Geoscience Canada

Metals in the Environment: Philosophy and Action by the Metals Industry

Bruce R. Conard

Volume 28, Number 2, June 2001

URI: https://id.erudit.org/iderudit/geocan28_2art05

See table of contents

Publisher(s)

The Geological Association of Canada

ISSN

0315-0941 (print)
1911-4850 (digital)

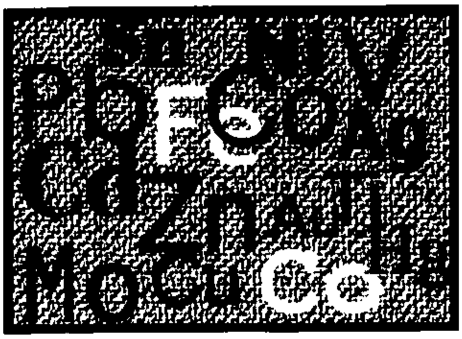
Explore this journal

Cite this article

Conard, B. R. (2001). Metals in the Environment: Philosophy and Action by the Metals Industry. *Geoscience Canada*, *28*(2), 65–70.

Article abstract

A critical issue facing our industrial society is to determine how to continue the beneficial use of metals while minimizing adverse effects metal releases may have on people or the environment. The best way to examine potential adverse effects is to carry out risk assessments. The metals resource industry and certain federal government departments have taken aproactive approach to gaining needed information for risk assessments on metals by forming the Metals in the Environment (MITE) Research Network. This Network, receiving significant funding from NSERC for university research across Canada, is administering a 5-year integrated program defined by government and industry in a truly co-operative and integrated fashion. The program is focussing on: sources of metals, both industrial and natural; processes that move and control metal species; and impacts of metals on flora and fauna.



Metals in the Environment: Philosophy and Action by the Metals Industry

Bruce R. Conard
Inco Limited
145 King Street West
Toronto, Ontario M5H 4B7
bconard@inco.com

SUMMARY

A critical issue facing our industrial society is to determine how to continue the beneficial use of metals while minimizing adverse effects metal releases may have on people or the environment. The best way to examine potential adverse effects is to carry out risk assessments. The metals resource industry and certain federal government departments have taken a proactive approach to gaining needed information for risk assessments on metals by forming the Metals in the Environment (MITE) Research Network. This Network, receiving significant funding from NSERC for university research across Canada, is administering a 5-year integrated program defined by government and industry in a truly co-operative and integrated fashion. The program is focussing on: sources of metals, both industrial and natural; processes that move and control metal species; and impacts of metals on flora and fauna.

RÉSUMÉ

Continuer à utiliser les métaux tout en minimisant les effets néfastes d'effluents de métaux pour les humains et l'environnement constitue l'un des principaux défis de notre société industrialisée. La meilleure approche permettant d'étudier les effets néfastes potentiels consiste à mener des études d'évaluation des risques. L'industrie des ressources métalliques avec certains ministères du gouvernement fédéral ont adopté une approche proactive dans le but d'amasser les données nécessaires aux évaluations des risques des effluents de métaux et ils ont créé le *Réseau de recherche des métaux dans l'environnement* (RRME). Doté d'un financement substantiel par le CRSNG, le RRME administrera un programme quinquennal pan-canadien de recherches universitaires de manière véritablement intégrée et coopérative. Ce programme porte en particulier sur les sources des métaux, naturelles ou industrielles, les processus de transport et de sélection des espèces de métaux, ainsi que l'impact des métaux sur la flore et la faune.

INTRODUCTION

Society and human progress have benefited by the use of metals. Questions are now being asked, however, as to whether the continued use of metals is harmonious with the concept of sustainable development. Furthermore, some misperceptions about the dangers of all metals to the environment and human health are clouding proposed regulatory actions worldwide. The critical issue facing society is to determine what risks exist for each metal and metal compound, and to develop risk management strategies that will minimize adverse outcomes from the production and use of these substances.

Whether assessing the hazard or the risk (they are different) of a substance, scientific information is needed, as it also is in making effective regulations and implementing risk management of chemicals. Canada is well positioned to take a leadership role in determining where needed information is missing and in undertaking studies to obtain the information. This position has been demonstrated by the formation of the Metals in the Environment (MITE) Research Network, as outlined in this paper.

HUMAN ACTIVITY AND ENVIRONMENTAL CONCERNS

One of the outstanding characteristics of humans is our creativity in designing and using tools to assist us in providing shelter, warmth, food, and defense. Today, with the interconnecting web of society becoming increasingly complex, newly developed tools and machines facilitate transportation, communication, and information processing. Because of such properties as durability, strength, formability, and machinability, metals have played a central role in the fabrication of such tools and machines. Metals have long been sought through exploration, mining, smelting, and refining. Indeed, the advancement of human civilization and the production and use of metals have been inexorably connected.

Every industrial activity in society operates with the permission of society. Society has to receive value from the product, and undesirable consequences associated with the activity have to be minimized. Society alone judges the balance between the value generated and the possible adverse consequences. As the human population and activity has increased, particularly in the 20th century, questions have arisen about the ability of the planet to sustain such activity without dire consequences. A new paradigm evolved as a result of these questions. In the past we viewed nature as an unalterable constant; now we recognize that our activities can affect the quality of air, water, and soil, and some unabated activities may significantly alter the ecological balance of the Earth. Whether a new state of balance will permit us and our progeny to live our lives in a valued way is one of the complex questions the human family faces.

THE CONCEPT OF SUSTAINABLE DEVELOPMENT

A United Nations Commission, chaired by G.H. Brundtland, was asked to address this question. The Commission's report, Our Common Future (World Commission on Environment and Development, 1987), introduced the concept of environmentally sustainable economic development. The report stressed that industrial and economic growth must continue to meet current needs, but must be done in a manner so that future generations are not prohibited from meeting their needs. The concept of sustainable development (SD) has been a central focus for several Earth Summits and has further evolved over the last decade. Sustainable development now means that industrial development must no longer be evaluated strictly on economic bases, but must include the values of environmental protection and the on-going needs of the local societies in which the development occurs.

The metals resource industry responded to these developments. The industry recognized that its permission to explore, mine, and produce metals is given by society and that societal values affecting that permission are changing. Organizations such as the Mining Association of Canada (MAC) and the International Council on Metals and the Environment (ICME) are incorporating the concept of SD into their charters. Most boards of directors of major mining companies are discussing changes in corporate values, policies, and operating procedures to be consistent with the broad concept of SD.

Sustainable development is often seen within a narrow perspective, namely, whether development can be sustained forever. Due to the finite non-renewable resources that exist on Earth, some argue that mining and the metals resource industry are in fundamental contradiction with SD. I do not share that view. The concept of SD is far more complex than simply judging whether an activity can be continued forever. Instead, I believe the question is: can metals' use be continued forever? In answering, one should consider the components of SD as laid out by Cragg (1998):

- Can the continued mining and use of metals be conducted with the core value of protecting the environment, that is, can mining be carried out without causing excessive pollution, and can the area mined be returned to a natural condition?
- Can the costs and benefits of mining and its products be equitably shared?
- Can non-monetary values of stakeholders be considered?
- Can unreasonable imposition of costs on certain stakeholders be avoided?
- Can the resource be efficiently refined for first use, and can it be effectively recycled for multiple uses?
- Can the metals resource industry be held accountable by comparing its stated commitment to SD with its performance? (Cragg, 1998).

Achieving behaviours in harmony with these elements of SD provides a considerable challenge for the metals resource industry. Nothing within these elements is fundamentally at odds with producing and using metals, however. In addition, metals' recycling is becoming more important and will continue to account for a greater fraction of all metals' production. In this likely scenario the mining of metals will become a "top up" process to recycling.

More central to the scepticism of mining as compatible with SD is the historical legacy of poor practices. For example, many mines have disturbed large areas without proper rehabilitation. Rock wastes and tailings have been allowed to generate run-off waters containing high acid levels. Communities have suffered massive upheavals when the ores ran out. While some small companies continue these practices, most mining companies have demonstrated their intention for proper stewardship. Examples are the Whitehorse Mining Initiative (Mining Association of Canada, 1994) and the adoption of the International Standards Organization's 14000 series environmental management standards by many companies. Most progressive mining companies accept SD concepts in recognition that process and product stewardship are critical aspects of being competitive and of gaining customer and public endorsement.

PERCEPTIONS OF THE DANGERS OF METALS

Most companies realize that increasing public concerns about environmental preservation will mean tighter regulation of industrial practices. There should be no argument from industry when such regulations are based on sound scientific principles and experimentation. However, some recent proposals and legislation on a global scale (*e.g.,* the European Union, United States, and Canada to name a few countries) regarding the safety of metals have been met with alarm by the metals resource industry. The alarm is caused by some regulations being formulated with what the industry perceives as a lack of regard for scientific analysis or input, or where scientific information is classified as irrelevant if it contravenes existing governmental policies. An example of this kind of action is the recent initiative in Europe to classify austenitic stainless steels as skin sensitizers because these steels contain nickel. While elemental nickel and soluble nickel compounds are known sensitizers for allergic skin reactions, it is also well known that divalent nickel ions must be transported through the skin at a certain threshold flux before sensitization can occur. It is also well known that most grades of stainless steels have been developed with high resistance to corrosion and the concomitant release of nickel ions. Basing the classification for skin sensitization of a nickel-containing substance on the single fact that it contains nickel is inappropriate in that it ignores the wealth of scientific literature about the specific corrosion properties of each substance.

What controls the perceptions of regulators (and politicians and the public) concerning the safe use of metals? Why has there been a dramatic increase in regulatory activities toward metals? The second question is easily answered. There is more attention being paid to metals because the initial priority in the 1960s, 1970s, and 1980s was on synthetic organics. The signing of the United Nations Environmental Program's Persistent Organic Pollutants protocol is an example of a targetted endpoint for organics. With the recognition that organics are addressed in what is deemed a satisfactory way, regulatory attention is turning to inorganics, of which metal-containing substances are by far the largest group.

It is my opinion that metals have a tendency to be viewed by politicians and the public in the following ways:

- Metals, metalloids, and metal-containing substances are viewed as no different than organic substances. Therefore, since much work has already been expended to create a set of criteria for judging the hazards of organic substances, the same criteria should be applied to inorganic substances.
- Metals being emitted to the environment are viewed as being generated mainly from anthropogenic activities and may be transported for long (intercontinental) distances. Therefore, metals entering the environment must be controlled at their industrial sources.
- Metals and metalloids are viewed as having severe toxic properties. The most widely known toxicity to humans results from exposure to lead, mercury, and cadmium, the so-called "heavy metals."

All metals are viewed as having similar toxicity and therefore exposure to metals is dangerous.

These are some of the perceptions that currently drive public policy and are the motivations for regulatory control. If the perceptions are incorrect, then society's resources and energies will be expended incorrectly. Society cannot afford to make such mistakes. It is in all stakeholders' interests to make sure that perceptions of danger are based on reality, and that the criteria used for judging the potential for harm for any substance are applied in a meaningful manner.

PERSISTENCE, BIOACCUMULATION, AND TOXICITY

A case in point may be useful. The criteria developed to classify the threat of organic substances and to prioritize protective action is abbreviated as PBT, which stands for Persistence, Bioaccumulation, and Toxicity. The reasoning behind these criteria is sound fundamentally. That is, if a substance remains in a bioavailable form for a long time (it persists), then organisms have a greater probability of being exposed to it. Bioavailability refers to the possible transport of a substance across a cellular membrane to enter an organism. Substances may be present outside an organism, but only those substances able to enter an organism under the specific conditions existing at that time will be able to exert a toxic — or beneficial — effect. If such a bioavailable substance is taken up actively by an organism and accumulates within the organism, the substance has a greater probability of reaching a target organ and possibly causing a deleterious effect. And finally, if a substance exerts a toxic effect at a low concentration, it has greater potential for harm than a substance inducing a toxic effect at a higher concentration, assuming that the effects are of equivalent severity.

The PBT approach may be sound fundamentally for all substances, but the simple application of a single set of criteria may not be appropriate across all types of substances. The expectation that society should have for the successful application of such criteria is an ability to separate the bad actors from the medium to not-so-bad actors. The application of the criteria should discriminate between and among families of compounds. An intense debate (as listed in Table 1) is occurring as a result of a proposed simple application of PBT criteria to aquatic hazards of metals (Experts' Workshop, 2000).

At the nub of the debate are questions such as:

- Since metals are naturally occurring, what proportion of the total release enters the environment from human activity? By controlling such releases, do we effectively control metals entering the environment?
- If metals are uniformly judged as highly persistent because they are chemical elements, does this give proper discrimination between metals that may persist in bioavailable form (*e.g.*, methyl mercury) from those that do not (*e.g.*, high-temperature insoluble nickel oxide)?
- If simple bioaccumulation is deemed to be an indicator of hazard, how should metals that are essential nutrients for life be classified when their beneficial action is directly linked to their ability to be bioaccumulated?
- If the most soluble compound of a metal is used to judge the hazard of all members of that metal's family of compounds, is proper differentiation between compounds of the same metal obtained?

While industry is worried by some actions being taken by governments, industry recognizes that the proper answers to these questions must have a scientific foundation. Furthermore, there is an increasing understanding by both industry and governments that hazards alone should not induce regulation. Rather, risk is the driver for action and control, where risk incorporates both the severity of the hazard and the probability of exposure to the hazard. Accordingly, more emphasis is being put on risk assessment and risk management for both environmental and health outcomes (ICME, 1996; ICME and Eurometaux, 1999).

Table 1 Elements of debate for metals in aquatic media.

SIDE A		SIDE B
· Anthropogenic	*versus*	· Naturally ubiquitous
· Persistent	*versus*	· Bioavailable forms not persistent
· Bioaccumulation	*versus*	· Essential for life
· Use most soluble compound as surrogate for family	*versus*	· Each substance is unique

THE METAL INDUSTRY'S RESPONSE TO THE NEED FOR IMPROVING SCIENTIFIC INFORMATION

Whether the resolution of these issues is to be decided by applying specific criteria or by applying risk assessment methodologies, there is a clear need for improving the quality and quantity of relevant scientific information. The Mining Association of Canada (MAC) believes that Canada, due to its long history of mining and metal production and its resulting high level of expertise in metals and their properties, has an important role to play in developing international consensus on the safe production and use of metals. Accordingly, MAC organized a workshop (CNTC, 1996), convening people from government, academia, and industry to discuss how science concerning the behaviour of metals in the environment could be advanced. In particular, the workshop participants were asked to delineate areas of consensus from areas of disagreement about the behaviour of metals. With areas of conflict identified, the workshop then specified the types of scientific research needed to resolve the conflicts. A very important component of this resolution was the recognition and acceptance by the experts present that research had to be truly co-operative and integrated across many fields of study.

Encouraged by the success and obvious co-operation present at the workshop, MAC, joined by Ontario Power Generation (OPG), continued to fund a steering committee to refine proposals for research. The central participants at this stage were from Natural Resources Canada including the Geological Survey of Canada, Environment Canada, Fisheries and Oceans, several university environmental and toxicological scientists, and MAC. It was clear that existing programs focussing on metals within Environment Canada and Natural Resources Canada would continue and, in some cases, would be enhanced. It was also clear that these existing government programs would benefit by being integrated into a university-based program addressing the data needs for public policy and regulatory development.

With specific research proposals in hand, the parties successfully applied to the Natural Sciences and Engineering Research Council of Canada for major funding support of the university portion of the program. The Council granted 5-year funding amounting to about $3.5 million, for the period 1999-2004. This joined industry funding of $1.95 million from MAC and OPG, with minor contributions from the Nickel Producers Environmental Research Association, the International Lead-Zinc Research Organization, and the International Copper Association. With the expected in-kind support from industry and government, the total program, including funds in hand or pledged for the period 1999-2004, is $7.1 million.

THE METALS IN THE ENVIRONMENT RESEARCH NETWORK

The MITE Research Network, which began with the receipt of NSERC funding in 1999, is organized into three research areas: sources, processes, and impacts. In addition, integration of all research will be done within a risk assessment framework, and quality control of data and data archiving will be carried out by distinct groups. The focus of each of the three research areas is summarized as follows.

Sources

There exists some understanding of total amounts of metals released from mining and production facilities in Canada (ARET, 1998; Skeaff and Dubreuil, 1998; Nriagu and Pacyna, 1988). Very little information exists about characteristics such as emitted particle size distributions, which play important roles in chemical reaction kinetics both prior to and following particle deposition. The Network will measure quantities, species, and particle sizes from metallurgical stacks and within plumes. It will also measure the radial extent of the emissions by measuring metals in soils and sediments downwind of stacks to obtain quantitative information about long-range transport of specific metals. Another important component of the Network's program is to determine whether diagenesis within sediments plays a role in altering metal profiles within sediments. An understanding of the importance of this phenomenon is necessary when relying on sediment profiles as historical records of depositional fluxes.

Releases from natural sources are crude estimates at best (Nriagu, 1989; Rasmussen, 1996). Releases to the soil and aquatic environments, as a result of chemical weathering of natural materials, are being studied in order to determine the rates of release of a range of metals, and the factors controlling those rates. The knowledge gained in estimating chemical weathering rates and the fluxes from geological compartments to the aqueous environment will assist in improving natural release estimates of metals. This will form, together with the information on the industrial releases, the basis of discussion on the relative importance of natural and anthropogenic inputs to the environment.

Processes

Between knowing the sources of metals and their ultimate fates in environmental compartments, lie a large number of processes by which various metal-containing species undergo reactions and move within and between compartments. Exposure to bioavailable forms of such species can occur during this movement (see Hrudley *et al.*, 1996). Network scientists are examining the processes and factors that affect metal speciation and bioavailable metal. Projects are being carried out to determine how metals from all sources are cycled by terrestrial vegetation, and the biotic and abiotic factors that control partitioning to woody and herbaceous material. Metal accumulation in trees, for example, will be examined using growth ring analysis in an effort to determine whether the metal levels can be correlated with pollution events.

Water movement is the driving force behind the transport of metals within the soil column; it follows that the partitioning of metals between the pore water and the solid phase is of crucial importance. A key component in soil-water equilibria is natural organic matter, both as a sorbent and as a metal-complexing/metal-reducing ligand in the mobile phase. The Network proposes to refine current estimates of partitioning coefficients and to incorporate these constants into models designed to predict the behaviour of metals in the terrestrial environment and their movement into aquatic systems.

Impacts

Network research will be carried out on how metal speciation in the exposure medium is related to metal-induced effects at cellular and organism levels. This will involve measuring metal accumulation, both total body burden and specific organ accumulation, in various organisms (primarily aquatic) and relating metal speciation within the organism to induced effects. Investigation into essentiality of certain metals and metabolic detoxification of other metals will be performed. There will be work carried out on chronic exposure and whether metal-containing food quantity and quality affect metal toxicity. An emphasis will be made on field studies related to areas of high-metal input, due either to natural processes or human activity.

Ecological Risk Assessment (ERA)

This activity will evaluate the potential for adverse ecological effects to occur as a result of exposure to metal-containing compounds or species. It will provide information for policy development, remediation strategies, and risk management. The major steps in an ERA are: 1) hazard identification involving knowledge about the intrinsic toxic properties of a substance; 2) the dose-response relationship, which indicates the kind and severity of toxic response from a substance to a receptor; 3) exposure assessment to estimate the pathways and concentrations of substances to which organisms may be exposed; and 4) a risk characterization which integrates the previous steps (see Dyck *et al.*, 1999).

Organization

The Network structure is shown in Figure 1. The Board of Directors consists of 12 people who are senior officials within industry, government, and non-governmental public interest groups. It is critical to the success of the Network that these people can influence the application of research findings to government policies and industry risk management strategies. Advising the Board is an Expert Advisory Panel, consisting of seven environmental/health scientists of significant international reputation. These people, some of whom are from outside Canada, have no opportunity to receive funding for research from the Network. Instead, their task is to review proposals and reports of progress from Network researchers and to advise the Board as to the appropriateness of the methodologies used and the interpretations given. Also reporting to the Board is the Scientific Steering Committee, which is composed of scientists from Network stakeholders, including the co-leaders of the each research area and representatives of the Secretariat. The Secretariat is the Canadian Network of Toxicology Centres CNTC), located at the University of Guelph, Ontario.

Dr. Peter Campbell of the University of Quebec is the Research Director of the Network and Chairman of the Science Steering Committee (SSC). The research area co-leaders (sources, processes, impacts; Fig. 1) and the ecological risk assessment expert report to Dr. Campbell and serve on the SSC. Besides periodic meetings of the SSC, the Network holds an annual Research Symposium where researchers and interested parties gather to discuss progress. In addition, researchers hold meetings with either subject or field location focus in order to plan activities, discuss results, and seek synergies.

TRAINING

Both industry and government are in need of qualified personnel to resolve environmental and health issues of concern to society. People must be educated in the particular properties and behaviours of metal-containing substances. They must appreciate the differences between synthetic organic and inorganic substances, and recognize that application of criteria to assess concerns for organics may not be the same as those for metals and metal compounds. The Network provides a wonderful opportunity for students in undergraduate and graduate programs to work on problems in the real world, because field studies are an extremely important component of Network research. The students work with multi-disciplinary groups with the common objective of establishing a sound scientific foundation upon which to decide how to minimize the risks metals may pose, so that the beneficial and sustainable use of metals can be achieved without causing harm to anyone or anything.

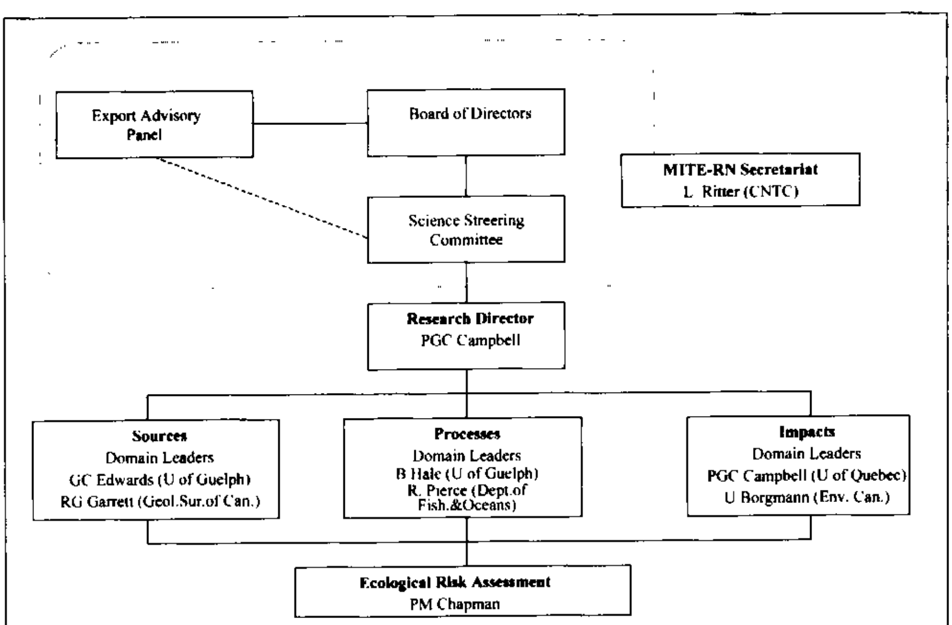


Figure 1 Organizational structure of the MITE research network.

ACKNOWLEDGMENTS

I wish to acknowledge the work of MAC and CNTC in guiding the Network through its formative stages. Appreciation is expressed to NSERC, MAC and Ontario Power Generation for generous funding. I also thank Len Ritter, Peter Campbell, Beverley Hale, Adrienne Laroque, Robert Garrett, Ron Pierce, Uwe Borgmann, Robert Prairie, and Rod Allan for their efforts in helping to define the research needed and the capabilities for conducting such research within Canada. I thank Robert Garrett, Peter Chapman and Lisa Ortego for their helpful comments as critical reviewers of this manuscript.

REFERENCES

ARET, Accelerated Reduction/Elimination of Toxics, Progress Report, 1998, Environmental Leaders 2 Update: Environment Canada, Ottawa, 49 p.

Dyck, W., Del Bel Belluz, D. and Craig, L., 1999, Current Directions in Environmental Risk Assessment and Management: Network for Environmental Risk Assessment and Management, University of Waterloo, Waterloo, ON, 53 p.

CNTC, Canadian Network of Toxicology Centres, 1996, Metals in the Environment Workshop Final Report: University of Guelph, Ontario, 107 p.

Cragg, W., 1998, Sustainable development and mining: opportunity or threat to the industry? *in* Skeaff, J.M., ed., Metals and the Environment: Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, p. 191-203.

Experts' Workshop, 2000, Review of the State-of-Science regarding PBT concepts and metals and metal compounds, held in Arlington, VA, 19 January 2000, under the auspices of the US EPA, EPRI, *et al.*, 261 p.

Hrudley, S.E., Chen, W. and Rousseaux, C.G., 1996, Bioavailability in Environmental Risk Assessment: CRC Press, Boca Raton, FL, 49 p.

ICME, the International Council on Metals and the Environment, 1996, Report of the International Workshop on Risk Assessment of Metals and Their Inorganic Compounds, held in Angers, France, 13-15 November 1996: ICME, Ottawa, 180 p.

ICME, the International Council on Metals and the Environment, and Eurometaux, the European Association of Metals, 1999, Report of the Workshop on Environmental Risk Methodologies for Metals and Inorganic Metal Compounds held in Montpellier, France, 18-20 Oct 1999, Doc. 15201: ICME, Ottawa, 29 p.

Mining Association of Canada, 1994, Whitehorse Mining Initiative: Leadership Council Accord, Final Report: Mining Association of Canada, Ottawa, 69 p.

Nriagu, J.O. and Pacyna, J.M., 1988, Quantitative assessment of worldwide contamination of air, water and soils by trace metals: Nature, v. 333, p. 134-139.

Nriagu, J.O., 1989, A global assessment of natural sources of atmospheric trace metals: Nature, v. 338, p. 47-49.

Rasmussen, P.E., 1996, Trace Metals in the Environment: A Geological Perspective, Bulletin 429, Geological Survey of Canada, Ottawa, 26 p.

Skeaff, J.M. and Dubreuil, A.A., 1998, Calculated emission factors of trace metals for Canadian non-ferrous smelters, *in* Skeaff, J.M, ed., Metals and the Environment: Canadian Institute of Mining, Metallurgy and Petroleum, Montreal, p. 105-115.

World Commission on Environment and Development, 1987, Our Common Future: Oxford University Press, Oxford, UK, 400 p.

Accepted as revised 24 April 2001