

12/28/2009

Condensed Curriculum Vitae
STEVE E. HRUDEY

CURRENT APPOINTMENTS:

Title: Professor Emeritus
Division of Analytical and Environmental Toxicology
Department of Laboratory Medicine and Pathology
Faculty of Medicine and Dentistry
University of Alberta
Edmonton, Alberta T6G 2G3

Title: President, Steve E. Hruddy & Associates Ltd.
1016 Lawrence Grassi Ridge
Canmore, AB T1W 3C2

Recent and Other Appointments

Title: Chair, Environmental Appeals Board (July 2005 – July 2009)
306 Peace Hills Trust Tower
10011 – 109 St.
Edmonton, AB T5J 3S8

Titles:	Adjunct Professor School of Public Health & Preventive Medicine Monash University, Melbourne, Australia	Visiting Professor of the University Cranfield University Cranfield, England U.K.
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EDUCATIONAL QUALIFICATIONS:

D.Sc (Eng), Environmental Health Sciences and Technology,
University of London, 2002 (higher doctorate degree based on career research publications)

Ph.D., Public Health Engineering,
University of London, 1979 (Advisor: Professor Roger Perry)

M.Sc., Public Health Engineering
Imperial College, University of London, 1971 (Advisor: Professor Roger Perry)

B.Sc., Mechanical Engineering (with electives in life sciences)
University of Alberta, 1970

PROFESSIONAL AFFILIATIONS:

- Canadian Public Health Association
- Society for Risk Analysis
- International Water Association
- American Water Works Association
- Association of Environmental Engineering and Science Professors
- Association of Professional Engineers, Geologists and Geophysicists of Alberta

AWARDS AND HONOURS

- 2007 Fellow of the Society for Risk Analysis
- 2006 Fellow of the Royal Society of Canada, Academy of Science
- 2006 Donald R. Stanley Best Environmental Paper Award, Canadian Society of Civil Engineering, for: "*Occurrence of N-nitrosamines in Alberta public drinking water distribution systems.*" J.W.A. Charrois, J.M. Boyd, K.L. Froese and S.E. Hrudey. 2007. *J. Environ. Eng. Sci.* 6: 103-114.
- 2006 National Water Research Institute (Canada) Distinguished Speaker for 2006
- 2006 TD Canada Trust Walter Bean Visiting Professor in Environment, University of Waterloo
- 2005 Inaugural Schultz Oration for the Donal Herbert Schultz Endowment to the Flinders Research Centre for Coastal and Catchment Environments, Flinders University, Adelaide, Australia
- 2003-04 Killam Annual Professor, University of Alberta.
- 2002 D.Sc (Eng), Environmental Health Sciences and Technology, University of London, (higher doctorate degree award based on career research publications)
- 2002: Honorary Professor, Department of Epidemiology and Preventive Medicine, Monash University Medical School. Melbourne, Australia.
- 1997: Association of Environmental Engineering Professors Distinguished Lecture: "*Health Risk Assessment and Risk Management for Algal Toxins in Drinking Water Supplies*" at the American Water Works Association Annual Conference in Atlanta, June.
- 1995: Emerald Award for Environmental Research Advances, Alberta Foundation for Environmental Excellence
- 1993-98 *Eco-Research* Chair in Environmental Risk Management – NSERC-SSHRC-MRC
- 1991: Albert E. Berry Medal for significant contributions to Environmental Engineering in Canada, Canadian Society for Civil Engineering
- 1990: The Owen Holmes Science Lecture, The University of Lethbridge.
- 1989: National Lecture Tour, Environmental Engineering Division, Canadian Society for Civil Engineering.
- 1987-88: McCalla Research Professorship, University of Alberta

SCIENTIFIC AND PROFESSIONAL JOURNAL EDITORIAL BOARDS

Associate Editor

Environmental Reviews

published by the National Research Council of Canada, Ottawa, 1993-present

Member of Editorial Committee

Environmental Health

published by the Australian Institute of Environmental Health, 2000 - present

Editorial Board Member

Environmental Technology,

published in London, U.K., 1985-2002

(Regional Editor for Canada, 1979-1985)

Associate Editor,

Environmental Engineering Science, 1997 - 2000

formerly Editorial Board Member,

Hazardous Wastes and Hazardous Materials,

published in New York, 1988-1997

Editor and Member of Editorial Review Board,

Water Environment Research, (formerly, *Res. J. Water Pollut. Control Fed.*)

published by the Water Environment Federation, Washington, D.C., 1989-1993

Associate Editor for Environmental Engineering,

Canadian Journal of Civil Engineering,

published by the National Research Council of Canada, Ottawa, 1988-1992

PUBLIC AND PROFESSIONAL SERVICE (~ last 10 years):

Chair, Expert Panel on Environmental and Health Impacts of Canada's Oil Sands Industry, Royal Society of Canada, October 2009 to present.

Member, Expert Advisory Panel on Water Quality, Washington Aqueduct drinking water supply, U.S. Army Corps of Engineers, Washington, D.C., September 2009 to present.

Testimony at Legislative Council, Western Australian Parliamentary Review into Recreational Access in Drinking Water Catchments and Storages, Perth, Australia, November 24, 2009.

External Peer Review, Draft Drinking Water Health Advisory on NDMA, U.S. Environmental Protection Agency, August 2009.

Invited Testimony at the Standing Senate Committee on Energy, the Environment and Natural Resources, Victoria Building, Ottawa regarding Bill S-206, An Act to amend the Food and Drugs Act (Clean Drinking Water), 29 April, 2008.

Member, Technical Advisory Committee to the Minister of Health, British Columbia Ministry of Health on Turbidity and Microbial Risk in Drinking Water, November 2007 to February 2008.

Member, Expert Panel on Groundwater Management in Canada, Council of Canadian Academies, Ottawa, May 2007 to May 2009.

Invited Testimony at the Standing Senate Committee on Aboriginal Peoples, Houses of Parliament, Ottawa regarding the Expert Panel Report on Safe Drinking Water for First Nations, May 15, 2007.

Member, Expert Panel reporting to the Minister of Indian and Northern Affairs to conduct public hearings and report on regulatory options to assure safe drinking water in First Nations communities in Canada, May 2006 – November 2006. Report tabled in the House of Commons on December 7, 2006.

Member, Sub-committee for a Professional Guideline on Risk Management, Association of Professional Engineers, Geologists and Geophysicists of Alberta 2004 – 2006

Member of Research Advisory Panel to the Walkerton Inquiry, August 2000 – May 2002

Chair, International Expert Panel for Health Canada, To Identify Critical Endpoints for Assessment of Health Risks Related to Trihalomethanes (THMs) in Drinking Water. September 2002 to March 2003.

Peer Review, Health Canada, CDBP (Chlorinated Disinfection By-Products) Task Force Water Quality Issues Sub-Group Final Report

Member, Independent Peer Review Panel for the Giant Mine Task Force of Indian Northern Affairs Canada review of risk management options for arsenic trioxide dust (237,000 tonnes) stored in the mined out areas of the Giant Yellowknife Mine., Yellowknife, September 2002 - 2005

Member of Working Party to the National Health and Medical Research Council on developing a Framework for Water Quality Management – From Catchment to Consumer for the current revisions to the Australian Drinking Water Guidelines and Research Collaborator with the Cooperative Research Center for Water Quality and Treatment, Adelaide, Australia, 2000-2003

Chair, Expert Review Panel, Royal Society of Canada, Socio-Economic Modelling for the Canada Wide Standards for Respirable Particulate and Ozone, November 1999 to January 2001.

Independent Reviewer, Alberta Environment air quality studies of intensive livestock operations in the Lethbridge region and resulting critique by the Chinook Health Region., September 2000.

Member, Science Advisory Committee to Alberta Health and Wellness on Environmental Health Risk Advisories, January 1998 -

Member, Sour Gas Advisory Panel to the Energy and Utilities Board, January 2000 – November 2000

Member, National Advisory Panel on Environment, Canadian Chemical Producer's Association, November 1994- November 1999.

Expert Panel Member reporting to the World Health Organization for preparation of a monograph addressing management of health risks from cyanobacterial toxins in drinking water supplies. 1997-1999.

Review of Environmental Risk Assessment for Resolution Island PCB Cleanup. The Nunavut Impact Review Board. Cambridge Bay, Nunavut, December 1999.

Review of Precautionary Principle Application to Disinfection By-Products in Drinking Water, Pollution Probe, Ottawa, October 1999.

Member, Syncrude Landscape Reclamation Technical Advisory Panel, November 1995 – January 2000.

Expert Panel Member reporting to the Laboratory Centres for Disease Control on evaluation of human health risks from drinking water disinfection by-products, 1997-98.

ACADEMIC AND RESEARCH SERVICE (~last 10 years):

Management Advisory Board, Alberta Water Research Institute, March 2007 to October 2009.

Visiting Consultant, Ontario Council on Graduate Studies, to assess the proposed MPH at the University of Guelph, October 2008.

Visiting Consultant, Ontario Council on Graduate Studies, to assess the proposed MPH at the University of Waterloo, March 2006.

Member, Science Advisory Council, Public Health National Collaborating Centres, Public Health Agency of Canada, Ottawa, July 2005 – 2007

Program Leader, Protecting Public Health, Canadian Water Network NCE. May 2001 – June 2005.

Reviewer of the NSERC – SSHRC Chair in Population Health Risk Assessment, University of Ottawa, 31 Oct, 2005.

Member, College of Reviewers, Special Research Opportunity program, NSERC, Ottawa, 2003-present

Member, College of Reviewers, Canada Research Chairs, Ottawa, 2002-present

Reviewer for the National Research Council, Board on Environmental Studies and Toxicology, U.S. National Academy of Sciences, 2002

Member, NSERC Advisory Group on Interdisciplinary Research, Ottawa, October 2000 -

Member, STAR Graduate Fellowship Selection Panel, U.S. Environmental Protection Agency, Washington, D.C. October 2000 – January 2001.

Chair, Expert Advisory Panel, Metals in the Environment Research Network, NSERC-funded, Guelph, 1999-2002.

Member, Project Advisory Committee, Removal of Cyanobacterial Toxins from Drinking Water (Adelaide

INVITED PRESENTATIONS (last 5 years):

Prevention is Painfully Easy in Hindsight - Fatal E. coli O157:H7 & Campylobacter Outbreak in Walkerton, Canada 2000. *Global Issues in Water, Sanitation and Health. Institute of Medicine, U.S. National Academy of Sciences*, Washington, D.C., U.S.A., 23 Sep 2008.

A Risk Context for Assessing Drinking Water Disinfection. *Ontario Drinking Water Advisory Council International Workshop on Disinfection Alternatives*. Toronto, ON, 22 Sep 2008.

Why Water Safety Plans are Essential to Safe Drinking Water. *Keynote Address – World Health Organization – International Water Association Specialty Conference on Water Safety Plans*. Lisbon, Portugal, 12 May 2008.

Disinfection By-Products A Health Risk Assessment Perspective. *Keynote Address to the Annual LaRonge Drinking Water Conference*. LaRonge, SK, 17 Apr 2008.

Turbidity and Microbial Health Risk in Drinking Water, *B.C. Medical Officers of Health Meeting*. Victoria, BC, 1 Apr 2008.

Risky Business – Bridging the Barriers Between Science and Public Health. *Keynote Address to the First Annual Research Symposium of the University of Alberta School of Public Health*. Edmonton, AB, 15 Nov 2007.

Drinking Water Safety in Smaller Communities. *Public Health Works – Capital Health Authority* (with video conferencing across Alberta and to 3 other provinces. Edmonton, AB, 16 Oct 2007.

Why “Effective” Risk Management is Essential to Safe Drinking Water. *Keynote Address to National Workshop of the National Health and Medical Research Council on the Implementation of the Australian Drinking Water Guidelines*, Adelaide, Australia, 2 Oct 2007.

Safe Drinking Water - Walkerton 7 Years On. *Special Seminar for the Water Corporation of Western Australia*, Perth, Australia, 28 Sep 2007.

Safe Drinking Water – What Makes People Sick? *Knowledge Translation Workshop for the Canadian Water Network Project on Safe Drinking Water for Small Communities*. Walkerton, ON, 10 Sep 2007.

Lessons from Recent Drinking Water Outbreaks. *Ontario Ministry of Environment Annual Drinking Water Conference*. Toronto, ON, 24 Apr 2007.

Safe Drinking Water for First Nations Communities – Challenges and Opportunities, B.C. *Centres for Disease Control – Monthly Rounds*. Vancouver, BC, 16 Mar 2007.

When Organisations Fail – Insights from Walkerton and Other Drinking Water Disasters. *Cranfield University – Professional Short Course on Risk Management*, Cranfield, U.K., 22 Jan 2007

Challenges in Providing Safe Drinking Water for Small Systems. *TD Canada Trust Visiting Professor in Environment*. Department of Civil and Environmental Engineering, University of Waterloo. 29 Nov 2006.

Perspectives on Risk, Water Quality and Public Health. *Watersheds and Source Protection: Governance, Science and Health*. The Peter Wall Institute, UBC, Vancouver, 24 Nov 2006.

Role of Science and Best Judgement in the Walkerton Inquiry. National Conference of the Canadian Water Network, Montreal, 21 Nov 2006.

Safe Drinking Water from Walkerton to Kasechewan. *Water in Canada and the World: Rising Tensions in the 21st Century – Issues and Solutions*. The Royal Society of Canada. 17 Nov 2006.

Challenges for Safe Drinking Water in Small Systems. International Network on Small Community Water Management. Kelowna. 19 Sep 2006.

Safe Drinking Water for Small Systems. Infrastructure Workshop, Canadian Water Network, Toronto. 18 Sep 2006.

Risk Analysis for Better and More Credible Utility Decisions. AwwaRF Technology Transfer Workshop. San Francisco. 13 Sep 2006.

Keynote Speaker: Disinfection By-Products and Alternative Disinfection - Where Are We and How Did We Get Here? *Enviro 06*, Melbourne, Australia, 9 May 2006.

Banquet Speech: “150 Years and Counting - Drinking Water Safety Lessons are Learned Slowly” *Annual Banquet for the TD Canada Trust Walter Bean Visiting Professorship in Environment*, University of Waterloo, 2 Mar 2006.

Keynote Speaker: “From Walkerton to Kashechewan – Is Safe Drinking Water Really so Difficult?” *National Water Research Institute Distinguished Speaker for 2006*, February 13, 2006.

“Role of the Environmental Appeals Board in Alberta.” International Institute for Resource Industries & Sustainability Studies Seminar Series, Haskayne School of Business, University of Calgary, 16 Dec 2005.

Keynote Speaker. “Safe Drinking Water and Risk Management – Converting Hindsight into Foresight” *Emerging Trends in Environmental Law, Municipal Governments Seminar*, Brownlee-Fryett, Edmonton, 7 Dec, 2005.

Inaugural Schultz Oration: “150 Years Later - How Are We Doing with Drinking Water Safety?” *Donal Herbert Schultz Endowment to the Flinders Research Centre for Coastal and Catchment Environments*, Flinders University, Adelaide, Australia, 22 Nov 2005.

“The Alberta Environmental Appeals Board – A Primer for Practitioners” *Canadian Bar Association – Edmonton Branch*, Monthly Meeting, 10 Nov, 2005.

“Risk Analysis Strategies for Better and More Credible Utility Decisions” *Advancing the Science of Water – The Future of Water Utilities: Reading the Crystal Ball*, American Water Works Association Research Foundation, Detroit, 21 Oct, 2005

Keynote Presentation: “Turning Hindsight into Foresight – Lessons from Recent Drinking Water Outbreaks” *Annual Conference of the Atlantic Canada Water Works Association*, Halifax, 17 Oct, 2005.

Keynote Presentation: “A Nose for Trouble - The Role of Off-Flavours in Assuring Drinking Water Safety” 7th *International Water Association Specialty Conference on Off Flavours in the Aquatic Environment*, Cornwall, Ontario, 6 Oct, 2005.

“Risk Analysis Strategies for Better and More Credible Utility Decisions” *Advancing the Science of Water – The Future of Water Utilities: Reading the Crystal Ball*, American Water Works Association Research Foundation, St. Louis, 27 Sept, 2005.

Keynote Presentation: “Drinking Water Disease Outbreaks – Legal Perspectives of Problems and Resolutions” *Annual Conference of Environmental Lawyers in Government*, Edmonton, 12 Sept, 2005.

Keynote Presentation: “Safe Drinking Water – Protecting the Public’s Health” *Rural Community Action Partnership 2005 Conference – Rural Issues and Best Practices*, Washington, D.C., 23 Aug, 2005

“Safe Drinking Water - Converting Hindsight into Foresight” *Special Presentation to the State Water Council of Western Australia*, Perth, Australia, 29 July, 2005

“Safe Drinking Water – Walkerton 5 Years On.” *Special Seminar of the Australian Water Association - Western Branch*, Perth Australia, 28 July, 2005

“Safe Drinking Water - Converting Hindsight into Foresight” *Special Seminar for the Water and Rivers Commission of Western Australia*, Perth, Australia, 28 July, 2005

“Current DBP Issues –A Health Risk Assessment Perspective” *Cooperative Research Centre for Water Quality and Treatment Research Symposium*, Brisbane, 26 July, 2005

“Drinking Water Safety in Canada Saving a Victim of Success” *Water Education Institute*, Kananaskis, Alberta, 8 July 2005.

“Preventing Drinking Water Emergencies – Water Quality Monitoring Lessons from Recent Outbreak Experience” *UK Conference*, Manchester UK, 14 June, 2005.

“The Lessons Learned? Converting Hindsight into Foresight” *Symposium on Converting Hindsight into Foresight - Walkerton 5 Years On - Canadian Water Network Public Health Workshop*, Walkerton, May 31, 2005

Keynote Presentation: “Waterborne Disease Outbreaks in Affluent Societies” *Public Forum for Walkerton 5 Years On - Canadian Water Network Public Health Workshop*, Walkerton, May 30, 2005

“Recent Drinking Water Disease Outbreaks in Developed Countries, *Special Seminar*, Beijing University, 18 May, 2005

“Quantitative Risk Assessment – Useful Insight or Misleading Disinformation?” 2nd *Chinese International Symposium on Persistent Toxic Substances*, Beijing, 17 May, 2005

“A Population Health and Drinking Water Safety Perspective on Guidelines for Canadian Drinking Water Quality” *Federal-Provincial-Territorial Committee on Drinking Water*, St. Johns, Nfld, 2 May 2005.

“Risk Management – Lessons for More Credible Decision-Making” *AwwaRF International Workshop on Risk Analysis Strategies for Better and More Credible Decision Making*, Banff, Alberta, 6 April 2005.

“Safe Drinking Water – Converting Hindsight into Foresight”, Invited Seminar in the Series - *Shaping Future Water Policy: The Role of Science*, Michigan State University, East Lansing, Michigan, 25 March 2005.

Invited Testimony: on Safe Drinking Water before the *Standing Senate Committee on Energy, Environment and Natural Resources*, Edmonton, 9 March 2005

Keynote Speaker: "Waterborne outbreaks in affluent nations - causal themes common to small systems", *Federal Drinking Water Providers, First Annual Workshop*, Health Canada, 9 Feb, 2005.

"Safe Drinking Water – Confronting the Truth" *Edmonton Section, Canadian Bar Association*, 14 Dec 2004.

Keynote Speaker: "Safe Drinking Water – Turning Hindsight into Foresight" *Breakfast for MPs and Senators, Parliament Hill, 15th Annual Meeting of the Networks of Centres of Excellence*, Ottawa, 2 Dec 2004.

"Environmental Health Risk Management – Understanding Reality." *Air and Waste Management Association*, Edmonton, 30 Nov, 2004.

Special Seminar: "Safe Drinking Water – Lessons for Australians from Recent Outbreaks in Affluent Nations." *Australian Water Association – South Australia Branch*, Adelaide, 25 Nov, 2004.

"Water Quality Monitoring Evidence for Drinking Water Risk Management" *Workshop on Developing Evidence-Based Water Quality Monitoring Systems, Monash University*, Melbourne, 22 Nov, 2004.

Keynote Speaker: "Drinking Water and Risk Management". *Victorian Department of Human Services Special Conference for Drinking Water Authorities*. Melbourne, 19 Nov, 2004.

Special Meeting: "Outbreaks in Small Systems" *Ontario Advisory Council on Drinking Water Standards*. Toronto, Nov, 2004.

Keynote Address: "Safe Drinking Water – Lessons from Recent Outbreaks." *2004 Annual Conference Saskatchewan Water and Wastewater Association*. Saskatoon, 5 Nov 2004.

Keynote Address: "Water System Factors that Have Contributed to Human Illness: An International Review." *2004 Drinking Water Conference for B.C. Drinking Water System Regulators*. Vancouver, 3 Nov. 2004.

"Safe Drinking Water and Emergency Preparedness" *Specialty Conference, Australia Water Association – Tasmania Section*. Hobart, Sept 28, 2004.

Special Symposium: "Safe Drinking Water – Lessons from Walkerton and Beyond" *Annual Conference of the Australian Society of Microbiology*. Sydney, Sept 26, 2004.

Keynote Address: "Safe Drinking Water – Lessons from Walkerton and Beyond" *Safe Drinking Water Conference of the New South Wales Department of Health*. Sydney, 24 Sept 2004.

"Safe Drinking Water" *Special Section Meeting of the Australian Water Association*. Brisbane, 20 Sept 2004.

Keynote Address: "Safe Drinking Water – Lessons from Recent Outbreaks in Affluent Nations" *Annual Conference of the Canadian Science Writers Association*. Toronto, 7 June 2004.

Keynote Address: "Risk of Source Water Contamination Impairing Drinking Water Safety – Learning Lessons from Past Failures." *Source Water Protection Specialty Conference Alberta Environment and Western Canada Water and Wastewater Association*. Red Deer, 18 May 2004.

Keynote Address: "Walkerton and the Inquiry – A Human Tragedy and Wakeup Call for Canadians." *U.S. EPA sponsored International Colloquium Protecting Public Health in Small Water Systems, Montana State University*, Bozeman, Montana, 10 May 2004.

"Safe Drinking Water – Lessons from Recent Outbreaks in Affluent Countries." *Society for Environmentally Responsible Land Ownership*, Red Deer, 17 Jan 2004.

PUBLICATIONS:

Books:

- Hrudey, S.E. & E.J. Hrudey. 2004. *Safe Drinking Water – Lessons from Recent Outbreaks in Affluent Nations*. IWA Publishing, London. 514pp.
- Thomas, S. P. & S. E. Hrudey. 1997. *Risk of Death in Canada- What We Know and How We Know It*. University of Alberta Press, Edmonton, 292 pp.
- Hrudey, S.E., Chen, W. & C. Rousseaux. 1995. *Bioavailability in Environmental Risk Assessment*. Lewis Publishers, CRC Press, Boca Raton, Florida, 291 pp.
- Vandermeulen, J.H. & Hrudey, S.E. 1987. **Ed.** *Oil and Freshwater: Chemistry, Biology and Countermeasure Technology*, Pergamon Press, 510 pp.
- Barnes, D., Forster, C.F. & Hrudey, S.E. 1987. **Ed.** *Surveys in Industrial Wastewater Treatment: Manufacturing and Chemical Industries*, Vol.3, Longmans Ltd., London, 217 pp.
- Barnes, D., Forster, C.F. & Hrudey, S.E. 1984. **Eds.** *Surveys in Industrial Wastewater Treatment: Petroleum and Organic Chemical Industries*, Vol.2, Pitmans Ltd., London, 233 pp.
- Barnes, D., Forster, C.F. & Hrudey, S.E. 1984. **Ed.** *Surveys in Industrial Wastewater Treatment: Food and Allied Industries*, Vol.1, Pitmans Ltd., London, 326 pp.

Book Chapters and Specialty Proceedings Publications

- Hrudey, S.E. & E.J. Hrudey. 2009. Prevention is Painfully Easy in Hindsight: Fatal *E. coli* O157:H7 and Campylobacter outbreak in Walkerton, Canada, 2000. Global Issues in Water, Sanitation and Health. Institute of Medicine of the National Academies. National Academies Press. pp. 127-152.
- Bradshaw, R.A., Pollard, S.J.T., Jalba, D.I., Charrois, J.W., S.E. Hrudey and N.J. Cromar. 2009. Evaluating cause-effect relationships and impact of incidents – a learning approach for operations and asset management. In: *Water Contamination Emergencies – Collective Responsibility*, Gray, J. and Thompson K.C. (eds.) Royal Society of Chemistry, Special Publication No. 317, pp. 82-116.
- Hrudey, S.E. 2006. Fatal Disease Outbreak from Contaminated Drinking Water in Walkerton, Canada. In: *Case Studies in Environmental Engineering and Science*. Eds: A. Bhandari & M.A. Butkus, Association of Environmental Engineering and Science Professors, Champaign, Illinois. pp. 4-18.
- Hrudey, S.E. 2006. Waterborne Outbreak of Cryptosporidiosis – North Battleford, Canada. In: *Case Studies in Environmental Engineering and Science*. Eds: A. Bhandari & M.A. Butkus, Association of Environmental Engineering and Science Professors, Champaign, Illinois. pp. 19-34.
- Hrudey, S.E. and S. Rizak. 2006. Preventing drinking water emergencies – water quality monitoring lessons from recent outbreak experience In: *Water Contamination Emergencies: Enhancing our Response*. Eds. K.C. Thompson and J. Gray, Royal Society of Chemistry, Special Publication No. 302, pp.42-52.
- Pollard, S.J.T., J.E. Strutt, B.H. MacGillivray, J.V. Sharp, S.E. Hrudey and P.D. Hamilton. 2006. Risk management capabilities – Towards ‘Mindfulness’ for the international water utility sector. In: *Water Contamination Emergencies: Enhancing our Response*. Eds. K.C. Thompson and J. Gray, Royal Society of Chemistry, Special Publication No. 302, pp. 70-80.
- Leiss, W. and S.E. Hrudey. 2005 *On Proof and Probability, Introduction to Law and Risk*, Chap 1, 1-19, Law Commission of Canada. University of British Columbia Press and Les Presses de l'Universite Laval, 208pp.

- Hrudey, S.E. and E.J. Hrudey. 2004. *Converting Hindsight into Foresight – Understanding the Causes of Waterborne Outbreaks*, Chap. 9 In: *Microbial Waterborne Pathogens*, Ed. Cloete, T.E., J. Rose, L.H. Nel and T. Ford. IWA Publishing, London. 205-217..
- Hrudey, S.E. Ed. 2003. *Drinking Water Safety – A Total Quality Management Approach*. Proc. Inter. Conf. Water & Health, Ottawa, Sept 23-25, 2002, NERAM – IRR, University of Waterloo. 476pp.
- Hrudey, S.E. 2000. Limits to Science for Assessing and Managing Environmental Health Risks. *Science, Truth and Justice*. Canadian Institute for the Administration of Justice, Les Éditions Thémis. Faculté de Droit. Université de Montréal. ISBN 2-89400-151-7 pp. 127-150
- Hrudey, S.E., M. Burch, M. Drikas and R. Gregory. (1999). Remedial Measures. Chapter 9. In: *Toxic Cyanobacteria in Water – A Guide to Public Health Consequences and their Management in Water Resources and Supplies*. Eds: I. Chorus and J. Bartram, World Health Organization. E & F.N. Spon. London. 275-312.
- Jardine, C.G. and S.E. Hrudey. (1999). "What is Risk?" Chap 17. *Environmental Health For All*. Kluwer Academic Publishers. 205-211.
- Jardine, C.G. and S.E. Hrudey. (1999). "Promoting Active Public Participation?" Chap 13. *Environmental Health For All*. Kluwer Academic Publishers. 157-168.
- Hrudey, S.E. 1998. "Quantitative Cancer Risk Assessment - Pitfalls and Progress." *Issues in Environmental Science and Technology*. Eds. R.E. Hester and R.M. Harrison 9: 57-90, Roy. Soc. Chem. Pub., Cambridge
- Leiss, W. and S. E. Hrudey. (1997). "Dioxins or Chemical Stigmata." Chapter 3. *Mad Cows and Mother's Milk: The Perils of Poor Risk Communication*, Eds: D. Powell and W. Leiss. McGill-Queens University Press, pp 41-76.
- Hrudey, S.E., Whitfield, F.B. & McGuire, M.J. (1995). Ed. "Off-Flavours in Drinking Water and Aquatic Organisms" International Association on Water Quality, Pergamon Press, Oxford, England., 280 pp.
- Hrudey, S.E. (1991). "Specific problems in risk analysis and environmental monitoring" In: *Hazardous Waste Incineration Calculations*. Eds. Reynolds, J.P., Dupont, R.R. and Theodore, L., Wiley Interscience, pp 31-37, 131-142.
- Fedorak, P.M. & Hrudey, S.E. (1988). "Anaerobic Degradation of Phenolic Compounds with Applications to Treatment of Industrial Wastewaters" In: *Biotechnology Applied to Environmental Problems: A Bioenvironmental Systems* Ed. Wise, D.L., CRC Press, pp 169-225.
- Vernick, A.S., Langer, B.S., Lanik, P.D. & Hrudey, S.E. (1984). "Petroleum Refining Industry Wastewater Management." Chapter 1. *Surveys in Industrial Wastewater Treatment: Petroleum and Organic Chemical Industries*, Vol. 2, Eds. Barnes, Forster & Hrudey, Pitmans Ltd., London, pp 1-64.
- Hrudey, S.E. (1984). "Meat and Poultry Products Industry Wastewater Management." Chapter 3. *Surveys in Industrial Wastewater Treatment: Food Processing Industries*, Vol.1, Eds: Barnes, Forster & Hrudey, Pitmans Ltd., London, pp 128-208.
- Smith D.W. and Hrudey, S.E. (1981), Eds. "Design of Water and Wastewater Services for Cold Climate Communities", In: *Water Science and Technology*. 13(supp.) 184 pp., Pergamon Press Ltd., London.
- Hrudey, S.E. (1977). General Sampling Techniques, Chapter 1. *Handbook of Air Pollution Analysis*, Eds: R. Perry & R. Young. pp.1-83, Chapman and Hall Ltd., London, J. Wiley & Sons Inc., New York.

Expert Panel Reports

- Bruce, J.P., W. Cunningham, A. Freeze, R. Gillham, S. Gordon, S. Holysh, S.E. Hrudey, W. Logan, K. MacQuarrie, P. Muldoon, L. Nowlan, J. Pomeroy, S. Renzetti, B. Sherwood Lollar, R. Therrien. (Expert Panel on Groundwater) 2009. Sustainable Management of Groundwater in Canada. Council of Canadian Academies. Ottawa.

- Hrudey, S.E. (Chair), M.J. Allen, R.W. Brecher, R. Copes, P. Turbidity and microbial risk in drinking water. Ministerial Technical Advisory Committee for the Minister of Health pursuant to Section 5 of the Drinking Water Act (S.B.C. 2001).
- Swain, H., Louttit, S. and S.E. Hrudey. 2006. Report of the Expert Panel on Safe Drinking Water for First Nations. Minister of Indian and Northern Affairs, Ottawa, November 2006 (Vol. 1 and 2)
www.eps-sdw.gc.ca/rprt/index_e.asp
- Fazil, A., Paoli, G., Lammerding, A.M., Davidson, V., Hrudey, S., Isaac-Renton, J. and M. Griffiths. 2005. Microbial Risk Assessment as a Foundation for Informed Decision-Making. Microbial Food Safety Assessment Unit, Public Health Agency of Canada, Guelph, ON.
- Hrudey, S.E. (Panel Chair), Bathija, A., Bull, R.J., Dodds, L., Jenkins, G., King, W., Murphy, P., Narotsky, M., Reif, J., Savitz, D. and B. Thomas. 2003. Executive Summary. International Expert Workshop for Health Canada to Identify Critical Endpoints for Assessment of Health Risks Related to Trihalomethanes (THMs) in Drinking Water. March 2003.
- Langley, A. et al. 2002. *Environmental Health Risk Assessment – Guidelines for Assessing Human Health Risks from Environmental Hazards*. En Health: Department of Health and Ageing. Canberra, Australia.
- Callan, P., Cunliffe, D., Howard, J., Hrudey, S.E., Rizak, S., Sinclair, M. and R. Vulcano. 2002. *Framework for Management of Drinking Water Quality – A Total Quality Management Approach from Catchment to Consumer*. (Incorporated into the Australian Drinking Water Guidelines) Working Party to the National Health and Medical Research Council. Canberra, Australia.
- Sinclair, M., Bull, R., Froese, K., Hrudey, S.E., Nieuwenhuijsen, M. and S. Rizak. 2002. Disinfection By-Products and Health Effects. Summary of an International Expert Workshop. CRC for Water Quality and Treatment. Occasional Paper No. 5. Salisbury, South Australia.
- Adamowicz, V., Dales, R., Hale, B.A. Hrudey, S.E. (**Panel Chair**), Krupnick, A., Lippmann, M., McConnell, J., and P. Renzi. 2001. *Expert Panel to Review the Socio-Economic Models and Related Components Supporting the Development of Canada-Wide Standards for Particulate Matter and Ozone*. The Royal Society of Canada. Ottawa. 240pp.
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FINDINGS AND RECOMMENDATIONS
of the
BDCM EXPERT PANEL MEETING
SEPTEMBER 22nd and 23rd, 2008

Context:

Health Canada leads the development of the Guidelines for Canadian Drinking Water Quality to establish maximum acceptable concentrations (MAC) of contaminants in drinking water, based on up-to-date scientific and technical information. The Guideline Technical Document for trihalomethanes (THMs) in drinking water, which includes a specific guideline for Bromodichloromethane (BDCM), was published in May 2006. The document establishes a MAC of 0.1 mg/L (100 µg/L) for THMs, as a running annual average of quarterly samples. This MAC is based on the health effects of chloroform, and applies to the total concentration of chloroform, BDCM, dibromochloromethane (DBCM) and bromoform.

The Guideline Technical Document also establishes a MAC of 0.016 mg/L (16 µg/L) for BDCM in drinking water. This MAC is based on a cancer endpoint and is designated as a “not-to-exceed” value as a precaution for potential adverse reproductive effects. Health Canada had used the 1987 NTP study, which used corn oil as a vehicle, as the key study to derive a MAC based on BDCM's carcinogenic potential.

Since the development of the MACs, several new relevant scientific papers have been published on the health effects of BDCM and of THMs. The 2006 NTP study on BDCM used drinking water as the vehicle, and it suggests that BDCM in drinking water may not cause cancer in laboratory animals, which contradicts the findings from the 1987 NTP study. New epidemiological studies have been published on the reproductive effects of BDCM, which are not showing an association between exposure to BDCM and adverse reproductive results.

Consequently, Health Canada has identified a need to review the scientific evidence now available to ensure the approach used to derive the BDCM guideline is still appropriate and to determine whether a MAC specific to BDCM is still necessary and if so, at what level.

As part of this review, Health Canada commissioned three reports (two consultant reports and one internal report) to assess current science. The first report, entitled “*Evaluation of the vehicle effects on the internal dose and carcinogenicity of BDCM based on PBPK modeling and mode-of-action*” (Krishnan, 2008a), examined the NTP 1987 and 2006 data, in addition to the current literature on the potential carcinogenic effects of BDCM exposure. The second report entitled “*Potency estimation for BDCM based on PBPK models*” (Walker, 2008) focussed on the statistical manipulation of the data and modeling to calculate tumorigenic doses (TDs), the increases in tumor rates over background. The final report, “*Cancer dose-response analysis for BDCM*” (Krishnan, 2008b), converted the TDs from Walker’s report into human environmental doses using a PBPK model.

These reports were used as a starting point for discussions with experts, which marks the beginning of the review process of this guideline. A panel of experts was convened in September 2008 to provide expert advice and to make recommendations to Health Canada and to the Federal-Provincial-Territorial Committee on Drinking Water (CDW) regarding BDCM in drinking water. Advice was sought from the Expert Panel on three specific issues of concern:

- 1- Reproductive and developmental toxicity of BDCM;
- 2- Carcinogenicity of BDCM;
- 3- Risk assessment approach to develop BDCM guideline.

The Expert Panel reached a consensus on all key issues identified, and its main conclusions and recommendations to Health Canada and the Federal-Provincial-Territorial Committee on Drinking Water on each issue are provided below.

Expert Panel Members:

Linda Dodds, Dalhousie University, Canada

Kannan Krishnan, Université de Montréal, Canada

Rex Pegram, U.S. Environmental Protection Agency, USA

Robert Tardiff, The Sapphire Group, Inc., USA

Richard Bull, Pacific Northwest National Laboratory, USA

John Fawell, Independent Consultant on Drinking Water and Environment, UK

Issue 1: Reproductive and developmental effects

Epidemiological evidence

At the time of the update of Health Canada's Guideline Technical Document on THMs, there was some epidemiological evidence for an association of BDCM exposure with reproductive and developmental effects (i.e., spontaneous abortion). The MAC of 16 µg/L for BDCM in drinking water was based on a cancer endpoint, but identified as a "not-to-exceed" value as a precautionary approach for potential reproductive effects.

Recent evidence, from epidemiological studies with improved protocols and exposure assessment technologies, demonstrates no or inconsistent association for most reproductive or developmental endpoints with BDCM exposure at current levels.

Based on their knowledge of the science at the time of the meeting, the expert panel on BDCM agreed to the following consensus responses to Health Canada's questions:

Question from Health Canada: Does the current weight of evidence from epidemiological studies support an association between adverse reproductive and developmental effects in human and environmental exposure to BDCM?

Response from the Expert Panel: *"Overall, the evidence from epidemiological studies is inconsistent and by international standards, the current weight of evidence is not sufficient to support an association between adverse reproductive and developmental effects in humans and environmental exposures to BDCM."*

Question from Health Canada: Do you know of any new or upcoming studies that could have an impact on the weight of evidence for an association of adverse reproductive and developmental effects in human with environmental exposure to BDCM?

Response from the Expert Panel: L. Dodds identified four groups of studies currently underway whose findings will need to be considered in the future, once they are completed and published:

- Levallois et al.
- U.S. EPA, National Center for Environmental Assessment, Dr. Michael Wright
- Nieuwenhuijsen et al.
- Dodds et al.

Toxicological evidence

As cancer was considered to be the endpoint of concern to derive the 2006 MAC for BDCM, the toxicological effects of BDCM on reproduction and development in animals were not considered in the derivation of the guideline value. In animal models, the adverse reproductive and developmental effects of BDCM were observed only at very high doses and were inconsistent among animal models. Results also varied according to the method of BDCM administration and only limited data explore modes of action for reproductive and developmental toxicity.

Based on their knowledge of the science at the time of the meeting, the expert panel on BDCM agreed to the following consensus responses to Health Canada's questions:

Question from Health Canada: Does the current weight of evidence from toxicological studies support an association between adverse reproductive/developmental effects and BDCM exposure in animals?

Response from the Expert Panel: *“Although BDCM has been shown to cause adverse reproductive effects in animals, these have only been observed at maternally-toxic doses which are 5000 to 15000 times higher than levels found in drinking water. Overall, the current weight of evidence from toxicological studies does not support an association between adverse reproductive/developmental effects and exposure to BDCM at concentrations that occur in chlorinated drinking water.”*

Question from Health Canada: Do you know of any new or upcoming studies that could have an impact on the weight of evidence for an association of adverse reproductive and developmental effects in animals with exposure to BDCM?

Response from the Expert Panel: R. Pegram identified several new studies, that are underway but not yet published, and whose findings will need to be considered in the future:

- Lasley et al., (University of California, Davis). 1. Further analysis of the effect of BDCM on human placental cell differentiation in vitro. 2. Effects of DBP mixtures on human placental cell function in vitro.
- Bielmeier et al., (U.S. EPA). BDCM-induced reduction in LH secretion in the SD rat.
- Narotsky et al. (U.S. EPA). Effects of inhaled BDCM on pregnancy and relevant endocrine functions.

Issue 2: Carcinogenicity

The current guideline for BDCM in drinking water was developed using the 1987 NTP study as the key study, which used corn oil as a vehicle, and found increased tumours in F344/N rats. The 2006 NTP study found no evidence of increased carcinogenic activity of BDCM in male F344/N rats or female B6C3F1 mice when BDCM was administered via drinking water.

Based on their knowledge of the science at the time of the meeting, the expert panel on BDCM agreed to the following consensus responses to Health Canada's questions:

Question from Health Canada: Considering the findings from the new NTP (2006) study and from other recent toxicological data, does the current weight of evidence support BDCM carcinogenicity in animals?

Response from the Expert Panel: *“The evidence from a lifetime study of BDCM given to rodents by corn oil gavage is that it is an animal carcinogen. However, a second NTP lifetime study,*

which tested lower doses of BDCM in drinking water does not support this determination. The combined data from the two studies do not support a linear dose response.”

“Some shorter term studies demonstrate the development of aberrant crypt foci in the rat large intestine when BDCM is given in drinking water, which suggests that BDCM may play a role in carcinogenesis.”

Question from Health Canada: At the time of the expert panel meeting, BDCM was classified in Group II – probably carcinogenic to humans, with sufficient evidence in animals and inadequate evidence in humans (Health Canada, 1994). Should BDCM still be considered probably carcinogenic to humans?

Response from the Expert Panel: *The NTP 2006 drinking water study diminishes the weight of the evidence that BDCM is “probably” carcinogenic in humans. However, the possibility that a mutagenic mode of action contributes to the carcinogenic effects of BDCM in the intestine cannot be dismissed. Therefore, the Panel concluded that the NTP (2006) data alone are not sufficient to change the classification to “possibly” carcinogenic in humans.*

Issue 3: Risk assessment

BDCM is classified in Group II, “*probably carcinogenic to humans*”, based on sufficient evidence in animals, but insufficient evidence from human epidemiological studies. Because BDCM is considered to be “probably” carcinogenic to humans, the MAC is derived based on the estimated lifetime cancer risk. Health Canada considers a lifetime cancer risk range of 10^{-5} to 10^{-6} to be “essentially negligible”. The 2006 guideline was derived using the Linear Multistage [LMS] method of Howe (1995), based on the results from the 1987 NTP key study. The MAC for BDCM in drinking water is considered as a “not-to-exceed” value, rather than an annual average, as a precautionary approach for potential reproductive effects.

Based on their knowledge of the science at the time of the meeting, and on the previous discussions on Issue Sheets 1 and 2, the expert panel on BDCM agreed to the following consensus responses to Health Canada’s questions:

Question from Health Canada: Is the current science sufficient to justify re-assessment of the BDCM guideline?

Response from the Expert Panel: *“Sufficient new evidence exists to support the reassessment of the BDCM guideline.”*

Question from Health Canada: Given the total THMs MAC, is the individual MAC for BDCM in drinking water still necessary?

Response from the Expert Panel: *“At this time, it is unlikely to be necessary to retain a BDCM guideline, however, the risk assessment needs to be completed.”*

Question from Health Canada: Is the overall proposed approach for risk assessment of BDCM based on carcinogenicity appropriate? If not, what do you recommend? Are there any factors/considerations we omitted?

Response from the Expert Panel: *“Carcinogenicity is the key endpoint for risk assessment. The appropriate dose metric is internal dose, and issues related to human metabolism and kinetics need to be considered in the assessment. Two low dose extrapolation approaches should be considered for illustrative purposes (linear vs non-linear). An approach based on carcinogenicity is most likely to be protective of non-cancer health effects including reproductive/developmental effects.”*

Question from Health Canada: Should reproductive and developmental effect be considered as key endpoints when deriving the MAC for BDCM? If yes, which animal model would be appropriate, which key study should be used for reproductive/developmental effects in animals, and what would be the NOAEL?

Response from the Expert Panel: *“Reproductive and developmental effects must be considered in the risk assessment, although they are unlikely to be the key endpoint. Two drinking water studies could be used (Christian et al., 2001 & 2002); each study generated a NOAEL.”*

Question from Health Canada: Should “not-to-exceed” still be applied to the BDCM guideline value to protect the Canadian population against potential adverse reproductive and developmental effects of BDCM in drinking water?

Response from the Expert Panel: *“Since the current weight of evidence does not support the need for a BDCM guideline based on reproductive/developmental toxicity, the concept of “not-to-exceed” for BDCM is no longer applicable.”*

Additional Comments from Expert Panel

Based on their knowledge of the science at the time of the meeting, and on the discussions held during the meeting, the expert panel on BDCM suggested that Health Canada also take into consideration the following comments when updating its Guideline Technical Document:

- *“Water suppliers should keep disinfection by-products as low as possible at all times without compromising disinfection.”*
- *“New human data on the absorption of THMs via inhalation and skin contact may need to be considered to further inform the risk characterization.”*
- *It was noted that an association between exposure to total THMs and adverse reproductive outcomes may exist.*
- *“It remains important that Health Canada continue to monitor the emerging scientific evidence in order to ensure that the guidelines for DBPs are kept up to date within a reasonable timeframe.”*