ford, U.S. EPA, Office of Research and Development, National Risk Management Research Laboratory, Ada, OK

Donald Langmuir, Hydrochem Systems Corp., Colorado School of Mines, Golden, CO[1]

Deborah Luecken, U.S. EPA, Office of Research and Development, National Exposure Research Laboratory, Research Triangle Park, NC

Michael Newman, The College of William and Mary, Gloucester Point, VA

Robert Puls, U.S. EPA, Office of Research and Development, National Risk Management Research Laboratory, Ada, OK

Bernard Vigneault, CANMET Mining & Mineral Sciences Laboratories/Natural Resources, Ottawa, ON, Canada[1]

Bioavailability and Bioaccumulation:

Michael Beringer, U.S. EPA, Region VII, Kansas City, KS

John Drexler, University of Colorado, Boulder, CO[1]

Nicholas Fisher, State University of New York, Stony Brook, NY[1]

Gerry Henningsen, H&H Scientific Services, Centennial, CO[1]

Roman Lanno, Ohio State University, Columbus, OH[1]

Jim McGeer, Natural Resources Canada, Ottawa, ON, Canada[1]

Keith Sappington, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Washington, DC[1]

Exposure:

Gary Diamond, Syracuse Research Corp., Syracuse, NY[1]

Charlie Menzie, Menzie-Cura & Associates, Inc., Chelmsford, MA[1]

Jacqueline Moya, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Washington, DC[1]

Michael Newman, The College of William and Mary, Gloucester Point, VA[1]

Jerome Nriagu, University of Michigan, Ann Arbor, MI[1]

Human Health Effects:
Ed Bender, U.S. EPA, Office of Research and Development, Office of Science Policy, Washington, DC

Michael Beringer, U.S. EPA, Region VII, Kansas City, KS

Harlal Choudhury, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Cincinnati, OH[1]

Dominic Di Toro, University of Delaware, Newark, DE

Mari Hirtzel Golub, University of California, Davis, CA[1]

Robert Goyer, University of Western Ontario, National Research Council Board Member/Chair[1]

Mike Hughes, U.S. EPA, Office of Research and Development, National Health and Ecological Effects Research Laboratory, Washington, DC[1]

Richard Hertzberg, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Atlanta, GA

Elaina Kenyon, U.S. EPA, Office of Research and Development, National Health and Ecological Effects Research Laboratory, Washington, DC[1]

Fran Kremer, U.S. EPA, Office of Research and Development, National Risk Management Research Laboratory, Washington, DC

Deirdre Murphy, U.S. EPA, Office of Air, Research Triangle Park, NC

Mark Stifelman, U.S. EPA, Region X, Seattle, WA[1]

Ecological Effects:
William Clements, Colorado State University, Ft. Collins, CO[1]

Heidi Bell, U.S. EPA, Office of Water, Washington, DC

Peter Chapman, EVS Environment Consultants, N. Vancouver, BC, Canada

Dale Hoff, U.S. EPA, Region VIII, Denver, CO

Larry Kapustka, Ecological Planning and Toxicology, Inc., Corvallis, OR[1]

Michael Newman, The College of William and Mary, Gloucester Point, VA

Paul Paquin, HydroQual, Inc., Mahwah, NJ[1]

Cindy Roberts, U.S. EPA, Office of Water, Washington, DC

Mark Sprenger, U.S. EPA, Office of Solid Waste and Emergency Response, Washington, DC[1]

Dan Wall, U.S. Department of the Interior, U.S. Fish and Wildlife Service, Washington, DC

Linda Ziccardi, Exponent, Boulder, CO[1]

METALS ISSUE PAPER AUTHORS[2]

Environmental Chemistry of Metals:

Donald Langmuir, Hydrochem Systems Corp., Colorado School of Mines, Golden, CO

Paul Chrostowski, CPF Associates, Inc., Takoma Park, MD

Rufus Chaney, U.S. Department of Agriculture, Beltsville, MD

Bernard Vigneault, CANMET Mining and Mineral Sciences Laboratories/Natural Resources Canada, Ottawa, ON

Metal Exposure Assessment:

Michael Newman, The College of William and Mary/VIMS, Gloucester Point, VA

Gary Diamond, Syracuse Research Corp., Syracuse, NY

Charles Menzie, Menzie-Cura & Associates, Chelmsford, MA

Jerome Nriagu, University of Michigan, Ann Arbor, MI

Ecological Effects of Metals:

Lawrence Kapustka, Ecological Planning and Toxicology, Inc., Corvallis, OR

William Clements, Colorado State University, Fort Collins, CO

Linda Ziccardi, Exponent, Boulder, CO

Paul Paquin, HydroQual, Inc., Mahwah, NJ

Mark Sprenger, U.S. EPA, Edison, NJ

Daniel Wall, U.S. Fish and Wildlife Service, Denver, CO

Human Health Effects of Metals:

Robert Goyer, University of Western Ontario, ON

Mari, Golub, University of California, Davis, CA

Harlal Choudhury, U.S. EPA, Cincinnati, OH (contributor)

Michael Hughes, U.S. EPA, Research Triangle Park, NC (contributor)
Elaina Kenyon, U.S. EPA, Research Triangle Park, NC (contributor)

Marc Stifelman, U.S. EPA, Seattle, WA (contributor)

Bioavailability and Bioaccumulation of Metals:

John Drexler, University of Colorado, Boulder, CO

Nicholas Fisher, State University of New York, Stony Brook, NY

Gerry Henningsen, H&H Scientific Services, Centennial, CO

Roman Lanno, Ohio State University, Columbus, OH

Jim McGeer, Natural Resources Canada, Ottawa, ON

Keith Sappington, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Washington, DC

Michael Beringer, U.S. EPA, Region VII, Kansas City, KS (contributor)

PEER CONSULTATION WORKSHOP PARTICIPANTS

Breakout Group 1 (Overall Framework):

Pat Doyle, Environment Canada, Ottawa, ON (breakout group lead)

Charles Menzie, Menzie-Cura & Associates, Chelmsford, MA (Workshop Chairman)

Bruce K. Hope, Oregon Department of Environmental Quality, Portland, OR

Breakout Group 2 (Environmental Chemistry):
Rufus Chaney, U.S. Department of Agriculture, Beltsville, MD (breakout group lead)

Donald Langmuir, Hydrochem Systems Corp., Colorado School of Mines, Golden, CO

Mark Barnett, Department of Civil Engineering, Auburn University, AL

Roman Lanno, Ohio State University, Columbus, OH

Jim Ryan, U.S. EPA, Office of Research and Development, National Risk Management Research Laboratory, Cincinnati, OH

Breakout Group 3 (Terrestrial Exposure/Effects):
John Drexler, University of Colorado, Boulder, CO (breakout group lead)

Lawrence Kapustka, Ecological Planning and Toxicology, Inc., Corvallis, OR

Bradley Sample, CH2M Hill, Sacramento, CA

Beverly Hale, University of Guelph, Guelph, ON

Breakout Group 4 (Aquatic Exposure/Effects):
Keith Sappington, U.S. EPA, Office of Research and Development, National Center for Environmental Assessment, Washington, DC (breakout group lead)

David Mount, U.S. EPA, Office of Research and Development, National Health and Environmental Effects Laboratory, Duluth, MN

Jim McGeer, Natural Resources Canada, Ottawa, ON

Steve Klaine, Clemson University, Clemson, SC

Paul Paquin, HydroQual, Inc., Mahwah, NJ

Anne Smith-Reiser, Analytical Services Inc., Jessup, MD

Breakout Group 5 (Human Exposure/Health Effects):
Steve Devito, U.S. EPA, Office of Environmental Information, Washington, DC (breakout group lead)

Mari Golub, University of California, Davis, CA

Herman Gibb, Sciences International, Alexandria, VA

Rosalind A. Schoof, Integral Consulting, Inc., Mercer Island, WA

Deirdre Murphy, U.S. EPA, Office of Research and Development, Office of Radiation, Office of Air Quality Planning and Standards, Research Triangle Park, NC

Alexander McBride, U.S. EPA, Office of Solid Waste and Emergency Response, Washington, DC

Margaret MacDonell, U.S. Department of Energy, Argonne National Laboratory, Argonne, IL

Bob Jones, U.S. EPA, Office of Prevention, Pesticides, and Toxic Substances, Washington, DC

Richard Troast, U.S. EPA, Office of Solid Waste and Emergency Response, Washington, DC

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[1]Scientific expert commissioned to develop paper on issues and state-of-the-art approaches in metals risk assessment.

[2] Information from the metals issue papers was used in the development of this framework.

EXECUTIVE SUMMARY

The Framework for Inorganic Metals Risk Assessment is a science-based document that addresses the special attributes and behaviors of metals and metal compounds when assessing their human health and ecological risks. The document describes basic principles to be considered in assessing risks posed by metals and presents a consistent approach for use across the Agency when conducting these assessments. Although the audience for the framework is primarily intended to be Agency risk assessors, it will also communicate principles, tools, and recommendations for metal risk assessment to stakeholders and the public. The Agency developed this framework document to supplement previous guidance for use in site-specific risk assessments, criteria derivation, ranking or categorization, and other similar Agency activities related to metals.

One of the purposes of this document is to present key principles that contain specific issues which differentiate inorganic metals from other chemicals when assessing their risk to human health and the environment. While we recognize that organic compounds, for example, undergo bioaccumulation, there are unique properties, issues, and processes within these principles that assessors need to consider when evaluating metal compounds. For example, the latest scientific data on bioaccumulation do not currently support the use of bioconcentration factor (BCF) and bioaccumulation factor (BAF) data when applied as generic threshold criteria for the hazard potential of inorganic metals (e.g., for classification as a "PBT" chemical). These principles should be addressed and incorporated into metals risk assessment to the extent practicable. They include the following:

• Environmental background concentrations • Essentiality • Environmental chemistry • Bioavailability	• Accumulation/bioaccumulation and bioconcentration • Acclimation, adaptation, and tolerance • Toxicity testing • Mixtures

This document discusses, in Section 2, why these principles are important in ecological and human health risk assessments and presents conceptual models on metal-specific attributes and bioavailability. In Section 3, the framework provides assessors with recommendations and method applications, and supports these recommendations with technical discussions, in Section 4, on metal-specific topics, including environmental chemistry, human health exposure pathway and effects analysis, and ecological exposure pathway and effects analysis. Section 5 presents research needs to improve the science supporting the assessment of metals and metal compounds. This framework document will not be a prescriptive guide on how any particular type of assessment should be conducted within a U.S. EPA program office. Rather, it is intended to provide recommendations and foster the consistent application of methods and data to metals risk assessment in consideration of the unique properties of metals.

While this document discusses scientific issues and makes recommendations about scientific approaches, this framework does not address the science policy questions and issues which are raised. Rather, it is intended to make recommendations and foster the consistent application of methods and data to metals risk assessment in consideration of the unique properties of metals. Consistent with these recommendations, the Agency will be analyzing the science policy implications and developing appropriate policy approaches which are protective of human health and the environment.

The framework is the result of contributions from a variety of individuals inside and outside the Agency. Their combined expertise and enthusiasm have improved the technical quality of the document and its applicability for various risk assessment activities.

1. INTRODUCTION

Metals and metal compounds have unique characteristics that should be considered when assessing their risks. Some of these characteristics are typically not considered when assessing the risks of organic substances. For example, although metals are neither created nor destroyed by biological or chemical processes, they are transformed from one chemical form to another. Native (zero valence) forms of metal and some inorganic metal compounds are not readily soluble, and as a result, toxicity tests based on soluble salts may overestimate the bioavailability and toxicity of these substances. Some metals are essential elements at low levels but toxic at higher levels (e.g., copper, selenium, and zinc), whereas others have no known biological functions (e.g., lead, arsenic, and mercury). Because metals are naturally occurring, many organisms have evolved mechanisms to regulate accumulations, especially those of essential metals. Because the majority of compounds assessed by the U.S. Environmental Protection Agency (EPA or the Agency) are organic substances, the various guidance documents provided for risk assessments of either human health or ecological receptors lack specificity on how to account for these and other metal attributes.

1.1. PURPOSE AND AUDIENCE

The Agency developed this framework document to supplement previous guidance for use in site-specific risk assessments; criteria derivation, ranking, or categorization; and other similar Agency activities related to metals. This framework document will not be a prescriptive guide on how any particular type of assessment should be conducted within an EPA program office. Rather, it is intended to provide recommendations and foster the consistent application of methods and data to metals risk assessment in consideration of the unique properties of metals.

The inorganic metals risk assessment framework describes basic principles to be considered in assessing risks posed by metals and presents a consistent approach for use across the Agency when conducting these assessments. Although the primary audience will be Agency risk assessors, the framework will also communicate principles, tools, and recommendations for metals risk assessment to stakeholders and the public. In addition, the framework relies heavily on issue papers developed, under EPA commission, on key scientific topics pertaining to inorganic metals. The papers are available on EPA's website at http://cfpub.epa.gov/ncea/raf/recordisplay.cfm?deid=86119.

The metals framework is intended for guidance only. It does not establish any substantive "rules" under the Administrative Procedure Act or any other law and will have no binding effect on EPA or any regulated entity. Rather, it represents a nonbinding statement of policy. EPA believes that the metals framework provides a sound, up-to-date presentation of principles, tools, and recommendations for assessing the risk posed by metals and serves to enhance the application of the best available science in Agency risk assessments. However, EPA may conduct metals risk assessments using approaches and tools that differ from those described in the framework for many reasons, including, but not limited to, new information, new scientific understandings, and new science policy judgments. The science surrounding metals risk assessment continues to be intensively studied and thus is rapidly evolving. Specific principles, tools, or recommendations presented in the framework may become outdated or may otherwise require modification to reflect the best available science. Application of this framework in future metals risk assessments will be based on EPA decisions that its approaches are suitable and appropriate. These judgments will be tested and examined through peer review, and any risk analysis will be modified as deemed appropriate.

1.2. METALS FRAMEWORK SCOPE

The metals risk assessment framework is a science-based document that focuses on the special attributes and behaviors of metals and metal compounds affecting human health and ecological risk assessments. It does not set forth a step-by-step process to assess the risk of metals to human health or the environment but, rather, focuses on principles, tools, and methods coupled with recommendations to guide assessors in addressing the unique properties of inorganic metals. It supplements existing guidance and does not cover elements of the risk assessment process that are not unique to metals because these are adequately addressed in other Agency guidelines and strategies (e.g., U.S. EPA, 2003a, 2000a, 1998a).

The Agency regulates metals and their inorganic and organometallic compounds because they have the potential to harm human health and the environment. The Agency's Science Advisory Board has stressed the importance of environmental chemistry and its relevance to the assessment of both inorganic and organometallic compounds. However, the complexities of addressing all types of metal compounds within a single document would result in a framework that would be difficult to follow or to apply in specific cases. Because organometallic compounds exhibit properties common to both

Metals and Metalloids of Interest

Aluminum	Manganese
Antimony	Mercury (inorganic)
Arsenic	Molybdenum
Barium	Nickel
Beryllium	Selenium
Boron	Silver
Cadmium	Strontium
Chromium	Tin
Cobalt	Thallium
Copper	Vanadium
Iron	Zinc
Lead	

organic substances and inorganic metal compounds, the properties of both the organic moieties of these compounds and their inorganic components would need to be addressed. Frameworks and associated guidance documents for assessing properties of organic compounds have already been developed by EPA and do not need to be discussed further here. Therefore, this document addresses only those assessment issues associated with inorganic metal compounds. The framework does discuss natural transformation pathways that form organometallic compounds and refers the reader to appropriate Agency documentation or research efforts related to relevant risk assessment issues.

In this document, the term "metals" generally refers to metals and metalloids that may pose a toxic hazard and are currently of primary interest to EPA. However, the principles and approaches set forth in the framework are applicable to all metals. In some instances, metal-by-metal considerations are included, either to serve as examples or to highlight particular exceptions.

1.3. RISK ASSESSMENT FRAMEWORK

Risk assessment provides a qualitative and quantitative comparison of the relationship between environmental exposures and effects in exposed individuals and other organisms. In 1983, the National Research Council described four primary steps in the process of risk assessment: hazard identification, dose-response assessment, exposure assessment, and risk characterization. EPA has developed a similar framework for ecological risk assessment and included a problem formulation step (U.S. EPA, 1998a). This framework document provides recommendations, including applications and limitations of currently available tools and methods, for conducting metals risk assessment. These recommendations are designed to be incorporated into current principles and elements of human health and ecological risk assessment guidance developed by the U.S. EPA (e.g., U.S. EPA, 2003a, 2000a, 1998a). Additional general risk assessment information is also available on EPA's website at http://cfpub.epa.gov/ncea/ and http://cfpub.epa.gov/ncea/raf/index.cfm.

Figure 1-1 broadly illustrates the overall risk assessment/risk management process, and by way of example, identifies in the problem formulation and analysis steps some metals-specific considerations. An effective risk assessment for metals will consider the unique aspects of metals, differentiating them from other substances, early and throughout the risk assessment process. These unique aspects are captured and formulated in this framework as metals concepts and principles; they are summarized in Section 2 and discussed throughout the framework. They include environmental background concentrations; essentiality; environmental chemistry; bioavailability; bioaccumulation and bioconcentration; acclimation, adaptation, and tolerance; toxicity testing; and mixtures.

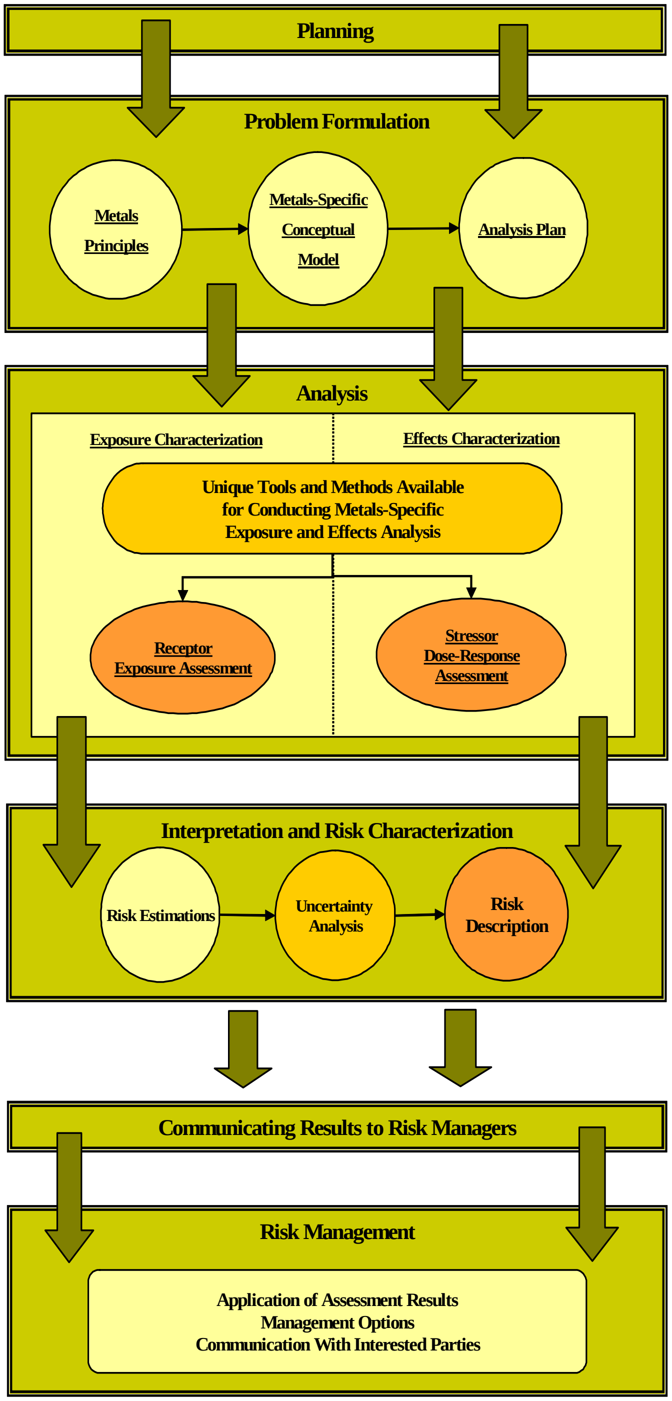

Figure 1-1. Risk assessment/risk management process for metals.

1.4. METALS ASSESSMENT CONTEXT

The context for the risk assessment is a major factor in determining the type of analysis that is appropriate for any particular situation. To provide a context for discussion of the framework principles for metals, EPA has defined three general categories of assessments: national ranking and categorization, national-level assessments, and site-specific assessments. Each type of assessment can vary in level of detail from simple screening analysis to highly complex definitive assessments.

1.4.1. National Ranking and Categorization

In the first type of assessment, EPA may rank or categorize chemicals on the basis of their potential to cause risk. For many chemicals, there are significant data gaps regarding their chemistry, environmental fate, toxicity, or exposure potential, notably with regard to location-specific characteristics that directly influence these factors and make broad generalizations difficult. Nonetheless, EPA is tasked with protecting human health and the environment from the potentially harmful effects of these chemicals and thus had to develop methods to identify those most likely to pose a significant threat.

Hazardous Waste Listing Determination

Under the Resource Conservation and Recovery Act, EPA is required to make formal decisions on whether to designate certain specific industry waste streams as hazardous. For waste streams that are listed as hazardous, the generators and handlers of those wastes must comply with a comprehensive set of management and treatment standards.

In determining whether to list a waste as hazardous, the Agency evaluates the ways in which that waste is currently being managed or could plausibly be managed by the generators and handlers of the waste. The Agency also assesses the physical and chemical composition of the waste. Based on the waste characteristics and management practices, EPA then conducts an analysis to determine whether potentially harmful constituents in the waste might be released and transported to human or ecological receptors. In conducting these analyses, the Agency evaluates the potential for constituents in the waste material to be released to air, surface water, soil, and ground water. It then models the fate and transport of those constituents to potential receptors.

With more than 80,000 chemicals currently listed on the Toxic Substances Control Act (TSCA) inventory that can legally be used in commerce within the United States (not including pesticides or chemicals that are created as byproducts during industrial processes), the Agency needs a way to prioritize substances for review or action. Many of the statutes administered by EPA provide specific lists of chemicals that require consideration, but often those lists are based on information and analyses previously developed by EPA. In addition, the statutes generally provide for adding or deleting chemicals from the initial list on the basis of their potential threat to human health or ecological receptors. Consequently, a need exists for methods that rapidly screen chemicals for placement on lists or that prioritize potentially hazardous substances.

Some of the ranking and categorization methods used by EPA involve identifying certain attributes of chemicals that can then be used as indicators of potential risk. Example attributes include toxicity, production volume, quantities released to the environment, persistence in the environment, mobility in the environment as indicated by volatility or solubility, and potential to accumulate in the food chain. Other methods, which may be less quantitative, rely more on a combination of expert judgment, stakeholder input, and availability of information to determine the priority or categorization of chemicals for decision making or other action. Examples of programs where EPA identifies or categorizes chemicals for priority action include the following:

- Selecting chemicals for the Agency's Toxicity Characteristic regulation that defines hazardous wastes;
- Establishing reporting thresholds for spills of hazardous materials under Superfund;
- Setting priorities for revisions to the Ambient Water Quality Criteria (AWQC);
- Listing chemicals under the Toxics Release Inventory;
- Determining priorities for developing drinking water standards;
- Setting priorities for hazardous air pollutant data collection and assessment; and

Ambient Water Quality Criteria

EPA's Office of Water is charged with developing Ambient Water Quality Criteria (AWQC) to support the Clean Water Act goals of protecting and maintaining physical, chemical, and biological integrity of waters of the United States. Examples of chemical-specific criteria include those designed to protect human health, aquatic life, and wildlife. Although AWQC are typically derived at a national level, there is a long history behind the development of methods to accommodate site-specific differences in metals bioavailability. For example, since the 1980s aquatic life criteria for several cationic metals have been expressed as a function of water hardness to address the combined effect of certain cations (principally calcium and magnesium) on toxicity.

Recognizing that water hardness adjustments did not account for other important ions and ligands that can alter metals bioavailability and toxicity, EPA developed the Water Effect Ratio (WER) procedure as an empirical approach for making site-specific bioavailability adjustments to criteria (U.S. EPA, 1994a). This approach relies on comparing toxicity measurements made in site water with those made in laboratory water to derive a WER. The WER is then used to adjust the national criterion to reflect site-specific bioavailability.

More recently, the Office of Water has been developing a mechanistic-based approach for addressing metals bioavailability using the Biotic Ligand Model (BLM) (U.S. EPA, 2000b; Di Toro et al., 2001; Santore et al., 2001). This model, which is described in further detail in Section 4, predicts acute toxicity to aquatic organisms on the basis of physical and chemical factors affecting speciation, complexation, and competition of metals for interaction at the biotic ligand (i.e., the gill in the case of fish). The BLM has been most extensively developed for copper and is being incorporated directly into the national copper aquatic life criterion. The BLM is also being developed for use with other metals, including silver. Conceptually, the BLM has appeal because metals criteria could be implemented to account for predicted periods of enhanced bioavailability at a site that may not be captured by purely empirical methods, such as the WER.

- Setting priorities for reviewing existing chemicals under TSCA.

This list of needs for ranking or categorizing chemicals is not comprehensive but does provide an indication of the kinds of activities that EPA conducts in this regard. In addition, the Agency may set national standards and guidelines for specific chemicals, including metals, as described in the next section.

1.4.2. National-Level Assessments

National-level assessments may be performed when the Agency is setting media standards or guidelines for chemicals (e.g., Maximum Contaminant Levels [MCLs], National Ambient Air Quality Standards, AWQC, Superfund soil-screening levels) or when the Agency is using risk assessments to establish controls for environmental releases from industry or other sources (e.g., hazardous waste listings under the Resource Conservation and Recovery Act, residual risk determinations under the Clean Air Act, pesticide registrations). EPA also is charged with establishing controls on environmental releases based on the best available treatment technologies (e.g., maximum achievable control technology for air emissions, best available treatment technology for surface water discharges and for hazardous wastes). However, even though the standards are based on technological achievability, the Agency typically performs risk assessments in support of these regulations to help inform management decisions and for use in cost/benefit analyses.

Differing environmental conditions across the country affect the biogeochemistry of metals, making it difficult to set single-value national criteria (national standards that apply at the point of exposure, such as MCLs, are less affected by these factors). To conduct such assessments, the Agency commonly undertakes several approaches. One is to define one or more exposure scenarios and to conduct a relatively detailed analysis. The difficulty in this approach is in selecting the appropriate scenario; typically, the Agency tries to ensure that the scenario is sufficiently conservative to be protective of the population at highest risk (such as populations exposed above the 90th percentile) without being so conservative that the standards are protective of hypothetical individuals whose calculated risks are above the real risk distribution. In selecting the appropriate scenario, the Agency needs to consider all of the factors that may affect potential risk, including environmental factors affecting the fate, transport, exposure potential, and toxicity of the chemicals released.

Another common approach for a national assessment or criteria derivation is to conduct a probabilistic analysis (such as a Monte Carlo analysis), wherein the variability of the key factors is described by parameter distributions used as inputs to the probability analysis procedure. The result is an integrated distribution of potential risk levels. The difficulties related to conducting this kind of analysis are in developing appropriate distributions for each parameter and in ensuring that adequate attention is paid to potential correlations among key parameters. These correlations often are more complex and difficult to describe for metals than for organic compounds.

Establishing Water Discharge Permit Conditions

The Clean Water Act establishes a two-tier process for setting water discharge permit conditions. First, all dischargers must meet the technology-based effluent guidelines limitations requirements. Second, if those limitations are not adequate to allow the receiving stream to achieve its designated water quality standards, then more stringent limits are developed to ensure that those standards are met.

The water quality standards are established by the states and consist of a designated use for the waterbody and a set of criteria for individual chemicals that allow that use to be achieved. EPA has published national water quality criteria values for the states to use as guidance in setting their standards.

Once the standards that include the criteria have been established and it has been determined that the effluent guidelines alone will not be sufficient to allow those criteria to be met, the state prepares a wasteload allocation for all the dischargers to that stream segment, including, where appropriate, the nonpoint source discharges. The wasteload allocation generally consists of modeling the potential impact on the stream from each discharge of the chemicals of concern and then setting the allowable discharges to ensure that the criteria for the chemicals are met.

The modeling process can be quite complex, potentially taking into account the interactions of the ambient stream conditions with the chemicals in the discharge, including dilution, chemical transformations, degradation, settling, resuspension, and other processes. For metals, stream characteristics such as pH, organic content, suspended solids levels, and numerous other factors can significantly affect how the metal will behave and affect aquatic life in the stream segment. Therefore, it is important to understand these processes in conducting the wasteload allocation.

1.4.3. Site-Specific Assessments

Site-specific assessments are conducted to inform a decision concerning a particular location and may also support some national regulatory decisions. Examples include the following:

- Determining appropriate soil cleanup levels at a Superfund site,
- Establishing water discharge permit conditions to meet ambient water quality standards, and
- Determining the need for emission standards for sources of hazardous air pollutants.

An accurate site-specific assessment for a metal requires knowledge of the form of the metal as it enters the environment, the environmental conditions affecting the metal (climatological conditions, soil geochemistry, water and sediment chemistry, etc.), the existence of plants and/or animals that might accumulate the metal as well as the uptake factors for whatever form(s) the metal may be in, plausible pathways and routes of exposures to the human or ecological receptors, and the effect the metal will have on target organisms in whatever form in which it reaches that organism and its target organ/system. Although many of these same factors also affect the risk potential of organic chemicals, models for predicting fate, transport, and toxic properties are generally better defined for organic chemicals than for metals.

In summary, the Agency conducts a variety of assessments, from site-specific risk assessments to national criteria setting and ranking. All of these assessments share common elements and rely on accurate information and knowledge about how chemicals behave in the environment and when they come in contact with humans or other organisms of concern. Metals have unique environmental and toxicological properties that may confound such assessments if they are not given consideration. This framework provides the basic tools for application in each of these programmatic contexts so that metals assessments can be conducted with rigor, precision, and accuracy.

1.5. Organization of Metals Framework

The framework includes sections on metals principles and conceptual models, recommended methods for metals assessment, and metal-specific topics and methods. Section 2 begins with a discussion of metals principles and their importance in the assessment of inorganic metals. A conceptual model is presented that highlights the areas where metal-specific information is required to move through the risk assessment, criteria development, or classification/ranking process. This discussion provides additional direction to where in the document the guidance material is discussed for each issue identified. Also in Section 2, a conceptual model on bioavailability is presented (McGeer et al., 2004) along with definitions developed by authors of the issue papers.

Section 3 provides recommendations to guide risk assessors in incorporating metal-specific issues and application of tools and methods into the phases and levels of risk assessment. Discussion is included about which tools are appropriate for screening-level assessments and which information is most useful for detailed, in-depth analyses. Detailed discussion of metal-specific tools and methods occurs in Section 4, where each subsection is devoted to a particular metals issue. Specifically, Section 4 is organized as follows:

- Section 4.1. Environmental Chemistry
- Section 4.2. Human Exposure Pathway Analysis
- Section 4.3. Human Health Effects
- Section 4.4. Ecological Exposure Pathway Analysis
- Section 4.5. Characterization of Ecological Effects

For each issue, a brief description of the concepts to be addressed is presented, and reference is given to existing issue papers that cover it in greater depth. This is followed by a presentation of currently available tools and methods for developing the needed information, such as look-up tables, default values, appropriate models, and other sources. Each subsection concludes with a brief discussion of the limitations of current tools and methods, any new methodology currently under development, and a suggestion of where the process could be improved in the future.

It is important to stress that Section 4 does not precisely follow the risk assessment framework of exposure assessment and effects assessment but, rather, presents all the necessary metal-specific attributes to consider when conducting a hazard and risk assessment. This is because several of the issues are cross-cutting (e.g., environmental chemistry discussions in Section 4.1) and may have application to both exposure and effects assessments. Furthermore, because this framework addresses only the aspects of the risk or hazard assessment that are specific to metals, it does not provide a comprehensive overview of the entire process.

The document concludes with a discussion about research under way, planned, and needed to reduce uncertainty (Section 5). Although our understanding about metals issues is broad based, specific methods and data are more readily available in some areas (e.g., freshwater ecosystems) than in others (e.g., soils). This Section highlights the areas where active research is expected to move the science forward within the next 5 years and identifies other aspects that need further attention. The need for continued research and development of metals-specific risk assessment methodology should in no way detract from the expectation of applying sound science to our current way of doing business, as the framework provides substantial guidance on process enhancements that can occur with currently available information.