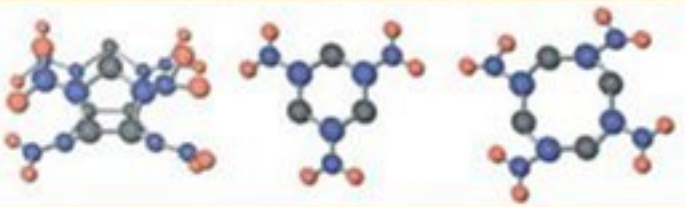
ECOTOXICOLOGY OF EXPLOSIVES

Edited by
Geoffrey I. Sunahara • Guilherme Lotufo
Roman G. Kuperman • Jalal Hawari



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Preface

An international meeting of defense ministries and department representatives from Australia, Canada, New Zealand, the United Kingdom, and the United States was held in Edinburgh, Australia, on February 23–25, 2004, under the auspices of The Technical Cooperation Program (TTCP). At this meeting, the Conventional Weapons Group (WPN) Technical Panel 4 (TP-4) for Energetic Materials and Propulsion agreed that a project "Development of Environmental Threshold Values for Defense Sites Contaminated with Energetic Materials" be conducted to promote the data acquisition and sharing of ecotoxicological information to address environmental problems related to energetic materials (EMs). The first objective of this international collaboration involved the development of environmental threshold concentrations for explosives and propellants. These criteria were needed for the ecological risk assessment (ERA) of sites contaminated with EMs, that is, to know "how clean is clean." Although the choice of approach and the use of ERA tools may differ from country to country, the assurance of quality and direction of ecotoxicological research were recognized as key concerns shared by the scientific community.

The second objective of this project was to review the accessible fate and ecotoxicological data for EMs and the methodologies for their development, and to make them available to interested parties through the publication of a book on the ecotoxicology of explosives. The book presented here is structured to first characterize the fate of explosives in the environment; then to provide information on the their ecological effects in key environmental media, including aquatic, sediment, and terrestrial habitats; and finally to describe the practical application of fate and ecotoxicological information to the environmental risk assessment of EM-contaminated sites. Information presented in this book follows the recognition that the ecotoxicological characterization of an EM-contaminated site can be accomplished through establishing a relationship between the measures of exposure to the EMs determined by chemical analyses and the measures of the effect of the EMs determined by toxicity testing. Approaches to assembling these lines of evidence for environmental risk assessment purposes may not be obvious to the nonspecialist and are discussed in relevant chapters of the book.

In this book, the reader is introduced to the fate and transport of EMs in the environment. The knowledge of the transport, transformation, and degradation pathways of these chemicals in the environment will help the reader to understand the potential hazardous impact and bioaccumulation of EMs in different terrestrial and aquatic ecological receptors. The genotoxic effects of EMs as well as the current understanding of the cellular and molecular mechanisms underlying the toxicity of these chemicals are reviewed. Integration of the preceding information is important for ERA of EM-contaminated sites.

The chapter authors focused primarily on the peer-reviewed publications in the open literature, although technical reports were also reviewed for this book. Each chapter of this book has been evaluated by at least two external peer reviewers

familiar with the specified research area. This book is intended for readers at the graduate and undergraduate university levels, as well as for a wide range of environmental professionals, including scientists, engineers, consultants, site managers, regulators, and decision makers at EM-contaminated installations and ranges.

The editors and contributors wish to thank the many individuals who assisted us with the peer review process of this book, and Helen E. Blaho for proofreading and typing the manuscript. We acknowledge the U.S. Strategic Environmental R&D Program (SERDP) and the TTCP for their vision and support during the preparation of this book.

Geoffrey I. Sunahara

The Editors

Geoffrey I. Sunahara is a senior research scientist and the group leader of Applied Ecotoxicology at the Biotechnology Research Institute (National Research Council–Canada) in Montreal. He has more than 20 years of professional experience in the field of biochemical toxicology and environmental risk assessment, having gained this expertise in Canada, the United States, and Europe. He has more than 200 research publications, proceedings, and presentations. His current fields of research include the ecotoxicological characterization of recalcitrant soil contaminants such as the energetic substances (TNT, RDX, and HMX) and their metabolites using whole organisms (bacteria, plant, and earthworm toxicity tests) and cultured cell approaches (mutagenicity and cell proliferation). Sunahara has served on several editorial boards, and he was the lead editor of the recent ecotoxicology book *Environmental Analysis of Contaminated Sites*. He has participated on expert advisory committees for Environment Canada, Natural Sciences and Engineering Reesearch Council of Canada, U.S. Strategic Environmental Research and Development Program (SERDP), and U.S. EPA research projects. Sunahara received his M.Sc. in pharmacology from the University of Toronto and his Ph.D. in pharmacology and toxicology from the University of British Columbia in Vancouver, Canada. He was a Fogarty International Post-Doctoral Fellow at the National Institute of Environmental Health Sciences (National Institute of Health, North Carolina). Sunahara was a corecipient of the TTCP Frances Bérubé Award for Environmental Awareness (2005) and holds academic positions at McGill University and Concordia University.

Guilherme R. Lotufo was born in Brazil and earned a bachelor's degree in biology and a master's degree in zoology from the University of Sao Paulo, and a Ph.D. in zoology from Louisiana State University. He is the lead scientist for a wide diversity of ecotoxicology-related projects for the U.S. Army Research and Development Center in Vicksburg, Mississippi. Most of his research relates to sediment quality assessment, bioaccumulation of hydrophobic organic compounds in aquatic environments, and ecological risk assessment. He has expanded his expertise to numerous investigations of the aquatic toxicology of explosive compounds under funding from the Army and Navy. Lotufo has

maintained active collaborations with leading national and international research organizations. Lotufo has authored more than 40 scientific articles in renowned journals.

Roman G. Kuperman has more than 20 years experience in field and laboratory methods for assessment of the ecological effects of soil pollutants using invertebrate, microbial, and molecular toxicology methods. He earned his Ph.D. in entomology from the Ohio State University in 1993. As a principal investigator at Edgewood Chemical Biological Center, Kuperman leads U.S. Strategic Environmental Research and Development Program (SERDP)-funded research programs developing data on environmental fate and the effects of explosive materials. He leads the Key Technical Area (KTA 4-32-04) "Development of Environmental Tolerance Values for Defense Sites Contaminated with Energetic Materials" of The Technical Cooperation Program (TTCP) Weapons Technical Panel (WPN TP-4), an international organization that collaborates in defense scientific and technical information exchange activities for Australia, Canada, New Zealand, the United Kingdom, and the United States. Kuperman also serves as the Soil Ecology Society liaison on the U.S. National Academy of Sciences National Committee for Soil Science; the U.S. representative on several international work groups developing new international standardized testing methods for ecotoxicological research, and is a member of the U.S. Environmental Protection Agency-sponsored Ecological Soil Screening Levels (Eco-SSL) National Task Group. Kuperman chaired the Society of Environmental Toxicology and Chemistry (SETAC) Contaminated Soils Advisory Group and is a member of several international scientific advisory committees. Kuperman has published more than 200 scientific papers in peer-reviewed journals, symposia proceedings, and technical reports.

Jalal Hawari has been with the National Research Council of Canada since 1983. He is a principal research scientist and leader of the Environmental and Analytical Chemistry Group at the Biotechnology Research Institute (BRI). He obtained his Ph.D. in chemistry from the Christopher Ingold Laboratories at University College London. Since 1994, Hawari has served as an adjunct professor at McGill University. His current research is focused on detection, fate, and ecological impact; biotransformation pathways of pollutants and new substances; and development of green processes for the extraction and conversion of renewable feedstocks into value-added products such as fine

chemicals and biopolymers. Working at the interface of chemistry and microbiology, the group develops enabling bioanalytical tools to identify microorganisms and to measure the environmental fate, transformation pathways, and health risk associated with the use of nitramines and nitroaromatics in soil, groundwater, and marine sediments. In the last few years, the group received several prestigious research grants from Defence Research and Development Canada–Department of National Defence (DRDC-DND; Canada), the Office of Naval Research (U.S. Navy), and the Strategic Environmental Research and Development Program (SERDP; United States) to determine the microbial degradation and environmental fate and impact of emerging contaminants in marine sediments and coastal waterways. Hawari has won a number of Canadian (2002 NRC Outstanding Achievement Award for Industrial Partnership, 2002 Golden Medal–Queen Elizabeth II, 2004 NRC Outstanding Achievement Award for External Recognition, and four Director General awards) and international awards (2003 SERDP–Cleanup Project of the Year Award, 2004 ES&T–American Chemical Society Excellence in Review Award; 2005 TTCP Frances Bérubé Environmental Awareness Award). In addition, Hawari holds seven patents, shares a licensed soil bioremediation technology, and has published over 200 scientific articles and 150 proceedings and critical reviews.

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Abbreviations

[^{14}C]DDT	[^{14}C]-dichlorodiphenyltrichloroethane
[^{14}C]HMX	[^{14}C]-octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
[^{14}C]RDX	[^{14}C]-hexahydro-1,3,5-trinitro-1,3,5-triazine
1,2-DNB	1,2-dinitrobenzene (o-DNB)
1,3,5-TNB	1,3,5-trinitrobenzene (TNB)
1,3-DNB	1,3-dinitrobenzene (m-DNB)
1,4-DNB	1,4-dinitrobenzene (p-DNB)
2,2′-AZT	4,4′,6,6′-tetranitro-2,2′-azoxytoluene isomer
2,3,6-TNT	2,3,6-trinitrotoluene
2,3-DNT	2,3-dinitrotoluene
2,4,6-TNT	2,4,6-trinitrotoluene (TNT)
2,4′-AZT	2′,4,6,6′-tetranitro-2,4′-azoxytoluene
2,4-DANT	2,4-diamino-6-nitrotoluene (2,4-diaminonitrotoluene)
2,4-DAP	2,4-diaminophenol
2,4-DAT	2,4-diaminotoluene
2,4-DNA	2,4-dinitiroaniline
2,4-DNP	2,4-dinitrophenol
2,4-DNT	2,4-dinitrotoluene
2,5-DNP	2,5-dinitrophenol
2,5-DNT	2,5-dinitrotoluene
2,6-DANT	2,6-diamino-4-nitrotoluene (2,6-diaminonitrotoluene)
2,6-DAT	2,6-diaminotoluene
2,6-DNP	2,6-dinitrophenol
2,6-DNT	2,6-dinitrotoluene
2′,4-AZT	2,4′,6,6′-tetranitro-2′,4-azoxytoluene
2-A-3,6-DNT	2-amino-3,6-dinitrotoluene
2-A-3-NT	2-amino-3-nitrotoluene
2-A-4,6-DNT	2-amino-4,6-dinitrotoluene (2-ADNT)
2-A-4-NT	2-amino-4-nitrotoluene
2-A-5-NT	2-amino-5-nitrotoluene
2-A-6-NT	2-amino-6-nitrotoluene
2-ADNT	2-amino-4,6-dinitrotoluene (2-A-4,6-DNT)
2-NP	2-nitrophenol (o-NP)
2-NT	2-nitrotoluene (o-NT)
3,4-DNT	3,4-dinitrotoluene
3,5-DNA	3,5-dinitroaniline
3,5-DNT	3,5-dinitrotoluene
3-A-2,4-DNT	3-amino-2,4-dinitrotoluene
3-A-2,6-DNT	3-amino-2,6-dinitrotoluene
3-A-4-NT	3-amino-4-nitrotoluene
3-AP	3-aminophenol (m-AP)
3-NP	3-nitrophenol (m-NP)