Black Holes of Risk:

Collected Papers on
Risk Management, 1995-2017

Volume II: Nuclear Waste Storage

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Author's Note:

The last four chapters in this volume were prepared with the collaboration of a number of other authors. Please see the chapter headings for details.

Table of contents

Part Three: Case Studies in Risk Management

Part Four: Long-Term Storage of Nuclear Waste

PREFACE

The ultimate goal of risk management and risk communication is to assist stakeholders, consumer and the general public in understanding the rationale behind a risk-based decision, so that they may arrive at a balanced judgement that reflects the factual evidence about the matter at hand in relation to their own interests and values. Risk communication should not be seen as an attempt to convince or persuade people to adopt the judgement of the communicator about the tolerability or acceptability of risks. It is rather the attempt to help people to make more informed judgments and enable them to have agency over the risks that they face in their own lives. In addition, effective risk communication is a central prerogative for taking an active part in contemporary discourses about risks, and in particular technological and environmental risks. Being well informed about and aware of risks posed by new technologies and changes in lifestyle is also paramount to all involvement and participation programs that are directed towards more direct codetermination for designing and shaping regulations and standards.

Effective risk communication can make a strong contribution to the success of a comprehensive and responsible risk management programme. Through effective risk communication one can: (1) ensure that society is or becomes aware of the risks associated with new products, technologies and human interventions into nature; (2) build public confidence in appropriate risk assessment and management decisions and the associated risk/benefit considerations; (3) contribute to the public's understanding of the nature of risk, the magnitude of risks in a comparative review of potential threats; and (4) provide fair, accurate, and appropriate information, so that society and its institutions are able to choose among a variety of options that can meet their own "risk acceptance" criteria.

The two volumes written by William Leiss include seminal papers and analyses on the two topics: risk management and risk communication. They are a strong reminder that risks can be managed, governed and communicated. Scientific advances, professional expertise and management skills are key to reducing risks in modern live to a standard that appears acceptable to society. The acceptability level that a society is willing to tolerate is a political decision that requires intensive public discourse and effective democratic institutions for decision making. Informing this discourse and guiding societal actors through the complex evidence about potential harm is one of the most important tasks for risk scholars and communicators alike.

William Leiss is one of those risk pioneers who has the rare gift of being a highly competent scientist in risk analysis and management and a dedicated and effective communicator. The two volumes that he has authored speak to the comprehensive and interdisciplinary competence in many risk fields but also to his ability to make complicated insights into risk management challenges easily understood by an attentive lay public. His contributions to the field have and continue to have major impacts on risk discourses in the public. In particular, he has pointed out where society has probably spent too much attention and resources on minor risk threat and not enough attention on those systemic risks that pose long-lasting threats to Canada and the rest of the world. When society gets too concerned about marginal risks such as food additives it may be distracted from the larger risk scene where issues such as climate change emerge into potential global disasters.

The author does not convey a pessimistic outlook into our future. On the contrary, he points out that society has been very successful in reducing risks in many domains of life. As a professional in the field, he has also induced and inspired many managerial changes in Canada that helped to improve risk management practices and make governance efforts more effective. Furthermore, he has introduced improved manuals and guidelines for institutions all over the world to be better prepared and skilled to deal with complex risk situations. I myself was privileged to cooperate with William Leiss for initiating and guiding a substantive relaunch of the risk communication program of the German Federal Agency for Risk Assessment. This program is still in place and does what it has been designed for: help people to deal prudently with risk in their daily life.

The two volumes represent a large array of the major accomplishments and ideas of William Leiss over a professional lifespan of many decades. They testify to the author's competence and ability to make a difference in the risk world. Moreover, the book is highly informative, educational and inspiring. It is a "must" for all those who have an interest and/or an obligation to continuously reduce the level of unwanted risks to society.

ORTWIN RENN
Berlin, October 31, 2017

Introduction

Risks are everywhere, ubiquitous. For the individual, they begin even before conception, in the genetic matchups from one's parents that could presage becoming afflicted with one of the more than ten thousand known inherited diseases, many of which have catastrophic consequences. They carry on throughout pregnancy, with rates of miscarriage and complications exceeding 30%, and into early childhood; before modern public safety and medicine, about half of all newborns died before the age of five. And then throughout life, with premature mortality resulting from accidents, disease, and acts of deliberate malice.

Should a realization about the ubiquity of risk induce in us a state of paralyzing, overwhelming fear? Should it send us into a catatonic state, unable to function at all? Quite the contrary, for it tells us that we are well on our way to *domesticating* risks, to becoming, if not comfortable with them, then at least understanding them far better than we have done before: That we are steadily learning what substances, behaviors, activities and conditions are quite likely to be harmful to us, and which ones are much less likely to do so, enabling us to set priorities for spending time and money on figuring out how to reduce the impact of potential harms on our health, well-being, and longevity.

The great discovery about risk in the modern West was simply that risks are *measurable*, whereas dangers are not. (The early history in this area is wonderfully told by Peter L. Bernstein in his 1998 book, *Against the Gods: The Remarkable Story of Risk*.) In other words, what is really important about the things that may do us harm is just how much harm may be approaching, from a specific source, and how likely it is to strike us. And because risks are measurable, that is, quantifiable, we can rank a collection of them in order of importance, estimating how much more likely one is as opposed to another, and also how much more harm one may do to us than some other one may.

But there is a downside as well: Because risk is *the chance of harm*, what we can never have is any certainty about who exactly might be harmed – that is, ourselves, our neighbors or distant relations, or complete strangers everywhere on the globe. The apparent randomness of outcomes bedevils the appreciation of risk: For most risks of any importance, every one of us among those in a discrete human community is constantly or sporadically at risk, throughout our lives, but only some few will be struck down from a particular type of threat which hangs over all. Where risks are closely studied on an ongoing basis, as they are in modern societies, the apparent randomness gradually turns out to be an illusion, as the proximate causes for the distribution of risks among populations are better understood and the underlying patterns of outcomes become more predictable. And yet, some pure randomness will always prevail as a result of simple accidents and unforeseeable circumstances.

And then there is uncertainty, which to many persons appears to be the same thing as randomness, that is, the equivalent to something being utterly unknown. Because risk is inherently the *chance* (or the possibility) of harm, it is also inherently uncertain as to either the likelihood, or the consequences, that harm will actually be inflicted in any particular case. But it is not necessarily (thus not inherently) random: There are distinctive patterns to the harms inflicted, although not in all cases. Those patterns can be described and, in fact, when sufficient evidence is available, described quite precisely. A famous definition by Frank Knight referred to risk as "measurable uncertainty." In risk estimation, uncertainty appears in the form of upper and lower ranges around a most-likely number. An example can be drawn from Chapter 3 in this volume.

When one needs a blood transfusion in hospital, the nurse will fill out a requisition drawing on the local blood bank, a supply donated by one's fellow citizens. The benefits of receiving blood are huge, and sometimes life-saving, but the blood carries risks to the recipient as well, although medical authorities try to reduce those risks to the lowest possible level. Among the risks is the chance of contracting HIV/AIDS, and in Canada it has been quite carefully estimated: About 1 in every 8 million liters of donated blood may be contaminated (that amounts to about ten years of blood donations in this country). It *may* be 1 in 8 million, but the uncertainty is large, ranging from a high of 1 in 3 million to a low of 1 in 20 million. But this is the bottom line: Even if one were to take the highest estimate, 1 in 3 million, what we are told is that *once every decade* there is a 1-in-3-million-chance that one liter of blood administered to a patient in a Canadian hospital may be contaminated with HIV/AIDS. And that is too small a risk to worry about.

The foregoing helps explain why, to many people, risks appear to be black holes for understanding, devouring infinite amounts of information without yielding clear directions for action. And, to be honest, there is some truth in this suspicion. Almost everyone drinks caffeinated beverages and, if one samples the substantial scientific literature on the subject of caffeine, the conclusions therein about benefits and possible harms appear to be about equally distributed. There are many examples of this kind, especially for high-profile issues such as breast-cancer screening or dietary and health-supplement advice, where the average citizen who tries to follow the twists and turns of the newest information might be left depressed. But in fact the scientists are not being deliberately perverse, for the simple reason that risks are tricky; and, to some extent, it is the scientists' continued search for more and better evidence, on which to base advice to the public, that is responsible for the ongoing difficulty with risk information.

Nowhere is the seemingly ambiguous nature of risks more apparent than in the matter of *dose*, as in the famous phrase, "the dose makes the poison." In other words, there are many, many substances for which relatively small amounts are quite beneficial, whereas just a bit more can bring serious harm. Getting the right dose in prescribed medicines, for example, makes all the difference in the world, sometimes a life-and-death difference. Few substances are more ubiquitous in human life than alcohol, the production and use of which can be traced back as far as 3000 BCE, and here dose is very important. A little, on a regular basis, can be relatively harmless for most people, and may even be beneficial; more consumption, especially regularly, can lead to serious disease, because alcohol is a carcinogen. Women can tolerate quite a bit less than men, adjusted for body weight; and repeated, long-term binge drinking can cause permanent brain damage. Right down to the present day, it remains difficult for public health authorities to communicate convincingly, especially with young people, on this risk issue.

The good news for everyone is that, despite inevitable randomness and uncertainties, most of the lifetime risks we face can be managed. This is becoming increasingly true even of the first-mentioned risk in our list, that of inherited diseases. For example, there is adrenoleukodystrophy (ALD), caused by a single defective gene among the nineteen or twenty thousand that make up the human genome. It affects about one in 20,000 boys, and its effects are truly devastating, turning a bright and healthy youngster, around seven years old, into one who cannot walk, talk, or eat, and later cannot even see, hear, or think, until death intervenes five years later. Now there is both an effective treatment and a cure (involving gene therapy), although both are expensive and not always successful.

Risks are managed through our gaining evidence about their causal factors and the availability of preventative or mitigating strategies to control them. Simple examples abound, such as reducing traffic-accident fatalities by aggressively combatting drunk and distracted-driving behaviors, mandating childhood vaccinations for infectious diseases, or (outside the USA) strictly controlling gun ownership. And yet, the mention of vaccination points to one of the best examples of how the sheer, frustrating perversity of the human intellect erects limits to risk management: In many cases, presenting evidence to people about proven ways to control risks simply causes them to intensify their efforts to invent more reasons why their contrary views are in fact correct, or to redouble their search for apparently disconfirming evidence, however bizarre or anecdotal. Or even (but only in the USA) to pass laws forbidding the use of public funds to compile evidence about the deleterious consequences of virtually uncontrolled gun proliferation.

On the level of personal risk management, there are actually a few helpful rules that can be followed, provided that one is prepared to put one's trust in evidence-based reasoning. They are just three in number, and one can follow them for all the things that are most worrying: First, be proactive, rather than waiting until harm strikes; second, be precautionary, that is, take some practical steps to reduce the expected harm; third, focus primarily on the potential downside, and ignore the expected benefits. Here's an example for a parent worrying about the risk of alcohol abuse by their teenage children. First, follow the always-developing medical literature on the long-term effects of alcohol abuse, so that you can offer specific reasons for your advice; second, introduce responsible alcohol use in your home, rather than waiting for it to occur first outside the home; third, recognizing how strong the positive socialization benefits of alcohol use are for teenagers, focus your advice only on the most serious deleterious consequences, especially the serious risks associated with binge-drinking.

To take another example, pertinent to North America, consider the case of concussion risk for youngsters who are playing organized sports involving physical contact, such as football and ice hockey. Recent publicity about the long-term physical and mental effects of repeated violent contact have made parents more aware of the severity of this risk. So, what should they do? First, be proactive, paying close attention to developing medical research that better characterizes the true frequency and consequences of the risk. Second, be precautionary, including promoting the development of no-contact sports in your area (such as flag football) and enrolling one's children therein. Third, work with your children to diminish the social prestige aspects of the traditional violent-contact sports and to focus on the serious downside risks – in terms of potential lifelong adverse health consequences – of those sports.

The paradoxes involved in our experience with risk management in modern times are legion. None is more potentially consequential than the truly desperate urge on the part of many to shield themselves from scientific knowledge about the risks of climate change. To be sure, this is a devilishly complicated business: The risk estimation requires using global models that can only run on the largest supercomputers, synthesizing evidence derived from the work of literally thousands of talented scientists. The conclusion drawn therefrom, considered to be of high likelihood and high confidence, is that we humans are engaged in "dangerous anthropogenic interference" with the global climate system; and the only remedy for this activity is to drastically reduce the emission of greenhouse gases to the atmosphere. But despite the direst warnings about failing to do so, many prefer to take refuge in simple denial, and have done so for so long that it is less and less likely, with each passing year, that any effective measures for avoiding the most serious adverse future consequences will be available.

Half of the world's population currently lives in proximity to oceans. The latest predictions, from the National Oceanographic and Atmospheric Administration (NOAA) – in the United States, where most of the climate-change deniers live – suggest a sea-level rise of up to six feet by 2100. Such predictions have always erred deliberately on the conservative side, so the actual result could be considerably worse. And the prediction points out that the world's oceans will continue to rise, after 2100, *for centuries to come*. Having reached that point, at the turning of a new century, there will no longer be any option left for us to change the coming course of events.

About sixty-five million years ago, a massive asteroid crashed into the sea-bed off the coast of Mexico. To be sure, we are now entitled to regard such an event as a very rare occurrence indeed, to be expected on our planet on average once every 100 million years or so. But after the asteroid gouged out the Chicxulub crater, the ensuing years of huge volcanic eruptions induced severe climate change that brought the reign of the top predators, the land-based dinosaurs, to an end. At the time the largest mammal was the size of a rat, the evolutionary success of mammals having been kept in check by those predators. The Cretaceous Period ended, to be followed by the Cenozoic Era, the "age of mammals," and ultimately, us. To be sure, the species of modern humans will survive the coming climate change, but it will not be a pretty sight, as billions of people are set in motion by the rising seas. Most of the great achievements of our evidence-based risk management will probably be swept away in the chaos. We in advanced, science-based societies would be well-advised to "eat, drink and be merry" while the good times last.

Guide to the Studies that Follow

Following the opening section, entitled "Prelude: A Risk Sampler," Part One of this volume is a compilation of eight studies, either published in peer-review journals or otherwise disseminated in the period 2003-2008, on the risk-based approach to decision-making, which illustrate both the considerable strengths, as well as the persistent weaknesses, in that approach as it is now practiced. These studies deal with issues that range from the safety of blood and drinking water to the risk assessment of climate change. Part Two looks at risk communication practice, which is the aspect of risk management dealing with the need for a sustained, two-way dialogue between risk managers, on the one hand, and stakeholders and the general public, on the other, that is a necessary precondition for building public confidence in the whole risk management enterprise.

Part Three consists of one paper on carbon capture and storage, and two extensive case studies on the management of the prion diseases BSE (mad cow disease, affecting domesticated cattle) and CWD (chronic wasting disease, affecting both wild and farmed deer and other species). These eighteen studies in all make up Volume I. Part Four is a collection of seven studies, all of which deal with managing radioactive nuclear waste, both high-level as well as low and intermediate-level; they make up the entirety of Volume II. A short introductory note for three of the four parts offers some additional information about the context within which the various studies were researched and written.

With the sole exception of Chapter 2 (where I am the second author), I am either the sole author, or the lead author, for all of the studies collected in Volume I. However, in every one of the multiple-author papers included herein, the designation as lead author is largely an honorific title. In all of them my collaborators, who are without exception distinguished authorities in their own right, provided important and indeed indispensable contributions, drawn from many different specialized academic disciplines, in none of which do I have any expertise. These collaborations have been a source of deep personal satisfaction as well as of academic accomplishment. And in Volume II, the last four chapters were prepared with the collaboration of a number of other authors; please see the chapter headings for details.

My three earlier books in the field of risk management, all of them published by McGill-Queen's University Press (MQUP), contain eighteen additional case studies, many of which are also the result of collaborative efforts. They are:

A. *Risk and Responsibility* (with Christina Chociolko, 1994):
1. Electric and magnetic fields (high-voltage power lines);
2. Alar, a pesticide used on apples;
3. Antisapstain chemicals, pesticides used in the softwood lumber industry.

B. *Mad Cows and Mother's Milk* (with Douglas Powell, 1997), 2nd edition (2004):
1. Government communication on mad-cow disease in the U.K.;
2. Dioxins;

3. The bacterium *E. coli* in hamburger meat;
4. Silicone breast implants (with Conrad Brunk);
5. rBST in milk;
6. Genetically-modified foods;
7. PCBs in mother's milk (with Pascal Milly);
8. BSE in Canadian cattle;
9. A Night at the Climate Casino (with Stephen Hill);
10. Genomics (with Mike Tyshenko).

C. *In the Chamber of Risks* (2001):

1. MMT, A Risk Management Masquerade (with Stephen Hill);
2. Frankenfoods;
3. Radio-frequency fields for cellular telephones (with Greg Paoli);
4. Pulp-mill effluent;
5. Tobacco.

These three volumes are available on the MQUP website:

1) http://www.mqup.ca/risk-and-responsibility-products-9780773511941.php?page_id=73&
2) http://www.mqup.ca/mad-cows-and-mother-s-milk--second-edition-products-9780773528178.php?page_id=73&
3) http://www.mqup.ca/in-the-chamber-of-risks-products-9780773522466.php?page_id=73&

Hamilton, Ontario, Canada
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Black Holes of Risk, Volume II:
Nuclear Waste Storage

Part Four: Long-Term Storage of Nuclear Waste

Part Four:

Long-Term Storage of Nuclear Waste

Chapter 19

Introductory Note to Part Four

The next chapter in Part Four is from an academic journal, but all the remaining chapters originally were produced as consulting reports. Chapter 21 was commissioned by the Nuclear Waste Management Organization (www.nwmo.ca), an agency authorized by the Government of Canada to recommend to the Minister of Natural Resources an acceptable plan for the long-term storage and disposal of high-level nuclear waste. ("High-Level Nuclear Waste" is extremely hazardous and long-lasting radioactive material extracted from Canada's civilian "Candu" nuclear reactors, which generate electricity.) Chapter 22 was commissioned by the Canadian Nuclear Safety Commission (CNSC), a federal agency charged with responsibility for regulating the use of radioactive materials in Canada. Both of these reports were also solo efforts.

The final four documents were prepared by, or on behalf of, an *ad hoc* four-member body, called the Independent Expert Group [IEG], made up of the following persons: William Leiss, Chair; Maurice Dusseault; Tom Isaacs; and Greg Paoli. (For Chapters 24 and 25, we had the expert assistance of Dr. Anne Wiles.) The IEG's work was commissioned by the Joint Review Panel (JRP), a three-member group appointed by two agencies of the Government of Canada, the Canadian Environmental Assessment Agency (CEAA) and the Canadian Nuclear Safety Commission. These agencies jointly directed the IEG to answer specific questions posed to it by the JRP. The JRP itself was charged with making recommendations to two federal ministers on the acceptability of a proposal by Ontario Power Generation (OPG) to build a permanent repository for low- and intermediate-level nuclear waste on the site of the Bruce Nuclear

Station near the town of Kincardine, Ontario. ("Low- and Intermediate-Level Nuclear Waste" is made up of materials and supplies used in the operation of the Candu reactors; it is much less hazardous than the high-level waste, but is still radioactive over long periods of time, and by law it too must be sequestered securely.)

The IEG's work was fully independent, but it worked closely with senior scientific personnel from OPG, which was the proponent for the project. All of our reports were place by the JRP in the public domain, thus being made available to all interested parties. The IEG prepared three separate reports, which form the four Chapters 23 to 26 in this volume (one of the three reports has been split into two separate chapters). In addition, the IEG members were required to attend public meetings organized by the JRP, and to respond there to questions from the Panel and from the intervener groups and individuals who had official standing for those hearings. The verbatim written transcripts, as well as video records, of those sessions are likewise in the public domain. The URLs are provided in the individual chapters. For a detailed list of all the documents filed during the review process, go to: http://www.ceaa.gc.ca/050/details-eng.cfm?evaluation=17520 (includes full transcripts of hearings). For discussion of the three IEG reports during the public hearings conducted by the JRP on 11 and 12 September 2014, go to:
http://www.ceaa.gc.ca/050/documents/p17520/100053E.pdf
http://www.ceaa.gc.ca/050/documents/p17520/100058E.pdf.

[Note; The paper reproduced in Chapter 22 was also the subject of a public hearing before the JRP; see the transcript at:
http://www.ceaa.gc.ca/050/documents/p17520/95270E.pdf]

The four members of the IEG worked very closely together, although we have very different backgrounds and specializations.

Maurice Dusseault, whose name is listed first for Chapter 23, is a distinguished Canadian geologist. Greg Paoli, who is one of Canada's leading experts in risk assessment, and whose name appears first for Chapter 26, designed the innovative graphical representations used to make qualitative risk comparisons among different options for storing nuclear waste. William Leiss assumed lead responsibility for writing Chapter 25 and oversight responsibility for Chapter 24. Tom Isaacs, who has had a long and distinguished career in the nuclear science field, made valuable contributions to all three IEG reports.

It may be interesting for readers to realize that the formal environmental assessment review process, of which the IEG's work was but a small part, commenced at the beginning of 2006, and a final decision by the federal ministers is expected before the end of the year 2017. The Report of the Joint Review Panel was issued on 6 May 2016 and may be found in its entirety at:
https://www.ceaa-acee.gc.ca/050/documents/p17520/101595E.pdf

If you are interested in these materials, I recommend that you download the PDFs at your earliest convenience and save them on your computer. Materials of interest from government or other websites sometimes become no longer available or are not archived.

Biographies of Members of the Independent Expert Group

Maurice B. Dusseault, PhD (U Alberta, Engineering 1977), PEng (AB and ON), is Professor of Geological Engineering in the Department of Earth and Environmental Sciences Department, University of Waterloo. He carries out research in coupled problems in geomechanics, oil production, and novel deep waste disposal technologies. Geomechanics interest areas include CO2 sequestration, hydraulic fracturing, oil and gas well integrity, steam injection for heavy oil production, biosolids injection, and thermohydromechanical coupling in fractured rock systems. He holds 10 patents and has co-authored two textbooks as well as over 500 conference and journal articles. Maurice works with governments and industry as an advisor and professional instructor in petroleum geomechanics. He was a Society of Petroleum Engineers Distinguished Lecturer in 2002-2003, visiting 19 countries and 28 separate SPE sections, speaking on New Oil Production Technologies. He teaches a number of professional short courses in subjects such as production approaches, petroleum geomechanics, waste disposal, and sand control, presented in 20 different countries in the last 10 years. Maurice has served on the Council of Canadian Academies Expert Panel Report on Shale Gas Environmental Impacts (expected May 2014); he is a member of the Scientific Advisory Council of the New Brunswick Energy Institute, a member of the Hydraulic Fracture Review Panel of the Government of Nova Scotia, a senior science advisor to the Alberta Department of Energy, and a technical advisor to the Alberta Energy Regulator.

Tom Isaacs works on issues at the intersection of nuclear power, national security, waste management, and public trust and confidence. He is a Visiting Scientist at Lawrence Livermore National Laboratory and a Visiting Scholar at the Stanford University Center for International Security and Cooperation. He was a member of the National Academy of Sciences Board on Nuclear and Radiation Studies, and was the lead advisor to the U.S. Blue Ribbon Commission on America's Nuclear Future formed at the request of President Obama, which made its recommendations in early 2012. Among the organizations Tom has advised recently are the U.S. Department of Energy, the Canadian Nuclear Waste Management Organization, the Japanese Nuclear Waste Management Program, and the Korean Atomic Energy Research Institute. He is an annual lecturer at the World Nuclear University Summer Institute held at Oxford University. Tom began his career with an extended tenure at the Atomic Energy Commission and the U. S. Department of Energy. During his career, Tom has helped design advanced nuclear reactors, developed nuclear safety programs, brought the discipline of decision analysis to nuclear affairs, managed a large government organization responsible for safeguards and security, led a national security analytical organization, help several senior management positions in government, led the U.S. siting effort for waste management facilities, worked directly with Congress to draft and implement new laws, managed a major international program for a decade, sat on advisory committees for university departments, and published and presented papers in a very wide network of domestic and international settings. His degrees are in chemical engineering from the University of Pennsylvania and engineering and applied physics from Harvard University.

William Leiss is a Fellow and Past-President (1999-2001) of the Royal Society of Canada and an Officer in the Order of Canada. From 1999 to 2005 he held the NSERC/SSHRC Research Chair in Risk Communication and Public Policy in the Haskayne School of Business, University of Calgary, and from 1994 to 1999 he held the Eco-Research Chair in Environmental Policy at Queen's University. His earlier academic positions were in political science (Regina, York), sociology (Toronto), environmental studies (York), and communication (Simon Fraser). At Simon Fraser he was also Vice President, Research. He is currently a Scientist with the McLaughlin Centre for Population Health Risk Assessment, University of Ottawa. He was a member of the Senior Advisory Panel for the Walkerton Inquiry (2000-2), Chair of the Task Force on Public Participation for Canadian Blood Services (2002), and an advisor on risk management to the Commission of Inquiry into the Investigation of the Bombing of Air India Flight 182 (2008-2010). He is author, collaborator or editor of fifteen books and numerous articles and reports. Three books are made up of case studies dealing with controversies, in Canada and elsewhere, about health and environmental risks: *In the Chamber of Risks: Understanding Risk Controversies* (2001); *Mad Cows and Mother's Milk: The Perils of Poor Risk Communication* (with Douglas Powell, 1997; second, enlarged edition 2004); and *Risk and Responsibility*, 1994 (with Christina Chociolko). Earlier books are *The Domination of Nature* (1972), *The Limits to Satisfaction* (1976), *Social Communication in Advertising* (1986, 1990, 2005), *C. B. Macpherson* (1988, 2009), and *Under Technology's Thumb* (1990), all of which are currently in print. With the exception of *Social Communication in Advertising,* all of these titles are published by McGill-Queen's University Press. His newest book, *The Doom Loop in the Financial Sector, and Other Black Holes of Risk*, was published by The University of Ottawa Press in October 2010. Over many years he was responsible for organizing expert panel reports on behalf of The Royal Society of Canada.

Greg Paoli serves as Principal Risk Scientist and COO at Risk Sciences International, a consulting firm specializing in risk assessment, management and communication in the field of public health, safety and risk-based decision-support. He has experience in diverse risk domains including toxicological, microbiological, and nutritional hazards, air and water quality, climate change impacts, and engineering devices, as well as risk assessment for natural and man-made disasters. He specializes in probabilistic risk assessment methods, uncertainty analysis, the development of risk-based decision-support tools and comparative risk assessment. Greg has served on a number of expert committees devoted to the risk sciences. He is currently serving on a U.S. National Research Council Committee on Safer Chemical Substitutions. Recently, he was a member of the U.S. National Research Council committee that issued the 2009 report, Science and Decisions: Advancing Risk Assessment, also known as the Silver Book. He serves on the Canadian Standards Association Technical Committee on Risk Management. He has served on several expert committees convened by the World Health Organization. Greg completed a term as Councilor of the Society for Risk Analysis (SRA) and is a member of the Editorial Board of Risk Analysis. He was awarded the Sigma Xi – SRA Distinguished Lecturer Award. Greg holds a Master's Degree in Systems Design Engineering from the University of Waterloo.

CHAPTER 20

NUCLEAR WASTE MANAGEMENT AT THE INTERFACE OF SCIENCE AND POLICY

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"Nuclear Waste Management at the Interface of Science and Policy:
The Canadian Experience,"
Energy and Environment **19** (No. 3+4, 2008), 413-426.
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Abstract

This paper reviews briefly the history of Canada's civilian nuclear energy program and the consideration of the problem of long-term disposal of nuclear waste. It shows that, after a period of twenty years of initial official deliberations on this problem, the decision-making process foundered in the face of a specific dilemma: how to include, within an integrated assessment framework, both "technical" (expert judgment) and "social" (public acceptability) considerations. It argues that an expanded risk management framework, illustrated below, now provides such a framework:

Science /Risk Management	vs.	Science/Public Policy
(1)	vs.	(2)

Interface (1):	Interface (2):
Risk Assessment	Public Perception of Risk
Risk Control	Risk Acceptability
Risk Mitigation	Public Trust

The remainder of the paper reviews and comments on a decision-making exercise, carried out in Canada in the year 2004, and using a method known as multi-attribute analysis (MUA), that provided a new approach to the issue of the management of nuclear waste. It argues that the MUA method has some distinctive advantages, over earlier approaches, where intrinsically controversial risk management situations are concerned.

Introduction.

At last count thirty-two countries around the world, among them Canada, were operating some 435 nuclear power plants to generate electricity, and thus also producing nuclear waste of different types. By 2004 almost 16% of the world's electricity came from nuclear installations, over 50% of which was produced in just three countries: France, Japan, and the United States. The first such power plants commenced operations in the mid-1950s, and thus the waste has been accumulating in various "temporary" storage facilities for over fifty years.

About a dozen of the countries using nuclear power have active programs in place to choose an acceptable form of long-term storage or disposal of the waste: Canada, Finland, France, Germany, India, Japan, Republic of Korea, Russia, Sweden, Switzerland, the UK, and the USA (NWMO 2005, pp. 360-3). In all cases where detailed consideration has been given to the method of disposal, the preferred choice is an engineered repository placed underground in a suitable geological medium. Of the dozen countries listed above, Finland and Sweden appear to be furthest along in actually choosing sites that have strong community support for hosting a long-term underground storage facility (Sweden 2009, Finland 2009).

Canada's role in the "nuclear club" began during World War II, when in 1942 Britain sent a group of nuclear scientists to a research facility in Montreal. Uranium mining and processing was already ongoing in Canada, and the government operated a heavy water plant in Trail, British Columbia; both contributed to the U. S. atom bomb project Weart 1979, chapter 14). The research group eventually succeeded in building, at a dedicated site in Chalk River, Ontario, the first operating nuclear reactor outside the U. S., which was known as ZEEP – zero energy experimental pile (1945). Based on this wartime success, the Government of Canada then established a crown corporation, Atomic Energy of Canada, Ltd. (AECL) in 1952; AECL designed the CANDU reactor, which is operating in Canada as well as in South Korea, India, Argentina, Romania, and other countries.

In Canada, the first demonstration reactor began supplying electricity to a grid in 1962, and the first commercial-scale plant commenced operations in 1968. Canada currently has twenty-two nuclear power plants, located in three of its provinces: Ontario (20), Québec (1), and New Brunswick (1). Together they supply 14% of Canada's total electricity output (whereas hydro provides 60% and coal 25%) – but in Ontario, Canada's largest province, nuclear's share is 40%.

The CANDU reactor used in all Canadian installations is a pressurized heavy-water type that uses natural (unenriched) uranium as an energy source. The fresh fuel is composed of 99.28% U-238 and 0.72% U-235. When it is removed from the reactor at the end of its useful life (a period of 12 to 18 months), its composition is:

Uranium-235: 0.23%
Uranium-236: 0.07%
Uranium-238: 98.58%
Plutonium-239 0.25%
Plutonium-240 0.25%
Plutonium-241 0.03%
Fission Products 0.74%

Upon removal from the reactor the used fuel bundle is both highly radioactive and hot; it is placed in a pool under water and after one year both heat and radioactivity have decreased to 1% or less of their initial values. After 100 years the radioactivity will have decreased to 0.01% of its initial level, and after about 1 million years it will approach that of natural uranium (NWMO 2005, p. 341). After ten years the fuel bundles are removed from the pool and transferred to reinforced concrete casks on the plant site. As of the end of 2004 Canada had accumulated in temporary storage about 1.9 million used fuel bundles, representing about 36,000 tonnes of uranium. When projected to the end of the useful life of the current generation of CANDU reactors, the volume of waste will approximately double from its 2004 level (*ibid.*, pp. 350-1).

Early Consideration of Nuclear Waste Disposal Options.

In 1977, a mere fifteen years following the first commencement of electrical power generation from a nuclear reactor in Canada, the federal government named an expert body to recommend a strategy for the safe long-term storage of nuclear waste. The resulting study, known as the Hare Report after its chair, Ken Hare, recommended the use of a deep geological repository for the waste. For the next twenty years, Atomic Energy of Canada Limited (AECL), the federal crown corporation which had developed the CANDU reactor, busied itself with a myriad of technical studies characterizing the "concept" of such a repository (it was limited to conceptual design because no actual site had been selected). In 1987 the Atomic Energy Control Board (AECB), at that time the regulatory authority over the nuclear industry, published guidelines for the disposal of radioactive wastes which supported the idea of disposal in a repository. (AECB was replaced as the federal regulator by the Canadian Nuclear Safety Commission [CNSC] in May 2000.)

Then in 1988 the Government of Canada accepted the advice of a parliamentary committee which recommended that the disposal concept be reviewed by an independent commission, one having a responsibility to seek broad public input. The following year it published the terms of reference for an environmental assessment panel charged with reviewing AECL's "concept of geologic disposal of nuclear fuel wastes in Canada along with a broad range of nuclear fuel waste management issues" (AECL 1993). [Atomic Energy of Canada Limited (AECL) had done pioneering work in the use of probabilistic simulations to estimate the radiation hazard for a period of 10,000 years after the waste had been entombed in an underground facility.] It asked the panel to look at what was happening elsewhere in the world and to make recommendations on the "acceptability of the disposal concept." The panel's work was delayed by procedural matters as well as by a number of changes in panel composition, and as a result its final report, completed under panel chair Blair Seaborn, did not appear until early 1998, a full decade after the recommendation to strike it had been made (CEAA 1998).

The panel's long-awaited report shocked both the government and the nuclear industry. Its key conclusions were:

- "From a technical perspective, safety of the AECL concept has been on balance adequately demonstrated for a conceptual stage of development, but from a social perspective, it has not.

- "As it stands, the AECL concept for deep geological disposal has not been demonstrated to have broad public support. The concept in its current form does not have the required level of acceptability to be adopted as Canada's approach for managing nuclear fuel wastes."

The report was denounced by industry partisans in hyperbolic language; for example, one insisted that "a social perspective is not relevant to safety as normally defined" (Robertson 1998, p. 28). But the damage was done: Twenty years of federal government policy on nuclear waste lay in a shamble, and a new path had to be created.

Ten months later, in December 1998, the government responded officially to the Seaborn Panel report, and its response was turned into new legislation four years thereafter. The *Nuclear Fuel Waste Act* (2002) contains the following key provisions:

1. Safe management of nuclear waste from civilian nuclear reactors is the responsibility of the reactor owners and operators;

2. The owners must establish an arm's-length entity [NWMO, the Nuclear Waste Management Organization], and this entity must re-study the disposal issue and recommend a preferred solution to government *within a period of three years*;

3. The federal government will establish and oversee a trust fund, holding funds supplied by the owners on a schedule established by regulation, to be used to pay the costs of a permanent disposal facility.

Sovereign governments have certain advantages not possessed by the rest of us: Having failed in their own efforts to resolve a policy problem, they may compel other named parties to solve that problem for them—and, should those parties be unable to do so, face the prospect of fines and jail time. Fortunately, they were able to do so, thus averting a potential constitutional crisis, since the waste owners are, effectively, the crown corporations (electrical utilities) owned by three of Canada's provinces.

NWMO was indeed established. It carried out the study it was compelled to do, and duly made the recommendations it was commanded to make, before the deadline dictated to it, in November 2005. On 14 June 2007 the federal Minister of Natural Resources announced that the NWMO's solution had been accepted. As of that moment, according to another provision in the *Nuclear Fuel Waste Act*, NWMO became the implementing agency for nuclear fuel waste management. It is now required to find an actual site for a facility, somewhere in Canada, ideally in partnership with a "willing host community," and (at long last) to create an engineering design that will be subjected to a formal review under the terms of the *Canadian Environmental Assessment Act.* If all goes well, some thirty years from now Canada will be able to start putting its waste down a deep, safe hole.

Acceptable Risk.

The unhappiness of many nuclear experts with the Seaborn Report's conclusions was in fact foreshadowed in the panel's terms of reference—specifically, the inevitable ambiguities inherent in its charge to examine the "acceptability" of the geological disposal concept. For most nuclear engineers, acceptability was identical with the technical demonstration of an acceptable level of safety in the design. But once the discussion embraced the wider public, which was what the Seaborn panel was asked to do, it was a foregone conclusion that the panel would encounter a far wider range of interpretations of acceptability. This is indeed what happened; for example, church-based groups insisted that an ethical perspective on both nuclear power generation and nuclear waste management must be placed on an equal footing with the technical evaluation of safety and reliability.

The nature of these new considerations indicates that two major changes had taken place. First, at the time when the first expert analysis of deep geological disposal was carried out in Canada, in the Hare Report, what

I call “the language of risk” was not nearly as prominent as it has subsequently become (indeed, the terminology of risk has largely replaced the word “safety”). Second, broad public consultations, on many types of issues that used to be decided entirely behind closed doors, had become a requirement of government policy-making. During the twenty years that separates the Hare panel’s private deliberations, on the one hand, and the 1996-7 public hearings of the Seaborn panel, on the other, the technical issue—the feasibility of deep geological disposal for nuclear wastes—had remained the same. But the substantive context of government decision-making on such matters had undergone a sea-change.

I am among those who believe that the language of risk provides both a powerful and an appropriate tool for the evaluation and management of concerns about environmental threats to our health and well-being. Properly understood, risk management offers a level of precision, in addressing those threats, that is unmatched in its ability to identify variations in the level of concerns, to target precisely the types of control and mitigation strategies available to us, and therefore to help us allocate resources in this domain more efficiently. But it is also capable of addressing that other challenge mentioned above, namely, a heightened level of public interest and intervention in such matters. While not using the language of risk, the Seaborn panel’s conclusions, in insisting on the equal legitimacy of “social” and “technical” determinants of acceptability, had recognized well this new reality.

In risk management, the technical description of a risk is always the necessary starting-point. This description uses first the basic sciences (in its analysis of the nature of any hazard), then applied sciences, such as epidemiology and engineering, to get a handle on the actual scope of the hazard under known environmental conditions; finally, it uses statistical methods to estimate the likelihood that some harms, related to a particular hazard, will occur. This is wrapped up, in quantitative risk assessment, in a neat formulation: The average annual risk for a specified population, of some specific type of harm to occur, is, say, 3 chances in ten thousand (3 x 10^{-4}).

Ever since the mid-1980s, however, and largely as a result of the pioneering research of Paul Slovic, the professional risk community had begun to learn that non-expert members of the public "process" risk assessments in very different ways. Gradually, and as yet not completely, the awareness has taken hold, especially in the circles of government officials who cannot avoid daily interactions with the public, that these divergent ways of assessing risks cannot simply be dismissed as the products of ignorance or irrational fear. The bottom line is that what we call "acceptable risk" will always represent the result of some process of "negotiation" between two radically different ways of processing risk information. The result—a risk management decision that is scientifically sound and also enjoys widespread explicit or tacit public support— is often less than perfect, but it can also be both workable and reasonably cost-efficient.

One of the great strengths of the risk-based approach is that it can find ways of accommodating progressively larger sets of decision inputs while maintaining an acceptable level of technical rigor. This is shown in the following schematic:

Science /Risk Management	vs.	Science/Public Policy
(1)	vs.	(2)
Interface (1):		Interface (2):
Risk Assessment		Public Perception of Risk
Risk Control		Risk Acceptability
Risk Mitigation		Public Trust

At the interface of science and risk management, we find the technical disciplines of risk assessment, control, and mitigation, which ideally tell us what are options are, how well certain precautionary measures are likely to perform, what consequences are likely to follow from failures in risk control, and what it will cost us to achieve certain levels of risk mitigation. And yet this is now known to be only one-half of the full equation. Decisions on how to manage a whole set of major risks, such as pandemic influenza and climate change, occur in an open international arena in which a huge host of interested parties, members of the general public, and governments consider our options and maneuver for relative advantage. On a purely domestic level, the same types of interveners debate narrower issues, such as vaccines, diets and obesity, and drug use; their conflicts and engagements are played out for all to see in the daily mass media. Increasingly, in all of these engagements contributions from scientists and professional risk assessors are explicitly referenced in the public debates.

What we have learned in the past two decades is that for many risk issues we face, including all of the major ones, we cannot any longer expect to confine the debate to the purely technical side of risk assessment. The "social" dimension, which is where the acceptability of a variety of risk management solutions is debated, has become an integral part of risk management. Where matters of risk are perceived by the public as having been managed poorly by those in charge, the process known as "social amplification of risk" can cause the decision-making process to spin out of control (Pidgeon et al. 2003). Increasingly, for major risks, risk management and risk issue management become two sides of the same coin (Leiss 2001).

What happened in Canada in the case of nuclear waste management during the period 1977-1997 is a perfect illustration of these general points. The many members of the public who showed up to argue before the Seaborn Panel refused to accept the legitimacy of a process in which only one type of technical solution could be evaluated and in which only purely technical considerations could be debated. They insisted on widening the dimensions of the discussion in both these respects. To their great credit, the members of the Seaborn Panel understood and accepted this viewpoint, and the government of the day had no choice but to ratify the outcome. But as a result no solution to the risk management issue was left standing.

The NWMO Study.

As mentioned above, the *Nuclear Fuel Waste Act* required a new organization, set up by the nuclear reactor owners, not only to find an acceptable solution for this impasse, but also to do it in three years' time. The core strategy in the approach to this task that was adopted was a simple one: NWMO's study would, first, take the conclusions of the Seaborn Panel report as its starting-point; and second, it would address, directly and systematically, every one of the key deficits that had prevented the Seaborn Panel from coming up with a broadly acceptable solution to the problem of the management of used nuclear fuel:

1. There would be no inherent bias toward a preferred option;

2. A comparative risk-benefit approach to the selection of a preferred option would be taken;

3. The evaluation of management options would blend the "technical" and the "social" dimensions seamlessly into a unified framework of evaluation;

4. The managerial choices would be subjected to a test of appropriateness based on an independently-derived ethical framework;

5. A thorough, indeed exhaustive, program of several rounds of public and stakeholder consultation would be employed throughout every stage of the study process.

Meticulous attention to the fruits of the Seaborn Panel deliberations meant that NWMO could build on the achievements of this earlier work, which had (despite the industry criticisms) done a magnificent job in exploring the larger dimensions of the nuclear waste issue. In addition, the findings of the new public consultation processes were fed back into the organization's internal deliberations at every step along the way—something that is all too rarely done.

Evaluation Method.

The Seaborn Panel report's conclusions had reflected honestly the fact that, after fully two decades of intensive evaluation, a decision-making impasse had been reached in Canada with respect to the management of nuclear fuel waste. The public hearings conducted by the panel exposed the inherent weakness of a process that had been far too circumscribed from the outset. For not only members of the public, and interested parties such as religious groups, showed up at these hearings; the opinions of a broader range of technical experts were heard as well. Many of them thought it was obvious that more than one option (deep geological disposal) was available, and that any process that overlooked this simple fact lacked a requisite degree of transparency and honesty.

To be sure, simply enlarging the range of technical options under evaluation would not have satisfied a range of other objections. For example, a number of voices had insisted that the issue of nuclear waste, with its time-frames of up to a million years of inherited responsibility, raised issues such as inter-generational fairness that had always been frozen out of conventional, technically-based environmental assessments. The Seaborn Panel acquitted itself admirably in not declining to confront these difficult issues, and also in conceding, in effect, that the panel itself could not do justice to them within its terms of reference. In its stark conclusions, that social perspectives must be given equal weight with technical ones, the panel implicitly argued that the evaluation process needed to be re-designed from the ground up.

And yet, quite obviously, this is easier said than done. It is still today pretty much the common pattern for environmental assessments to focus primarily on technical aspects (impacts on groundwater quality, wildlife habitat disturbance, dispersion modeling, and so forth), and then to bring in social and ethical matters as an entirely separate consideration. In effect, the latter become the basis of a test of wills between affected members of the public and their governments that takes place after the environmental assessment has been completed. Rarely is a thorough effort made to see whether social and ethical issues can be integrated and incorporated, along with narrower technical matters, within the same evaluation framework and at the same assigned level of priority.

This is what the evaluation process adopted by NWMO sought to do. The rest of this paper is devoted to a brief overview of the design and results of that process, which was carried out by a small team, composed of a majority of independent outside consultants working together with a few employees of NWMO. Its report was issued soon thereafter (NWMO 2004).

NWMO's first key decision involved choosing the focus of its own evaluation, and everything that followed was a consequence of this initial choice. The previous exercise, carried out under the Seaborn Panel, had been dominated—in terms of the simple volume of professionally-prepared material—by the technical assessment of the reliability of an engineered storage facility to be emplaced underground in a suitable geological medium. So one choice NWMO might have made was to undertake a similar type of assessment for other risk management options, such as a storage facility to be constructed above-ground, and then to undertake a comparative assessment of the available options, using risk-cost-benefit analysis. This choice was unacceptable because it would have continued to exclude the social and ethical issues as an intrinsic, rather than extrinsic, part of the decision-making. Instead, NWMO decided *to place its emphasis on finding a robust decision -making process itself,* one that would be capable of integrating technical and social dimensions into a single, unified framework—and thus one capable of responding to the core deficiency identified by the Seaborn Panel.

NWMO's decision about its second choice, involving the composition of its Assessment Team, followed automatically from the first. The designated task required assembling a team of professionals with diverse backgrounds; two of the nine members had some expertise in fields related to nuclear science, but the rest did not. Rather, a wide range of competencies, including organizational behavior, energy economics, environmental sciences, risk management, consumer research, and others, was included. (It should be noted, however, that throughout its work the team had access to a very large body of literature and analyses on all aspects of nuclear waste management, including legal, economic, and social-impact analysis, much of it recent work that had been commissioned by NWMO. The team also could seek assistance on specific points at any time from other technical experts.)

The team's first exercise was to narrow the range of managerial options that could be subjected to further analysis in a decision-making framework. In addition to more familiar options, others are, for example, disposal in oceans, outer space, ice sheets, and deep boreholes. All but three were screened out of further consideration as being "methods of limited interest," either because they would violate international conventions and/or were deficient in "proof of concept" for a variety of reasons – excess cost, excess risk, or absence of feasibility studies (NWMO 2005, pp. 386-92). Thus three options were left on the table, all of which would represent some type of engineered facility: permanent storage at a number of different reactor sites, where most of the wastes are generated and currently placed in temporary storage facilities; a centralized repository either above-ground or shallow underground; and a centralized repository emplaced deep underground in a suitable geological medium.

The team next searched for a suitable assessment methodology, a search that was constrained by the need to find a candidate method that would permit the simultaneous evaluation, within the same overall structure, of a variety of both social and technical considerations. For a variety of reasons, which are explained briefly in its report, the team selected multi-attribute utility analysis (MUA) (NWMO 2004, chapter 4). This method has its own set of prescribed technical requirements—including scoring, scaling, weighting, and aggregating—and requires the use of a dedicated software program. The team had the assistance of a talented professional in the area, Lee Merkhofer, in carrying out the MUA exercise (on MUA generally, see Merkhofer 2009).

An overriding consideration in the choice of a methodology, for both the Assessment Team and NWMO, was its degree of potential transparency for outside audiences. Although there are some highly technical aspects in the details of the MUA method itself, which are not necessarily easy to relate to general audiences, its overall structure is made up of an orderly sequence of steps that is quite easy to grasp. Thus it can, at least to some extent, avoid the notorious "black-box" characteristic of so much of decision-making, both in risk management and other domains: Even when the decision inputs are known in detail, the way in which they are "rolled up" into an overall judgment of "yes or no" remains a mystery. In the long series of public meetings at which the Assessment Team report was presented and debated, for the most part the method was found to be easy to communicate, except for a few specific aspects (weighting, for example). In fact, it would be possible to construct a simplified version of the method that members of the public could run through for themselves, although to the best of my knowledge no one has as yet undertaken to provide such a resource.

As mentioned, the multi-attribute utility analysis method involves a stepwise approach, including, in the present case:

1. Choice of variables to be assessed;
2. Construction of influence diagrams;
3. Discussion and scoring by team members (single or multiple rounds);
4. Sensitivity analysis (weighting exercises);
5. Validation of results against scenarios.

The choice of variables is, of course, the decisive step, for it delimits the conceptual range of the entire subsequent exercise.

Initial decisions also were made as to how the vast body of relevant technical information, including quantitative analysis, would be utilized. In this specific application of the MUA method, the Assessment Team resolved to use the following approach:

a) *Subjective Judgment:* The estimates of likelihood and consequences (How well would a particular method perform in terms of a specific criterion?) were offered by each Team member, for the most part, without reference to any specific body of literature: While expert opinion (from technical reports) could be and was referenced in this process, in the end no "coercion from authority" was permitted.

b) *Qualitative Judgment:* The Team decided that it was under no obligation to refer to any quantitative analysis for likelihood or frequency, for any parameter, or to seek to have such an analysis prepared on its behalf.

c) *Discursive Judgment:* The many rounds of Team discussion and disputation were the core aspect of its decision-making process. All team members accepted the obligation to explain and defend each judgment that was called for; but, at the same time, each member's considered personal judgment was allowed to stand at the end of the day.

   These choices reflected the fact that the members of the Assessment Team did not regard themselves as making up what is called an "expert panel" (as that designation is used by national academies, for example). Rather, they sought to mimic the reasoning process of a group of well-informed but non-expert members of the general public who were in a position to deliberate for a considerable period of time on a specific issue.

As mentioned, NWMO was obliged by its government terms of reference to include three "technical" methods of permanent waste disposal/storage in its assessment. The Team's next choice had to do with the number of time-frames: As opposed to almost every other risk management issue, nuclear waste has a *minimum* period of ten thousand years in which facility integrity must be assured (some experts will dispute this, but not many). Thus some form of time breakdown is essential; on the other hand, a too finely discriminated reckoning would make the decision problem excessively complex. We compromised on a two-period dichotomy, in effect near- and far-term (more precisely, about 0-200 years and 200+).

This was a consensus judgment by the group; other choices are certainly possible. But the course of our deliberations made it plain that for any length of time exceeding the lifespan of the current generation, novel managerial issues, such as confidence in ongoing capacity of society to ensure the provisioning of the requisite funds and competencies, are indeed introduced and must be factored into the choices of alternative strategies. So far we had five variables.

The real key to the whole exercise lies in the choice of objectives that must be satisfied by any technical solution. (A more precise way of expressing this is to ask: How well will a specific solution perform, within one of the chosen time-frames, with respect to a specific objective [*Risk Analysis* 1999]? When asked in this form, the answer can be given by means of a score along a scale, say 1–100.) Here is where the integration of the social and the technical dimensions takes place, as can be seen in the final list of eight objectives chosen by consensus of the assessment team members:

1. Fairness (including inter-generational fairness);
2. Public health and safety;
3. Worker health and safety;
4. Community well-being;
5. Security (e.g., against terrorist attack);
6. Environmental integrity;
7. Economic viability;
8. Adaptability.

A key decision in the MUA method is to assign all objectives equal priority (at a later point, weighting exercises are performed as a test of robustness). [The team's choice of objectives was influenced in part by the results of one of the major public consultation exercises previously carried out by NWMO, which upon analysis yielded a version of the set of dominant public concerns about nuclear waste. This was one of the ways in which NWMO sought to "keep faith" with the members of the public who had taken the trouble to participate in the consultations.] The final result is a set of “situations” or matrices: 3 [solutions] x 2 [time-frames] x 8 [objectives]– except that the objective of fairness was not divided into two time-frames. Each of the resulting 45 situations was individually scored, on the relative performance scale of 1-100, by each of the team members (collectively, therefore, with nine team members there were 405 separate scores).

Scoring took place in group sessions, in two rounds separated by intensive discussion and debate. Before this occurred, however, an “influence diagram” was constructed, by group consensus, for each objective. These are “bubble diagrams” which seek to tabulate the key factors that make any objective important in this context (NWMO 2004, chapter 6, shows all of the influence diagrams). For example, influences on “fairness” include: decision flexibility; level of participatory decision-making; distributional fairness; and intergenerational fairness. One of the main uses of such diagrams, in the context of the MUA method, is to allow team participants to highlight specific factors when defending the assignment of a score. The deliberative process that occurs between the initial and final rounds of scoring, therefore, is amenable to reasoned discussion. In point of fact, team members often changed their initial scores as a result of points made by others during the discussion periods. (There was also a certain amount of heated argument, balanced by a roughly equal quantity of good-natured banter.)

A Personal Perspective on the Evaluation Method.

As someone used to the lonely routines of academic writing, in the course of preparing something like two dozen extensive case studies on troublesome risk management issues, participation in the NWMO Assessment Team exercise was a change of pace that turned out also to be a personally satisfying experience. Our collective confidence in the final outcome rested in large part on the knowledge that all team members had struggled to provide honest and well-reasoned justifications for the scores they assigned. But another source of personal satisfaction was the element of suspense that built up as the exercise proceeded. For although one could make an educated guess as to where it was all headed, I at least was unable to compute the overall result on the basis of intuition alone. And so, after four weeks of collective deliberation, spread out over a period of four months, our expert facilitator pressed a key on his computer and the software program rolled up the scores.

What emerged was a ranked series of overall performance scores for each of the three technical methods as assessed in each of the two time-frames. Taken together, the results were, in order of how well each was expected to perform overall:

1. A deep underground facility in a suitable geological medium (in Canada's case, this is an unfractured granite formation in the two-billion-year-old rock of the Canadian Shield);

2. A centralized facility either above-ground or shallow underground;

3. Permanent storage at the various reactor sites.

Once the final result of its own protracted deliberations was known to the members of the Assessment Team, of course, we realized that the bottom-line outcome could appear to be something of an anti-climax, since it appeared simply to reiterate the conclusion that had been first drawn almost thirty years prior.

However, the various outputs of the MUA method mitigate the possible disappointment on this score to some extent. For one thing, the variations in the ranges in the team scoring results show clearly that there can be disagreements among a group of "reasonable persons" and identify exactly where such differences in views are most pronounced (e.g., with respect to specific objectives) in this exercise. For another, the overall results demonstrate that there is in fact no perfect solution, or even a solution that is "best" in any unqualified sense; rather, there is only a hierarchy among the members of a set of identified options that are, on balance, better or worse in relation to each other. Finally, whatever its flaws, the MUA method offers to interested citizens an elaborated framework, with at least some degree of transparency, within which they can speculate on what their own judgments might be across the whole range of decision variables.

Postscript.

Once the federal government accepted the NWMO assessment in mid-2007, the NWMO automatically was recast (under the federal legislation) as the formal implementing body for the approved solution. Many high hurdles remain for the future. Perhaps the two most daunting are, first, finding a "willing host community" for the facility—or, should this fail, having two governments (the federal and one provincial government) approve a site without local consent; and, second, having the detailed site plan and formal environmental impact assessment pass muster under the terms of the Canadian Environmental Assessment Act. It is fair to say that the degree of broad public interest in the NWMO's activities to date has been very low. As everyone knows, such interest becomes intense only when one or more specific sites have been named as being under consideration. When that point is reached both local citizens and environmental groups will gird for battle.

It is impossible to say whether, at that time, what the NWMO and its Assessment Team did prior to completing its Final Report in 2005 will have any influence at all on subsequent events. In other words, it is impossible to guess whether either the MAU decision-making process itself, or what emerged from it at the hands of the Assessment Team, will have any impact on the final outcome of this long process. For example, one can imagine a future scenario in which the preferred method of disposal cannot be implemented due to implacable public resistance against any designated site, and the default option—leaving the waste at the reactor sites indefinitely—then becomes the only one that can be implemented. In the Canadian case, both of the other two assessed options require the waste to be moved some considerable distance away from the reactor sites; and opposition to the transport itself could become a major factor in the final decision.

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CHAPTER 21

THREE DISCUSSION PAPERS ON COMMUNITY ENGAGEMENT ABOUT USED NUCLEAR FUEL STORAGE AND DISPOSAL

Commissioned by the Nuclear Waste Management Organization

(November 2009)

PAPER #1: THINKING ABOUT RISK AND SAFETY

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You may obtain a separate PDF File of this Paper from the Nuclear Waste Management Organization at:

https://www.nwmo.ca/~/media/Site/Files/PDFs/2015/11/04/17/34/1673_nwmosr-2010-10_paper1_thinking.ashx?la=en

1A. Introduction.

Citizens in three of Canada's provinces – Ontario, Québec, and New Brunswick – have for many years depended on nuclear power stations for a portion of their electrical energy. In another province, Saskatchewan, there are some of the richest uranium ores on the planet, which are mined and processed into fuel bundles in order to provide the raw material for nuclear power.

In Canada, after the uranium fuel bundles reach the end of their useful life and are removed from the nuclear power facilities where electricity is generated, they must be first stored temporarily at the plant site and then moved to a dedicated underground facility. And if it is later determined that the used fuel bundles do not have any further useful purpose, then the permanent storage site will become a facility dedicated to permanent disposal of these materials.

Communities throughout the four provinces of New Brunswick, Québec, Ontario and Saskatchewan recently have been asked to consider whether they wish to become involved in discussions about the project for permanently storing used uranium fuel bundles in a dedicated facility, or the planned siting process for the facility, or both. These discussions will encompass many different topics, for example: What kind of material is being stored? What type of facility is going to be constructed? What kinds of impacts is the host community likely to experience over the lifetime of this project? And what kinds of long-term benefits, such as jobs and infrastructure investments, will the community receive?

These are all important questions, as is also the matter of what kinds of risks the project will bring with it – risks to people in the community itself, to people elsewhere in Canada, and to the environment and other species as well. Risks are commonly described as substances and activities that can cause serious harm~~s~~ to the health of people or the environment. People naturally worry about the things that can harm them, which is why the consideration of risks will be a very significant part of all community discussions about the possibility of locating the nuclear fuel waste permanent storage site at any particular location.

This is the first in a series of three papers is designed to assist interested people in communities, who may be less familiar than others are with written materials and debates about risks in general, to determine for themselves the best way to come to grips with the risks associated with nuclear fuel waste storage and disposal. There are three papers in this series, which are designed to be read in sequence:

- Paper #1: How should matters of risk and safety be discussed?
- Paper #2: How might communities organize their discussions about hosting a site for used nuclear fuel?
- Paper #3: What is happening in other countries where similar issues about used nuclear fuel are being discussed?

In Canada and other countries, what is called a "safety case" has been made for the idea of permanently storing used nuclear fuel waste deep underground in a suitable location, for example, in the granite formations of the Canadian Shield. A safety case is, in effect, an argument that no significant foreseeable harms to people or the environment will occur if the storage facility is properly designed and constructed. The safety case is addressed both to citizens in general and, in particular, to the responsible government agencies which must issue permits for the construction of the facility. In effect, it says that the risks associated with this project should be regarded as acceptable.

The way in which a safety case is made will be described later in more detail. However, no attempt will be made in these three papers to persuade the reader that the existing safety case about the risks associated with the permanent storage of used nuclear fuel should be either accepted or rejected, in whole or in part, by the communities which decide to enter a dialogue about the hosting of this facility. Rather, the sole purpose of this series of short papers is to assist people in communities in determining how they might go about making up their own minds about the safety case as well as other aspects of the repository siting issue.

1B. Managing Risks

Risks are the things and activities that can harm us. They include a vast range of threats – natural and technological threats, as well as social and political ones. Familiar natural threats include infectious agents such as viruses, diseases such as cancer, violent weather such as tornados and hurricanes, fires, drowning, falls, and excessive exposure to sunlight. Technological threats include many industrial chemicals, motor vehicle accidents, firearms, electrocution, machinery accidents, and devices of warfare. [Of course, natural threats usually entail no benefits, whereas our technological devices – many of which exist to protect us against natural hazards – have clear benefits alongside the threats they also represent.] In addition, the continued viability of a society can be jeopardized by internal conflicts and disorders that arise among its own citizens or that originate in other countries.

In order to maintain a modern lifestyle none of us can avoid entirely a regular encounter with natural, technological and social risks of many different kinds. Instead, what we try to do is to *limit* either our exposure to the threat or the amount of the damage it can potentially do to us. So, for example, for exposure to sunlight and its damaging forms of radiation, we can limit the time we spend outdoors in summer and also use protective clothing and sunscreens. We can employ good safety practices with respect to threats of fires and drowning and construct buildings that can withstand earthquake shocks. With most other technological threats, the protective measures are essentially the same; for example, to guard against the worst consequences of motor vehicle accidents, many new safety features have been required in vehicle construction over the preceding decades.

The strategy of limiting the damage that can be done by our daily exposures to many different technological and natural hazards is what is meant by the phrase "managing risks": We manage risks because, with very few exceptions, we simply cannot eliminate them entirely. Diseases caused by viruses can be controlled by vaccinations, but the diseases themselves persist in natural reservoirs. There are small additional risks caused by our intervention strategies themselves, but these are usually minor in comparison with the benefits gained.

There are, quite literally, thousands of different and specific risks of different kinds, for which we have developed "management" strategies. Through a combination of both *foresight* (anticipating harm) and *precaution* (taking protective action before the harm occurs), we put in place an elaborate network of laws, regulations, policies, and codes of good practices that succeed in making our surrounding environment, and the activities we engage in, far safer than they would otherwise be.

When it comes to the technologies we have developed, however, we do always have the option of simply eliminating certain specific types of risks rather than trying to manage them. Industrial chemicals known by the acronyms PCBs and DDT, for example, have been banned from further production and use in many countries. But since they were developed for important uses in the first place, often (as with PCBs) other, less-harmful chemicals were substituted in their place. In North America we decided we could do without DDT because other pesticides that did less environmental damage could replace it. But in African and other countries where malarial mosquitoes cause terrible disease and hardship, lack of access to DDT comes at a very high price – showing just how tricky it is to balance risk and benefit wisely.

In the context of the risks discussed in these papers, it would be possible to ban further development of nuclear power plants and in this way eliminate entirely the risks that the used fuel wastes from as-yet-unbuilt nuclear plants would otherwise represent. To do so would require both (1) finding other sources for the large quantities of electricity such plants could have generated, and (2) using a complex technical assessment to try to insure that we did not encounter an equal or greater level of risks of different types from the alternative sources of electrical power. And, of course, citizens would still have to deal with the used nuclear fuel wastes already housed in temporary storage as well as the wastes that would continue to be created until existing nuclear plants ceased operating.

The main point in the preceding paragraph is that such choices are available to citizens who live in a free and democratic society such as Canada. The caveat is that these choices are best made in the light of full knowledge of all of the trade-offs between risks and benefits that are implied in decisions of this kind. Also, the information necessary to make these kinds of informed decisions should be tested in forums where citizens can debate opposing views. In a later section of this first paper, as well as in the second paper, a few suggestions are offered about these requirements.

1C. Frames of Reference for a Discussion about Nuclear Fuel Waste Risk and Safety

The very first consideration that arises in a risk and safety context is: How wide should the frame of reference be for this discussion? Choosing a particular frame of reference is a way of determining how narrow or how broad the set of questions and issues that need to be debated will be. Obviously, the greater is the breadth of issues, the more complex the discussion will need to be; however, in itself this is not a sufficient reason for choosing a narrower range. The following discussion illustrates what is involved in making a choice about what is the right frame of reference for a discussion in a community about hosting a site for the permanent storage and disposal of used nuclear fuel.

<u>(A) The Energy Policy Frame.</u>

First: If we decide to stay at the narrowest end of this frame, we will put on the table for discussion only a single issue:

- Will a storage facility for used nuclear fuel, as it is built and operated over a very long period of time, be sufficiently safe for the host community so that both current and future generations living there will *never* have to worry about being harmed by it?

As shall be seen in the section on the safety case (in paper #2), even this very limited issue will raise many, many complex technical questions, having to do with engineering design, geological analysis, environmental impact assessment, imaginary scenarios, and the calculation of statistical probabilities of harm over a period of thousands of years. Experts will be asked to give their judgments on these matters and to explain in great detail the reasoning and scientific studies that, they believe, support their judgments. But once that elaborate exercise is concluded, it should be possible for the citizens in a community to summarize an answer to their question about safety in a single word: "Yes" or "No."

Second: If a community decides, on the contrary, that it has an obligation to put the issue of used nuclear fuel in the broadest possible context, a much larger set of issues will be put on the table, including all of the following aspects:

1. The general rationale for a provincial energy policy, that is, the mix of energy-generating technologies (fossil-fuel, hydroelectric, solar and wind, nuclear) that is considered to be optimal for the particular province in which a community is located;

2. The basis for that general rationale, in terms of cost-benefit calculations, as it relates to the values that a particular community wishes to support and promote (e.g., sustainability, environmental protection, energy conservation);

3. How nuclear energy in particular is perceived, in terms of its intrinsic appropriateness, within the mix of energy supply options, considered in terms of the future;

4. How the environmental problems associated with each energy supply option compare with one another (in particular, climate change from greenhouse-gas emissions *versus* radioactive waste from nuclear plants);

5. The adequacy of the safety case for the storage and disposal facility for used nuclear fuel.

In this, more elaborate way of framing the relevant concerns, the single one mentioned earlier (the safety case) is only the last in a series of complex issues. With the exception of number 3, the others in this list would have levels of technical complexity comparable to the fifth. Thus the information and analysis requirements for the whole set could be very large, and the debate about the whole set of issues would be long indeed. Moreover, organizing a set of meaningful discussions on the full set of issues would require a community to seek to raise the necessary resources, from its own and a variety of external sources, to fund it.

Third: A community may decide that its requirements fall somewhere between the two ends of the spectrum as described above. Thus, for example, it might choose not to consider, say, the first one in the list of five above, or perhaps the fourth one. Almost certainly various communities will differ in the choices they make in this regard, and in the amount of financial and other resources they are prepared to commit to this endeavor.

Whatever these choices are, no one can ignore the last-mentioned, namely, the adequacy of the safety case. Therefore, this can be regarded as the minimum basis for community attention in every case. This is why the safety case is given additional attention later on.

<u>(B) The Risk and Safety Frame.</u>

As mentioned earlier, risks are the things and activities that can harm us. In considering *how* harmful something might be, we have to consider both the kind of activity it is, and how regularly we engage in it. For example, operating vehicles on roadways involves the chance of serious injury or death through collisions or losing control while driving. This is one of the most serious risks we face in everyday life, both in terms of how likely it is that we will be harmed in this way, and also how serious the health consequences can be if we are unlucky enough to be involved in a vehicular accident.

In this context, there are important choices to be made by members of a community with respect to framing a discussion about risks. For example, many experts encourage the public not to think about specific risks in isolation from others, but rather to compare one set of risks to another. Thus, for example, someone might claim that the risks arising from a proposed permanent waste storage site will be "far lower" than many familiar risks which already exist in a community as a result of collective decision-making, such as the siting of highways and railroads, traffic control schemes, industries, correctional facilities, and other types of waste management and energy generation facilities.

This is called a "relative risk" comparison, and it is one way for people to get a sense of the quite different *levels* of risk that are known to be associated with various substances and activities. On the other hand, when people are worried about a specific type of risk, an argument that brings in a whole lot of other kinds of risks, wholly unrelated to the one of interest, can seem to be irrelevant and a needless distraction.

Whatever the level of risk is thought to be, people need to have a certain level of comfort with it, which is what is known as "acceptable risk" or "risk tolerance." For example, people are regularly reminded through traffic accident reports in their locality, that driving on roadways always involves a fairly significant level of risk. They also know that when teenage drivers (especially male teenagers) are involved, the level of those risks goes up. But most people continue to drive their cars on a regular basis, and we can infer from their behavior that they are willing to tolerate the relatively high level of risk it involves.

Just as in the case of the energy policy frame of reference, the risk and safety frame can be construed very narrowly, very broadly, or somewhere in between. A *narrow framework* for discussion of risks associated with used nuclear fuel would be something like the following:

- Used nuclear fuel is dangerously radioactive and therefore must be stored safely, so that neither people nor biota (plants and animals) in their environment come into contact with harmful levels of radiation. In a narrow risk discussion framework, a decision is made to focus *only* on these specific risks and no others. In addition, there will be no comparison between these specific risks and any others, which arise from other sources, and no attempt to weigh risks against community benefits, for example, the jobs that a storage facility will provide.

- The risks associated with long-term storage of used nuclear fuel can therefore be regarded as "acceptable" only on the basis of a convincing demonstration of the safety case, with a clear bottom line: It is very unlikely that harmful levels of radiation will *ever* escape from the designated facility. Nothing else is relevant.

By way of contrast, a *broad framework* would be something like this:

- Here the safety case would still have to be made, but it would then be placed in a wider context. For example, a risk comparison matrix might be created, one which would set the overall level of risk associated with the used nuclear fuel storage facility (a new set of risks) against some other sources of risk that already exist in a community, for which there are reliable statistics about levels of risk.

- If most people observed from this matrix that the new risk seemed to be a good deal less significant than the ones they already were dealing with on a daily basis, they might conclude that the new risk was nothing to get especially worried about. Or, on the contrary, they might come down on the side of the opposite view, and conclude that they already had too many things to worry about and didn't need another one.

- At the same time, or alternatively, some people might advocate the framing of this decision as a matter of benefit – risk tradeoffs. Here the new risks would be juxtaposed against the set of long-term, tangible community benefits that would accrue to a locality that decided to host the storage facility for used nuclear fuel. Secure professional and support employment opportunities, greater property tax revenues, and new infrastructure facilities provided at no cost are examples of benefits that might be expected.

- Such benefits can be presented in terms of dollar values, but they can also be seen as a way of reducing other types of risks to community viability: Such things as declining property values and a risk in unemployment-related crime are among the many risks communities face when secure and well-paying jobs disappear and cannot be replaced.

Something in between would be, for example:

- Both relative-risk comparisons and cost-benefit tradeoffs undoubtedly add considerable levels of complexity to the already challenging technical description of the safety case. In addition, there will be some who say that *any* consideration of community benefits in this context is a potentially dangerous exercise, because it means that the community is being bribed to overlook what would otherwise be regarded as unacceptable risks.

- The allegation also might be made that vulnerable communities – those facing economic decline and without other good options for reversing the trend – have been deliberately targeted by those searching for a host community, and that this is an unethical act.

There is no easy resolution to these difficulties. What is perhaps clear and indisputable is that being comfortable with the safety case is the basic precondition for any robust community decision in this situation. Thus the wisest course of action might be to start the community deliberations around the safety case and, if that discussion ends with a general sense of comfort with the possibility of being a willing host for the site, a decision could be made to either explore the matter further, in a broader framework, or, alternatively, to stop at that point.

On the other hand, if the review of the safety case does not give rise to a strong feeling of comfort with the proposal, there is really nothing left to discuss.

(c) The Overriding Values Frame.

For many citizens, a sense of fundamental values – values so important that they override other important considerations, such as economic benefits – are brought to bear on a wide range of issues, including energy policy. For some, using nuclear energy to generate electricity has never been an acceptable proposition. More recently, others think that few issues are as pressing as doing something about climate change, and in energy policy terms this means rejecting further use of fossil-fuel sources. And, even though strong popular support is building for relying more heavily on alternative energy sources, especially wind and solar, plans to place large wind farms in rural areas run up against strong opposition in the name of protecting the traditional landscapes and amenities of life in the countryside.

Most people who appeal to fundamental values in social decision-making also know that values can conflict with each other, resulting in dilemmas about which one should have the higher priority. Thus communities facing major decisions, such as whether to consider becoming the host community for a permanent storage site for used nuclear fuel, likely will need to find a way to integrate a frame of reference for fundamental values into their deliberations.

Here are some examples of how value considerations might arise into community deliberations about a nuclear waste repository site:

- A values argument can be made to the effect that there is a clear ethical duty to assist in the project to safely store used nuclear fuel, rather than leaving the issue unresolved into the future, simply because this is the right thing to do, in terms of protecting health and the environment.

- A related argument would connect this duty to resolve the issue, within the near future, to the fact that people now living in certain Canadian communities have benefited from the energy generated at nuclear plants during their lifetimes: In other words, those who have benefited (the "upside") should also accept the responsibility to manage the resulting "downside" (taking care to store the waste in a way that minimizes risk).

- A contrary argument would be to insist that, since using nuclear power to generate energy is wrong in and of itself, then there is no ethical duty to assist in the resolution of the nuclear waste issue unless and until governments in Canada have made an irrevocable, binding commitment to cease using nuclear power within a defined time-frame.

- A different argument could be made as follows: (1) Global climate change resulting from fossil-fuel use is by far the most disturbing legacy that past and present generations are leaving to the future; (2) there is no practical solution, on a global scale, for reining in climate change that does not include continuing, and perhaps expanded, use of nuclear energy; (3) thus there is a duty to continue to use nuclear energy, but in a way that is clearly environmentally responsible, and this necessarily includes starting now to ensure that used nuclear fuel waste is safely and permanently stored.

- Contrary to the argument just made, one can start from the premise that climate change is the most disturbing legacy we are leaving for the future, but this problem must be dealt with solely on its own terms, and cannot provide a justification for continued or expanded use of nuclear power.

- An argument could be made that, since *all* energy-generating technologies have environmental impacts of some kind, the most important value is to ensure that every technology is used in an environmentally-responsible manner, whether it is fossil-fuel, nuclear, or an alternative.

Finding a way to have a reasoned and fruitful set of community discussions about different conceptions of fundamental values, and also about how value positions influence choices among policy options, will not be easy. However, it is a challenge that each community that wishes to consider hosting a nuclear waste repository must be able to respond to successfully.

(D) The Geographical Frame.

Finally, a less contentious but still meaningful frame of reference has to do with the relation between the specific locality within which a potential host community is located, on the one hand, and the larger regional, national, and international context, on the other. Some aspects of this frame may be identified by starting at the local community and gradually moving toward the bigger context. The options are:

First, to consider only one's own local situation and nothing else: What are the risks and benefits to the community itself, considered over the length of time during which the project will be active?

Second, to consider the regional and provincial situation as well as the local one: What are the additional risks and benefits at the regional level? For example, since the used nuclear fuel waste must be transported some distance from its present location to the community's storage site, what will be the situation of other communities that happen to lie in the path of the transportation corridor?

Since municipalities and regional government authorities are creatures of provincial governments, what role will provincial government agencies play at the time when communities are considering the opportunity to host a storage site? Can a community expect that the provincial government will be a partner with the community from the beginning, or will the community be "on its own" until sometime later?

Third, to consider the national as well as the local situation: Since the federal government has ultimate legal jurisdiction over nuclear-related materials in Canada, should the community expect that there will be any federal role during the community deliberation process? Or will the federal role be restricted to carrying out the official environmental assessment and project approval hearings at a much later time in this whole process?

Fourth, to consider all of the above, plus the international situation: Over thirty countries around the world now have nuclear fuel waste in temporary storage, and others are actively contemplating starting up a nuclear power program. Like Canada, a few of those other countries are moving towards finding a site for permanent storage at this time. Is this international situation relevant to the beginning of the search for a willing host community that is now occurring in Canada?

1D. Conclusion.

Interested parties in various communities may very well discover that there are other relevant frames of reference, in addition to the ones discussed above, once they start thinking about the question of hosting a permanent storage site for used nuclear fuel waste. There are many complexities attached to this question, as should be evident by now. But it is possible that, by using the idea of frames of reference to structure the various aspects of that question, the choices about what kinds of deliberation each community will need to have can be presented in a systematic way.

PAPER #2:

HOW MIGHT COMMUNITIES ORGANIZE THEIR DISCUSSIONS ABOUT HOSTING A SITE FOR USED NUCLEAR FUEL?

THIS IS A PUBLIC DOCUMENT

You may obtain a separate PDF File of the Original Paper from the Nuclear Waste Management Organization at:

https://www.nwmo.ca/~/media/Site/Files/PDFs/2015/11/04/17/34/1671_nwmosr-2010-11_paper2_howmight.ashx?la=en

2A. Introduction.

Beginning in the late 1990s, there emerged a strong consensus among Canadian policy-makers about the necessary conditions for finding an appropriate solution to the problem of storing used nuclear fuel safely in this country. Those conditions are, first, that there must be a broad public understanding of the underlying issues, and second, that there must be explicit public support for the preferred solution. A third condition is that, as the search for a solution moves toward the siting of a permanent storage facility for used nuclear fuel, any community being considered as the site for the facility must have expressed a clear and adequate level of support for the project. And over the course of the preceding decade, a number of other countries which also have nuclear waste to store safely have come to the same conclusions.

The expected involvement of communities in four Canadian provinces (New Brunswick, Québec, Ontario, and Saskatchewan) in discussions about a siting process will take place on an entirely voluntary basis. This is intended to be the initiation of a gradual process that begins with informal information exchanges and concludes some years later with a formal agreement, involving a single community, for hosting a storage site for used nuclear fuel (NWMO 2009). Between the beginning and the final step, however, a number of communities might participate in these discussions for a certain period of time before deciding not to proceed further with the idea of hosting a storage facility.

At the end of this process, only a community which has convinced itself that it has become fully informed about all aspects of this project, and also later has concluded that it wishes to be the host community for the facility, will fulfill the criteria for being called a "willing host." In addition, of course, in the context of the formal environmental assessment that will precede any final decision on siting, the potential host community will have to convince others outside its boundaries that its candidacy truly reflects the will of its citizens.

The importance of thinking ahead is very important, for one simple reason: Almost certainly, only one facility of this type will be constructed in Canada over the course of the foreseeable future; on the other hand, the desirable geological features required for safe storage of this waste are found across wide swaths of this country. In principle, therefore, there could be dozens of different communities that could be, at least at first glance, suitable hosts for this facility and which might wish to become engaged in some of the steps in any siting process. Still, each of them must recognize that all but one of the communities which start down the road in this engagement, and all but one of the communities which happen to go quite far down that road, will not end up being the host for a nuclear fuel waste storage facility.

Ideally, all participating communities, whether their engagement in this process is relatively short, or alternatively quite extensive, should come away from their participation in it with the view that it has been a positive experience for them. However, many citizens have strong feelings about both nuclear power and nuclear waste and vocal disagreements among citizens should be expected to occur throughout the period when the idea of hosting a facility is under active consideration. Thus it might be desirable for communities to think through the process of engagement in advance, and in some detail, before their discussions about storing used nuclear fuel get under way.

The procedure for eventually finding a willing host community necessarily involves openly engaging a fair number of possibly interested communities during the early stages, and inviting some of them to consider entering into a gradually more intensive involvement over time, even though all but one of them will not end up being the host. But the other side of this process is that many others will have taken part in extensive discussions about the possibility of being a willing host. For all of them, and not just for the one that may be eventually chosen, it would be unfortunate if they were to conclude that their participation had not been a positive experience.

Some protection against this eventuality has been built into the design of the engagement process itself, in that it envisages a series of discrete steps, beginning with some fairly straightforward information-gathering exercises. However, it should not be assumed that all unpleasantness caused by strong disagreements among community members necessarily can be avoided even in the early stages of this process. There may very well be those among them who are adamantly opposed to the whole concept, for whom even taking a first step on this journey is something to be avoided at all costs, lest the first step lead by small increments to an ever-deeper involvement in the process.

It is for this reason, if none other, that each community should spend some time considering how the process of engagement might unfold in the context of its own unique situation, in the period leading up to taking a decision about the initial engagement. The following sections of this paper are designed to be helpful in this regard, by describing some types of formal and informal methods for facilitating reasoned debates about controversial issues. Of course, many communities may have had extensive prior experience with some or all of these methods in dealing with other types of serious issues or options, for example, economic development initiatives or conservation and environmental protection challenges.

Before some of the ways through which productive community debates can be carried out are described, the idea of the "safety case" for the nuclear waste storage facility will be presented briefly. The reason for doing so is to use a concrete example for the types of subject matter that are likely to be raised in the community dialogues. *The safety case can be regarded as the minimum necessary topic of discussion for every community that wishes to consider the possibility for hosting this facility.* In other words, although communities will differ in terms of the range of issues that will or will not be raised for debate – for example, energy policy or sustainability – none of them will be able to avoid dealing with the safety case.

2B. The Safety Case.

"A safety case is the synthesis of evidence, analyses and arguments that quantify and substantiate a claim that the repository will be safe after closure and beyond the time when active control of the facility can be relied upon" (NEA 2004, p. 7).

A safety case for the long-term storage and disposal of used nuclear fuel is an argument intended to persuade government regulators to approve an engineering design at a specific location for the storage facility. The presentation of the safety case will be made in an elaborate set of technical documents and in presentations at public hearings of the review board authorized by the federal government. Many of these formal documents and presentations will not be available until sometime much later in the decision process – in part because one or more specific locations for a possible site need to be identified first.

However, members of interested communities certainly will want to hear and debate the elements of the safety case long before the formal hearings phase gets under way. This is why technical experts seek to prepare a “conceptual” safety case well in advance – and, in fact, in Canada and elsewhere they have been doing so for decades. The conceptual case takes the known features of geological formations such as the granite of the Canadian Shield, plus the known features of fabricated materials such as steel and copper casings, and evaluates them against a set of necessary performance criteria or objectives for a specified purpose: in this case, storing used nuclear fuel over a very long period of time.

As described in many publications that are available to the public on the Internet (for example, NWMO 2003a), the radioactive materials in used nuclear fuel represent a serious risk to humans and the environment. The well-described nature of this hazard is what determines the key objectives for the performance of the facility, which are:

- To *isolate* the waste from the biosphere;
- To *contain* the waste as its radioactivity slowly decreases;
- To *inhibit* the migration of radioactive substances beyond the bounds of the facility;
- To *identify* the uncertainties in the analysis.

The basic engineering strategy for the storage site is to construct what is referred to as a *multi-barrier* facility featuring *passive control* of the waste:

1. The *barriers* designed to prevent the radioactive material from moving from the space into which they are deposited include, among others: the steel-and-copper containers in which the waste is packaged; the clay shield around the containers, which inhibits movement of water; the features of the rock formation, deep underground, that will be excavated in order to hold the waste, which isolate the area from groundwater movement; and the location of the facility in an area that does not normally experience dangerous levels of seismic activity (earthquakes).

2. *Passive control* refers to the idea that, once the waste is emplaced as above, those barriers will be sufficient to keep the waste isolated and

contained where it is, indefinitely into the future, without the need for any additional active human intervention.

Finally, a credible safety case is expected to be prepared in a way that reflects the requirements for transparency, traceability, openness, and peer review:

- *Transparency*: Using clear language and, where the general public is concerned, showing an effort to present technical material in a way that is understandable to non-expert audiences, without sacrificing rigor;

- *Traceability*: Sources for the data are indicated, and assumptions are identified and justified;

- *Openness*: Uncertainties are specified and reasons are given for the estimates of the confidence in the expected performance of the facility;

- *Peer Review*: Independent critical review has been undertaken by experts of established reputation who are not connected to the organization that prepared the original studies.

The safety case can be taken as illustrating an important discussion topic (one of many) for community dialogues about storing used nuclear fuel. What are some ways in which a community could organize for itself a variety of forums for holding such a discussion?

2C. Some ways of organizing community discussions.

Three quite different strategies for discussion are presented, and a number of different methods for implementing such discussions will also be offered. The three types are:

1. *Deliberative*, relying on expert presentations and technical information;
2. *Instrumental*, involving a balancing of perceived benefits and costs (risks);
3. *Values-driven*, using reasoning based on ethical principles.

Each of them has great potential value, and obviously some communities will want to utilize all three, especially if they are among the group which decides to maintain their involvement in the engagement activities through more than just the first of the series of steps. This is because the level of intensity of the community dialogues might be expected to rise as a community's involvement progresses toward the later steps.

It is possible that some communities might want to begin using one or more of these strategies as early as the transition between Step 1 (information exchange) and Step 2 (preliminary screening for site suitability) in the sequence presented in the Appendix, at the end of this paper. Or perhaps, these strategies could be deployed during the transition period between Step 2 (preliminary screening for site suitability) and Step 3 (potential site feasibility study).

(A) Deliberative Discussion Processes.

In this orientation for discussion community members will seek ways in which qualified experts can help them comprehend the many and complex technical issues that will be raised in connection with a repository siting. There are two aspects to this need: first, the simple translation of technical terminology into terms understandable to non-experts; and second, figuring out whom to trust among the experts addressing these issues when challenges are raised to the credibility of any specific experts. Neither of these aspects is easily dealt with, and that is why formal procedures of some type are usually found to be necessary when confronting them.

Since the safety case is being used here as an example of technical complexity, an example drawn from a recent document on this topic, available on the Internet, will illustrate the need referred to above: "The deep horizontally-layered shale and argillaceous limestone sedimentary sequence that will overlie and host the DGR [deep geological repository] is geologically stable, geometrically simple and predictable, relatively undeformed and of large lateral extent." (Kempe et al. 2007, p. 5)

Obviously, the geological characteristics of a candidate repository site are a very important part of any such safety case, and therefore this type of analysis simply cannot be omitted from the discussion. But few among the rest of us who are not geologists would presume to be able to evaluate fairly, on our own, the accuracy of this statement. Thus the need for help.

What is required is a set of forums that have been designed to incorporate presentations by reputable experts within the larger purposes of a community dialogue. A few examples are provided below.

(A1): A Citizens' "Grand Jury."

Here a community would agree on a fair process for selecting a representative, relatively small sample of its members, say 10 to 20 in number, who would serve as a kind of grand jury. The jury would first select a knowledgeable professional person, perhaps an outside consultant, to conduct proceedings in its presence and, in effect, to act as a "prosecutor."

The jury members would instruct the prosecutor as to what specific issues of a technical nature it wishes to have examined during its time in this role. The prosecutor, perhaps assisted by others, would then select a number of well-informed individuals, groups, and organizations and invite them to appear before the jury. Notes of these meetings would be kept, but preparing a verbatim transcript almost certainly would be unnecessary.

The invited persons would submit in advance some materials appropriate to the issue, including technical documents and briefs. A kind of "cross-examination" of the expert witnesses would be conducted by the prosecutor, who would include in the list of questions those submitted by jury members. In specific matters where the jury was presented with sharply conflicting points of view by witnesses, an effort could be made to find "neutral" parties who could attempt to reconcile the conflicting statements or at least assist the jury in interpreting those differences.

Neutral parties could also be asked to help the jury to understand some of the most difficult matters that are common to all technical assessments, especially the interpretation of uncertainties and probabilities.

At the end of the hearings the jury members would decide on how to report its "verdict" on the matters before it – perhaps by a vote, or else by some other way of indicating its collective judgment. Its reasons for judgment, and any recommendations for further steps that might be needed, should be written up, perhaps with assistance by a professional writer, and released to the public.

(A2): A Consensus Conference.

Here the kinds of discussions that would occur in a long series during the grand jury sessions would happen all at once, over a period of days, in a conference setting open to the community (and recorded for later playback by others). Panels of diverse experts would be asked to prepare short papers on specific technical topics, and to orient those papers to a non-expert audience. They would speak to their papers at the conference sessions and respond to questions from the audience. Conference organizers would assemble a written record of meeting, including the Q and A sessions, for later dissemination in print and web-based formats.

Depending on the scope of the topics that is of interest to community members, either one conference, or a series, could be planned.

(A3): A Series of Focus Group Meetings with Background Papers.

Professionals with an expertise in conducting focus groups could be retained and asked to meet with community volunteers for intensive discussions, designed to elicit the specific concerns of community members at a particular point in time.

Using inputs from these meetings, community officials could then commission the preparation, by neutral third parties who are recognized experts in the relevant fields, of short papers that addressed directly the most common and serious of the issues raised in the meetings. Print and web-based formats would be used for dissemination.

(B) Instrumental Discussion Processes.

Community members can take an entirely different view of their most crucial information needs from what is suggested in the preceding section. In other words, they can reasonably take the view that it is government agencies, working on their behalf, which should and must resolve all of the technical issues implicit in the safety case, for example. The rationale for this view is that the full safety case is of such great complexity that only qualified experts can truly understand it and ultimately recommend its rejection or approval. Governments, on this view, must configure the decision process that subjects the analyses and recommendations of technical experts to rigorous examination, resulting ultimately in a judgement that the safety case has or has not been made satisfactorily.

Thus from this standpoint, rather than listening to debates among experts on many subjects in which they have little or no expertise, citizens should have a quite different kind of debate among themselves. This may be called an "instrumental" discussion, because it would be about their own *perceptions* – in other words, their own considered personal judgements – about how the storage facility project would impact daily life in their community.

For such discussions, they would use their own personal information base, as gathered from Internet searches, occasional talks with friends and neighbors, participation in community meetings, or whatever. The main difference between this approach and the preceding one is that, in the present case, they would have made their own selection about what information is relevant to the decision options they have been presented with from among the information sources familiar to them.

Their perceptions would encompass a sense of potential benefits from the project, as well as potential risks and costs. They would still have to choose how to conduct their discussions along these lines, but here the most appropriate choices are likely to be in the form of more informal settings, such as town hall meetings or neighborhood gatherings, without the keeping of a record of meeting.

In the absence of any sustained call for the adoption of more formal settings, such as the ones described earlier, it would be presumed that the informal discussions were a sufficient basis for the expression of a collective judgement, one way or the other, perhaps through a referendum or a resolution by the municipal council, at some point in time, on the facility hosting opportunity.

(C) Values-Driven Discussion Processes.

Debates driven by different senses of fundamental values are likely to be the most difficult to manage well. It is possible to imagine that two members of the same community could feel equally strongly that the place where they live has a clear ethical duty or responsibility in this matter – the one, to accept the hosting role, and the other, to oppose it. If such a division is broadly representative of the feelings of large numbers of people in the community, a rancorous and long-running dispute could be opened up within their ranks.

Although this situation may turn out to be unavoidable for some communities, it also may be possible to seek to confront it head-on and, hopefully, to reduce the amount of discord. This may be done by seeking the assistance of qualified external resources among those who have expertise in ethics and values, such as in university departments. These professionals are experienced in methods for situating values debates in modes of reasoned discourse.

For example, in the period 2003 – 2005, the NWMO used both an International Panel, composed of three members of high international standing, as well as a separate six-member roundtable on ethics, to provide guidance on values issues during its deliberations on the policy choices for a permanent storage site for used nuclear fuel. Records from their activities, available on the Internet (NWMO 2003b), may be consulted by community members who wish to see examples of how ethical reasoning can make a distinctive contribution to the formulation of principled positions on these types of decisions.

2D. Conclusion: The Element of Trust.

The record of public and community engagements (and controversies) over facilities siting, especially for facilities designed to store and dispose of hazardous wastes, has been studied extensively and reported in the academic literature. A special focus of such studies is the attempt to understand how one of the most important human values, namely trust – as between members of communities, on the one hand, and the people and organizations which are the proponents of the facility to be sited, on the other – can be either generated or destroyed.

As detailed in the published literature in this area, in these situations two elements in the "construction" of trust stand out, namely the perception of the *integrity* and the *competence* of the proponents, on the part of community members. In comparing the two, the qualities that make up competence are perhaps easier to pin down. For example, during the detailed scrutiny of the safety case in open public hearings where evidence and reasoning is examined closely, it should be possible for community members to form a confident judgement that the facility owners will or will not achieve the requisite level of safety in their management of the proposed project over the long haul.

Reaching a judgement on the matter of integrity involves more subtle modes of thinking. But some, at least, of the essential characteristics that are involved here can be specified:

- Do the proponents have an attitude of openness and frankness with regard to their own objectives, ethical principles, and the information sources on which their proposals are based?

- Are the proponents respectful of the diversity of community viewpoints, and do they display a willingness to engage all those who wish to be involved in the process?

- Are the proponents willing to assist community members in their efforts to assess the adequacy and credibility of the information presented by the proponents?

- Are the proponents prepared to provide a reasonable level of assistance to potentially interested communities, in terms of accessing the resources that are needed to define adequately the community's response to the siting opportunity?

The answers to these and related questions, which can be expected to become obvious over the course of the early stages of the engagement process, ought to be sufficient for the community to make a definitive judgement on the matter of the perceived integrity of the proponents.

Appendix:

The Proposed First Six Steps of Community Engagement

(NWMO 2009)

1. The NWMO will provide information, answer questions, and build awareness among Canadians and communities about the project and the siting process.

2. At the request of the community, the NWMO will evaluate the potential suitability of the community against a list of initial screening criteria.

3. At the request of the community, a feasibility study will be conducted to determine whether a site in the community has the potential to meet the detailed requirements of the project.

4. For interested communities, potentially affected surrounding communities are engaged and detailed site evaluations are completed.

5. Communities with confirmed suitable sites decide whether they are willing to accept the project and negotiate the terms and conditions of a formal agreement to host the facility with the NWMO.

6. The NWMO and the community with the preferred site enter into a formal agreement to host the project.

Resources Available on the Internet

Section I: Safety Case.

Belgium 2004: Federal Agency for Nuclear Control, Government of Belgium, "Geological Disposal of Radioactive Waste: Elements of a Safety Approach": http://www.fanc.fgov.be/download/Safety_approach_final_2004.pdf

IAEA 2006: International Atomic Energy Agency, "Geological Disposal of Radioactive Waste: Safety Requirements": http://www-pub.iaea.org/MTCD/publications/PDF/Pub1231_web.pdf

Kempe, T. et al. (2007), "Developing a Safety Case for Ontario Power Generation's L&ILW Deep Geologic Repository": www.nwmo.ca/publications?media_file_id=630
[L&ILW = low and intermediate-level wastes, thus not including used nuclear fuel wastes; listed here because the safety case is clearly described]

NEA 2004: Nuclear Energy Agency, OECD (Organisation for Economic Co-operation and Development), "Post-Closure Safety Case for Geological Repositories": http://www.nea.fr/html/rwm/reports/2004/nea3679-closure.pdf

Nuclear Waste Watch (Canada, 2009): http://www.cnp.ca/nww/index.php

Sierra Club Canada (2005), "Nuclear Waste Disposal: Action Alert and Backgrounder": http://www.sierraclub.ca/national/programs/atmosphere-energy/nuclear-free/reactors/high-level-waste.shtml

Section II: Other Resources.

COWAM (Cooperative Research on the Governance of Radioactive Waste Management):

COWAM 2003: "Nuclear waste management from a local perspective: Final Report": http://www.cowam.com/documents/cowam-fr2003.pdf

COWAM 2006: "Final Synthesis Report": http://www.cowam.com/IMG/pdf_cowam2_Final_Synthesis_Report_v4.pdf

EC 2008: European Commission, Community Research, Project on Comparison of Approaches to Risk Governance [CARGO], "Risk

Deliberation," by L. Reynolds et al., University of Lancaster: http://www.cargoproject.eu/docs/project-deliverables/wp3_risk_deliberation.pdf

IAEA 2007: International Atomic Energy Agency, "Factors affecting public and political acceptance for the implementation of geological disposal": http://www-pub.iaea.org/MTCD/publications/PDF/te_1566_web.pdf

NWMO 2003a: Nuclear Waste Management Organization, "Health Effects of Radiation and Radioactivity": http://www.nwmo.ca/healtheffects

NWMO 2003b: Roundtable on Ethics: http://www.nwmo.ca/round_table_on_ethics and International Panel http://www.nwmo.ca/international_panel

NWMO 2009: Nuclear Waste Management Organization, "Moving Forward Together: Designing the Process for Selecting a Site": http://www.nwmo.ca/designingasitingprocess.

"Oskarshamn Model":
Harald Åhagen and others, "Repository Siting – Public engagement an asset or an obstacle?" (2004): http://web.wpab.se/lko/Data/public-se/en_dokument_visa.asp?ID=84&MainTyp=1

"Repository of used nuclear fuel, site investigation phase, Municipality of Oskarshamn Organization" (October 18, 2004): http://web.wpab.se/lko/Data/public-se/en_dokument_visa.asp?ID=96&MainTyp=1

"Site Investigation in the Municipality of Oskarshamn: Decision on Site Investigation, Decision Statement" (October 18, 2004): http://web.wpab.se/lko/Data/public-se/en_dokument_visa.asp?ID=83&MainTyp=1

PAPER #3: WHAT IS HAPPENING IN OTHER COUNTRIES? [UPDATED 2017]

THIS IS A PUBLIC DOCUMENT

You may obtain a separate PDF file of the Original Paper from
The Nuclear Waste Management Organization at:

https://www.nwmo.ca/~/media/Site/Files/PDFs/2015/11/04/17/34/1672_nwmosr-2010-12_paper3_whatisha.ashx?la=en

Note to the Reader:

This paper contains a large number of web-links to Internet sites. Like information from any source, the information content one finds on any specific web site may range from highly reliable to seriously misleading. For example, Wikipedia entries are generally quite reliable, but specific details can be wrong or incomplete. *For any specific points that are important to you as a reader, always check and compare a number of different sources during your Internet search.* The web-links provided in this paper were active as of mid-November 2017. If you are searching for a specific document, and a web-link appears to be unusable, try a general search using the name of the document.

3A: Introduction.

At last count thirty-one countries around the world, among them Canada, (https://en.wikipedia.org/wiki/Nuclear_power_by_country) were operating some 435 nuclear power plants to generate electricity, and thus also producing nuclear waste of different types. The first commercial-scale power plants commenced operations in a few countries in the mid-1950s and in 1968 in Canada. So far, no permanent storage or disposal facilities have been completed for wastes from these sources and the radioactive waste has been accumulating in various temporary storage facilities here and elsewhere for over fifty years. In most countries that have announced publicly a commitment to construct some type of permanent facility, the proposed timelines indicate that many more decades will elapse before those structures are ready to receive the wastes.

One important distinction in this area is between what is called “HLW” (high-level waste) and “L&ILW,” that is, low- and intermediate-level waste. As its name implies, HLW is highly radioactive when it is first handled, continues to generate heat and thus requires cooling for a number of years, and continues to be radioactive for very long periods of time. Some countries, notably Russia and the United States, also have substantial quantities of HLW originating in nuclear weapons production. In Canada’s CANDU nuclear reactors, which use unenriched uranium as a fuel source, HLW is represented by the fuel bundles that are removed from the reactors at the end of their useful life.

L&ILW, on the other hand, has minimal radioactivity and does not require cooling or special shielding. In Canada L&ILW includes: operational low-level wastes from routine maintenance (mops, rags, etc.); operational intermediate-level wastes (e. g., reactor core elements); refurbishment waste (motors, valves, etc.); and, in the future, decommissioning waste (the entire nuclear reactor itself, when it is at the end of its useful life). L&ILW may also include radioactive wastes from medical, industrial, and research sources.

This paper deals primarily with HLW and summarizes what is currently known about the plans of various countries to deal with their high-level radioactive waste. All of the information is taken from publicly-available Internet sources, most of which are websites maintained either by national agencies that have legal responsibility for the waste within their borders, or international agencies with other types of mandates in this area. A complete list of the URLs for the Internet-based information sources is given in both the “Country Profiles” and the “References” sections later in this paper. Downloading and using the PDF file for this paper onto a computer with Internet access will enable one to click on these URLs and be taken directly to the various websites.

With a single exception (the website of the agency in France, which is in French), all of the chosen websites are in English. An attractive feature of many of these sites is the availability of maps, diagrams, and illustrations, such as drawings of the waste canisters and the engineering of sites. The WIPP facility in the United States (at Carlsbad, New Mexico) has an office located at the site that is open to the public, and one of the websites for the German proposed site at Gorleben features a "virtual tour" of the facility: http://www.dbe.de/en/sites/gorleben/1/index.php.

3B: Overview.

In all cases where countries have given detailed consideration to the method of disposal, the preferred choice is an engineered repository placed 300-1000 meters underground in a suitable geological medium. "Suitable" refers to an underground formation that resists intrusion from water; granite rock, salt domes, sedimentary rock, and clay formations are all regarded as qualifying for this purpose.

The following nations have made public commitments to using deep geologic disposal for the long-term isolation of highly radioactive wastes: Belgium, Canada, China, Finland, France, Germany, Japan, Russia, Spain, Sweden, Switzerland, the United States, and the United Kingdom. In three of those countries – China, Russia, and Spain – there have only been announcements of future plans, without further details. In two others, Italy and South Korea, decisions have been taken quite recently that will result in the formulation of plans for repositories, but no specific directions have been set. But in Belgium, Canada, Finland, France, Japan, Germany, Sweden, Switzerland, the United Kingdom, and the United States, many years of detailed studies have been carried out in exploratory shafts and underground laboratories. See generally:

- https://en.wikipedia.org/wiki/High-level_radioactive_waste_management

- http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/radioactive-waste-management.aspx

Of the countries named in the first list above, only Finland has actually chosen a repository site and set a date (2012) for the beginning of construction work. Sweden is perhaps next in line, announcing in June 2009 the choice of a site near the community of Östhammer, which has shown strong community support for hosting a facility. At the other end of the spectrum, in the United States, where the Yucca Mountain location had been originally chosen twenty-two years ago, in 1987, the siting process seems to be grinding to a temporary halt as a result of determined opposition from the state of Nevada and others. As of early 2009, the U. S. Secretary of Energy had decided to strike a special panel to examine an alternative plan for high-level radioactive waste disposal.

The following section contains brief accounts of the current situation for the disposal of HLW in selected individual countries. The phrase "NEA profile" stands for the most current information available on the website of the Nuclear Energy Agency, which is a specialized agency within the OECD (Organisation for Economic Co-operation and Development). Based in Paris, the organization provides its member countries with advice on nuclear safety, radioactive waste and nuclear plant decommissioning, nuclear science and law, and related areas: http://www.nea.fr/).

All of the countries listed below are among those which have adhered to the "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management," which came into force in 2001 and is managed by the International Atomic Energy Agency (IAEA), a United Nations entity. The Convention specifies the obligations, which the contracting parties have agreed to, with respect to the management of radioactive materials:

- http://www.iaea.org/Publications/Documents/Conventions/jointconv.html

- https://www.iaea.org/publications

Of course, not all countries that are currently operating civilian nuclear reactors have revealed their plans for dealing with HLW on a long-term basis. But, based on publicly-available information, it appears to be accurate to say that all nations which have announced plans for dealing with HLW to date have indicated that they will construct a deep geologic repository for these wastes.

3C: Country Profiles.

1. Belgium.

Belgium has been generating electricity from nuclear power since 1975, but in 2003 the federal parliament approved a measure to begin a gradual phase-out of commercial nuclear power plants beginning in 2015. In 1980 the government created a separate agency, the Belgian Agency for Management of Radioactive Waste and Enriched Fissile Materials, known by the French/Dutch acronym ONDRAF/NIRAS, with responsibility for both HLW and L&ILW.

The agency opened an underground research laboratory, the High Activity Disposal Experimental Site, in the so-called "Boom clay" layer in the Mol-Dessel area of Belgium, where work continues up to the present time. The 2005 NEA profile (the most recent available) states: "The current plan for conditioned high-level and long-live, alpha-bearing waste is disposal in deep geological formations, and an extensive R&D programme, started in 1974, is concerned with assessing the use of a clay formation as host rock for a repository." An interim safety assessment completed in 2002 concluded that the Boom clay would provide a viable host material for long-term disposal of the country's HLW. The ONDRAF website states that the R&D program is ongoing and that final decisions about a timeline for developing the disposal site have not yet been made.

Websites:

- http://www.ondraf-plandechets.be/nieuw/downloads/Waste%20plan%20-%20English.pdf
- http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/belgium.aspx
- https://www.ondraf.be/ [French]

2. *CANADA.*

In 2007 the Government of Canada accepted the recommendation, made by NWMO (the Nuclear Waste Management Organization), that used nuclear fuel produced in Canada (HLW) should be permanently stored or disposed of underground in a suitable deep geological repository located somewhere in the nation where a community agrees to serve as a willing host for this material. In May 2009 NWMO issued an "Invitation to review a proposed process for selecting a site" for a deep geologic repository. The Government of Canada announced in January 2009 that an environmental assessment process was being commenced to review the proposal for a deep geologic repository for low- and intermediate-level radioactive waste (L&ILW) near the community of Tiverton, Ontario and the Bruce nuclear reactor site, and this review was completed in 2016.

Websites HLW:

- www.nwmo.ca
- http://www.nwmo.ca/designingasitingprocess

L&ILW:

- http://www.ceaa.gc.ca/050/details-eng.cfm?evaluation=17520

3. *CHINA.*

China is now operating eleven nuclear power reactors, but the country is in the midst of a tremendous wave of construction for energy plants. In addition to many coal-fired plants, 15 new nuclear reactors are under construction and an additional 18 are in the planning stage, with many more on the drawing boards. The Chairman of China's Atomic Energy Authority, Chen Quifa, gave a major speech on his country's nuclear policy in April 2009 at a NEA conference, including special mention of China's adherence to the international Joint Convention, which the national legislature had ratified in 2006. In this speech mention was made of a commitment to develop a deep geologic repository for high-level radioactive waste, but no further details or timelines were offered.

Websites:

- http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx
- https://en.wikipedia.org/wiki/Nuclear_power_in_China
- http://english.people.com.cn/200604/29/eng20060429_262209.html "China's legislature approves convention on nuclear waste management" (2006)
- https://www.reuters.com/article/us-china-nuclearpower/china-halts-work-on-15-billion-nuclear-waste-project-after-protests-idUSKCN10L0CX

4. *Finland.*

Electricity generation from nuclear power began in Finland in 1977, and by 2008 nuclear accounted for about a quarter of total electricity supply. A proposal to establish a deep geologic repository, to be located in an underground granite formation at Onkalo, located a few miles from Olkiluoto, where a nuclear power plant is operating, was made ten years ago. Eurajoki, the host municipality, gave its approval in 2000 and the national government ratified the decision in May 2001. An underground research facility was established at the site in 2004; construction is scheduled to begin in 2012 and the disposal facility is expected to begin operating in 2020.

Websites:

- www.posiva.fi/en/
- http://en.wikipedia.org/wiki/Olkiluoto_Nuclear_Power_Plant
- https://en.wikipedia.org/wiki/Onkalo_spent_nuclear_fuel_repository
- https://www.economist.com/news/international/21720591-finland-shows-way-project-expected-span-100000-years-how-dispose

5. *France.*

France began using nuclear energy to generate electricity in 1959, and of all nations using this energy source, France has by a wide margin the largest percentage of its national total produced in this way – 59 plants generating close to 90% of the nation's total, with additional amounts produced for export. France developed a major waste reprocessing facility for the enriched uranium fuel used in its reactor design; it also provides this service for waste shipped from Japan and the United States. A complex three-stage process, which recovers uranium and plutonium for re-use, is carried out first at the reprocessing unit at La Hague and then in two other uranium conversion facilities. Electricité de France (EdF) expects to generate 20% of its power from recycled uranium and plutonium by 2010. This recycling through reprocessing reduces considerably the volume of HLW that ultimately must be disposed of, but since some very hazardous wastes still remain, construction of a long-term disposal facility is required.

ANDRA (the National Radioactive Waste Management Agency) was established by legislation as the radioactive waste management authority in 1991. The French government passed the Nuclear Materials and Waste Management Program Act in June 2006. It declared that deep geologic disposal is the preferred solution for high-level and long-lived radioactive wastes, setting 2015 as the target date for licensing a repository and 2025 for opening it. An underground research laboratory has been established at Bure, in a clay formation, which lies in or near a small zone that is likely to be selected as the site of a repository. The current schedule indicates that during the years 2009-2013 a site selection process, including public input, will be carried out, with 2013 as the target date for selection of a preferred site. Following site selection, construction of a facility is expected to take ten years.

Websites:

- http://www.andra.fr/ [French]
- http://www.andra.fr/international [English]
- http://www.world-nuclear.org/info/inf40.html
- http://en.wikipedia.org/wiki/Nuclear_power_in_France

6. *GERMANY.*

Commercial use of nuclear power began in Germany in 1961 and by 2002 nuclear plants were producing about a quarter of that country's electricity. However, in 2002 a law was passed instituting a moratorium on all new nuclear plants and requiring existing ones to be phased out between the years 2009 and 2023. On June 30, 2011, following the Fukushima disaster, Germany ordered the immediate shutdown of eight of the country's 17 reactors and outlined a timeline for taking the rest of the nuclear plants offline by 2022.

The Federal Office for Radiation Protection (German acronym: BfS) has official responsibility for regulating high-level radioactive waste. As long ago as 1975 German legislation stipulated that HLW should be disposed of underground in a suitable geologic formation, and for most of that time formations known as salt domes have been preferred. One such site, Gorleben, was identified already thirty years ago as the best of these sites and preliminary exploratory work was carried out for many years until political opposition brought it to a halt in the year 2000. Further characterization of this site has been delayed indefinitely since that time.

Websites:

- http://www.bfs.de/SharedDocs/Interviews/BfS/EN/2015-12-10-bfs-koenig-kfk.html
- http://www.dbe.de/en/sites/gorleben/1/index.php
- http://en.wikipedia.org/wiki/Nuclear_power_in_Germany
- http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/germany.aspx
- https://en.wikipedia.org/wiki/Nuclear_power_phase-out

7. *ITALY.*

Italy is an unusual case, having begun its nuclear power program in 1963 and then abruptly shutting it down entirely in 1987, at the time when three plants were operating, as a result of the government's interpretation of the results of a national referendum held in the aftermath of the Chernobyl disaster. Plans had been put into place for decommissioning those plants and dealing with the HLW and L&ILW kept in temporary storage at the plant sites. But – despite a continuing flurry of laws, policies, and ministerial decrees – essentially nothing has been done except to "mothball" the sites.

Then, in July 2009, the Italian parliament passed a law authorizing ENEL, the country's electricity producer, to re-enter the nuclear sector. In August 2009 ENEL signed an agreement with Electricité de France, its French counterpart, setting up a joint venture under which at least four new nuclear plants will be built. The government has promised to issue more ministerial decrees within a short period, dealing both with the sites for the new plants as well as for nuclear waste repositories.

Websites:

- http://www.world-nuclear.org/info/inf101.html
- http://en.wikipedia.org/wiki/Nuclear_power_in_Italy
- http://large.stanford.edu/courses/2015/ph241/rossi2/

8. JAPAN.

Japan began using nuclear-generated electricity in 1966 and by 2008 there were 63 nuclear reactors producing about 35% of the nation's power. For many years Japan has shipped used nuclear fuel to both France and the UK for reprocessing; the highly radioactive waste residues were vitrified (turned into a glass form) at the reprocessing sites and shipped back to Japan for interim storage. Japan has now constructed its own reprocessing facility as Rokkasho. NUMO, the Nuclear Waste Management Organization of Japan, has legal responsibility for dealing with radioactive wastes of all types. The Horonobe Underground Research Center carries out research and development programs on geological disposal for high-level radioactive waste.

On December 19, 2002, NUMO officially announced the "Start of Open Solicitation for Volunteers for Preliminary Investigation Areas (PIAs) for a HLW Repository," and all municipalities in Japan were eligible to apply. In January, 2005, Toyo town in Kochi prefecture submitted an application to become a volunteer area. This initiated an internal procedure at NUMO to confirm geologic conditions in Toyo, leading up to a more detailed literature survey of the area. Meanwhile, NUMO continued to call for other municipalities to volunteer. In April 2007, Toyo withdrew their application after the election of a new mayor who opposed the siting of a facility in the municipality. Japan's announced timeline for the repository siting process was once stated as follows:

1. 2008-12: selection of areas for detailed observation;
2. 2023-37: selection of a site for repository construction;
3. ~2025: design of a repository, start of construction;
4. 2033-37: start of operation.

Obviously, Japan's entire nuclear industry, including its plan for deep geological disposal of waste, was thrown into disarray following the disaster at Fukushima in March 2011. There appears to have been very little progress on the nuclear waste disposal file since then.

Websites:

- http://en.wikipedia.org/wiki/Nuclear_power_in_Japan
- http://www.numo.or.jp/en/jigyou/new_eng_tab03.html
- http://www.jaea.go.jp/english/04/horonobe/index.html
- http://www.nea.fr/html/rwm/profiles/Japan_profile_web.pdf
- https://www.japantimes.co.jp/news/2017/07/28/national/meti-posts-map-potential-nuclear-waste-disposal-sites/#.Wd_LbltSzA4

9. *SOUTH KOREA.*

The Republic of Korea began commercial production of nuclear power in 1978 and currently has twenty-three operating nuclear reactors, which generate about 30% of the country's electricity consumption. Korea is thus one of the nations in the world that is most heavily dependent on nuclear power for electricity generation. Additional nuclear plants are planned.

Korea operates two different types of nuclear reactors (including the CANDU type), and HLW is kept in temporary storage at the reactor sites.

In a recent development, the government enacted a "Radioactive Waste Management Act" which came into force on the first day of 2009; among other provisions, it establishes a separate agency, the Korea Radioactive Waste Management Corporation, to manage these wastes. There are as yet no details about the type of HLW repository that will be chosen.

Websites:

- http://en.wikipedia.org/wiki/Nuclear_power_in_South_Korea
- http://www.nea.fr/html/rwm/profiles/Korea_profile_web.pdf
- https://en.wikipedia.org/wiki/Gyeongju_nuclear_waste_disposal_facility
- http://english.yonhapnews.co.kr/news/2016/07/25/0200000000AEN20160725007300320.html

10. The Netherlands.

There is a single nuclear power plant in the Netherlands (Borssele) that supplies a relatively small percentage of the country's needs; discussion continues about whether to build any new nuclear plants. The Central Organization for Radioactive Waste (COVRA) stores HLW at the Borssele site, including the wastes that are returned from Britain and France after reprocessing. A deep geologic repository is considered to be the only viable option for long-term disposal of HLW, and there are candidate sites in both clay and salt formations. A research program on the feasibility of retrievable disposal was completed in 2001, but no decisions have been taken on a process for finding a specific site.

Websites:

- https://en.wikipedia.org/wiki/Nuclear_energy_in_the_Netherlands
- http://www.nea.fr/html/rwm/profiles/Netherlands_profile_web.pdf
- http://world-nuclear.org/information-library/country-profiles/countries-g-n/netherlands.aspx

11. Russia.

Russia's commercial nuclear power plants date from 1963 and it currently has 31 operating reactors, with plans to expand that number considerably; Russia also exports nuclear power plants and technology to countries such as China, India, and Iran. Like the U. S., Russia (the former Soviet Union) also has varied, extensive, and extremely hazardous radioactive wastes from weapons and military applications.

Until 2008, when a new law on radioactive waste management was presented, Russia had no legislation dealing with these wastes. Article 30 of the bill proposed the creation of one or more deep geologic repositories for HLW and created the "Enterprise for Radioactive Waste Management RosRAO" as the responsible agency. At present, the State Atomic Energy Corporation "ROSATOM" still retains many responsibilities for nuclear wastes, with RosRAO scheduled to assume those roles in 2010. In terms of candidate sites for deep geologic repositories, mention has been made of sites in the Kola Peninsula, the Chita region, and Krasnoyarsk Region, all of them areas in the far north and east (Siberia) of the country, with the Nizhnekansky Rock Massif (Krasnoyarsk Region) appearing to be the first choice.

Websites:

- http://en.wikipedia.org/wiki/Nuclear_power_in_Russia
- https://www.nap.edu/catalog/10667/end-points-for-spent-nuclear-fuel-and-high-level-radioactive-waste-in-russia-and-the-united-states
- https://gsa.confex.com/gsa/2016AM/webprogram/Paper276767.html
- https://www.oecd-nea.org/rwm/profiles/Russian_Federation_report_web.pdf

12. SPAIN.

Spain's nuclear program began in 1968 and its eight nuclear reactors currently supply about 20% of its electricity needs. Radioactive waste management was placed in the hands of ENRESA (Empresa Nacional de Residuos Radiactivos SA) in 1984. A law was passed in 2006 authorizing the construction of a centralized interim storage facility while research efforts to continue on the non-site-specific conceptual designs for a permanent deep geologic repository in a granite, clay, or salt formation.

Websites:

- http://www.world-nuclear.org/info/inf85.html
- http://www.nea.fr/html/rwm/profiles/Spain_profile_web.pdf
- http://www.enresa.es/eng/

13. Sweden.

Sweden has been using nuclear power since 1972 and the ten plants currently in operation account for nearly half of all electricity generation in the country. In 2001 the government approved a process for site selection for the construction of a deep geologic repository.

In early June the Swedish Nuclear Fuel and Waste Management Company (SKB) chose Forsmark, in the municipality of Östhammar, a crystalline bedrock site, as the place for its deep geologic repository, where HLW will be emplaced at a depth of 500 meters. Östhammar is near Sweden's east coast, about 125 km northeast of Stockholm. For SKB this concluded a process lasting about twenty years, during which feasibility studies had been carried out in a total of eight municipalities that had expressed some interest in hosting the facility.

During the last stages of the process, the options had been confined to two candidates from that larger group – Östhammar as well as the Laxemar site in the municipality of Oskarshamn (where one of Sweden's nuclear power plants is located and where an interim storage facility also has been established). SKB explained its final choice of a site as being influenced by the particularly favorable qualities of the rock formation at Forsmark. However, SKB had made a commitment to the two communities that, no matter which one was chosen as the repository site, both would have an important role in the future development of the HLW disposal strategy and that both would benefit from the long-term infrastructure investments made for this purpose.

Websites:

- http://en.wikipedia.org/wiki/Nuclear_power_in_Sweden
- http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx
- http://www.skb.com/skb-swedish-nuclear-fuel-and-waste-management-company/v
- http://www.radioactivity.eu.com/site/pages/Disposals_Projects_Sweden.htm
- http://www.acsept.org/AIWOpdf/AIWO1-04-Wikberg.pdf
- http://www.government.se/49bbd2/contentassets/ecdecd2ee26c498c95aaea073d6bc095/sou-2016_16_eng_webb.pdf

14. Switzerland.

Commercial nuclear power operations begin in Switzerland in 1969 and there are now four nuclear power plants generating about 40% of the nation's electricity, and additional plants are planned. Implementation responsibility for waste management has been devolved to the National Co-operative for the Disposal of Radioactive Waste (NAGRA), a consortium of the reactor operators. The country's Federal Council adopted a "Sectoral Plan for Deep Geological Repositories (Conceptual Part)" in April 2008. The plan sets out a three-stage process for site selection:

1. Identifying suitable sites based on safety and geological criteria;

2. Consultation with citizens in the proposed site areas and their participation in socio-economic studies, leading to a selection by NAGRA of at least two candidate sites for HLW;

3. Further geological characterization of the candidate sites, including drilling of exploratory boreholes, plus discussion of compensation measures with affected communities and specification of long-term monitoring programs.

Websites:

- http://www.nagra.ch/en
- http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/switzerland.aspx

- http://www.bfe.admin.ch/radioaktiveabfaelle/index.html?lang=en
- http://en.wikipedia.org/wiki/Nuclear_power_in_Switzerland

15. THE UNITED KINGDOM.

Great Britain, along with the United States, Russia, and France, is among the earliest users, beginning in 1956, of civilian nuclear power. The country is also one of the pioneers in nuclear fuel reprocessing, both for its own reactors and for used fuel shipped from other countries; reprocessing generates highly radioactive liquid wastes that are then vitrified and allowed to cool for long periods in interim storage.

The U. K. government is committed to developing a deep geological repository for HLW and its Nuclear Decommissioning Authority (NDA) currently is responsible for managing the process of site selection. The Department of Energy and Climate Change (DECC) has recently assumed regulatory oversight authority for radioactive waste. In June 2008 the government published a White Paper entitled "Managing Radioactive Waste Safely: A Framework for Implementing Geological Disposal" and also launched the voluntary process to site a facility. Since the launch two communities in the region of West Cumbria, located in the vicinity of the Sellafield nuclear chemical facility, which is owned by the NDA, have expressed interest in being considered as a host community for the disposal site.

The NDA also issued consultation documents on public and stakeholder engagement as well as on how environmental assessments of proposed sites are to be carried out. Specific suggestions have been made for engaging stakeholders at early stages in the decision process, including steps such as previewing work programs, participating in joint fact-finding programs, and reviewing the results of various work programs. In 2003 the Government had appointed an independent group to review these issues – the Committee on Radioactive Waste Management (CoRWM). This group solicited expert advice, and also carried out an elaborate public and stakeholder engagement process, on a variety of disposal options for HLW, before presenting its recommendation for deep geological disposal in July 2006. The committee remains active in this area, issuing two long reports on geological disposal in July and October 2009 (see below). CoRWM maintains a website with current information as well as an elaborate document archive on its activities to date.

Websites:

- http://www.onr.org.uk/wastemanage.htm
- https://www.gov.uk/government/organisations/committee-on-radioactive-waste-management
- https://www.gov.uk/government/publications/managing-our-radioactive-waste-safely-corwm-doc-700
- https://www.theguardian.com/environment/2015/aug/17/uk-radioactive-waste-disposal-site-search-continues-opposition
- http://www.wired.co.uk/article/inside-sellafield-nuclear-waste-decommissioning

16. The United States.

Commercial nuclear power plants started operating in the United States in 1960, and currently 104 units are producing electricity, accounting for about 20% of the nation's power. Used nuclear fuel (referred to there as commercial spent nuclear fuel) is reprocessed and the resulting liquid wastes are vitrified and placed in temporary storage, awaiting long-term disposal in a deep geologic repository, a plan that was first announced in the *Nuclear Waste Policy Act* of 1982.

The U. S. also has, of course, significant quantities of military and defence-related material, which it calls transuranic waste (see the Wikipedia entry listed below). Beginning in 1999, the Department of Energy (DOE) has been sending a large amount of this material to the Waste Isolation Pilot Plant (WIPP), located near Carlsbad, New Mexico, where it is emplaced in caverns half a mile deep in the Permian Salt Formation in the Chihuahuan Desert. Some of these wastes are sent long distances across the country. For many years DOE has carried out elaborate design, construction, and safety testing strategies for the containers and transportation modes used for shipping hazardous radioactive wastes.

Between 1982 and 1986 DOE screened a number of potential sites for a geologic repository for the commercial spent fuel, first narrowing the list to three; then, following almost 20 years of site characterization work at Yucca Mountain, this site was approved by a joint resolution of the U. S. Congress in 2002. In June 2008 DOE submitted a license application to the Nuclear Regulatory Commission for permission to begin constructing the repository at Yucca Mountain, with a projected start date for repository operations in 2017. However, in March 2009 the U. S. Secretary of Energy, Steven Chu, announced that "Yucca Mountain as a repository is off the table" and that he would set up a panel of experts to recommend alternative sites and strategies for long-term disposal of commercial spent nuclear fuel. In an interview two months later Chu suggested that possibly a salt formation – which is the type of geological structure already used for WIPP and being studied by a number of other countries, such as Germany – could replace the Yucca Mountain site.

Websites:

- http://www.wipp.energy.gov/
- http://www.nrc.gov/waste.html
- http://www.nwtrb.gov/
- http://en.wikipedia.org/wiki/Yucca_Mountain_nuclear_waste_repository
- http://www.technologyreview.com/business/22651/ [interview with Steven Chu, May 2009, on nuclear waste policy]
- http://www.yuccamountain.org/faq.htm
- http://www.yuccamountain.org/pdf/2015-32346.pdf
- https://www.cnbc.com/2017/03/16/the-yucca-mountain-nuclear-waste-dump-a-political-hot-potato-is-back.html
- http://www.vnf.com/webfiles/The%20Current%20Status%20of%20Nuclear%20Waste%20Issues%20-%20New%20Template.pdf

3D: Conclusions.

Military production of nuclear weapons began in 1945 and civilian nuclear power reactors used to generate electricity have been operating for almost sixty years. All of these uses of nuclear energy generate at least some residual wastes that are extremely hazardous due to radioactivity and that must be disposed of safely for very long periods of time. To date the only preferred type of solution for this problem is sequestration of the wastes in a deep underground geologic formation.

However, with the sole exception of the United States (at WIPP in New Mexico), no country has yet completed construction of a suitable facility for this purpose, and most countries utilizing nuclear energy are still some decades away from even starting this project. At the same time, construction of many new nuclear power plants, and active planning for many additional ones, has accelerated around the world in recent years. Thus a great deal more HLW is very likely to be created and stored in temporary holding facilities over the coming decades. The following chart summarizes much of what is known at this time about the state of progress in this area.

Table 3-1:

Status of Nuclear Waste Creation and Disposal at Present

Category	Countries
Nations with HLW and L&ILW:	
Deep repository operating	United States (WIPP, New Mexico) [military waste only]
Site for repository approved	Finland, Sweden
Early stage of public engagement under way for eventual site selection	Canada, Japan, United Kingdom
Technical assessment under way, no site selection process begun and/or completed successfully to date	Belgium, France, Germany, Netherlands, Slovak Republic, Spain, Switzerland, USA (commercial waste)

Commitment to deep repository, technical assessment planned	China, Czech Republic, Hungary, Italy, Mexico, South Korea, Russia
No disposal program under way or limited information available:	
large civilian nuclear operations	India (planned), Ukraine
smaller operations	Argentina, Armenia, Brazil, Bulgaria, Lithuania, Pakistan, Romania, Slovenia, South Africa, Taiwan
Nations with L&ILW only (plus a little HLW from research reactors):	
Disposal planning under way	Australia, Austria, Norway
Others with nuclear programs:	
Status unknown	Iran, North Korea
Nations announcing entry or re-entry into civilian nuclear power in future (proposed or planned):	Albania & Croatia, Bangladesh, Belarus, Egypt, Israel, Italy, Jordan, Kazakhstan, Morocco, Persian Gulf States,

		Poland, Thailand, Turkey, Vietnam

Individual Country Profiles: See section 3C above.

General:

- http://en.wikipedia.org/wiki/Nuclear_power
- http://en.wikipedia.org/wiki/Nuclear_power_by_country
- http://en.wikipedia.org/wiki/Nuclear_energy_policy
- http://en.wikipedia.org/wiki/High-level_radioactive_waste_management
- http://en.wikipedia.org/wiki/Radioactive_waste
- http://en.wikipedia.org/wiki/Deep_geological_repository
- http://www.nea.fr/html/rwm/profiles/
- http://www.radwaste.org/disposal.htm
- http://www-ns.iaea.org/tech-areas/waste-safety/disposable.htm

Chapter 22

Stigma and the Stigmatization of Place

A Paper commissioned by the Canadian Nuclear Safety Commission (2013)

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A SEPARATE PDF FILE OF THIS PAPER IS AVAILABLE ON THE WEBSITE

OF THE CANADIAN ENVIRONMENTAL ASSESSMENT AGENCY AT:

http://www.ceaa.gc.ca/050/documents/p17520/95576E.pdf

THIS DOCUMENT WAS THE SUBJECT OF A PUBLIC HEARING;

FOR THE FULL HEARING TRANSCRIPT TO:

http://www.ceaa.gc.ca/050/documents/p17520/95270E.pdf

ABSTRACT

The concept of stigma, and especially the notion of "stigmatization of place," has a long history in discussions of the siting of hazardous-waste facilities, and notably the siting of repositories for safely sequestering high-level and other forms of nuclear waste. The word "stigma" refers to some kind of mark that could be placed on a person in order to signify shame, disgrace and disapproval. It was originally applied only to *people*, but some later usage has extended it to *places* and *technologies* and sometimes to *products* as well. "Environmental stigma" is thought to become attached to contaminated places or sites, and its connotations include a high perception of risk, inequitable distribution of risk, and consequences flowing from the damage to places that are severe and long-lasting for the local communities that are in close proximity to such places. Part 1 of this paper discusses some of the analysis and conclusions that have been undertaken in many

studies of stigma; it finds that, whereas stigmatizing persons (notably social minorities) is a serious, ongoing issue for public policy, stigmatization applied to technologies, products and even places is a much more ambiguous process, especially over a longer period of time. Part 2 selects a few more recent studies from the academic literature, out of a much larger bibliography, to illustrate the analytical approach to the subject, focusing on perception of risk, community impacts, and consequences, especially property-value losses. Part 3 offers short country case studies of recent developments in Canada, Finland, Germany, Sweden, and the United States; hot-links to excellent websites are provided for further inquiry. Part 4 offers some general conclusions, with the prediction that a siting strategy centered on a willing host community is likely to become the preferred option around the world. Part 5 provides short responses to two questions addressed to me. Part 6 is a comprehensive reference list.

PART 1: THE IDEA OF STIGMA

Overview.

"Stigma" is an ancient Greek word meaning a "mark" placed on a person that would signify shame, disgrace and disapproval by the larger community. It was originally applied only to *people*, but some later usage has extended it to *places* and *technologies* and sometimes to *products* as well. As applied to people it signifies a powerful and indeed dangerous concept and practice, for the simple reason that within human groups the division between insiders and outsiders (and outcasts) is neither trivial nor benign. Properly understanding this form of stigma, including its implications as a public policy issue, remains an important challenge for democratic societies, communities, and their governments.

More recent usage applies the concept of stigma to places in the landscape that have come to be associated with serious and long-lasting damage, and in this context we encounter the idea of *environmental stigma*. Perhaps the best-known examples are hazardous waste disposal facilities of many different types, either as ongoing operations or as sites where operations have ceased but which need expensive remediation. In addition, people can be appalled when products they know well, especially those that are highly prized, such as blood, become tainted and unhealthy. Finally, the concept of stigma has also been applied to technologies that are thought to be problematic or unacceptable to many people; some of these overlap with operating sites, such as nuclear power stations, but others are as diverse as toxic chemicals (like dioxins) or genetically-engineered food crops.

Clearly something or someone that is stigmatized is perceived by some others as representing *potential harm* to those others' well-being, their families (especially children), personal security, livelihood, health, private assets, particularly property values, and other goods. Thus this mental process falls under the general category of what is commonly known as *risk perception,* that is, the belief that some harm might befall one by being exposed to a hazardous agent through some specific means. In general risk perceptions by individuals can have a very rational basis, since all of us face this type of exposure every day – in terms of infectious diseases, toxic chemicals, accidents causing injury and death, lifestyle choices (tobacco and alcohol use, dietary options), cancer-causing agents, and so forth.

Individuals require both abundant and credible information sources in order to understand what is known scientifically about these and other risks, and what impact their own personal choices may have on the level of risk they face and how those risks may be mitigated. But stigmatization seems to be a special category of perceived risk, where the nature of the risk itself seems to be "abnormal" or "unnatural" or "excessive." Thus in such cases some people will react with a similarly excessive response, to the effect that only complete avoidance of what is causing the offense – as opposed to a lessening or mitigation of it – will restore the sense of normality. These themes will be explored more fully in what follows.

My discussion will seek to show that although "stigma" is a very important and useful concept with respect to people – I call this the "strong" version of stigma – it is much less fruitful when it comes to products, places or technologies. This is not to say that many people do not have fundamental and legitimate concerns when it comes to contaminated sites or products or certain types of modern technologies. However, those concerns can be, in my opinion, appropriately addressed within the overall framework for risk-based decision making. This framework is committed to dealing seriously not only with the expert assessment of risk, but also with the risk perceptions of the general public and community groups. In short, as I shall argue, one does not need to add "stigma" to this mix because there is no evidence that doing so helps people to understand the issues before them or to resolve the differences among them over how to proceed where public policy choices have to be made. Therefore, I call this second category the "weak" version of stigma.

There is a sizable academic literature on diverse subjects related to the concept of stigma that will be summarized and discussed in this paper. However, special attention will be paid to the implications of the concept of stigma for the general area of storage and disposal of nuclear waste (both high-level waste and low-and-intermediate-level waste). This paper was commissioned in the context of the environmental assessment now under way for the Deep Geologic Repository (DGR) for Low and Intermediate-Level Waste proposed to be situated at the Bruce Nuclear Site (http://www.ceaa.gc.ca/050/details-eng.cfm?evaluation=17520) within the municipality of Kincardine, Ontario. Here the discussion will be informed by what has been happening at similar sites, some planned, some operating or under construction, in the United States, Canada, Sweden, and Finland.

Stigma: Persons.

As the strong version of this concept, stigma attached to persons is undoubtedly a very old and deeply-rooted phenomenon in human societies, one that persists into our own period:

As used today, the word denotes someone "marked" as deviant, flawed, limited, spoiled, or generally undesirable in the view of some observer. When the stigmatizing characteristic is observed, the person is denigrated or avoided. Prime targets for stigmatization are members of minority groups, the aged, homosexuals, drug addicts, alcoholics, and persons afflicted with physical deformities or mental disabilities. (Slovic et al. [2001], p. 91)

Missing from this list are other important categories such as foreigners, aboriginal peoples, racial, ethnic or religious minorities, or even entire very large racial or ethnic groupings. Stigmatization is a primitive way of arousing and reinforcing social bonds among a dominant majority in a population by calling attention to a minority group for disapproval or persecution. In modern times the paradigm case of this phenomenon is of course Nazi Germany, which not only singled out minority groups (Jews, homosexuals, Roma, the mentally ill) as objects of hatred, persecution and extermination, but also entire so-called races, notably the Slavic peoples. Forcing Jews to wear the "Star of David" on their outer clothing is the most obvious example of "marking." But it would also be uncharitable not to mention, as any visitor today to Berlin and other German cities could not avoid noticing, the huge, permanent public memorial sites which call attention to these atrocities, confronting the evil legacy of stigmatization in the hope that these reminders can help to prevent a recurrence of them.

Within living memory our own country has faced such challenges in a less virulent form. From the once-pervasive anti-Semitism, now mostly gone, to widespread prejudices against gays and lesbians, Muslims, Canadian aboriginal peoples, blacks, and others, Canada has experienced among its dominant majority populations a long series of challenges to the countervailing growth of enlightened public attitudes and values based on tolerance of differences. In my opinion the adoption of the Charter of Rights and Freedoms was a major step forward, in that protection of basic human rights for all persons received the support of law. Social changes of this type sometimes seem to have a "snowballing" effect, accumulating strength as time passes. Thus all evidence indicates that the current generation of younger persons in Canada is the most tolerant, and the most protective of minority rights, in our history. But eternal vigilance is the price of liberty, as the saying goes.

Stigma: Places, Products and Technologies.

Here we shift from "people" as potentially bearers of stigma to the broad category of "places, products and technologies" as possibly being marked by stigma. Such a shift immediately raises questions about whether the concept of stigma can be stretched this far while retaining any of its usefulness as a descriptor of social behavior. What are the essential elements in this shift?

> Stigmatized places, products and technologies tend to share several features. The source of stigma is a hazard with characteristics, such as dread consequences and involuntary exposure, that typically contribute to high perceptions of risk. Its impacts are perceived to be inequitably distributed across groups … or geographical areas…. Often the impacts are unbounded, in the sense that their magnitude or persistence over time is not well known. A critical aspect of stigma is that a standard of what is right and natural has been violated or overturned…. (Gregory, Flynn & Slovic [2001], p.4)

In the following brief discussion, I shall separate *products and technologies* on the one hand from *places* on the other, suggesting that stigma applied to places has some limited explanatory power, whereas this is not the case with products and technologies. To take products first, some prominent examples frequently cited in the literature are the Tylenol episode in 1982 and the "Alar and apples" one from 1989. Tylenol is a case of poisoning of customers through deliberate tampering with the product container, an event that imposed large costs on its maker, Johnson & Johnson. Alar was a pesticide once used on apple crops; as a result of a CBS *60 Minutes* segment, which said that Alar was known to be a carcinogen, apple sales plummeted and apple growers lost significant sums of revenue. So far as technologies are concerned, leading examples are biotechnology (including genetic engineering of animals and plants), nuclear energy, chemicals generally, and, more recently, electromagnetic radiation as a result of widespread use of cellular telephone technologies. (In terms of chemicals, there are separate structures of perceived risk associated with chemical-industry plants, on the one hand, and consumer products incorporated advanced chemistry, on the other.)

All of the instances cited above revolve around strong public perception of risk, in some (but not all) of which such perceptions differ from the risk estimations of experts. But in all cases good explanations can be offered for what the public believes or happened to believe at specific times and places. First, in the case of products, the examples of public avoidance cited (Tylenol and apples), as well as others, are usually event-driven phenomena that last for relatively short periods of time, after which the sales of products rebound. The risks as perceived in the cases of Tylenol or Alar were not irrational or trivial – but they were most certainly temporary or fleeting. One would be hard-pressed today to encounter anyone whose attitudes toward either of those products were influenced by those long-past episodes.

On the other hand, risks associated in the public mind with the technologies mentioned tend to reflect longer-lasting structures of belief, which form and change more slowly. At some level they can appear to be unreasonable, but, I would argue, again, they are not in most cases irrational – in other words, the perceived risks can be explained. For example, biotechnology can seem to reflect a human capacity to manipulate life, which makes some people uneasy. Nuclear energy has strong associations with nuclear war for some. And so far as chemicals are concerned, some explanation can be found in the fact that the most frequent references in media reporting are to toxic chemicals, that is, specific compounds that can have life-threatening properties.

Yet the plain fact of the matter is that, in Canada and all other developed societies, the majority of people live comfortably in close proximity to these and other technologies. Products from the chemical and biotechnological industries are everywhere in the consumer marketplace. For a long time, in three provinces, we have depended on electrical energy from nuclear generating stations; we would see this technology in more of our provinces, I am convinced, if cost-effective alternatives (coal, hydro) were to be less readily available.

To be sure, nuclear energy may be a special case, one where industrial accidents with a very high global profile (Three Mile Island, Chernobyl, and Fukushima) legitimately have made a strong impression on public attitudes. Human error at the plant level, in terms of radical deficiencies in both advance planning and daily operations, played a leading role in all of them, and some of those errors, especially at Chernobyl and Fukushima, are literally inexcusable. It is most decidedly not an irrational response for at least some people to think that such a powerful (if undeniably useful) technology – and the long-lasting hazardous wastes that it generates – is simply too dangerous to be left in human hands. But is *stigma* – that is, as defined above, a belief that these are cases marked by "abnormal" or "unnatural" or "excessive" risk – involved here? Perhaps for some people, of course, and if those individuals do frame their belief about the technology in these terms, it is undeniably their right to do so.

I will return to the subject of stigma and nuclear technology again later on. Here I want to note an important distinction among the list of technologies that have been mentioned. Two of them (chemicals and nuclear) have strong associations with *places*, that is, sites where industrial facilities, including waste-disposal facilities, are located; the other two, biotechnology and cellular telephones, generally do not. So this would be a good point at which to take a first look at the idea of stigmatized places.

Places and Environmental Stigma.

In a way the emphasis on places or sites returns us to where we started, that is, with people. For unlike products or technologies, sites are places where people have an intense, ongoing, daily involvement with their local environment and community, an engagement which may persist over an entire lifetime or even across multiple generations. This is why we must discuss places separately and in greater detail in any consideration of stigma.

> … [A] place is "stigmatized" if the following three conditions are met: (a) a large number of people feel an imperative to avoid the place, (b) this imperative stems from the fact that there is "something wrong" with the place, and (c) the sense of "something wrong" is represented by some sort of mark…. [T]he sense of "something wrong" can stem from many distinct perceptions: dangerous, contaminated, unpleasant, sick, immoral, unnatural, inferior. Environmental contamination and health risks are common sources of stigmatization, but many other sorts of events can stimulate this phenomenon…. Stigmatization also tends to confer negative traits … on the local residents…. Looking within a stigmatized community, it is not uncommon to find residents feeling victimized by forces beyond their control, leading to a pervasive sense of helplessness. (Easterling [2001], pp. 134-5)

The classic case often referred to in academic literature is what happened in the little city of Goiania, Brazil in 1987. Scrap dealers there had broken open a discarded medical device containing radioactive material which gave off a bluish hue and which was then distributed throughout a community as an entertainment. People were sickened and some died; when the news got out, all over Brazil, visits to the city abruptly ceased, residents were denied access to transportation out of Goiania, and the region's agricultural produce was shunned.

Some fifteen years ago, when social science researchers were focusing on "stigmatization of place," a favorite subject was the state of Nevada's determined struggle – including the filing of lawsuits – to prevent the U. S. government from certifying Yucca Mountain as the central repository for permanent disposal of that country's high-level nuclear waste (which includes military as well as civilian waste). The state authorities were convinced that siting the repository some 80 miles from Las Vegas would damage or destroy the state's lucrative tourism industry. Some researchers undertook detailed studies of public values and attitudes, finding (unsurprisingly, in my view, given the "charged" atmosphere of public discussion) that the majority of Nevada residents held strongly negative views about living in proximity to a nuclear waste storage site. Four separate studies on this theme, included in the stigma book edited by Flynn, Slovic & Kunreuther (2001), pp. 87-171, review not just the case of Yucca Mountain but also a nuclear weapons plant at Rocky Flats, near Denver. One of those studies predicted (p. 105) that "the already strong political opposition to the [Yucca Mountain] site can be expected to intensify, making it extremely difficult for the federal government to proceed with the project." That prediction has been perfectly validated in the years that followed; at present, the Obama administration's moratorium on further characterization of the Yucca Mountain proposed site remains in force.

But both those studies, as well as the state of Nevada's determined political and legal opposition, were based on what might be called *anticipated future stigma,* that is*, a risk of the stigmatization of place that might occur sometime later*, if and when the repository was ever constructed at the designated site and no countervailing forces had emerged in the interim.

Since a nuclear waste repository is a subset of the larger category of hazardous-waste disposal facilities, the widespread public opposition to the siting of such facilities, which had emerged in North America in the last part of the twentieth century, certainly provides relevant background for the nuclear case. In Canada such opposition, for example, derailed a major proposal by the Ontario Waste Management Corporation for a new hazardous waste facility to be located in the township of West Lincoln in southwestern Ontario (http://www.oen.ca/dir/detail.php?id=263).

Although these are complex issues, the public reaction did have a solid basis in "rational" thought processes, including the following factors: (1) the intrinsic problem with any such siting, namely, the excess risk faced by a local subset of the general population, whereas the entire population would be the beneficiaries of the facility; (2) a strong resentment of the loss of control by the local community, since in the past such facilities had often been imposed on them by higher authorities; (3) a growing feeling of lack of trust in the promises about the future ("don't worry, everything will be fine") routinely made by politicians and project proponents, who were usually nowhere to be found if and when later problems emerged.

Then, in Canada at least, came the Swan Hills Treatment Centre (www.shtc.ca/) in Swan Hills, Alberta, the only new hazardous-waste facility to be started in North America (to the best of my knowledge) in many decades. Opened in 1987 after 15 years of planning, with the explicit initial support of 80% of the local community, as of now it has been operating successfully for more than a quarter-century. Since then a new trend has emerged, at least in some parts of Western Europe and North America, a trend which seems to be in the process of "changing the game" for hazardous-waste-facility siting. It has an exceedingly simple core concept: namely, "willing host community."

The working model for the concept of willing host community provides, among other things, a specific set of responses to the earlier bases of community dissatisfaction with such facilities, as described just above:

1. Although the presence of any such facility represents some measure of excess risk in comparison with its absence, project proponents have an interest in providing the host community with a great deal of information about the facility risk assessment, as well as means for securing independent, third-party validation of the risk estimates, as a way of making the case that the facility's engineering design and

operating protocols represent an acceptable level of risk for the community.

2. A community's right to withdraw its initial willingness to participate extends well into the first series of steps in the facility planning process, up to the point where a "go/no go" decision is required.

3. Permanent community liaison procedures, including performance oversight, are built into the formal agreements that are drawn up once a decision to proceed has been made.

In Part 3 of this paper I will present briefly the case studies of four ongoing projects for nuclear-waste disposal facilities, all of which incorporate a commitment to the idea of a willing host community for the facility: Olkiluoto in Finland; Oskarshamn and Ȍsthammar in Sweden; WIPP in Carlsbad, New Mexico; and the NWMO process in Canada.

In Part 4, where some conclusions are presented, I raise the possibility of predicting a very different type of ultimate outcome than the one that was made some time ago with respect to the prospects for the Yucca Mountain site. The new prediction is this: The accumulating experience in Europe and North America with major project sitings based on the idea of willing host communities will result in a larger number of candidate communities for each of the future projects of this type. This positive evaluation will be based on a clear understanding that risks can be controlled within acceptable parameters and that strong, long-term benefits accrue to the host community. In other words, for this type of project at least, *stigma* may be replaced with *cachet*, the latter term defined as "an indication of approval carrying prestige."

PART 2: RECENT RESEARCH ON STIGMA, WITH SPECIAL REFERENCE TO STIGMATIZATION OF PLACE

Two recent reports sponsored by the OECD (Organization for Economic Cooperation and Development), of which Canada is a longstanding member, summarize much of what has been learned over the past decade, around the world, about siting radioactive waste facilities in willing host communities. They are relatively short and written in plain English, and are publicly available and can be downloaded from the Internet by anyone.

The first was prepared for OECD by Hank C. Jenkins-Smith, University of Oklahoma, and is entitled "Clarity, conflict and pragmatism: Challenges in defining a 'willing host community'" (21 pages, 2011: http://www.oecd-nea.org/rwm/docs/2012/rwm-r2012-4.pdf). Jenkins provides a first-rate discussion of basic issues, such as how a "community" is defined and how it exercises its rights in the context of a proposed siting decision. He also has a valuable emphasis on the process of decision-making, which can be expected to evolve over quite a long period of time – as, for example, the developments in Finland and Sweden illustrate well – in matters such as siting of nuclear waste repositories. He proposes that

> …[D]ecisions be taken through iterative stages, providing members of the host community (as well as the siting authority) the flexibility to understand and adapt to contextual changes. This stepwise approach is intended to provide sufficient time for development of a competent and fair discourse with members of the host community and other stakeholders. The sequential decision stages also allow for programmatic and design adaptation to new learning over time. Overall the iterative, staged and interactive process is intended to result in a community that is prepared to express an informed, reasoned and competent response.

The second document is *Reflections on siting approaches for radioactive waste facilities: Synthesizing principles based on international learning* (35 pages, 2012: http://www.oecd-nea.org/rwm/docs/2012/rwm-r2012-5.pdf). This document lists a number of fundamental objectives for any good siting process:

- "To increase familiarity and control by potential stakeholders.

- To enhance and maintain trust and confidence among the institutional actors and other stakeholders.
- To establish legitimacy and sustainability of the decision(s).
- To promote "ownership" of the policy and of current and future siting decisions, both now and in the future."

In Part 2 I have sought to summarize the results of relevant studies on stigmatization of place that have been published during the preceding five years, plus a selected few from earlier years; there are many other older studies, listed in Part 5 (References), that are not discussed here, although some other published studies are presented in the case-study discussions in Part 3. The dozen or so studies to be referred to here may be grouped under three headings:

A. Community Dynamics
B. Risk Perceptions and Public Concerns
C. Property and Asset Values / Loss Aversion

<u>A. Community Dynamics.</u>

R. S. Gregory & T. A. Satterfield (2002), "Beyond perception: The experience of risk and stigma in community contexts":

The authors write: "Stigma involves in part the experience of how one is seen by outsiders and the way the signaling of risk events exacerbates the psychological experience of an ecological or technological risk. The media is often a decisive factor in this amplification (signaling) of risks and the construction of stigma effects…. When the mental and physical experience of place undergoes a rapid and negative change, not only the economic welfare of residents but also their sense of self and well-being can suffer." This is an older article but it is very well written and has important methodological advances in the study of stigmatization of place. It focuses on resource-based communities, such as ones dependent on logging, and possible adverse effects related to how outsiders might perceive the community when negative events occur (such as criticism of clear-cutting in logging operations). But the article does not show that there are any lasting consequences to these episodic controversies, which always die down after a certain period of time.

T. Seppàlà (2008), "Does nuclear waste stigmatise a municipality selected for final disposal? Experiences and results six years after site selection in Finland":

The site selection process for a permanent high-level nuclear waste repository in Finland got under way as far back as 1983. In 1999, after detailed site investigations in four locations, Posiva Oy [the organization designated to manage the facility] recommended that the municipality of Eurajoki be selected as the site for final disposal. "One of the arguments for selecting Eurajoki was the willingness of the municipality to host the final repository." Between 1998 and 2006, when two separate surveys were conducted, "there have been positive changes in the image of Eurajoki. The residents of Eurajoki appreciate the development of the municipality and consider it as a good place to live. Consumers and representatives of businesses also see Eurajoki as a more dynamic municipality than eight years ago. The influence of final disposal on the attraction of the municipality is now estimated more favorably than before the decision on the site was made. In comparison with the results of the 1998 study, the residents now considered Eurajoki to be clearly more attractive both to tourists and as a place of residence."

J. B. Chung & H.-K. Kim (2009), "Competition, economic benefits, trust, and risk perception in siting a potentially hazardous facility":

The Korean government has been seeking a site for a permanent nuclear waste disposal facility since the 1980s, against strong opposition from community groups and environmentalists. In 2005, after a series of local referendums, Gyeongju city was selected, because in their referendum residents of Gyeongju had voted 90% in favor of the facility. The authors comment: "This study showed that while risk perceptions had strong negative effects on local acceptance, the most important factor in the model was not risk perceptions but perceived economic benefits. In addition, the factors of competition and trust were also important factors. This result can be interpreted as demonstrating that local residents in Gyeongju city accepted a potentially hazardous facility because of its potential economic benefits and in spite of the risks posed by the facility. In other words, they felt the risk was not severe enough to reject the benefits that the site might yield."

M. R. Greenberg (2009), "NIMBY, CLAMP, and the Location of New Nuclear-Related Facilities: U.S. National and 11 Site-Specific Surveys":

"Public and political opposition have made finding locations for new nuclear power plants, waste management, and nuclear research and development facilities a challenge for the U.S. government and the nuclear industry. U.S. government-owned properties that already have nuclear-related activities and commercial nuclear power generating stations are logical locations. Several studies and utility applications to the Nuclear Regulatory Commission suggest that concentrating locations at major plants (CLAMP) has become an implicit siting policy. We surveyed 2,101 people who lived within 50 miles of 11 existing major nuclear sites and 600 who lived elsewhere in the United States. Thirty-four percent favored CLAMP for new nuclear power plants, 52% for waste management facilities, and 50% for new nuclear laboratories. College educated, relatively affluent male whites were the strongest CLAMP supporters. They disproportionately trusted those responsible for the facilities and were not worried about existing nuclear facilities or other local environmental issues."

C. R. Colocousis (2012), "It Was Tourism Repellent, That's What We Were Spraying": Natural Amenities, Environmental Stigma, and Redevelopment in a Postindustrial Mill Town":

The author writes: "Many rural communities across North America are at a crucial point of transition. Traditional livelihoods in natural resource-based industries have been eroded by a combination of factors involving technological change, global competition, and energy costs. Ideas about redevelopment often hinge on the potential of places to attract tourists or in-migrants…." However, "a complex place stigma, rooted in a history of environmental degradation, presents challenges for economic reinvention and currently constrains the community's options for the future given that tourism is largely viewed as a desirable development strategy there." This is an excellent, in-depth study of a single New Hampshire town that had had a pulp and paper mill for over a hundred years before it closed permanently. The study shows that towns in this and similar circumstances can face severe challenges in terms of trying to re-invent their communities for the future.

Review and Short Commentary:

The Finland and South Korean studies in this group confirm the growing confidence around the world in the willing-host-community approach to siting hazardous waste facilities, certainly in the nuclear area. In the U. S., which has had so much political trouble over its early choice of Yucca Mountain as a preferred site, a long, slow rethinking is under way; the study presented here adds to the strength of the view that communities that are familiar with other aspects of the nuclear industry are likely to provide a welcome audience for proposals for waste facility siting as well. The Gregory and Colocousis papers, on the other hand, deal with resource-based communities where primary industries are in decline, and no other industrial facilities of a newer type are on offer as a replacement; these are cases that present unique challenges of their own.

B. Risk Perceptions and Public Concerns.

H. C. Jenkins-Smith & C. L. Silva (1998), "The role of risk perception and technical information in scientific debates over nuclear waste storage":

Although this paper was published 15 years ago, it is still a valuable contribution, given its substantial, in-depth analysis of one of the key issues in all nuclear waste facility siting developments: namely, the kind of credibility and salience that scientific information, especially risk analysis, has in the mind of the affected public. It also remains relevance because the case-study opinion survey it presents was based in New Mexico and refers to WIPP, which is, of course, still a very relevant facility today in terms of the future of nuclear waste disposal in the U. S. The authors conclude: "Among the more important findings are: (1) members of the public are able to make quite reasonable estimates about what kinds of positions on the risks of nuclear waste disposal will be taken by scientists from differing organizations…; (2) in assessing the credibility of scientific claims, members of the public place great emphasis on the independence of the scientists from those who fund the research; and (3) prior expectations about the positions (or expected biases) of scientists from different organizations substantially affects the ways in which members of the public weigh (and utilize) information that comes from these scientists."

J. Baxter & D. Lee (2004), "Understanding expressed low concern and latent concern near a hazardous waste treatment facility":

Although this is an older study, it is included here because the subject is a Canadian case, namely, the Swan Hills, Alberta facility. "This case study is an example of a community with apparently pervasive low concern. Swan Hills has lived with a hazardous waste treatment facility for over 13 years, and despite two accidents at the site, one leading to considerable PCB contamination and two large health studies, locals seem to agree that the facility represents minimal risk and is not worth worrying about…. Regardless of the level of danger posed by the facility, the study reveals that the low level of concern in the community can survive numerous insults and remain intact. Even in the face of potentially dangerous facility-related events like the 1996 leak, the residents have remained relatively unswervingly, unconcerned. Yet, as long as the community's attention is focused on outsider perceived to be threatening the SHTC and the community, complacency and distrust of negative information about facility hazards will likely remain an issue."

P. Hocke & O. Renn (2009), "Concerned public and the paralysis of decision-making: nuclear waste management policy in Germany":

Germany is one of a number of countries where the inception of a site selection process for a permanent nuclear waste repository goes back many decades (the 1970s in this case) and is still far from being completed. This article, written in 2008, summarizes the state of the controversy until then. In fact, it closely mimics what has happened in the USA, where an early decision was taken for a single site without considering other options (in Germany's case, the salt domes at Gorleben). The authors write: "However, public opposition and maneuvering by the major political actors prevented the completion of the site selection process, resulting in decades of political paralysis. The main reasons for this failure were the polarization in advocates and opponents of nuclear energy, the neglect for due process and participatory procedures, the inability to integrate technical, political, and social rationales in designing a viable nuclear waste policy, and the confusing mix of responsibilities between and among political actors." For an update on the German situation to 2013, see Part 3 below.

B.-M. Drottz-Sjòberg (2010), "Perceptions of nuclear wastes across extreme time perspectives":

This is a unique study in that it is a survey conducted in the two Swedish municipalities that have already been selected for the nuclear waste repository process (see Part 3 below), and also in that it is focused on very long time-horizons. "Citizens of the Oskarshamn and Östhammar municipalities (N=1,501) responded to a postal questionnaire regarding their participation in site-specific investigations for the building of the Swedish repository…. The importance of future generations' life situations was reported as high, and perceived to be of greater importance to oneself than to others. The construction of a safe final repository for spent nuclear fuel ranked the highest on a list of topics when respondents indicated the responsibilities of current generations."

R. Seidl et al. (2013), "Perceived risks and benefits of nuclear waste repositories: Four opinion clusters":

This is the newest of many articles in the literature on citizens' views of nuclear waste repositories. "In general," the authors write, "risk and benefit perception is seen as most essential for the acceptance of contested infrastructure, and affective response to the topic at hand influences both benefit and risk perception…. Furthermore, trust and confidence have been found to provide considerable explanatory power concerning the acceptance of repositories for nuclear waste: the higher both general trust and trust in institutions, the lower the perception of risk, especially of technological risk." This article looked at a neglected segment of the public, namely, those who express ambivalent, rather than strongly positive or negative, attitudes. "We conclude that a closer look at the often neglected but considerable number of people with ambivalent or indifferent opinions is necessary. Although the extreme factions of the public will most probably not change their opinion, we do not yet know how the opinion of the ambivalent and indifferent clusters might develop over time."

Review and Short Summary.

Two of these articles offer valuable insights into the ongoing controversies about nuclear waste disposal in two important countries, the United States and Germany, which have not yet, after many decades of trying, found their way to a robust siting process. A third piece provides additional information about an important case in Canada, namely the Swan Hills Treatment Centre in Alberta, which is one of the first successful cases in the entire world of longstanding support by a willing host community for a hazardous waste facility. The other two, concerning perception of risk about nuclear waste facilities in Sweden and the United States, provide some recent evidence on a theme that has been much studied in the academic literature for a long time.

C. Property and Asset Values / Loss Aversion.

J. J. McCluskey & G. C. Rausser (1999), "Stigmatized asset value: Is it temporary or long-term?":

This article is based on a case study of the impact of the discovery and cleanup operation of a hazardous waste site. The authors write: "Stigma is a loss in property value beyond the cleanup cost of the [environmental] contamination. There are two externality effects that cause stigma. The first is an environmental externality on the properties adjacent to a hazardous waste site: the contamination causes neighboring property owners to be concerned about health issues. The second is a neighborhood externality: the association with a hazardous waste site can affect the composition of residents in the neighborhood and other attributes that determine neighborhood quality and property values." The study finds that long-term stigma resulting in reduced property values is a function of proximity to the site involved, with neighborhoods within about 1 mile being permanently affected.

R. S. Wilson, J. L. Arvai & H. R. Arkes (2008), "My loss is your loss… sometimes: Loss aversion and the effect of motivational biases":

Loss aversion is a social-science term referring to the finding that people are more concerned with monetary losses than with gains (and thus more highly motivated to protect themselves against losses than to achieve gains). This is a technical paper which tries to apply loss-aversion theory to what they call "protected values": "In other words, subjects seem to be insensitive to the type of consequence (i.e., some level of gain or loss) but are sensitive to the fact that a critically important, protected value—such as job security or environmental health—is changing." Their general conclusion is that "those in decision-making authority should work to incorporate the affected parties into the decision-making process in order to better understand both their attitudes and beliefs, as well as to create the transparency necessary for shared values to be identified and trust and confidence to be built both in the individual and in the decision-making process." This reinforces what many other studies in this area have recommended.

J. B. Braden, X. Feng & D. Won (2011), "Waste Sites and Property Values: A Meta-Analysis":

"This paper presents a meta-analysis of the literature on North American waste sites issued between 1971 and 2008 measuring the economic impact of waste sites on real estate values.„, The estimation results … suggest that all classes of waste sites affect real estate prices, but sites classified as hazardous, especially aquatic hazardous sites, are associated with the greatest discounts. The estimated impacts of nonhazardous waste and nuclear sites are not statistically different from one another."

Review and Short Commentary.

These three studies, like all others in the same area of economics research, use complex methodologies that will be difficult for the general reader to grasp. In addition, the conclusions may be challenged; for example, some later studies take issue with the McCluskey and Rausser finding that relates depressed property values to distance from a contaminated site. So far as the Braden et al. paper is concerned, however, this analysis covers a large sample of actual sites and its conclusions appear to be robust. One possible explanation is that, in the past, citizens have encountered contamination problems with hazardous waste sites for the simple reason that many of these sites were very poorly engineered in the first place, making serious problems almost inevitable. Their findings put nuclear sites in a separate category, and the reason may be that much stricter regulations in this area means that these sites are and will be engineered, in countries such as Canada and those in Northern Europe, to a very high level of environmental protection.

PART 3: FIVE COUNTRY CASE STUDIES

Introduction.

In this section there are short summaries of the history and current situation with respect to the siting of permanent high-level nuclear waste facilities in five countries: Canada, Finland, Germany, Sweden, and the United States.

Four are in advanced stages of development, and one (Germany) is just now, as of Summer 2013, getting a fresh start under way, after many years of controversy and lack of progress. The other four are all proceeding in accordance with the idea of a willing host community.

1. CANADA:

Canada achieved a new beginning in its search for a high-level nuclear waste repository in 2002, when federal legislation created the Nuclear Waste Management Organization (NWMO) as an arm's-length body charged with fulfilling this task. After an intensive period of analysis, study reports, receipt of submissions, documentation, and consultation with many stakeholders across the country, NWMO announced its goals, processes and objectives in November 2005 in a document entitled *Choosing a Way Forward* https://www.nwmo.ca/en/Canadas-Plan/Selecting-APM-A-Three-Year-Study. In May 2010 NWMO published its plan for a siting process involving the choice of a willing host community: http://www.nwmo.ca/uploads_managed/MediaFiles/1545_processforselectingasiteforcan.pdf. Here one can find a current update on the NWMO activities, including the initial screening phase, involving a list of municipalities that have agreed to take part in the siting process: http://www.nwmo.ca/sitingprocess_whatsnew. Finally, here one can find the websites set up by the Community Liaison Committees of various municipalities in order to communicate with their residents about the site selection process: http://www.nwmo.ca/sitingprocess_clcwebsites

2. FINLAND:

Finland began its site investigation activities in 1986, and after little initial success restarted the process in 1995 under new legislation and a new organization (Posiva Oy) and mandate using much improved communication and community consultation procedures. In the late 1990s, studies by Posiva Oy explicitly raised the question about possible stigmatization of place in connection with a nuclear waste repository. In 1999, Posiva Oy determined that the Eurajoki site (including Olkiluoto

Island) was likely to represent a willing host community and asked for a "Decision in Principle" from the government on the siting; the municipality ratified this agreement in 2000 and Parliament ratified it in 2001. Construction of an underground site characterization facility began in 2004. Since that time Posiva Oy has continued to sponsor new studies on the community and the facility. Posiva Oy maintains a substantial and effective English-language website on this project, including a remarkably well-produced interactive program: www.posiva.fi/en/

3. Germany:

http://www.dw.de/bundestag-agrees-on-search-for-nuclear-waste-disposal-site-ends-gorleben-debate-for-now/a-16914720, June 28, 2013:
"The Bundestag has agreed to allow a commission of experts to launch a search for a new nuclear waste disposal site. The law ends radioactive transports to the controversial site in Gorleben for the time being. In one of its final decisions before adjourning for summer recess on Friday, Germany's lower house of parliament overwhelmingly agreed to launch a nationwide search for a new, more suitable nuclear waste disposal site. Critics of the current repository in Lower Saxony – Gorleben – have hounded politicians to find a safer location. Under the terms of the measure, the government will commission a group of roughly 30 experts to oversee the search. The panel, comprised of members of parliament, scientists and representatives from various interest groups, must present a list of criteria for the search by 2015. It must convene publicly before approving stipulations for the selection process. A federal office for nuclear waste disposal, slated for opening in 2014, is to oversee the project. German parliamentarians must approve a final repository for nuclear waste by 2031 at the latest."

4. Sweden:

As far back as the 1970s Sweden had made a commitment that siting of any nuclear facilities would be contingent upon local community acceptance. Early geological studies of suitable formations were carried out over the ensuing decades, and in the 1990s the designated organization for the management of nuclear waste, known by the acronym SKB, began inviting communities to express interest in hosting a waste facility. In this process SKB made a major commitment to providing abundant information for public discussion. By 1995 some cities had conducted referendums that resulted in decisive rejection for siting, but at the same time six municipalities had agreed to support feasibility studies for their locations. During the period 2007-2009 the two finalists, Oskarshamn and Ȍsthammar (both of which already hosted nuclear power plants), had concluded formal agreements with SKB. The innovative Swedish solution had divided the responsibilities between them into a central interim storage facility at Oskarshamn and a deep underground permanent disposal facility at Forsmark in Ȍsthammar.

English-language website: http://www.skb.com/

5. The United States:

The Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico, managed by DOE (the U. S. Department of Energy), opened in 1999, twenty years after it was authorized by the U. S. Congress. The location is an extensive underground salt basin in the Chihuahuan Desert; the facility takes transuranic (that is, low-level) radioactive wastes. During the 1990s, DOE had submitted the WIPP application to EPA, which undertook a major program of public outreach and meetings as well as engagement with ENGOs; during this decade, regular public opinion surveys showed a gradually increasing level of local popular support for the facility. Then in 1995, DOE decided to transfer all management responsibility to a local on-site office, which strengthened the support of local residents. A detailed review of the establishment and operation of WIPP can be found in a 2011 paper by J. Holm and available online; on page 7 we read: "In contrast to the Yucca Mountain project, WIPP is widely viewed as the model to follow in order to site and construct a repository. One fundamental difference between WIPP and OCRWM [DOE's Office of Civilian Radioactive Waste Management] was that Carlsbad, New Mexico was a willing host community that had significant political support locally and nationally. The site had been reviewed and analyzed with the help of the state resource agencies and universities. Western states with facilities with waste destined for WIPP could support the facility in principle and that created a different dynamic than that for Yucca Mountain. The western states have few nuclear utilities, but do have most of the defense waste." For a copy of the paper go to: http://cybercemetery.unt.edu/archive/brc/20120620222914/http://brc.gov/sites/default/files/documents/final_paper_stakeholder_involvement_holm_1_may_2011.pdf

Finally, there is a good general website for information on WIPP: http://en.wikipedia.org/wiki/Waste_Isolation_Pilot_Plant

Note: Additional Resource available on the Internet:

The following paper has extensive analysis of the themes stated in its title, including case studies of the process of siting a nuclear waste repository in Canada, Finland, and Sweden: T. Webler, S. Tuler, and E. Rosa, *Options for Developing Public and Stakeholder Engagement for the Storage and Management of Spent Nuclear Fuel (SNF) and High Level Waste (HLW) in the United States*, a paper commissioned by the U. S. Blue Ribbon Commission on America's Nuclear Future, 2011, 139 pages: http://cybercemetery.unt.edu/archive/brc/20120620223108/http://brc.gov/sites/default/files/documents/webler_etal_pse_report16june11.pdf

Part 4: Conclusions

As of the turn of the last century, around the year 2000, the most prominent discussions of stigma generally, and of stigmatization of place in particular, were dominated by the case of Yucca Mountain in the United States. The U. S. federal government's top-down choice of Yucca Mountain as the preferred site for a permanent national nuclear-waste repository had been greeted, in the state of Nevada, with determined opposition. Some of the stigma studies of this controversy (such as Easterling 2001 and Slovic et al. 2001) had documented the strong connection, in public opinion, between nuclear waste and a host of extremely negative word-associations, and dire predictions were made by state authorities about the expected demise of the state's lucrative tourism industry should the repository plan proceed. By 2010 the Yucca site had been taken off the table.

Meanwhile, elsewhere in the world, notably in Finland and Sweden, the early stages of careful planning and social initiatives had been completed, directed by the overriding idea that only finding a willing and competent local host community could hold out the promise of successfully siting a high-level nuclear waste repository. These initiatives were concluded successfully in both countries within the past decade, and some other countries, notably Canada, began following in their footsteps. At the same time, in the United States, a similar effort had paid off for the siting of a low-level waste repository in New Mexico.

This new pattern of development, where the willing host community becomes the centerpiece of strategy of protracted and information-rich engagement with potential willing host communities, which retain the right of opting out during the initial stages of the process, may very well become the "standard model" for nuclear waste repository siting around the world.

PART 5: BRIEF RESPONSES TO QUESTIONS ADDRESSED TO ME

Question 1:

To what extent would stigma have to be treated differently with respect to aboriginal relations?

Response:

I will respond by referring to the submission by the Saugeen Ojibway Nation [SON], because of its extensive discussion of stigma. I find the other parts of this submission, dealing in great detail with the risks associated with this project – in relation to what is called SON interests and to the unique legal and constitutional situation of aboriginal peoples – to be well-articulated, well-argued, and based on solid research on the key issues. These sections deserve to be read carefully and responded to fully and seriously, both by the Panel and by the many other interested parties who have made submissions to these hearings.

But I am not persuaded that the stigma discussion adds anything at all, of a substantive nature, to this risk-based discussion. These are my reasons: The risk-based arguments, as well as the positions about the relation between those arguments and the unique legal and constitutional situation of aboriginal peoples, are what I call "objective" discussions: they turn on evidence, including scientific evidence, on reasoning from that evidence to conclusions, and, in general, on rational processes of thought. On the other hand, as I have suggested in my paper, the idea of stigma applied to places is a purely subjective and speculative discussion: it says, in effect, that something bad *might* happen, although there is no way of telling whether or not it will happen (i.e., what the expected probability or likelihood is), or if it does, just how bad the consequences might be (i.e., trivial or serious, short-lived or long-lived). In short, I believe that the concept of stigma adds nothing at all to the serious and objective considerations which must be part of a project review of this type.

However, there is one other key consideration that ought to be an important part of these ongoing discussions. In the documents relating to the Kincardine Peer Review Report, which evaluated the Socio-Economic Environment Technical Support Document [TSD], I find that the following commitment was made by the project proponent: "OPG is prepared to address and monitor stigma effects." Given the importance attached to the concept of stigma in the SON submission, I feel strongly that SON, as well as other groups which have made interventions at these hearings, should take up this commitment by OPG and make it an important part of the project monitoring program, both in the short and the longer term – and to do so right away.

The reason why this must be done now, or in the near future, is that in order to make the OPG commitment meaningful and useful, one must establish a “stigma baseline” against which future “stigma effects” can be objectively measured. What I mean can be understood from the idea of property-value protection plan (discussed in the TSD, p. 224). Such a plan requires an initial benchmarking, and a method for assessing relative changes in property values, against which future changes can be measured. But this approach can be applied to any type of impact which is thought to be associated with a stigma – for example, prices for agricultural products or revenues from tourism.

So my suggestion is that interested parties immediately approach OPG with a request to discuss and negotiate an operational strategy for monitoring potential stigma effects with respect to the project under discussion. This would involve, among other things:

- Agreement on a set of specific types of impacts that are included in the concept of stigma for this project, including the scope of the geographical region at issue;

- Development of a set of benchmark indicators (i.e., present values, including numerical values) for those types of impacts;

- Development of a methodology for measuring future values for those types of impacts;

- Development of a future response plan by OPG for mitigating the stigma effects, if and when future adverse or negative impacts are detected.

I emphasize again the point that, in order to have any objective value, this operational strategy must be agreed-upon well before the project gets under way; it cannot wait until after either a construction license or an operating license has been granted to the project proponent. In conclusion, this is to my mind the only way in which the stigma discussion can have any useful outcome.

Question 2:

What is the burden of proof to show that a host community is willing?

Response:

What are the appropriate indicators for showing the long-term commitment of a proposed host community for a project such as a repository for nuclear waste? (In this context I recommend a close reading of the paper by Jenkins-Smith, "Clarity, conflict and pragmatism: Challenges in defining a 'willing host community'," cited and discussed at the beginning of Part 2 in my paper.) Of course, the only good answer is that the appropriate indicators will vary according to both the laws and the contemporary political realities of the region and nation in question. Ultimately, any formal agreement between a project proponent and a willing host community must successfully survive two potential challenges: (1) a purely legal battle in the nation's courts; and (2) a protracted "political" battle among interest groups, which if it persists over a long period of time in delaying the project, may cause the proponent to withdraw even if it has won any formal legal contest.

Obviously, any intent to base a project proposal on the cooperation of a willing host community gives the project proponent an enormous incentive to "get it right" when it comes to evaluating the breadth and depth of the community's commitment, both initially and in the long run. One way to create a robust operational strategy for this process is to design at the outset a logical series of stages and types of consent, with later stages based on both an increasing fund of information as well as increasing clarity over the nature and scope of the commitments expected by the proponent from the community. These stages can include financial support to the community, including support for independent studies on project impacts and the "safety case" for the project, and even possibly, at late stages in the process, financial penalties for reversing course after major preliminary investments have been made by the proponent. This means, in effect, that not just the proponent, but the community as well, has large incentives to "get it right" with respect to gauging the mood of the citizenry, ascertaining the type of consent that is necessary, and monitoring closely any changes in those factors.

To the extent that governments are not direct parties to any formal agreements between a project proponent and a community, governments have both a duty and an interest to establish robust frameworks, including legal frameworks, for any such agreements. They must, for example, look at potential impacts in the wider regions surrounding the host community, including transportation corridors, at the integrity of the financial arrangements being made, and at setting up robust long-term monitoring of the agreements for projects with very long time-horizons.

PART 6: REFERENCES

Note: The author wishes to thank Patricia Larkin of Ottawa for valuable assistance in locating and compiling the References.

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Chapter 23:

Maurice Dusseault, Greg Paoli, William Leiss, and Tom Isaacs

"Report of the Independent Expert Group on Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario"

Submitted to *The Joint Review Panel for the Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste (DGR), March 25, 2014*

This is a Public Document

You may obtain a separate PDF file of the Original Report (including Appendices) from The Canadian Environmental Assessment Agency at:

http://www.acee-ceaa.gc.ca/050/documents/p17520/99106E.pdf

Introduction

This report contains four sections and a set of appendices, as follows:

1. An Approach to the Task of Qualitative Risk Comparison
2. Narrative Description of the four Alternative Means
3. Qualitative Risk Comparison of Four Options
4. Results and Observations for the Qualitative Risk Comparison

Appendices:

I. Thematic Requests to the Expert Group from JRP and OPG
II. Concordance Table: JRP Requests and IEG Risk Pathways
III. Contributions to Sustainability (Sustainable Development and Precautionary Approach)
IV. Letter to OPG on the Matter of "Community Acceptance"
V. OPG: Description of Alternative Means
VI. Biographies of Expert Group Members
VII. Short List of Technical Sources

Please Note that the Appendices are not included here, because they contain a large amount of graphics which cannot be easily formatted for an E-book. If you wish to consult them, please access the PDF file and download it on a computer for ease of reading:

http://www.acee-ceaa.gc.ca/050/documents/p17520/99106E.pdf

If you are interested in these materials, I recommend that you access the PDF files and download them at your earliest convenience, since sometimes they become unavailable.

1. An Approach to the Task of Qualitative Risk Comparison

This report deals with the task of comparing a set of alternative management options (or alternative means) in a specific area, namely, the safe management of low- and intermediate-level radioactive waste (hereafter abbreviated as L&ILW) in Ontario. Further, the directives for this task indicate that it should be addressed in terms of the concept known as relative risk. The first step in this type of task is to develop a robust method for carrying out the comparison exercise.

Development of a method must begin with the selection of a set of criteria or parameters in terms of which the alternative management options may be arrayed against each other. These criteria are usually elaborated according to judgments as to how well any group of alternative options will perform against a set of underlying objectives, for example, environmental protection. Ideally, the set of criteria will not exclude any objectives that are regarded as being critically important to the overall performance of any management option, as judged by technical experts, policymakers, and the public. In addition, the various criteria should be independent of each other (that is, not overlap to any significant degree).

Next, comparison requires the specification of a scale of relative performance, either quantitative or qualitative. A quantitative scale uses a range of numbers, such as 0 – 100, to differentiate performance against objectives; a qualitative scale, on the other hand, expresses the same type of judgment along a scale of relatively better and worse. In either case the judgments may be made by a group of experts who have technical knowledge in specific areas (such as geosciences), or professionals with general expertise in the area of risk assessment, or others such as policymakers or members of the public.

Whatever the method that is chosen, it should be capable of being explained and applied in such a way that others, who were not involved in the original exercise, can understand the reasons behind the judgments that were made and also repeat some form of the exercise for themselves. In other words, the method should have the virtues of being *transparent, defensible, and repeatable.* These three virtues also encompass the requirement that the judgements that are made should be *evidence-based*, that is, arrived at with reference to a body of knowledge that is widely known and generally accepted as being reliable at the time when the decision exercise was carried out. The requirements for transparency and repeatability, on the other hand, reflect the legitimate expectation that judgments in such matters as these will have an element of subjectivity to them, and thus that another group of reasonable persons may very well come to different conclusions based on deliberations involving the same body of evidence.

As noted above, the assigned task for this report also included a requirement to undertake a relative risk comparison among four specific management options. Risk is the product of two dimensions, *probability* (or likelihood) and *consequences* (or outcomes). Undertaking a risk comparison requires us to consider both dimensions simultaneously. For example, the group of risks known as "high-probability, low-consequence" includes something like seasonal influenza: We expect it to occur each year without fail, but we also believe that we do not need to make extraordinary efforts to control the outcomes beyond the risk control measures already in place (such as vaccination). At the opposite end of the spectrum, there are "low-probability, high-consequence" risks, such as terrorism attacks: Experience to date indicates that, for a country such as Canada, such events will be rare (in part because of the precautionary measures we have implemented), but if they did indeed occur, they could be expected to have quite significant consequences – in part because our reactions to them include severe psychological shocks.

*   *   *

Section 2 of this report provides the understanding – on the part of the Independent Expert Group (IEG) – of the four management options (or alternative means) for the safe management of low- and intermediate-level radioactive waste. It is based on the following sources: a background study carried out by OPG, which is included in its entirety in Appendix V; technical knowledge contributed by members of the IEG; Internet searches; and on a review of a number of specific documents (see Appendix VII for a list).

Section 3 of this report explains a method of risk comparison which was designed specifically for this present task. It uses a matrix diagram in which relative probability is shown along one axis and relative consequences along the other. For each of the decision criteria or risk pathways, the four management options or alternative means are shown at a specific location on the matrix diagram. Their placement indicates the judgments made about the expected performance of each option, relative to the others, for each criterion. There are two different formats for each matrix diagram: The larger diagram format indicates relative likelihood and consequences using the "Status Quo" Option – the existing WWMF operation at the Bruce nuclear site – as the "base case" for the comparison exercise. (For this purpose, the Status Quo Option is placed at the center of the diagram.) The smaller, inset diagram format places all four options in relation to each other on the two dimensions of likelihood and consequences.

Section 4 of this report contains observations and discussion on the implications of the risk comparison exercise.

2. Narrative Description of the four Alternative Means

2.1 Introduction

In the following discussion, all four alternative waste management options are assumed to be operating indefinitely and to be holding 200,000 m^3 of L&ILW. Of the total, 80% by volume is LLW and 20% is ILW. The "inventory characteristics" of radioactive waste are assumed to be as shown in Figure 1.1 of Appendix V ("OPG: Description of Alternative Options"). For the LLW, the radioactivity will have decayed in 300 years; the ILW, however, contains longer-lived radionuclides and therefore "the options need to provide isolation and containment for a timeframe of at least 100,000 years" (Appendix V, p. 1).

2.2 Two Surface Storage Options

Conceptually, any surface disposal option assumes that (a) a robust societal structure exists indefinitely into the future, (b) an appropriate level of technical control can be maintained indefinitely to manage the surface requirements, and (c) the level of technical control in the future remains capable of coping with the expected events and changes that may take place. For all of the time spent in surface storage, the LLW and ILW will be retrievable and moveable, if required by events or technological changes.

2.2.1 The WWMF "Status Quo" Option

Here we provide a brief account of the existing Western Waste Management Facility at the Bruce nuclear site, with the assumption that it continues indefinitely as it is currently operating. (See Appendix V, Section 2, for a more complete description.) WWMF was established in 1974 and at present contains about 95,000 m^3 of L&ILW, almost half of all the expected wastes of this type that are planned to be held there under this option. The facility as a whole consists of:

- A LLW incinerator and low-force compactor;
- 14 LLW storage buildings (LLSBs);
- In-ground structures for LLW (trenches) and ILW (tile holes, ICs);
- Above-ground structures for ILW (quadricells);
- Steam Generator Storage Building (SGSB);
- Retube Component Storage Building (RCSB);
- Service Buildings.

The LLSBs and SGSB are constructed of pre-fabricated, pre-stressed concrete and have a geo-membrane beneath the structure. ILW materials stored above-ground are all in shielded spaces or containers to prevent radiation leakage. In-ground, covered trenches for LLW are made of reinforced concrete and waterproofed. In-ground structures for ILW consist of steel containers emplaced in concrete structures and separated by till and steel barriers. All facilities are monitored for radiation leakage. Buildings and containers have a 50-year design life, at the end of which they must be replaced. At the end of 300 years LLW could be moved to landfill; ILW, on the other hand, would have to be stored indefinitely (>100,000 years).

2.2.2 An Enhanced and Hardened Surface Storage Option

We are not aware of any definitive characterization of either an "enhanced" or "hardened" set of at-surface facilities that would be utilized for the *storage* (as opposed to *disposal*) of low- and intermediate-level radioactive waste. ["Definitive characterization" is used here to mean facilities that are well-described in published technical bulletins and widely-recognized by interested parties in discussions of radioactive waste management.] In the following paragraphs, we describe our understanding of the distinctions among the types of facilities that are relevant to our consideration of this Option.

(a) Storage vs. Disposal for Surface Facilities handling Low- and Intermediate-Level Waste.

The WWMF operation at the Bruce site is not, as indicated in the discussion of the "Status Quo Option," intended to be a permanent disposal facility. It is in this respect similar to the existing COVRA facility in the Netherlands (Appendix V, Figure 4.1). Facilities designed for interim at-surface storage of L&ILW are constructed and maintained with a view to transferring the waste to some other more permanent facility at some time in the future.

On the other hand, there are certain types of at-surface sites for such waste which are designed specifically for permanent disposal: "Near-surface disposal facilities at ground level: These facilities are on or below the surface where the protective covering is of the order of a few meters thick. Waste containers are placed in constructed vaults and when full the vaults are backfilled. Eventually they will be covered and capped with an impermeable membrane and topsoil. These facilities may incorporate some form of drainage and possibly a gas venting system" [NEA]. The sites themselves have been chosen in part on the basis of hydrogeological and geochemical features that also act as an additional barrier against leaching into the environment.

Examples of such facilities currently in operation are the ones at Centre de l'Aube in France and El Cabril in Spain. However, these facilities only accept LLW and certain types of ILW, specifically, ILW containing short-lived radionuclides with a half-life of 30 years or less. These are referred to with the acronym ILW-SL, as opposed to ILW-LL, and the latter are not thought to be suitable for disposal in the at-surface facilities in France and Spain.

"Below-surface" refers to facilities of a type (such as in Sweden and Finland) that are constructed in shallow underground excavations, at a depth of 50 – 100 meters: "Near-surface disposal facilities in caverns below ground level: Unlike near-surface disposal at ground level where the excavations are conducted from the surface, shallow disposal requires underground excavation of caverns but the facility is at a depth of several tens of meters below the Earth's surface and accessed through a drift [NEA]."

(b) "Hardened" Surface Storage.

An Internet search carried out on 4 March 2014 returned no results for the search phrase "hardened surface storage for low- and intermediate-level radioactive waste," but did return some results for a concept known as "hardened on-site storage (HOSS)." Following is an example of this usage which was presented before the Joint Review Panel (JRP) hearings:

- "Hardened On-Site Storage (HOSS) involves surrounding dry-cask nuclear waste containers in reinforced concrete and steel structures, and further protecting them by mounds of concrete, steel and gravel. Each of these mounds would be spread apart by about 60 to 70 feet—much farther apart than is currently done. This ought to provide a reasonable amount of security from a terrorist attack while keeping the waste on-site to prevent the vulnerability it would have during transport." (An excerpt from a presentation to the JRP by Angela Bischoff, speaking on behalf of the Canadian Voice of Women for Peace. The reference to "dry-cask nuclear waste containers" appears to indicate that it is high-level nuclear waste that is being (http://bluffsadvocate.ca/triptokinkardine.html.) being referred to.

- The Joint Review Panel then asked Ms. Bischoff for further clarification on (http://www.ceaa-acee.gc.ca/050/documents/p17520/94877E.pdf) HOSS. Among the additional statements referenced in that document are the following: (1) "HOSS facilities must not be regarded as a permanent waste solution, and thus should not be constructed deep underground." (2) "Although it is focused on high-level radioactive waste, the wisdom of HOSS can and should be applied to 'low' and 'intermediate' level radioactive wastes as well." And the supplementary information in this document, including the reference to "irradiated fuel," further supports the view that most discussion of HOSS is related to high-level waste (HLW), and is part of a more general argument advocating the retention of HLW at reactor sites, rather than moving them to a DGR in the near term, in order to avoid perceived risks associated with the transport of HLW over long distances.

- In these discussions "hardening" is described as producing a surface-structure configuration that would resist destruction by attacks using fuel-laden aircraft, missiles, and anti-tank weapons.

- The Internet search for Hardened On-Site Storage (HOSS) for Radioactive Waste turned up no other technical details about how such a facility would be constructed.

For the reasons given in the foregoing, we interpret the concept of an Enhanced Surface Storage Option as encompassing a temporary storage facility which is neither a permanent, at-surface disposal facility nor a hardened at-surface "HOSS" facility as described above. Rather, we view it as being a structurally-upgraded version of the existing WWMF, the features of which would be designed to increase the operating life of the buildings and waste containers in which the wastes are stored. Further details are provided in the following section.

(c) Reference Case for "Enhanced" Surface Storage.

In view of the potential range of viewpoints on what qualities an "enhanced and hardened" surface storage option might actually have, we have chosen to focus on a straightforward example of this option. This means an option which exhibits quite specific types of enhancements to an actual, operating surface storage facility (i.e., the WWMF) which will utilize existing technologies. Such varied enhancements include strengthening of both buildings and waste containers and volume reduction for LLW (in order to reduce the number of containers).

The improvements are assumed to be such obvious strategies as "thicker walls, more durable materials, and active control of storage options (e.g. control of humidity). In addition, it may be assumed that the structures are emplaced further apart than is current practice; this could limit the extent of releases from a single accident or malevolent act." A more secure perimeter with restricted access would also be envisaged. (See further Appendix V, Section 4, pp. 10-15.) In *these specific senses* an enhanced surface storage option located at the Bruce nuclear site could be considered to be a "hardened" facility.

In general, the enhanced option would seek to double the operating life of both the buildings and the waste containers, from the >50-year assumed lifespan in the "Status Quo" option to a 100-year life, thereafter replacing all of them during each 100-year period. The LLW (at half the volume after volume reduction) would be transferred to more robust containers, emplaced in more robust buildings, for a total period of 300 years, after which it could be moved to landfill. The ILW would be transferred to more robust in-ground and above-ground storage containers, which would also have to be less frequently extracted and re-emplaced, on a 100-year cycle, continued indefinitely.

2.3 Two Deep Geological Repository (DGR) Options

One of the two options is in the Cobourg Formation at the Bruce nuclear site (see Appendix V, Section 5 for a summary); it is, of course, characterized at much greater length in the technical documents cited in "Section 7: References" in Appendix V. The second option is based on the idea that a DGR for L&ILW could possibly be constructed in an appropriate granite formation somewhere in the Canadian Shield, although no actual site has been selected for this purpose. A short summary of this option, based on experience to date in the characterization of sites in similar geological formations elsewhere, is contained in Appendix V, Section 6.

The following narrative discussion of the two DGR options considers them together, rather than in sequence, in order to facilitate the comparison and contrast between them. It is based in part on the exposition and referenced materials in Appendix V, and also on a more general understanding of the characteristics of these geological formations that may be found in the available scientific and technical literature. Because such formations can have very complex characteristics, which are less familiar to people than are the surface features of land and water in the Bruce Peninsula, we have devoted more space to this discussion.

2.3.1 Deep Geological Repository (DGR): Introduction

Conceptually, any DGR option is based on a long-term passive storage approach that can be demonstrated to present extremely low risks, based on detailed geoscience and engineering analyses. It is assumed that the storage is passive so that no future human intervention will be needed, and that the LLW and ILW placed in the DGR will become inaccessible (within reasonable effort) to society. Therefore, once ultimate closure takes place, there are no longer requirements for active management or for assuming a continued existence of a robust societal structure. In this set of options, there is no requirement for the maintenance of a well-trained technical and professional cadre to oversee the facility in the post-closure phase. However, long-term geological issues now become dominant for the DGR options because other sources of risk (severe weather, malevolent acts, dropping of a container, etc.) have disappeared. For surface storage, on the other hand, the geological issues remain the same, and a number of other sources of risk also stay approximately the same over time because the storage facilities are assumed to be actively operated for the indefinite future.

TIME FRAME CHOICE

A 100-year time frame has been chosen to discriminate between "the short term" (or "pre-closure" for the DGR options) and "the long term" (or "post-closure" for the DGR options) because the DGR closure date is likely to be on the order of 100 years, or somewhat less. Furthermore, any assumption as to the elapsed time at which institutional control might be lost for a surface storage facility is difficult to fully justify (100 years, or 1000 years?). Hence, a 100-year elapsed time has been chosen to discriminate between long-term risk and short-term risk, accepting that this choice also strongly discriminates between the DGR and surface storage options because the closure of a DGR suddenly changes the nature of the risks in many categories.

2.3.2 Comparing the Bruce Site DGR vs. a hypothetical Canadian Shield DGR (Principal Author: Maurice Dusseault)

In weighing comparative risks of a DGR project in the sedimentary rock of the Bruce nuclear site and the risks associated with a DGR project at an unspecified site in the granite of the Canadian Shield, a first-order geological context must be established. The details of such a context for comparison are hard to specify: The Bruce site has been intensively studied, but there has been no similar level of characterization applied to a specific site in the Canadian Shield in Ontario that could conceivably become the DGR site for L&ILW. This is the major reason why we have considered the DGR in granite to be a conceptual option only – a hypothetical Granite DGR.

The IEG was also asked to consider the hypothetical granite site (hereafter called the Granite DGR) to be in many ways similar to the real Bruce site (called the Bruce DGR). For example, the directions indicated that the hypothetical Granite DGR site would have a similar geographical and hydrological disposition to the real Bruce DGR site as it is now understood, being defined as proximal to a (small) wetland area, a stream-and-small-lake region, and a Great Lake (i.e., sited near a large lake). It is also assumed by the IEG that:

- The geometrical dispositions of the Bruce and Granite DGR are the same in terms of depth (about 675 m below ground surface), underground volume, the number of galleries, the number of containers to be placed, and so on.
- The physical design in both cases is similar and appropriate to the mechanical properties of the rock mass, with similar steps being taken to avoid undue damage to the rock during shaft sinking and gallery creation.

- The hoisting equipment and all the other facilities related to the movement and placement of the containers in either of the two DGRs are identical.
- The method of abandonment of the Granite DGR and the Bruce DGR is essentially the same, although perhaps with minor design differences to account for the different rock types (igneous vs. sedimentary) and stratigraphic disposition.
- Other significant characteristics not explicitly mentioned here are similar, except of course the nature of the rock and rock mass in the two sites.

On this basis, it is possible to make some general comparisons between the hypothetical Granite DGR and the well-characterized Bruce DGR.

SOURCES OF RADIONUCLIDES: AQUEOUS AND GAS PHASE TRANSPORT

From a deep geological repository, the source of non-natural radioactive species (radionuclides) is the low-level and intermediate level wastes stored at depth. In order to intersect the biosphere and present a risk to nature and society, the radionuclides must experience transport to the surface. This can happen in one of three ways: solid transport, aqueous transport, and gaseous transport.

Solid Phase Transport: This requires the physical removal of some mass containing radionuclides from the repository level and bringing it to the surface. In turn, this must involve some process such as deliberate re-accessing of the DGR storage galleries through removal of the barriers and physically entering the repository by humans or robotic devices, or accidental drilling into the DGR if social control is lost in the future. There is no reason to differentiate between the Granite DGR and the Bruce DGR in this access aspect – the transport of radionuclides in the solid phase – and therefore solid phase transport will not be addressed further.

Aqueous Phase Transport: This transport mode requires that the radionuclides become incorporated into water in the form of dissolved species or small, colloidal-sized particles that can be carried by the water. Achieving this first requires that water come into the repository level (considered to be a certainty after some time), dissolve or entrain radionuclides into the water, and move toward the surface where the water might exit directly, enter into the local shallow groundwater, or exit under a body of surface water. Up to the point of transport, it is assumed that the Bruce and Granite DGRs will experience the same histories.

However, when it comes to the potential for transport to the surface in the aqueous phase, there are differences between the Granite DGR and the Bruce DGR. All granite bodies in the Canadian Shield are known to be naturally fractured, and the details of the disposition, extent, connectivity, and aperture (opening size) of these fractures are uncertain and no amount of investigation can reduce the uncertainty to zero. The sediments around and above the Bruce DGR have been determined by the site investigation carried out to date to be not only of exceedingly low permeability, but largely unfractured, such that there is no evidence of significant groundwater flow flux through the repository horizon for millions of years. This difference is discussed in greater detail below, and it is the major factor affecting a comparative risk assessment of the two cases (although the risk is expected to be exceedingly low in both cases.

Gaseous Phase Transport: There will be some amount of CO_2 and CH_4 arising from the wastes in the DGR from decomposition of the organic materials in the waste packages, as well as H_2 generated from anaerobic metal corrosion, especially when the wastes become fully contacted by water (considered to be inevitable in the long timeframe). Apparently, the only radionuclide of consequence in the gaseous transport mode is ^{14}C, as other radioactive species are not present in significant amounts in gaseous form because of a short half-life (e.g. radon) or because they are generated extremely small quantities and can only be transported dissolved (or suspended, which is exceedingly unlikely) in an aqueous phase. The same comment as in the previous paragraph applies: up to the point of transport of the gaseous phase, there is no reason to differentiate between the Granite and the Bruce DGRs. Once the point of potential transport is reached, the two cases are different because of the presence of natural fractures in the case of a Granite DGR. This is discussed in more detail below.

General Geological Disposition of the Bruce Site (Figure 1)

The sedimentary and evaporitic strata at the Bruce site include a number of ancient and geologically distinguishable formations made up of carbonates [$CaCO_3$, $CaMg(CO_3)_2$], shales (quartz-illite, sometimes with $CaCO_3$), evaporites (salt and anhydrite), and clastic strata (well-cemented, low-porosity, fine-grained particulate sediments such as fine-grained sand and silt with the grains being dominantly quartz, with some feldspars and other minerals). The sequence of sedimentary strata lie on the NE edge (the platform) of the Michigan Basin, and dip very gently toward the center of the Michigan Basin, which lies roughly west of the site near the center of the Michigan Peninsula that separates Lake Michigan from Lake Huron. To the east of the Bruce site, the oldest strata gradually disappear as the Algonquin Arch granites are found at shallower depth (Figure 1), and some individual formations terminate against the granites of the Algonquin Arch, or have been terminated at their top by erosion that took place over the hundreds of millions of years that these rocks have been uplifted and exposed to weathering and glaciation. The Algonquin Arch developed slowly and episodically as sedimentation took place so that most of the strata become slightly thinner in the up-dip direction to the east.

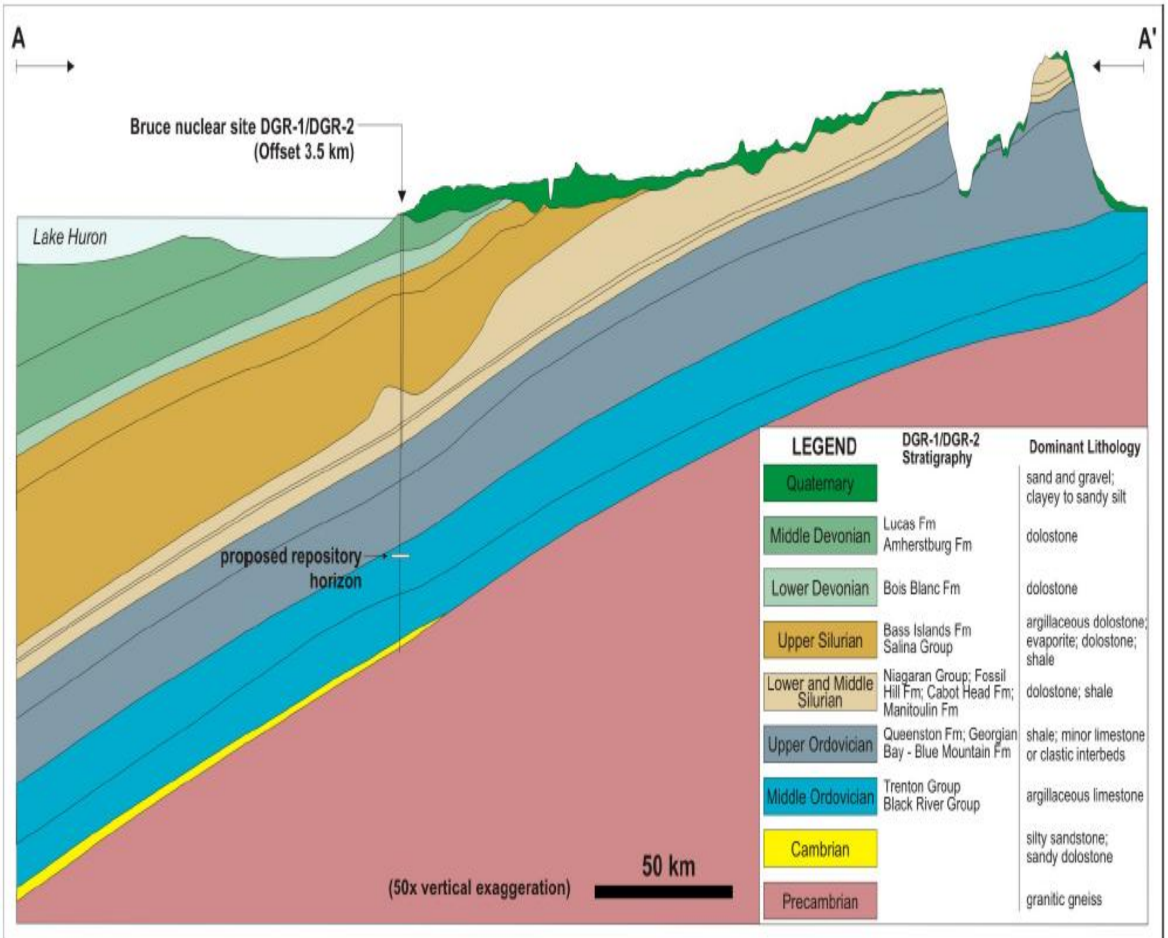


Figure 1: Geological Cross-Section of the Bruce DGR site. Figure 6.2.6-3 from the 2011 OPG Report – Environmental Impact Statement, Vol. 1 (00216-REP-07701-00001 R000). (Vertical distances are greatly exaggerated, dips are actually very low)

The sediments were deposited hundreds of millions of years ago, approximately 400 to 500 million, and are of Cambrian, Ordovician and Silurian geologic age. Slow geological processes involving burial (depths <1 km) coupled with physical and chemical compaction and cementation over hundreds of millions of years have resulted in lithification, leading to rocks that are now strong and stiff. The limestone and dolomitic strata tend to be relatively massive in nature, without a large number of bedding planes, whereas the shales have many bedding plane features disposed parallel to the near-horizontal dip of the bedrock formations.

Because there has been negligible tectonic activity in this part of the Michigan Basin Platform, there is no evidence of folding or faulting of the rocks since the time of deposition. Furthermore, there is no evidence of the existence of substantial extensional or compressional conditions in the past that would have led to the rock mass being subjected to an exceptional stress field in their remote geological history. Other than gentle uplift of the entire Michigan Basin, the slow development of the Algonquin Arch, and the erosion of the sediments that has gone on for the last 300 to 200 million years, not much has happened in the Bruce region. Because of the very slow uplift and erosion that has taken place, the horizontal stresses in the Ordovician-age sedimentary rocks at the depth of the Bruce DGR are likely to be greater than the vertical stresses, but because of the strength of the rocks and the depth of burial, higher horizontal stresses are almost certainly of no consequence to the site stability during or after construction of the DGR.

From a hydrogeological standpoint, the Bruce DGR site at the repository depth has been characterized by the geological and geotechnical studies carried out over the last decade as being stagnant, with the age of the groundwater being in the tens to hundreds of millions of years; essentially, the water at the repository level is not moving. The surrounding sedimentary formations are of low porosity and of exceedingly low rock mass permeability: if any groundwater flow pattern exists, the flow rates appear to be so slow that the velocity of through the strata water transport rates could only be expressed in terms of millimeters per year. Such slow rates are beyond sciences' ability to measure directly; they can be estimated through the study of the geochemistry of the small volumes of pore water in the rock mass (isotopic analysis) and estimation of the rates at which natural tracers dissolved in the water are moving. It appears that instead of bulk flow, mass transport through the sediments at the Bruce DGR site takes place by diffusion, an exceeding slow process in low porosity, low permeability strata.

Furthermore, it appears that there is no regionally interconnected natural fracture network in the Bruce DGR location at the repository depth, even though these sediments are carbonate rocks which are usually naturally fractured. There are geological reasons for this lack of fractures, such as the absence of any tectonic forces. Also, the hundreds of millions of years of compaction and loss of porosity, largely because of the movement of the calcium carbonate ($CaCO_3$), simply destroyed most of the original pores and any open natural fractures that developed. This process is called diagenesis, a form of chemical densification that takes place through the gradual dissolution and re-precipitation of calcium carbonate. In exceptional conditions of rapid flow of fresh water, calcium carbonate can dissolve to generate channels and large openings. In part, because of the lack of sub-aerial exposure and isolation by the overlying shale formation, this phenomenon (karstification) has never taken place in the carbonate rocks of the repository level, nor would it be expected to take place in the future.

Similar comments can be said of the overlying shales, which are comprised of silicate minerals including clays (<50%), but which have sequences that may be rich in precipitated salt or carbonate minerals that can reduce the porosity. Shales, however, tend to be of extremely low permeability in any case because of the tight compaction of the small grains so that the internal channels (pores and pore throats) are exceedingly small, and generally do not permit fluid flow of any kind. Because the shales above the repository level also appear to be generally unfractured, there are few pathways around the Bruce DGR site available for the transport and release of radionuclides.

General Geological Disposition of a Granite Site Repository

The assumed granite repository is in a high-quality unaltered body of relatively isotropic granite such as plutons, at a distance from through-going faults or major lithologically- different bodies of rock that might possess substantially different mechanical or transport properties. Such a site would be deliberately identified and chosen based upon extensive site investigation to lead to the demonstrated existence of a suitable rock mass that has a low density of natural fractures and where the natural flow system in the fractures can be shown to be relatively slow – a region of low topographic elevation differences, no strong recharge and discharge areas indicative of rapid groundwater flux, and so on.

The Granite DGR site would almost certainly be at a location where the granite is clearly exposed at the surface. In other words, the granite would be available for direct geological and geotechnical examination in its natural state so that various factors could be estimated, such as fracture density and spacing at the surface, the heterogeneity, the presence of lithologically different zones or zones that are more intensely fractured. These various characteristics are not the same at the surface as at the depth of the repository; progression of a detailed site investigation program will provide for the collection of more information about the granite site, reducing the uncertainty to levels that can be deemed acceptable for repository advancement (development of shafts, adits and galleries). Because exposed granite is desired, there will be no recent sediments covering the entire site, part of it will be bare rock. Because of the glaciation history of the Canadian Shield, the sediments would be very young (on the order of 10,000 years of age), would fill in all the lower parts of the site (the wetlands and shallow valley bottoms), and would be much coarser-grained and permeable than the surficial sediments at the Bruce DGR site.

However, the most important difference between the Bruce DGR and a hypothetical Granite DGR in the Canadian Shield is that there is a certainty of the existence of natural fractures in the igneous (granite) rock mass, whereas it seems almost certain, based on the site investigations to date, that the strata around and above the Bruce DGR are either unfractured or extremely lightly fractured, with the fractures likely to be closed or of low aperture. Tectonically, any site chosen for the Granite DGR will be completely inactive, with no evidence of folding, faulting or fracturing for the last half a million years. This is a characteristic of the rock and geological histories of the Canadian Shield, which is tectonically one of the quietest and oldest parts of the world's crust, which makes it appealing for a long-term repository for radioactive wastes. In this comparison between the Bruce DGR and a Granite DGR, as stated previously, only consideration of low-level and intermediate-level radioactive solid wastes is taking place.

Rock Strength and Stability of Mine Structures

Both the Bruce and a Granite DGR have exceptionally strong rocks at the repository level. There will be no significant differences between the two cases in terms of rock response. In both cases, the rock mass is extremely compact and strong, capable of supporting all of the loads arising from the excavation and use of the galleries for an indefinite time. The rocks are so strong and the design of the Bruce DGR is so conservative that there will be no instability over the time the repository is actively being used (and for many hundreds of years thereafter).

Assuming a similar design at a similar depth in a Granite DGR, the same may be said: there will be no significant instability over the open life of such a repository. There is no reason to differentiate between the two cases on the basis of rock strength, mechanical properties and the stability of the shaft and the underground structures. In both cases, there is every expectation of great stability during the active life of the DGR. The uppermost part of the Bruce DGR shaft (the shaft collar) will pass through some thickness of unconsolidated glacial sediments, on the order of 10 m, and then through a sequence of shallow rock that to a depth of about 200 m (450-500 m above the repository level) within which there is lateral groundwater flux. In a Granite DGR, the shaft collar would be directly embedded in exposed granite at the surface. This difference is considered to be inconsequential in terms of a comparison of risk between the two cases, as it is difficult to see how such a difference could affect future pathways. It is reasonable to assume that in both cases the shaft seal is equally effective.

Seismic Risk

Both the Bruce and Granite DGR cases may be assumed to be subject to exceedingly low seismic risk over millions of years. This is the case for the following reasons:

- There is no evidence of tectonic activity (faulting, folding, intense fracturing) having taken place for several hundreds of millions of years at the Bruce DGR site (ever since the sediments were deposited), and all potentially suitable Granite DGR sites in the Canadian Shield would also have no evidence of tectonic activity for several hundreds of millions of years in the geological past.

- Both sites are in areas where the level of seismicity measured over the last 60 years by geophysical methods (seismometers) has been determined to be extremely small. Seismic events that have occurred are far below any motion level which could cause damage at the surface, and the events that have been recorded to date are so small that they cannot even be felt at the surface by humans. The probability of a damaging seismic event in the geological future (tens of millions of years) is low.

- Deep tunnels and mines are much less sensitive to damage from seismic ground motion than surface facilities because the most damaging effects of earthquakes arise from the high-intensity surface waves ("ground roll"), which do not develop at depth.

- Given the earthquake history of the region, there is a low probability of any event which could cause significant damage to the surface facilities during the active period of waste container placement into the DGR. Furthermore, any such damage is even less likely to lead to a breach of a low-level or intermediate-level waste container.

- Surface facilities are expected to be operational for no more than 40-50 years after the start of construction.

- There is no rational geologic reason to expect seismic activity of significant magnitude to impact a DGR in the geologic future (millions of years) as there are no active volcanic processes, continental margins, or crustal deformation processes within a thousand kilometers or more.

In both cases, the seismic risks are exceedingly low, and it is not possible to differentiate between the proposed Bruce DGR and any suitable Granite DGR site anywhere within the Canadian Shield in Ontario.

MASS TRANSPORT

Transport through a rock mass can occur through diffusion or advection. Advective transport refers to the carrying of something (dissolved salt, a colloidal particle, gas dissolved into a liquid) in a fluid by bulk flow. If water can flow, it can transport material advectively. If water cannot flow, for example if it is truly stagnant or is very still because it is density stratified, then dissolved species or colloidal particles can still move through the water, but through diffusion processes driven by chemical gradients (differences in chemical compositions and concentrations). In the small pores in the intact rocks at both sites, advective mass transport is unlikely and diffusive solute transport is expected to be exceedingly slow. Gas can carry a radioactive species by advective transport, such as ^{14}C, which could be carried as part of CH_4 or CO_2.

It is reasonable to make the following assumptions for mass transport with respect to low-level and intermediate-level radioactive waste:

- Mass transport by advection through the intact blocks of rocks between natural fractures, either at the Bruce DGR or a Granite DGR, is extremely unlikely, if it can occur at all, because of the small size of pores in these materials and because many of the pores are not interconnected.

- In the absence of advection through the intact rock blocks between natural fractures, mass transport by diffusion must also be extremely slow for the same reason. In fact, if advective flow is not possible, then only diffusion can be considered to be a transport mechanism.

- Colloidal transport in matrix porewater or fracture groundwater is unlikely because of the absence of advective flow conditions and because of various filtration and adsorption processes that impede migration. It can reasonably be assumed not to happen in any realistic time frame at any rate of concern.

- Thus, the mass transport process of concern is the dissolving of radioactive elements and compounds in water and the advective transport (bulk flow) of this water through natural fractures.

- If species dissolved into water come into contact with minerals of high surface area and adsorptive capacities, the concentration will be reduced by adsorption unto the surfaces of the minerals, leading to a slowing of the rate of transport of the dissolved species compared to the bulk flow of the aqueous phase.

- Gas is a buoyant phase compared to water, therefore if a generated gas phase can overcome the capillary entry pressure associated with a vertical or inclined narrow aperture natural fracture, it can rise upward as a bubble or potentially develop a continuous flow path if there is enough gas and the pressure is high enough.

- Gas-phase transport is unlikely to carry significant dissolved salts or colloidal particles, only gases (mixtures of gases), as any likely rates of gas transport would be so slow as not be be able to entrain any colloidal particles or liquid micro-bubbles.

- As gases rise through water-containing pores and fractures, the gases will dissolve into the aqueous phases, thereby attenuating the transport process through the gas phase. For example, if there is ^{14}C in CO_2, and if the CO_2 is under a high enough pressure to enter the natural fractures and move upward through buoyancy-triggered advection, the amount moving will attenuate as the CO_2 dissolves in the water. This water will then be denser than the surrounding water, and will have a reduced tendency to advect and move to the surface more rapidly.

- Once gases are dissolved into water, geochemical processes such as CH_4 bacteriological consumption nearer the surface and CO_2 reaction (as weak carbonic acid) with minerals would severely attenuate flux, preventing and significant escape to the surface.

In a water-wet system, for gas to migrate through the rock mass, it is necessary to displace the water. There is a surface tension between the water and the gas, and this means it becomes increasingly difficult for gas to be forced into the smaller pores. This force that resists flow is called the capillary entry pressure, and it is the reason that it is impossible for gas to migrate through a fine-grained rock or through a natural fracture that is extremely tight (very small aperture or discontinuous aperture). In the

Bruce DGR at depth, the porosity of the rock matrix is very low and there is no evidence for the occurrence of open natural fractures. Hence, even if at some time in the future enough gas is generated so that a free gas phase under some pressure can exist without dissolution into the water (dissolving of the gas in the water), the gas would have to enter a crack or a pore as a free phase. Furthermore, there would have to be continuity of the pores or the cracks sufficient to allow the gas to continue to migrate under its buoyancy forces. The capillary entry pressure can be over 10 MPa for shale and low-porosity limestones, and this is a substantial barrier to gas migration.

In a suitable Granite DGR, the intact rock itself is very low permeability and no substantive flow through intact rock will take place; all of the flow capacity is through the natural fracture system. Because fractures tend to have some continuity and be interconnected in granitic terrain (at least in the shallower portion), it is more likely that if any free gas could be generated at depth and not be adsorbed into the water phases, it could escape from the repository horizon more readily than in the Bruce DGR case and move toward the surface under the buoyant forces. However, given the narrow aperture of cracks at depth expected in a competent granite pluton, the gas entry pressure would be high, on the order of several MPa at least, and flow capacity of the low-aperture natural fractures would be low, therefore the flow rates of any escaping gas would be expected to be low.

Water in the pores and joints in a rock mass usually has a density of between 1.0 g/cm^3 (fresh water) and 1.20 g/cm^3 (saturated NaCl brine). In the region of the Bruce DGR at the repository depth the waters are close to saturated with NaCl, therefore the density is close to 1.2 g/cm^3. Furthermore, in both cases, the Bruce and the Granite DGRs, it can be expected that the water in the pores and the natural fractures increases in density with depth (more saline with depth until the saturated condition is reached) as it has had less and less influence from the meteoric water (surface run-off, rain, snow). This increasing density with depth is a strong stabilizing factor in natural flow systems: the density gradient counteracts the tendency for surface recharge to penetrate deeply into the natural fractures or pore spaces, so that the active groundwater flow regimes fed by precipitation tend to be shallow.

For denser water to flow up from depth through less-dense water, the differential pressures have to be quite large to overcome the density effect. Thus, a density stratified groundwater system means that mixing by advection becomes even slower that it normally would be in a system where the fluid density is the same throughout. The increased water density with depth is the case at both at Bruce DGR and in a Granite DGR; the shallow water is fresh, the deep reservoir at repository level is saline and denser. This density difference is an important phenomenon mitigating upward groundwater flow or contaminant advection.

In either a Granite DGR or the Bruce DGR, groundwater systems exist (although the water at the depth of the Bruce DGR has been deemed to be essentially stagnant). Groundwater flow is activated by the presence of highlands (recharge areas) and low points (e.g. rivers, wetlands or lakes). At the Bruce DGR the highlands to the east comprise the recharge area and are several hundred meters higher in elevation than the site, but quite distant, more than 100 km east on the height of land of the Niagara Escarpment. There are shallow groundwater systems (local hills and streams or wetlands) at all scales, but the deep groundwater system is at the scale of a hundred kilometers. In other words, any deep flow in the system at the depth of the repository would be the result in the difference in head between Lake Huron and the regional height of land along the Escarpment. Furthermore, given the stratification and inclination of the rocks from the height of land to Lake Huron, it would be expected that the large-scale groundwater system (100 km scale at a depth greater than 500 m) would be characterized by near-horizontal flow or slightly inclined flow along the beds if these beds have some permeability anisotropy (higher permeability along bedding).

The greater density of the deep fluids at the Bruce DGR would also strongly act against vertical mixing because the topographic contrasts are modest. In the opinion of the IEG, the presence of departures from hydrostatic pressure conditions that have been measured at the DGR are of little consequence because of the low porosities and permeability. Their persistence over geological time constitutes further proof that the rocks are of such low permeability that flux rates are likely to remain close to zero indefinitely. It is expected that these departures from hydrostatic pressure at depth in the Ordovician age strata will persist in the future but will have no consequence on flow at the repository level.

Similar general conditions without departures from hydrostatic pressures would be expected at the depth of the repository galleries at a Granite DGR. It is likely that there would be a similar regional height of land some distance away (the IEG was asked to consider a Granite DGR as being in a similar hydrological disposition as the Bruce DGR). There remains one substantial hydrological difference between the two sites: the natural fractures at the Granite DGR site would be expected to have a higher overall fluid transmission potential than the dense, low porosity and low permeability sedimentary rocks at the Bruce DGR site.

Flow Path Length

Flow path length refers to the distance an element of gas or water has to travel through the rock before it interacts with the surface or with shallow potable groundwater. The greater the flow path length through the rock, the greater is the potential for the adsorption of radionuclides, for dispersion of the flow, and for long flow times leading to more radioactive decay before interactions.

One obvious potential flow path is the sealed post-closure DGR shaft. However, there is no reason to believe that there would be significant differences in the shaft seal performance between the two options, so that discrimination between the two DGR options based on the postulated long-term integrity of the shaft seal cannot be made.

Another potential pathway would be through the rocks from the repository level to the surface. At the level of the Bruce DGR, there is minimal flow of any kind (stagnant conditions). Nevertheless, suppose that at some remote time in the future fluid escape were to take place; the pathway for the exit of this water and the location of the exit region may be speculated upon. It is not possible to be precise as to the location or the length of the pathway, but given the stratigraphic disposition and the gentle dip of the beds to the west, the presence of slow flow in the upper 100-200 m of sediments, and the topographic high to the east, it is expected that any pathway would be approximately from east to west, many kilometers long (almost certainly more than 10 km), and debouching under Lake Huron.

Alternatively, if any radionuclides are transported vertically through diffusion from the repository depth, once the shallower sediments are encountered (the upper 100-200 m), they will be entrained in the westward-flowing formation water and debouche under Lake Huron. Although this pathway is length could be less than 10 km, the first part of the transport pathway, diffusive transport from the 675 m depth to a depth of 100-200 m will be so slow as to preclude this as a genuine concern for radionuclide escape.

These comments include the possibility that current pressure distributions will continue to become slowly modified as the effect of the past glaciation gradually attenuates. Development of strong upward vertical flow for long periods of time is not feasible in the terrane and sediments of the Bruce DGR. Furthermore, even if slow flow of water or gas containing radionuclides did reach the upper 200 m of the strata at the Bruce DGR, groundwater flux, surface dilution with rainfall and stream flow, and previously mentioned effects such as adsorption and dissolution of the gas into the shallow flowing groundwater, followed by geochemical immobilization or attenuation, would take place.

In a Granite DGR of similar hydrological disposition, it is likely that the flow path length would be shorter because of the presence of natural fractures in the granite rock mass. These fractures would allow for radionuclide transport toward the surface, if release from the repository takes place, to be more rapid than for the Bruce DGR case. The exit point could be into a local body of water, or it could be under the adjacent body of water (a "Great Lake"), but the flow path to the surface could conceivably be on the order of a kilometer to ten kilometers in length. It must be clearly stated that this is unlikely because of other features such as the density gradation of the groundwater in the natural fractures in the granite. Nevertheless, the presence of natural fractures in the hypothetical Granite DGR does point to the possibility of more permeable pathways than at the Bruce DGR because of the vertical nature of these fractures and the absence of horizontal bedding of great homogeneity.

In summary, in terms of flow path length, it is impossible to distinguish substantially between the two DGR options on the basis of flow path length alone. Many more important factors such as potential flux rate (gradients and permeability), transport mechanisms (advection versus diffusion), absorption potential and capillary exclusion are more important discriminators between the two DGR options.

Adsorption, Dissolution and Dilution of Radionuclides

Because of the probable differences in the rock masses between the Bruce DGR and a Granite DGR, the transport capacity for radionuclides is different. The major points are summarized here:

- Many mineral surfaces tend to be surface active, having some amount of unsatisfied surface charges, generally adsorptive of cations. These would absorb, attenuate and disperse any polyvalent dissolved species in the porewater, retarding the rate of radionuclide transport.

- At the hypothetical Granite DGR site, contaminant transport occurs primarily through natural fractures of limited surface area and limited adsorptive capacity. Far less adsorption and less retardation of the flux of radionuclide transport would take place, in comparison to the Bruce DGR site.

- There is a much thinner layer of recent clay-rich sediments in the Granite DGR, compared to the Bruce DGR site where glacial deposits are common and reasonably thick in most places. In fact, this layer will likely be absent or coarse-grained in much of the region around a Granite DGR, thus there is less adsorptive capacity in the granite site.

- There is expected to be no difference between the two cases in the dissolution tendency of the waters that eventually enter the repository galleries. There may be some geochemical differences in the waters because of the different minerals in the two cases; the Bruce DGR waters would be saline and saturated with $CaCO_3$; the Granite DGR site waters would have far less $CaCO_3$, but still be saline. The nature of the saline phase in the groundwater at the two cases will be different, but it is not considered to be an important issue in this comparison.

The solubility of the great majority of the possible radionuclide sources in the waste materials is low. If water is in contact with the waste materials for some time, there will be dissolution into the water until an equilibrium dissolved value is reached. Given that the invading water will be saline, its capacity to dissolve other materials is limited; since the radionuclides in the low-level and intermediate level wastes are not in the form of highly soluble salts, the capacity of the water to dissolve radionuclides is quite limited. This means that any water that has come into contact with the wastes will have only modest to very small amounts of radionuclides (depending on various chemical factors and the presence of organic compounds), and these radionuclides and any organic compounds in the water would be subject to adsorption and retardation (discussed above) as the water moved through the rock mass.

During transit through a porous rock mass or through a system of interconnected natural fractures that are filled with water, dispersion and dilution will also take place. This arises naturally as flow takes place in any heterogeneous porous system, so that the concentration of the dissolved species in water is gradually reduced, especially as the water comes closer to the surface where there is more rapid water flow and more mixing as the result of rainfall and groundwater flux. In both Granite and Bruce site DGR cases, dispersion and dilution will take place in the subsurface (as well as adsorption and retardation of the transport rate of dissolved species) so that any water exiting near the surface under a body of water will already be diluted by large factors.

Because groundwater exit points would be almost certainly under bodies of water, a further dilution will take place. For a comparison, assume that any plausible exiting flux of water that may have come into contact with radionuclides might be as large as 1000 m^3/year (this is considered highly improbable). The average rainfall onto the 60,000 km^2 area of Lake Huron is more than 700-800 mm/yr, or about 42 billion cubic meters per year (not counting river water flowing into the lake). The amount of water already in Lake Huron, which has an average depth of 60 m, is 100 times larger than the annual rainfall on the Lake, over four trillion cubic meters. Hence, the volumes of the bodies of water available for dilution at the surface are either immense (Great Lake) or actively flowing (rainfall >700 mm/yr, active streams and marshlands), so the dilution capacity is significant. The dilution capacity for a Granite DGR and the Bruce DGR are similar, as we were asked to consider a Granite DGR in a similar hydrological disposition. Differences in rainfall and snowfall exist, but these differences regionally are in the ranges of 10-50%, not orders of magnitude.

If a gas phase manages to reach the surface, dilution with the atmospheric flux will take place rapidly. Given any possible rate of gas escape, this dilution would reduce the concentration of the radionuclides (likely mostly ^{14}C) to vanishingly small levels. There are no apparent differences between the two sites in the capacity for dilution of any gases that might escape to the surface.

SUMMARY OF THE DIFFERENCES BETWEEN A GRANITE DGR AND THE BRUCE DGR

At a conceptual level, comparing the Bruce sedimentary rock site with a hypothetical granite site for the disposal of low-level and intermediate level radioactive waste, the following summary points are made:

- The long-term risks of escape of significant amounts or high concentrations of radionuclides at either a properly designed Granite DGR site or the Bruce DGR site are extremely low; in both cases there are many natural barriers and processes that attenuate, retard or dilute dissolved or gaseous species that might be available for transport to the biosphere.

- Granites and other igneous rock masses are naturally fractured, and there is a high probability that a natural fracture system at a Granite DGR in the Canadian Shield has a greater transport potential than the rocks that host and enclose the repository horizon at the Bruce DGR site. A granite site DGR could therefore require more engineered barriers.

- The sediments at the Bruce DGR are homogeneous and thus their properties are quite predictable over substantial distances, and differences in hydraulic properties (permeability and porosity) over these distances (many kilometers) are almost certainly minimal because of the depositional environment and subsequent lack of tectonic deformation in the geological past.

- In a Granite DGR, the distribution of specific natural fractures or fractured zones, their properties and geometry can be complicated, creating challenges for characterization with high degrees of certainty. The lateral predictability of sub-surface conditions over substantial distances (many kilometers) in granites is poor.

- In the case of possible radionuclide escape from a Granite DGR, the transport mechanism to the biosphere is more likely to be advective transport through natural fractures, whereas from the Bruce DGR, the transport mechanism is more likely to be diffusive transport, for at least several hundred meters of any postulated pathway. Given that diffusive transport is likely to be orders of magnitude slower than advective transport under any postulated escape scenario, the Bruce DGR has a much lower probability of release of a significant concentration of radionuclides to the biosphere.

- Compared to sedimentary rock, granitic rocks have an absence of clay minerals and thus, other factors being equal, have a lower adsorptive capacity for dissolved radionuclides being transported in water.

- Compared to a sedimentary site, the gas entry pressures within fractured crystalline rock is expected to be lower, therefore in a Granite

DGR site they would present less of a barrier to gas flow than the extremely low permeability and essentially unfractured rocks above and around the Bruce DGR site.

3. Qualitative Relative Risk Comparison of Four Options

Overview of the Approach

As requested by the JRP, the IEG conducted a qualitative risk assessment. This approach was designed to address a variety of pathways of harm, including those specified in the Information Requests from JRP. Each of these pathways was considered for each of the four disposal options described in Section 2. In addition, where appropriate, the risk posed by each pathway was separately considered for two different timeframes: the first 100 years (labelled "<100y") and an indefinite period into the future following the first 100 years (labelled ">100y").

The pathways of harm are listed in the Table 1 below. They are intended to be inclusive of all of the pathways of harm that were identified within the charge to the IEG provided by the JRP and further identified and clarified in letters between OPG and the JRP. The specific types of harm included and excluded from each pathway as well as other assumptions are described briefly in Table 1, with more detail with the risk assessment results below in this section.

The qualitative risk assessment approach included the following four steps:

1. Review of the JRP charge questions, and detailed assumptions underlying the four alternate disposal options.
2. Characterization of pathways of harm to be considered in the qualitative risk assessment.
3. Qualitative relative and absolute risk assessment for each pathway of harm.
4. Development of summary observations.

This section describes the first three of these steps and provides the results of Step 2 and 3. The summary observations of Step 4 are provided in Section 4.

Step 1: Review of charge and assumptions.

The IEG was briefed by the proponent on the detailed characterization of each disposal option, during three IEG meetings in Toronto. This included the provision of various documents available on the public record, presentations by proponent staff on the options (see Appendix III), and discussions with internal experts made available by OPG. The IEG reviewed the charge questions in detail, and sought clarification on a number of aspects from the proponent, who then sought clarification from the JRP where appropriate.

Step 2: Characterization of Pathways of Harm.

The charge to the IEG contained a diverse set of issues that were to be included in the alternatives assessment. They included consideration of specific sources of damage (e.g., extreme weather), specific mechanisms of exposure (e.g., transport of radionuclides, microbial degradation of containers, gas generation), and specific receptors (e.g., public, workers, receiving waters such as Lake Huron). To accommodate the charge and provide an appropriate structure for the relative risk assessment judgements, the IEG sought to create a set of mutually exclusive and exhaustive pathways of harm. These were then reviewed to ensure that they accommodated all of the relevant sources, exposure pathways and other issues identified in the charge from the JRP.

The list of these identified pathways is provided in Table 1.

Step 3: Qualitative Relative Risk Assessment.

In order to facilitate the process of reaching an expert group consensus on the relative risk associated with each of the disposal options and for each pathway of harm and timeframe, a set of assessment tools were developed prior to a three-day workshop in which the judgements of relative risk were elicited and recorded. The tools consisted of a relative risk visualization tool and a set of tables that were used to reach consensus and record the final determinations. The results of this assessment are provided in Section 3.3 below.

Step 4: Development of Summary Observations.

The charge provided by the JRP is explicit in calling for a relative risk assessment, while also being explicit in that the IEG is not to attempt to reach or express a conclusion on a preferred alternative among the disposal options. In keeping with the charge, the IEG developed a set of summary observations (provided in Section 4) which were deemed to be inevitable conclusions of the pattern of results found in the pathway-by-pathway relative risk assessment. The observations deliberately do not provide an overall relative risk assessment in which the "net" risk posed by each disposal option is derived or even implied. Such an assessment necessarily involves placing a relative weight on the impacts to different population groups and environmental receptors, impacts of widely different severities, and judgements regarding the importance of nearer-term versus very-long-term impacts that would be faced by different generations.

Results of Pathway Identification and Characterization

The results of the identification and characterization of pathways of harm are provided in Table 1. The table further identifies the timeframes over which each pathway was assessed, pointing out the three exceptions to the overall pattern of assessing each pathway over the near-to-medium term (first 100 years) and the very-long-term (an indefinite period beyond 100 years).

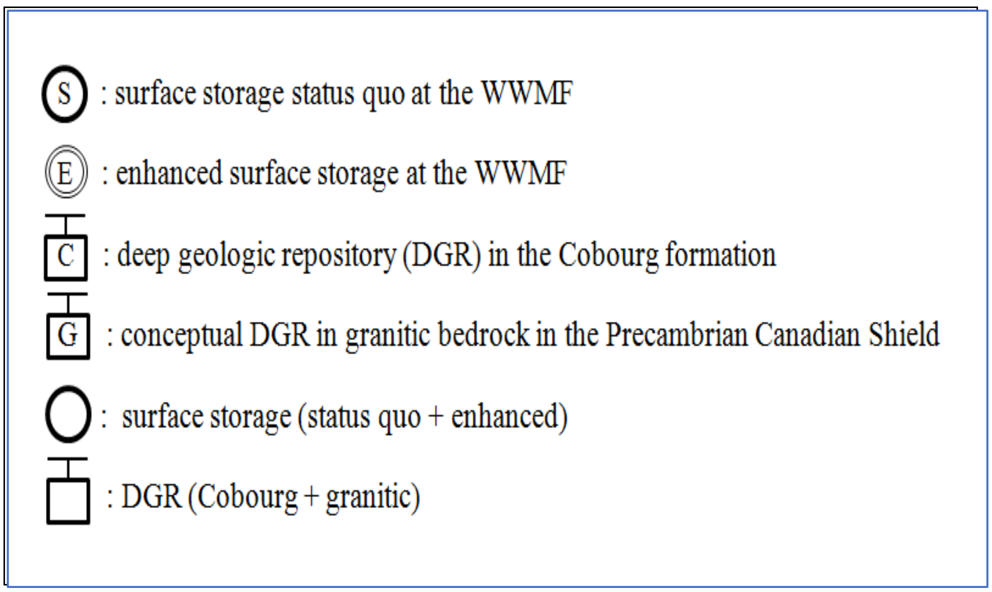
Please Note that Table 1 is not included here, because it cannot be easily formatted for an E-book. If you wish to consult this table, please access the PDF file and download it on a computer for ease of reading:

http://www.acee-ceaa.gc.ca/050/documents/p17520/99106E.pdf

Relative Risk Assessment Method

3.3.1 Visualizing Relative and Absolute Risk

To facilitate the process of reaching a consensus among the expert group on the relative risk associated with the four disposal options for each of the identified pathways, a visualization tool was developed for use during an in-person, three-day meeting (Toronto, Feb. 26-28, 2014). The visualization tool was developed specifically for the concept of a relative risk assessment. In the absolute and relative risk diagrams, the following symbols were used:



For some pathways of harm, there was thought to be no difference in the consequence and likelihood associated with the surface storage options. When the status quo and the enhanced storage provide the same likelihood and consequence, these two options are represented simultaneously by an unlabeled circle. Similarly, when both DGR options provide the same consequence and likelihood, they will be represented together as an unlabeled repository symbol. For simplicity, the Disposal Option labeled *Status Quo Surface Storage* was established as the baseline for comparison.

The relative risk assessment required the judgement as to the relative likelihood (or, relative probability) of damage scenarios, as well as the relative severity of the consequences of the scenario.

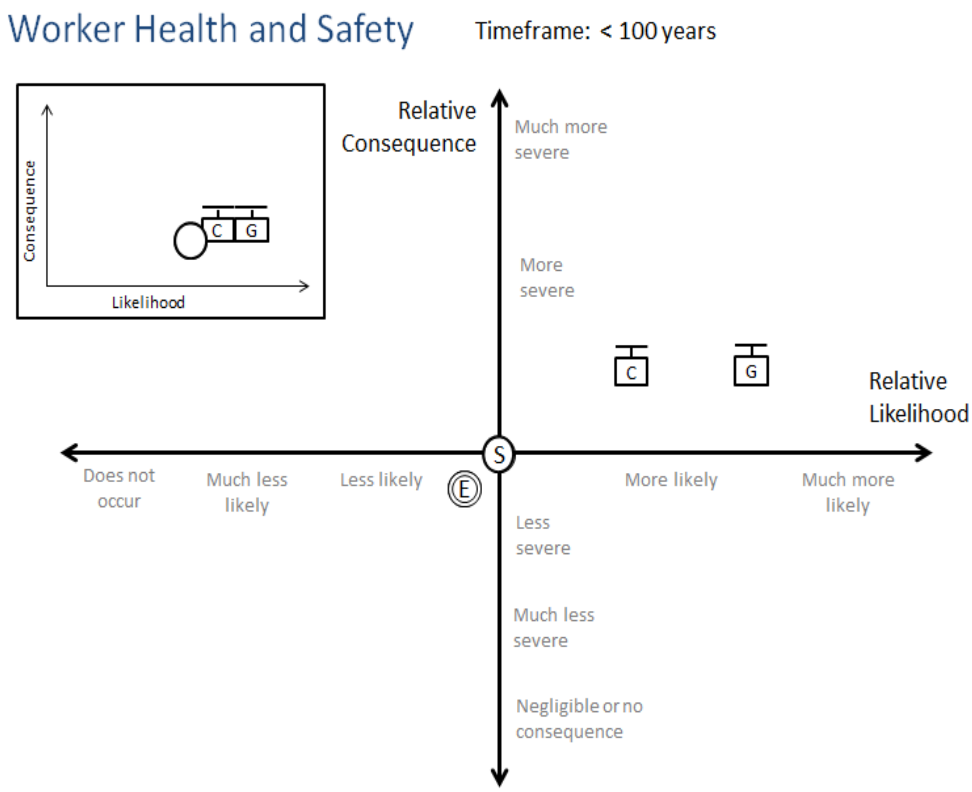


Figure 2: The visualization tool used to judge relative risk associated with the four disposal options, with the example of the Worker Health and Safety pathway of harm. Note: The Status Quo Surface Storage Option was established as the basis of comparison and is therefore always located at the centre of the main diagram. The absolute risk associated with the pathway of harm is characterized in the inset diagram to allow for comparisons of the relative importance of the pathways.

For each of the three other alternate disposal options, judgements were made as to the relative likelihood of harm (along the horizontal dimension), and the relative magnitude or severity of the consequences (along the vertical dimension). The Status Quo Surface Storage Option was established as the basis of comparison (i.e. "more" or "less" in any context is by comparison with the Status Quo Surface Option). This option is always located at the center of the main, relative risk diagram. It should be noted that the scales are considered to be of a logarithmic nature in that the probabilities involved span many orders of magnitude (e.g., from events that occur on the order of years or decades, to extremely rare events such as glaciation events), and the magnitude of consequences were also thought to span many orders of magnitude (e.g., ranging from minor transportation accidents to scenarios involving significant destruction of the disposal structures).

An exception to the "relative" notion of the assessment was provided to allow for the determination that probabilities or consequences are not expected to exist, or are so small as to be negligible. This is represented on the far-left side of the horizontal Likelihood axis as "Does Not Occur." This extreme is represented on the very bottom of the vertical Consequence dimension as "Negligible or No Consequence." An example of the use of this extremely low Consequence characterization is the impact of extreme weather events at the surface for the two Deep Geologic Repository disposal options, for the post-100-year timeframe when they would be expected to be closed and sealed (i.e., "Negligible or No Consequence"). An example of the use of the extremely low Likelihood characterization is for Waste Packaging Handling in the post-100-year timeframe for the DGR options (i.e., "Does Not Occur").

In order to provide important context to the assessment process, in addition to the relative risk characterization, the spectrum of likelihoods and consequences associated with the four disposal options was characterized on an absolute scale. This was conducted separately for each pathway of harm and each of the two timeframes. This was important since the pathways of harm represent such widely varying degrees of probability and consequence that is not evident from the purely relative characterization. This is intended to deliberately avoid any assumption that the pathways of harm should be considered equally important given the great variability among them in terms of the risk that they pose. The absolute risk assessment component is placed on the same diagram, but in an inset box in the upper-left of upper-right as required by the positioning of other symbols.

3.3.2 Interpreting the Relative Risk (RR) and Absolute Risk (AR) Diagrams

The implications of the RR and AR diagrams are best described using an example. Consider Worker Health and Safety as the pathway scenario. Table 1 summarizes the scope of this classification. For this example, interest lies in the timeframe of less than 100 years.

First, consider the main relative risk diagram. Note that the status quo symbol is placed in the middle; the current surface storage facilities at the Bruce site represent the baseline. The remaining three symbols representing the enhanced surface storage, the Cobourg DGR, and the granite DGR, are placed on this diagram relative to the baseline. In comparison to the status quo, any potential harm to workers would occur less frequently during the construction of an enhanced surface storage facility because fewer, stronger storage facilities are built less frequently. Furthermore, wastes are repackaged and moved less frequently. There is a slight reduction in the likelihood and consequences of accidents because there is less construction required. The symbol for enhanced storage is placed slightly leftward of the status quo, because it is slightly less likely, and slightly down from status quo, because the consequences are marginally less severe.

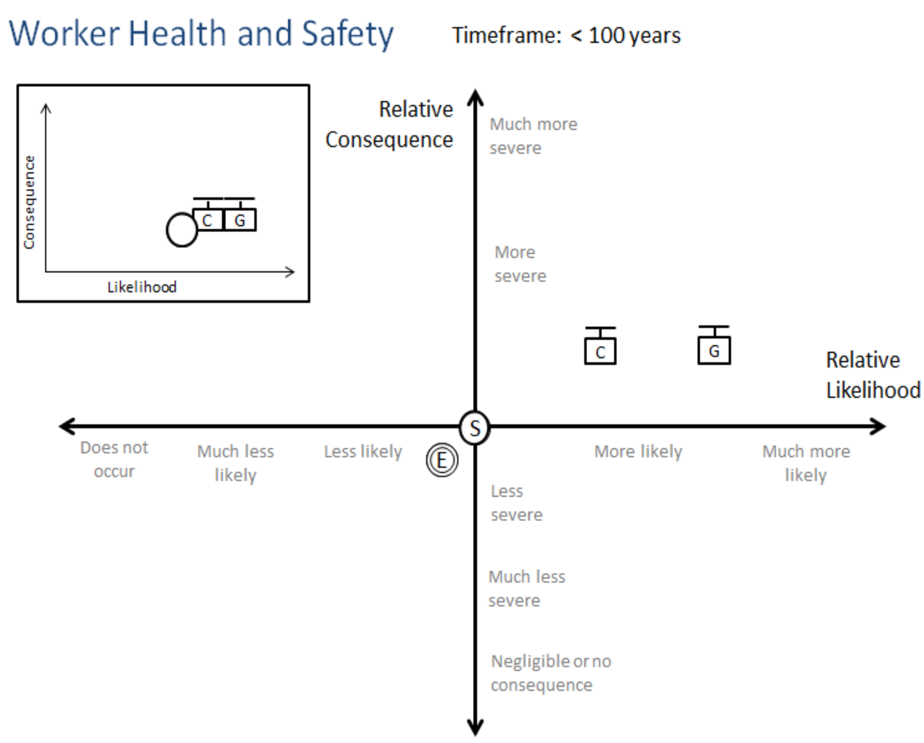


Figure 3: RR and AR diagrams for Worker Health and Safety.

As a second illustration of the method, consider the Bruce site DGR. Relative to the status quo, a potential threat to WH & S is more likely to occur at the Bruce site DGR because of the increased construction required to build mineshafts and infrastructure at the new site. The spectrum of accident consequences given this type of construction would be more severe. The symbol for the Bruce site DGR is placed to the right of the status quo, because a worker-involved accident is considered more likely, and upward from the status quo, because the spectrum of consequences would be more severe. A similar argument applies to the granite DGR site, assuming more construction is required for infrastructure at a new site, increasing the likelihood of a worker-related accident.

The absolute risk diagram in the top left-hand corner represents the absolute risk of each disposal method associated with a worker-related incident. An accident is very likely to occur within the next 100 years at both surface storage options; to reflect this judgement, the symbol is placed at some distance from the origin in the horizontal direction. The consequences of a worker-related accident (from a societal perspective, and compared to all possible consequences contemplated in the overall assessment) are not very severe, which are reflected on the AR diagram as a slight shift from the origin in the vertical direction. The extent and nature of construction required at the DGR sites provides for slightly more serious consequences. In the next 100 years, there is also a very high chance that a worker-related accident will occur.

For two or more different pathway scenarios, the relative risk diagrams may look very similar, however, they may represent two very different levels of actual risk. Consider the relative and absolute risk diagrams of two different pathways, displayed below for illustrative purposes.

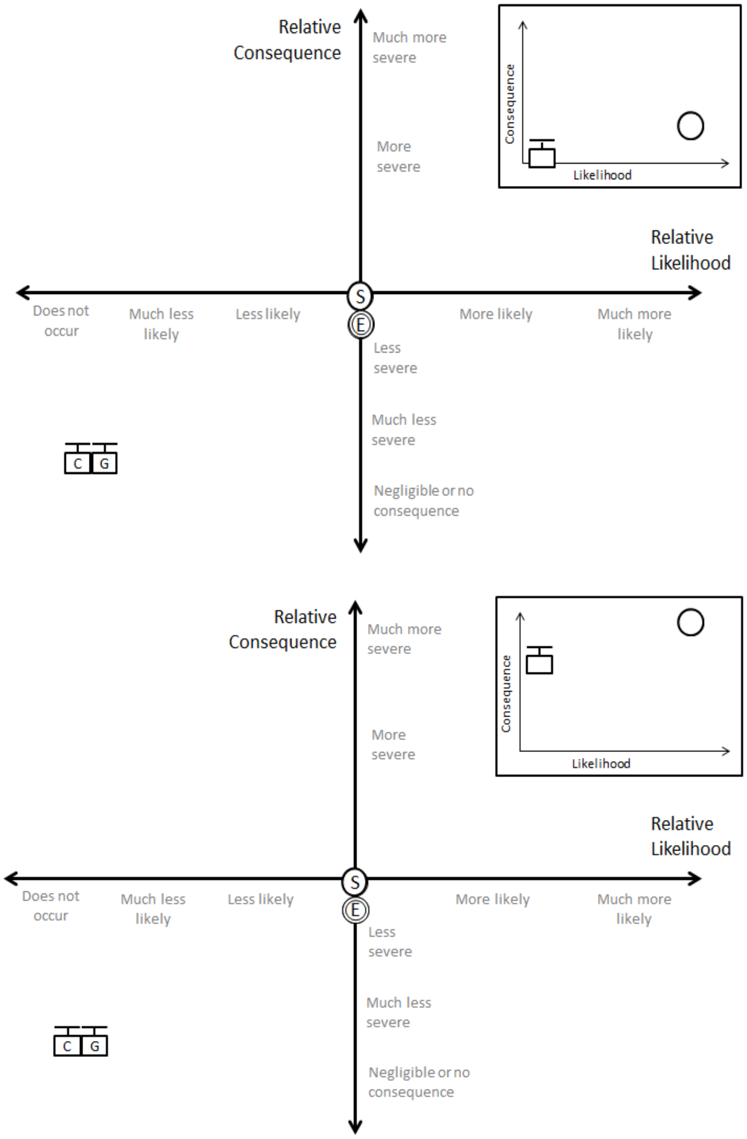


Figure 4: Hypothetical RR and AR diagrams of two different pathways. The consequences for the pathways depicted on the right are much more severe from an absolute risk perspective, though the relative risk patterns are the same.

The relative risk diagrams of these two pathways are identical. However, there is an obvious difference that emerges in the absolute risk (inset) diagrams. The range of consequences for the pathway on the left is quite small relative to the much larger consequences as seen in the absolute risk diagram on the right.

The illustration above demonstrates that the relative risk assessment on a pathway-by-pathway basis is an incomplete characterization of the overall relative risk, without considering the additional concept of the absolute level of either the likelihood or consequences associated with each pathway.

3.3.3 Tabular Component of Relative and Absolute Risk Assessment

The tabular component contains the evidence and reasoning that supports the diagram. All evidence is written comparatively; alternative options are assessed relative to the baseline. The text in this table provides insight pertaining to the placement of the symbols on the diagrams; the explanations address the consequence(s) of the pathway scope. Furthermore, a relative risk assessment is provided in the second row. These risk characterizations can be summarized as follows:

These risk characterizations can be summarized as follows:

Symbol	Explanation
↓↓↓ RISK	Alternative option is associated with much less risk than baseline.
↓↓ RISK	Alternative option is associated with less risk than baseline.
↓ RISK	Alternative option is associated with slightly less risk than baseline.
≈ RISK	Alternative option is associated with same risk as baseline.
↑ RISK	Alternative option is associated with slightly more risk than baseline.
↑↑ RISK	Alternative option is associated with more risk than baseline.
↑↑↑ RISK	Alternative option is associated with much more risk than baseline.

Table 1: The risk characterizations used in the relative risk assessment.

The table below represents the evidence and judgement that accompanies the Worker Health and Safety diagrams presented in Figure 2.

Worker Health and Safety Timeframe <100y			
Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	↑RISK	↑RISK
	Fewer, stronger buildings built less frequently. Wastes repackaged and moved less frequently. Initial elevated risk during volume reduction of LLW.	Significant new construction of surface facilities, mineshaft and underground caverns. Increased on- and off-site transportation. Gas released into confined mine environment increases risk to workers in both DGR cases.	Significant new construction of infrastructure (roads, power lines); additional surface and storage facilities, mineshaft and underground caverns. Increased risk of transportation accidents for workers due to waste transfer to repository.

Figure 5: Table representing Evidence and Reasoning: Example of Worker Health and Safety.

In the case of Worker Health & Safety, the enhanced surface storage option has a very similar range of likelihoods and consequences as the status quo surface storage option. For this reason, the risks associated with the enhanced surface storage option are described to be very similar to those belonging to the status quo. The additional construction required at the Bruce and granite sites provides more opportunity for accidents to occur; in comparison to the status quo, there is a slightly higher chance of a worker-related accident, resulting in a slightly increased (depicted by a single arrow denoting an increase) risk relative to the status quo.

Relative Risk Assessment Results

The tables and images on the following pages present the results of the relative risk assessment approach conducted by the IEG. There are 12 pathways depicted. Following these 12 pages, there are two pages which extract the absolute risk assessment figures, and summarize them for the 12 pathways grouped by the two timeframes. Section 4 provides some general observations of the IEG based on the patterns of results shown here.

Please Note that the full graphics for the 12 pathways are not included here, because they cannot be easily formatted for an E-book. If you wish to consult them please access the PDF file and download it on a computer for ease of reading:

http://www.acee-ceaa.gc.ca/050/documents/p17520/99106E.pdf

Worker Health and Safety

Includes:

- Normal operations and selected accidents
- Construction (buildings, roads, mines) and mining accidents
- Noise, dust, nuisance
- On-site and off-site transportation accidents
- Radiological exposure from normal operations

Excludes:

- Radiological exposures from accidents are assessed in other categories

Timeframe: <100 years

Status Quo S	**Enhanced Surface** E	**DGR Cobourg** C	**DGR Granite** G
BASELINE	≈RISK	↑RISK	↑↑RISK
	Fewer, stronger buildings built less frequently. Wastes repackaged and moved less frequently. Initial elevated risk during volume reduction of LLW.	Significant new construction of surface facilities, mineshaft and underground caverns. Increased on- and off-site transportation. Gas released into confined mine environment increases risk to workers in both DGR cases.	Significant new construction of infrastructure (roads, power lines); additional surface and storage facilities, mineshaft and underground caverns. Increased risk of conventional transportation accidents for workers due to waste transfer to repository.

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Building construction and repackaging every 50 years. Industrial accidents occur at the normal rate in perpetuity.	Fewer, stronger buildings built less frequently. Wastes repackaged and moved less frequently. Industrial accidents occur at the normal rate in perpetuity.	DGR closed and sealed. No workers present.	DGR closed and sealed. No workers present.

Public Health and Safety

Includes:

- Transportation on municipal roads and highways
- Noise, dust, and nuisance off-site
- Construction, operation, decommissioning, and post-closure phases

Excludes:

- Radiological exposures from normal operations and accidents

Timeframe: <100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	↑RISK	↑↑RISK
	Less frequent construction activity. Slightly elevated releases of radionuclides, within regulatory limits, during LLW volume reduction.	Significant new construction activity means more road traffic. Noise, dust, and nuisance effects associated with new mine.	Significant new construction of infrastructure, significant additional transportation requirements increases road traffic and accidents. Noise, dust, and nuisance effects associated with new mine.

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Building construction and repackaging every 50 years. Public risk associated with proximity to industrial activity and transportation occurs at the normal rate in perpetuity.	Fewer, stronger buildings built less frequently. Public risk associated with proximity to industrial activity and transportation occurs at the normal rate in perpetuity.	DGR closed and sealed. No further activity at surface.	DGR closed and sealed. No further activity at surface.

Transport of Released Radionuclides – Advective Water Flow

Includes:

- Radionuclide and other contaminants (e.g. metals) transport in the aqueous phase through existing fractures or porous media at depth or near the surface
- Dissolved gases such as carbon dioxide

Excludes:

- Free gas advection and atmospheric emissions are covered elsewhere

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
	The same shallow sediments as the status quo. Slightly lower risk than status quo because of enhanced containment.	DGR is closed; no human consequences at depth. Adsorption, dilution and very slow flow rates reduce transport rates to the surface of any dissolved radionuclides or contaminants (e.g. metals) to extremely low values. Any species reaching a large water body, such as Lake Huron, will be subject to substantial further dilution, reducing the potential dose to any receptor.	Similar to Cobourg, except in a Shield repository, there is a somewhat greater potential for transport to the surface than in the Cobourg repository because of the presence of fractures.

Transport of Released Radionuclides – Advective Gas Flow

Includes:

- Radionuclide transport in the gaseous phase through existing fractures or porous media
- Gas generation from waste off-gassing and degradation products
- Direct emissions to the atmosphere from surface facilities

Excludes:

- Gas transportation in aqueous dissolved phase
- Worker exposures underground

Timeframe: < 100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	≈RISK	≈RISK
Slow off-gassing generated from waste packages at the surface. Massive atmospheric dilution significantly limits any adverse consequences in the near-field and far-field (including Lake Huron).	Similar to the status quo.	Similar to the status quo while packages remain at the surface. Once underground, gas is generated, but adsorption, dissolution, and dilution of gases reduce adverse consequences at the surface to extremely low values. Further dilution in a very large water body such as Lake Huron further reduces the potential dose to any receptor.	Similar to the status quo while packages remain at the surface. Once underground, gas is generated, but adsorption, dissolution, and dilution of gases reduce adverse consequences at the surface to extremely low values. Further dilution in a very large water body such as a Great Lake further reduces the potential dose to any receptor.

Timeframe: > 100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
Continuous low-level off-gassing. Massive atmospheric dilution significantly limits any adverse consequences in the near-field and far-field (including Lake Huron).	Same as baseline.	DGR is closed; no human consequences at depth. Adsorption, dissolution, and dilution of waste generated gases reduce adverse consequences at the surface to extremely low values. Any gases reaching a large water body, such as Lake Huron, will be subject to massive further dilution, reducing the potential dose to any receptor.	DGR is closed; no human consequences at depth. Adsorption, dissolution, and dilution of waste generated gases reduce adverse consequences at the surface to extremely low values. Any gases reaching a large water body, such as a Great Lake, will be subject to massive further dilution, reducing the potential dose to any receptor.

Seismic Impairment

Includes:

- Any seismic event that is sufficiently large to lead to structural damage of buildings or underground shafts and tunnels
- Major geological fracturing associated with any form of seismicity

Excludes

- Long term tectonic processes

Timeframe: < 100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↓↓RISK	↓↓RISK
In both the Bruce and Canadian Shield regions, seismic risks are inherently low.	Enhanced surface containment is more resistant to surface waves.	Underground structures are extremely resistant to body waves, there are no surface waves at depth.	Underground structures are extremely resistant to body waves, there are no surface waves at depth.

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Given a sufficiently long time frame, the probability of a given seismic event becomes high.	Enhanced surface containment is more resistant to surface waves.	Underground structures are extremely resistant to body waves, there are no surface waves at depth. Once repository is closed, the seismic event will not impair its performance as a disposal facility.	Underground structures are extremely resistant to body waves, there are no surface waves at depth. Once repository is closed, the seismic event will not impair its performance as a disposal facility.

Structural and Mechanical Impairments

Includes:

- Buildings, equipment, impacts on building services, e.g. power loss, ventilation and pumping equipment failure, fire, flooding, rock fall
- Mechanical failures (e.g. hoist way)
- Equipment malfunctions

Excludes:

- Seismic induced failures, severe weather, and glaciation
- Failures of packaging

Timeframe: <100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↑RISK	↑RISK
Least robust structures.	More robust structures and packaging with longer operating life. Fewer handling events which reduces risks associated with structural and equipment failures. Volume reduction makes waste form less combustible.	More complicated mechanical systems and additional structures with greater probability of breaching a package during handling.	More complicated mechanical systems and additional structures with greater probability of breaching a package during handling.

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Re-packaging and movement to new buildings every 50 years. Cumulative probability over time of incidents approaches certainty.	More robust structures and packages reducing likelihood and consequences. Incidents less frequent, although cumulative probability over time still approaches certainty.	DGR closed and sealed; structural and mechanical integrity are no longer required. Some degradation of the structural and mechanical properties of the repository is expected but is inconsequential.	DGR closed and sealed; structural and mechanical integrity are no longer required. Some degradation of the structural and mechanical properties of the repository is expected but is inconsequential.

Waste Container Integrity

Includes:

- Storage and permanent disposal
- Seepage, release rates, microbial activity
- Package handling and breach

Excludes:

- Waste processing, structural and mechanical integrity of buildings and mine works
- Transportation accidents

Timeframe: <100 years

Status Quo Ⓢ	**Enhanced Surface** Ⓔ	**DGR Cobourg** C	**DGR Granite** G
BASELINE	≈RISK	↑RISK	↑RISK
All packages handled at least once for transfer from WWMF to new building. Packages monitored for integrity and replaced as needed.	More LLW handling due to volume reduction. Less risk later during the 100 years as wastes are transferred into more robust containers. Packages monitored for integrity and replaced as needed.	Packages handled as per status quo but more handling in order to move waste packages underground. More restricted space underground. Packages once underground are isolated and no longer monitored.	Packages handled as per status quo but more handling in order to move waste packages underground. More restricted space underground. Packages once underground are isolated and no longer monitored.

Timeframe: >100 years

Status Quo Ⓢ	**Enhanced Surface** Ⓔ	**DGR Cobourg** C	**DGR Granite** G
BASELINE	↓RISK	↓↓↓RISK	↓↓↓RISK
Re-packaging and movement to new buildings every 50 years. Cumulative probability over time of package handling incidents approaches certainty. Packages monitored for integrity and replaced as needed.	Somewhat less frequent re-packaging (e.g. every 100 years), although probability over time still approaches certainty. Less risk as wastes are in more robust containers. Packages monitored for integrity and replaced as needed.	DGR closed and sealed; packages no longer require integrity. Package degradation is certain but inconsequential.	DGR closed and sealed; packages no longer require integrity. Package degradation is certain but inconsequential.

Radiological Exposure During Transportation Accidents

Assumes:

- Additional waste t (200-2000 km) to granite repository WWMF
- No transport after 100 years
- Identical packaging technology in all transportation scenarios

Includes:

- Transfers from reactors to WWMF for all options
- Accidents

Excludes:

- Intra-site transfers covered under normal operations in WH&S
- Public risk due to physical harm due to transportation accident
- Malevolent acts

Timeframe: < 100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	≈RISK	↑↑RISK
Includes transport from reactors to WWMF. Experience to date demonstrates a well-performing transportation system. Radiological exposures for the majority of accident scenarios are very limited .	Same as baseline.	Same as baseline.	Requires additional transportation (200-2000 km) from WWMF to a distant repository site, increasing frequency of traffic accidents. Waste would be transported in certified packages, limiting extent of consequences.

Severe Weather

Includes:

- Extreme wind and hurricane
- Tornado
- Extreme precipitation
- Flooding and surface erosion
- Climate change

Timeframe: < 100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↓RISK	↓RISK
	Higher degree of structural protection lowers consequence for each severe weather event, probability of events remains the same	In first 100 years, DGR is being built and commissioned, followed by a gradual transition of the stored waste to the underground repository. Waste remaining at the surface will be vulnerable at the same level as the baseline; wastes that are moved underground will be unaffected , probability of events remains the same	Same as DGR Cobourg with the addition that there is a transportation program underway in which some waste may be in transit plus an additional temporary surface storage facility on-site.

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈ RISK	↓↓↓RISK	↓↓↓RISK
	For surface storage in perpetuity, major events are inevitable. The enhanced structural quality in this scenario may marginally reduce the consequences.	No event impacts after closure and sealing.	No event impacts after closure and sealing.

Glaciation

Assumes:

- The possible future re-occurrence of continental glaciation leading to the creation and movement of a thick ice sheet across the site
- Glaciation cycle is uncertain; assumes next glaciation in the timeframe of 10,000 – 100,000 years
- Cannot assume institutional control

Excludes:

- Any short-term possibilities (less than 100 years)

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
	Equivalent to status quo.	DGR is closed and sealed; repository is unaffected.	DGR is closed and sealed; repository is unaffected.

Malevolent Acts

Includes:

- All intentional acts regardless of motivation
- Theft, mischief, politically motivated acts
- Assumes presence of institutional controls in perpetuity

Excludes:

- Accidental intrusion

Timeframe: <100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	↓RISK	↓RISK	≈RISK
	Slight reduction in probability and consequences due to stronger structures.	Gradual reduction in likelihood and consequences as waste is moved underground.	Increased likelihood due to increased exposure to malevolent acts during transportation and an additional site. Gradual reduction in likelihood and consequences as waste is moved underground.

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
	Slight reduction in probability and consequences due to stronger structures.	DGR is closed; probability and consequences are negligible.	DGR is closed; probability and consequences are negligible.

Loss of Institutional Control

Assumes:

- Only relevant after 100 years
- Very high probability of occurrence at least once after 100 years and up to 100,000 years
- No changes in surface storage options over that same timeframe

Includes:

All pathways of harm (natural, operational, accidental, malevolent) that rely on continuous presence of institutional control

Timeframe: >100 years

Status Quo (S)	Enhanced Surface (E)	DGR Cobourg (C)	DGR Granite (G)
BASELINE	≈RISK	↓↓↓RISK	↓↓↓RISK
	Over the long term with loss of institutional control the surface options are essentially identical.	DGR is closed; very low probability of accidental intrusion remains, with limited consequences due to the volume of material that would be involved.	DGR is closed; extremely low probability of accidental intrusion remains, with limited consequences due to the volume of material that would be involved.

4 RESULTS AND OBSERVATIONS FOR THE QUALITATIVE RISK COMPARISON

The JRP has asked that four options be compared: the status quo of surface storage maintained into the indefinite future; an enhanced surface storage program then maintained into the indefinite future; geologic disposal in the sedimentary Cobourg Formation at the Bruce site as currently proposed; and disposal into a conceptual geologic formation in the granitic Canadian Shield.

The IEG identified the important features for comparing the options, assuring that all the elements in the JRP assignment were part of the assessment. The team identified twelve key features for comparison and evaluated each of them for the near term (<100 years) and long term (>100 years). In a few cases, only one of the time periods made sense (e.g., a comparison of the impacts of glaciation only makes sense for the long term). In each case, the IEG assessed two aspects for each element in the comparisons: (1) How did the four options compare to one another in expected performance? (2) How important was the feature in achieving the overall performance objectives of the waste management program as illustrated in the absolute risk charts in Section 3?

This careful evaluation is particularly necessary since the diagrams are populated on a log-log scale to be able to capture differences that may be one or more orders of magnitude. As an example, a feature that scores very high in likelihood or consequence or both may be a factor of 100 or 1000 or more different than one that scores low.

While there are a number of important factors in comparing these options, there are two fundamental issues among the options that were ascertained to be of the greatest consequence in the assessment: (a) the implications of indefinite surface storage versus permanent disposal in a deep geologic repository for the long term; and (b) the implications of choosing a granite repository site for geologic disposal at some distance away from the current waste management storage location, rather than in the sedimentary-rock Cobourg formation located adjacent to the current storage site, for the wastes.

Indefinite long-term storage versus geologic disposal.

The principal issue with regard to storage versus disposal is the degree of confidence one has in the very long term (many thousands of years) availability and operation of the active management required for both surface storage options. While low-level and some fraction of intermediate level wastes will decay in relatively short time periods, much of the intermediate level wastes remain potentially hazardous for much longer time periods. That has been the driver for the decisions made in many countries to provide for ultimate geologic disposal with the view being that once the wastes are emplaced deep underground in a suitable location, active management is no longer necessary.

The comparative assessment of the likelihood and consequences of the ultimate loss of institutional controls necessary to maintain assurance of protection of public and worker health and safety, security, and the environment becomes a key factor in comparing the surface and repository options. The assessment team judged that long term institutional controls (including the capacity, resources, expertise, political and societal will) cannot be guaranteed or even expected over the many thousands of years that the wastes remain potentially hazardous. The long term consequences of such a postulated eventual loss of institutional control are judged to be extremely high on very important elements such as protection against long term severe weather, glaciation, inadvertent intrusion, and malevolent acts.

Climate change and glaciation. The major consideration is that surface facilities will be more vulnerable to climate change and glaciation in the very long term. Even with assumed active institutional controls into the long term, severe weather would provide a significant challenge to surface facilities and if active controls were to cease at some point, the degradation of the facilities and waste packaging would make severe weather a much greater risk than in the repository options where deep emplacement would make the wastes safe from weather and climate considerations. Whenever a new glaciation period occurred, it may eventually be necessary to move the storage options to a new location where active controls can be maintained. Such glaciation implications would not affect the repository options.

Inadvertent intrusion. Intrusion in the future is a serious risk and must be precluded to the extent possible. In the storage options, as long as there is active control a security program would be kept in place to preclude inadvertent (or deliberate) intrusion. Should active controls be lost in the long term, the potential for intrusion would increase substantially and increase the risk accordingly. Once the wastes are emplaced in a deep geologic formation, the probability of inadvertent intrusion would decrease markedly, even though it is assumed that knowledge of the location of the repository is eventually lost. Siting of a repository requires an assessment finding that there are no significant known deposits of minerals or other materials that might credibly invite exploration into the repository at some time in the future.

Malevolent acts. While the probability and consequences of potential malevolent acts far into the future are unknown, the expectation is that disposal of the wastes into a deep geologic repository would make access much more unlikely and difficult to accomplish. As long as institutional controls are maintained, security (and its costs) would be an important component of the on-site responsibility. If institutional controls are eventually lost, access to the site and the wastes would be considerably easier and the probability of the malevolent use of the wastes would accordingly become higher, though over time the hazard would diminish somewhat as the wastes decay.

The shorter-term consequences of moving to geologic disposal are in some cases higher than for storage options as the construction and operation of a geologic repository will have short term consequences. These are anticipated to be limited much like the consequences of other modern mining operations and of much less consequence than the longer-term differences described above. The shorter term consequences of a repository sited in granite are expected to be greater than those for a repository at the Bruce site since siting at a granite site will require additional handling and transportation steps with their attendant worker and public safety consequences. These are judged to be similar to those associated with the transport of hazardous wastes in other industries.

Finally, while worker and public health and safety are anticipated to be low while institutional controls are maintained into the future, once the wastes have been emplaced into a deep geologic repository in either the Cobourg Formation at the Bruce site or a granite site, and the site then closed, the anticipated impacts on worker and public health and safety are judged to become lower. While the enhanced surface storage option provides some improvements over the status quo, these were judged to be valuable but of limited consequence when considering the long term implications of a loss of institutional control.

GEOLOGIC DISPOSAL IN THE COBOURG FORMATION AT THE BRUCE SITE VERSUS A GRANITIC REPOSITORY

The second key issue relates to the assessment of differences in building the geologic repository in the sedimentary Cobourg Formation at the current storage site for the wastes versus siting a repository in granite somewhere in the Canadian Shield. The IEG reads the description provided for the granitic repository to suggest that such a site in a hydrologic setting comparable to the proposed sedimentary site at Bruce should be considered.

Differences in a number of individual risks between the Cobourg Formation at the Bruce site and the generic granite site are described in the comparative evaluations in Section 3. Both would be expected to perform well within the regulatory requirements for long term safety and environmental protection. The need for additional handling and transportation steps influences the comparison between the two repository options. The additional step of moving the wastes off of the Bruce site, where the wastes are presently processed and stored, requires substantially more handling and more miles of waste transportation. Longer distances will increase the risk of more conventional transportation accidents. However, the potential for radiological exposure is judged to be quite low for both handling and transportation.

In conclusion: The Independent Expert Group was tasked by the Joint Review Panel to review and compare four specific management options for the safe management of low- and intermediate-level waste in Canada. The directive indicated that the IEG should address the comparisons in terms of the relative risks. Risk is the product of the probability and consequences for a number of factors that must be comparatively evaluated for the four management options. The IEG developed a framework for consistently and transparently evaluating the comparative risks, on a qualitative basis, for each of the four options against the important individual features that can discriminate among their safety performance. This analysis is intended to be inclusive of all of the pathways of harm that were identified within the charge to the IEG provided by the JRP.

CHAPTER 24

RISK PERCEPTION OF NUCLEAR WASTE DISPOSAL

A BACKGROUND STUDY (APRIL 2014)

Submitted by:
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Submitted to:
The Independent Expert Group

Contents

INTRODUCTION

This report presents an overview of research on the perception of risk from nuclear waste, with the aim of also providing insight into the conditions that may lead to community support for hosting a nuclear waste disposal facility. It has been prepared in response to a request made to the Independent Expert Group by the Joint Review Panel (JRP) for the Deep Geologic Repository Project for Low and Intermediate Radioactive Waste for a review of research on risk perception and community acceptance of a nuclear waste repository. This background study is in support of the JRP's review of a proposal by Ontario Power Generation (OPG) for a repository at the Bruce Nuclear Generating Station in Ontario.

The report describes research on the psychological and social contextual factors that shape individuals' judgements on the significance of a risk, and its acceptability in light of other considerations about the risk source. As the proposed facility will affect several Aboriginal communities whose traditional territories are in the region of the Bruce Nuclear Generating Station, the report discusses research on risk perception among Aboriginals in Canada as influenced by their cultural frameworks. It reviews research on perception of risk from nuclear power, and nuclear waste in particular, as a specific instance of risk perception and context for judgements on risk. It draws some conclusions from these research fields on two key concerns related to perception of risk from nuclear waste disposal, uncertainty and acceptability.

RISK PERCEPTION: SUMMARY OF KEY FINDINGS AND THEMES FROM THE LITERATURE

Risk.

Risk is a complex concept that is defined in different ways, according to the way in which the concept is to be used. However, there are several essential aspects incorporated in most uses of the concept, both casual and technical. The essential characteristic is uncertainty, referring to the chance or likelihood that an outcome of concern will occur. When used casually, risk has the sense of an unspecified chance of loss or harm from exposure to a danger; in the financial world the focus is on uncertainty, with the outcome being either positive or negative. Risks can be avoided, managed, actively taken, or carefully optimized.

When applied to the professional management of adverse risks, risk is a calculated quantity that incorporates several key factors:

- Hazard: a source of harm, inherent in a substance or activity
- Exposure: measured by type, duration and dose
- Consequence: a specific outcome that results from exposure to a hazard
- Probability: the likelihood that the specified consequence will occur, perhaps expressed as the likelihood with which it may occur (in time) or the incidence with which it occurs (in a population).

In many technical applications, risk is defined as probability times consequence, or simply P x C. It is the (generally) quantitative expression of the probability of occurrence, within a given timeframe, of a specified outcome of concern.

Risk Perception Research.

Research on the perceptions of risk by non-experts is conducted within several academic disciplines, each with a particular interest in an aspect of perception, and a related scale of focus and research methodology. These factors are in turn aligned with particular perspectives on risk as a concept and as an individual understanding, social concern and political debate. Each approach assumes a particular concept of risk and model of its function within society; and though risk research is increasingly multidisciplinary and appears more as a spectrum than as separate and discrete types, there are many debates about the appropriate scale, context and methods of research. To some extent the different scales used by the disciplines involved may be seen as complementary, partial perspectives that can be 'nested' to produce a comprehensive picture. However, they are also expressions of differences of opinion on the scale on which risk actually 'exists', the contextual factors that are relevant to an understanding of the concept, and the way it is apprehended by members of society.

In almost all risk perception research a primary distinction is made between 'expert' and 'non-expert', 'lay', or 'public' approaches to risk, though the analysis of the differences and the relationships between them varies. The disciplines are generally within the social sciences, and range from cognitive psychology, with an interest in the ways in which individuals use information to estimate probabilities; through social psychology, with an interest in personality and relational factors that contribute to individuals' judgements of the risks of hazards and social activities; to sociology, with an analytical and critical interest in the collective definition and negotiation of phenomena and relationships that are constructed as risks.

The understanding of risk perception in this paper that has been developed through dedicated research from the early 1970s is presented in three sections. The first outlines findings on individuals' cognitive judgements of risks and the factors that influence them; the second discusses research on judgements by individuals within a particular social and cultural context; and the third looks at the social impacts and broader implications of attitudes to risks and risk sources within the population.

PERCEPTION OF RISK

Cognitive processes and knowledge of risks.

Research carried out on risk perception by cognitive psychologists was founded on a concern with the processes people use in making judgements under conditions of uncertainty. Risk was interpreted as a probabilistic phenomenon, with uncertainty the most relevant consideration; assessing the probability of an event is a formal means of reducing uncertainty, in order to provide a basis for decision-making and risk management. The most appropriate means of making judgements under such conditions is through the correct interpretation of the information and application of the rules of probability.

An early finding was that non-experts deal with uncertainty not by systematically considering statistics, but by applying a set of mental shortcuts called heuristics. Heuristics are rules of thumb that enable people to use known information to evaluate a situation that appears to be similar. These heuristics lead to systematic biases in estimating probabilities and values (Tversky and Kahneman, 1974). The most common of these heuristics are representativeness, availability, and anchoring. The representativeness heuristic is the evaluation of a probability according to the degree to which it is considered to resemble, or be representative of, another risk that is better understood. The availability heuristic is the ease with which a type of event is brought to mind. This may be due to media coverage, for example, or to familiarity due to a recent similar event or combination of events, which may be a useful guide to a risk judgement, but can also bias the evaluation of a risk. In anchoring, people base an initial judgement on a value, which they then apply to other situations (Taylor-Gooby, 2004).

An important outcome of research on non-experts' perceptions of risks to health and safety is the psychometric paradigm. Using questionnaires to elicit individuals' ratings of a wide range of hazards of different types, researchers found that non-experts' perceptions were generally higher than experts', and were related to qualitative characteristics associated by respondents with those hazards. Non-experts' risk judgements are more contextual, and are more concerned with the consequences of a risk than with the probabilities of their occurrence. Furthermore, the notion of 'risk' is broader, and the consequences of concern are not limited to death or injury, but extend to harm to something that is valued, or a value or principle in itself. A key finding (Slovic, 1992: 120) was that:

> When experts judged risk, their responses correlated highly with technical estimates of annual fatalities. Laypeople could assess annual fatalities if they were asked to (and they produced estimates somewhat like the technical estimates). However, their judgments of 'risk' were sensitive to other factors as well (e.g., catastrophic potential, controllability, threat to future generations) and, as a result, differed considerably from their own (and experts') estimates of annual fatalities.

Another major finding from this research was that hazards showed 'personality profiles' that are related to their perceived risk. These characteristics were correlated with each other 'across a wide range of hazards' (Slovic 1992: 121), and were found to cluster into two factors that were termed 'dread' risk and 'unknown risk'. Laypersons' perceptions of the risk of a hazard – but not those of 'experts' – have been found to be related to the position of the hazard within the factor space. The characteristics that make up the dread risk and unknown risk factors are shown below; hazards that are high on the 'dread risk' factor are perceived as particularly high risk.

Demographic factors have also been found to influence perception of risk, although findings on these factors vary. Many risks, particularly environmental and technological risks (Siegrist et al., 2005) are rated as higher by women and by minority ethnic groups (Finucane et al. 2000). There are also differences among age groups and levels of education, with those with higher levels of education typically perceiving lower levels of risk. Other factors, notably social marginalization and poverty, were found to be predictive of higher risk perceptions (Boholm, 1998).

Psychometric studies have been conducted in many countries, and have found more similarities than differences among nationalities in the ‘cognitive map’ described by the two-factor space (Siegrist et al., 2005); “On an aggregated level, the patterns produced by the psychometric paradigm are very stable.” The psychometric paradigm does not describe individual variability as well, however; several factors have been put forward to explain individual variations in risk perceptions, including confidence and trust (Siegrist et al., 2005) and a range of personality factors such as levels of anxiety, desire for control, and experience with risks (Barnett and Breakwell, 2001; see Chauvin et al. 2008 for a list of references for studies on a wide range of variables).

Perceptions of different risk sources.

Certain types of risk are consistently judged to be higher, or lower, than actual rates of harm from those sources. Figure 1, below, shows the risk rankings in a recent survey of Canadians’ perceptions of a range of risks to health. Some of the risk sources that are associated with raised or lower perceptions of risk have characteristics known to influence risk judgements, such as voluntariness or lack of control. A major factor that has been observed is that people perceive risks from natural sources as being lower than risks from technological sources, such as industrial chemicals or processes. This bias may lead people generally to be unconcerned about the risks of some natural substances, such as natural radon (Golding et al., 1992; Slovic et al., 1995). Sjöberg (2000) has described an influential factor that he calls “unnatural risk” or “tampering with nature,” which expresses the sense that an activity interferes with nature, and incorporates a moral judgement about the activity.

People consistently perceive risks from technology as being greater than those from nature and have elevated perceptions of the risks of chemicals and industrial technologies and processes. In many cases perceptions of a technology differ with the application: for example, medical applications of biotechnology are perceived as lower risk than uses in food crops (Gaskell et al., 1999).

People rate a risk they undertake themselves, or are exposed to voluntarily, as being lower than one that is imposed on them. People ‘discount’ their vulnerability to lifestyle risks, over which they feel a sense of personal control (Sjöberg, 2000), but do not do so with so-called “societal” risks, the risks that are imposed and cannot be avoided by any personal competence.

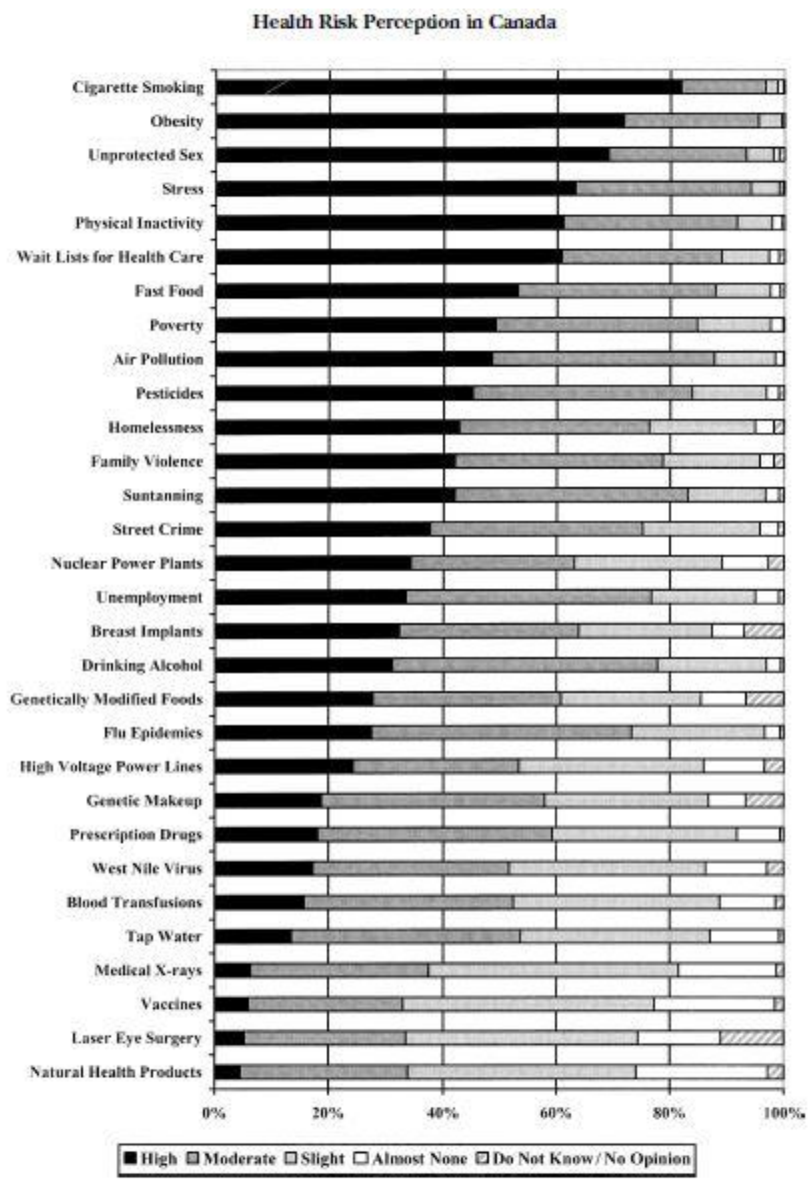

Figure 1 Perceived health risk of thirty hazards to the Canadian public. (Krewski et al., 2006)

Framing – benefit-risk dynamic.

Many of these qualitative perceptual factors that are inconsistent with actual rates of harm are explained through an understanding of the relationship of the individual with the risks and with the benefits of the risk source. Instead of perceiving and balancing separate judgements of the risk and the benefits of an activity or hazard, people integrate the two factors into a single coherent attitude to the risk.

Research within the psychometric paradigm found "an inverse correlation between perceived risk and perceived benefit across diverse hazards" (Alhakami and Slovic, 1994): perceived risk declines as perceived benefit increases. People construct comprehensive judgements or 'framings' of activities in to which 'risk perception' factors are integrated, to arrive at an overall 'risk-dominated' or 'benefit-dominated' perspective on an activity or other risk agent (Alhakami and Slovic, 1994). When people focus on the benefits of an activity they tend to downplay the risks. On the other hand, when people do not have personal experience with the benefits of an activity and perceive themselves to be susceptible to imposed risks, they are likely to frame that activity as a risk (Leiss, 1989; Leiss and Chociolko, 1994). Researchers related this framing dynamic to "intuitive and experiential thinking, guided by emotional and affective processes" (Alhakami and Slovic, 1994; Finucane et al., 2000); this was termed the 'affect heuristic' (discussed in more detail below), in which the dominant perspective is 'liked' and results in the downplaying of the other (Alhakami et al., 1994; Finucane et al, 2000).

Risk-benefit framing helps us understand some degree of the high perceptions of risk from many technologies. Risks from technology are often seen as imposed, often by large-scale industrial activities - primarily complex technologies or processes. These may produce diffuse benefits that may not be experienced directly by individuals, but carry risks to which individuals feel vulnerable, such as air pollution or chemical spills. People cannot control their exposure to these hazards and are dependent on remote social systems of control for protection from them. The downplaying of the benefits of these technologies is related to the 'feeling of powerlessness' in relation to them (Alhakami et al., 1994). In addition, many of these technologies are complex and not well understood by non-experts, adding an additional concern factor.

On the other hand, most people tolerate high risks from substances or activities that they benefit from, such as medications and driving, as they focus on the benefits that they experience from these activities and downplay the risks. Many people actively pursue risky activities, again focussing on the experience of benefits from the activity, and in many cases also valuing the personal control that they can exercise in the activity.

Trust.

Many studies have found that people's perception of the risk level of an activity is related to their trust in the authorities who manage it (Siegrist et al. 2000). This suggests that the public's disapproval of major technologies is associated with a lack of faith in government and industry (Slovic, 1993): "Public fears and opposition to nuclear-waste disposal plans can be seen as a 'crisis in confidence', a profound breakdown of trust in the scientific, governmental and industrial managers of nuclear technologies." This has been explained in part by the greater visibility of 'trust-destroying' events and the fact that they carry more weight than positive events; and to the American style of democracy that gives individuals and groups the right to intervene in proceedings, challenge government agencies, and pursue policy changes through litigation (Slovic, 1993: 680). Trust has emerged recently as a dominant consideration in the public acceptance of or aversion to a technology.

General social surveys have shown declining levels of trust in government and industry, as well as for the set of social and political values they represent and advocate.

Uncertainty.

Relatively little research has focused on the public understanding of uncertainty (Frewer et al., 2003). Research focused on eliciting the effect of uncertainty on the perception of a risk concluded that "uncertainty information had very little effect on perceptions of concern"; instead the qualitative factors described in the psychometric paradigm, such as natural or man-made, seemed to determine the risk perceived.

However, as noted above, research conducted within the psychometric paradigm has found that an unfamiliar risk, that is, one that is unobservable, or not understood, is associated with higher perceived risk. Similarly, people will often seek to reduce the uncertainty in an unfamiliar situation by likening it to one or another characteristic of a familiar one.

Risk perception research has often linked uncertainty with trust in risk managers, regulators and government. Based on a theoretical perspective that social or 'system' trust reduces complexity by delegating certain tasks to others (Bradbury et al., 1999), risk perception research has often observed that trust in managers of complex tasks or decisions helps reduce uncertainty to a more manageable level: "the less we know about an activity, the more we need to rely on others to make decisions and the more our judgements become a matter of trust" (Savadori et al., 2004; 1290).

The relationship of risk perception, uncertainty and trust is complex, and is discussed in more detail below.

Experts and non-experts.

As noted, a fundamental focus of attention from the beginning of risk perception research has been the 'gap' between experts' and non-experts' risk judgements; experts' judgements (of the same risk ranking tasks as non-expert study participants) are closer to 'actual' rates of harm, and are consistently lower than those of non-experts. The inference from this observation was that experts were applying a systematic and rational analysis to the risk estimation task, whereas non-experts applied heuristic strategies, or considered qualitative or emotional associations with the hazard, leading to systematic errors. Only when experts make judgements outside of their field of expertise are they thought to rely on perceptual factors commonly employed by non-experts (Beyer et al., 2012). It should be noted that the basis on which these conclusions about the relative accuracy of the experts were based would now be considered weak: the experts included in these early studies were a group of 15 individuals described as professional risk assessors, including a geographer, and environmental policy analyst, and economist, a lawyer and a government hazardous materials regulator (Wright et al., 2002). The hazards that were to be ranked spanned a wide range of technologies and activities that applied to no single field of expertise.

More recent studies using experts qualified in the field of the study have generally concluded that expert risk assessors also use a set of heuristics in formal risk assessment; heuristics are not simply "error-prone rules of thumb" used by non-experts, but function as a "series of rules for bounding problems, collecting data and making sense out of it" (MacGillivray, 2014: 785).

Research on risk perception finds that the difference between experts' and non-experts' risk perceptions is a function of the level of risk – that is, across many different risks, experts' judgements are lower than non-experts.' Experts make systematic errors in estimates of risk frequencies that are similar to those made by non-experts, and also use similar decision-making strategies and qualitative associations, within the context of the same psychological factors, as non-experts. For example professional underwriters were "a little better in their risk judgements [of annual frequencies of deaths from a range of causes] than the lay persons . . . but the differences in performance between experts and lay persons were small in magnitude, and the nature of the biases . . . were common to both groups." (Wright et al., 2002).

A study that asked a group of professional medical assessors to evaluate a portfolio of prescription drugs (Beyer et al. 2012) found that, while all assessors applied relevant technical risk assessment considerations, their assessments varied according to their degrees of worry for safety, consideration of product benefit, and emphasis on ethical issues. There were also differences attributed to differences among assessors: senior assessors were more risk averse than more junior assessors, and female assessors appeared to be less risk averse as a consequence of greater sensitivity to benefit considerations (Beyer et al. 2012). However an earlier study found that young female professional toxicologists had higher perceptions of risks than their older, male colleagues (Mertz et al., 1998).

Experts' attitudes to technologies are similar to those observed in non-experts' (Sjöberg, 2003); experts' opinions were often biased towards their own fields, with some 'acting as promoters of a technology', considering that the risks within their field had been exaggerated but that others had been neglected (Sjöberg, 2003). Experts in the same field may differ in their risk judgements. Some of this is related to professional orientation and affiliation; for example, toxicologists working for industry see chemicals as less dangerous than do toxicologists working in government and universities (Kraus et al. 1992; Barke and Jenkins-Smith, 1993). Members of disciplinary groups differed among themselves on key issues of scientific assessment and decision-making such as the value of animal studies for predicting health effects in humans, and the existence of a safe level of exposure to a carcinogen (Rizak and Hrudey, 2005).

One researcher (Sjöberg, 2002: 455) states that "there is no ground … for stating that experts' risk perception has a radically different basis than that of non-experts. On the contrary, the psychological dynamics appear to be similar when it comes to structural properties of risk judgements."

Broader attitudes, political values, social relations.

The findings of experimental psychology on individual cognitions and perceptions of risks continue to have relevance to understanding public judgements of certain types of activities; however, the analysis of these factors needs to take a broader perspective in order to capture the dynamic that is operating with risk issues. In 1992 a leader in this research field (Slovic, 1992: 120) claimed that the psychometric paradigm had come to "encompass a theoretical framework that assumes that risk is subjectively defined by individuals who may be influenced by a wide array of psychological, social, institutional, and cultural factors." However, he noted that "although the psychometric paradigm has been oriented toward cognitive psychology and behavioural decision theory, I believe that societal response to hazards is multidetermined and thus needs to be studied in a multidisciplinary way" (ibid: 149).

Research that takes a broader analytical perspective on the findings produced by psychometric research on the cognitive strategies that non-experts use in judging risks gives more useful insight into the formation and function of risk judgements in society. The integration of cognitive strategies used by non-experts to judge risks into broader attitudes and values reveals the logic that relates the risk associations and cognitive strategies into a coherent and rational approach to individuals' decision-making in complex society. Risk perceptions are stable attitudes that are shaped by prior and more fundamental social values.

Instead of piecemeal judgements on risks, and on benefits, based on cognitive shortcuts to reduce the complexity of probabilities and technical assessments, non-experts form judgements on risks based on their prior knowledge of, and experience with, the risk sources, such that the risk judgements are consistent with their attitudes. This view of risk judgements suggests not only that perceptions of risk involve broader considerations such as benefits of the activity, but also that the overall judgement is shaped by underlying and more general attitudes (Poortinga and Pidgeon, 2005). Risk attitudes are 'embedded in a system of general attitudes and values' that guide the derivation of more specific attitudes in a way that preserves the evaluative tendency of the higher-order attitudes" (Grunert et al., 2003: 439).

It has been found numerous times that people's risk judgements are influenced by, and are consistent with, their broader social and political attitudes and values, and that these are stable and do not shift with new information. For example, people's beliefs about and values for nature influence the risks they will perceive in technology. Those who hold "ecological" values are more likely to consider technology to be a risk (Axelrod, et al., 1999). Research on the perceptions of health risk among Canadians has found a correlation between respondent's judgements of risks and their broader attitudes; perceived risk from environmental and social factors correlated with "belief statements reflecting environmental and social concern" (Krewski et al. 2008: 175). Broader social and ideological orientations are influential, as are specific attitudes to a hazard or technology (Sjöberg, 2000).

This principle applies to experts' risk judgements as well as non-experts'. Professional ecologists, and university scientists in several plant biology disciplines, opposed genetic engineering of crops, stressing the unpredictable environmental effects of the crops but having little opinion on the benefits that are claimed for the crops. Scientists who supported the use of GM crops, on the other hand, tended to be employed in the biotechnology industry and to be confident in industry research; they believed that GM crops are not fundamentally different from their conventional counterparts and that there are benefits to be gained from their use (Kvakkestad et al., 2007).

When psychometric research variables are expanded to include broader attitudes and values, many judgements about risks are seen to be driven by social attitudes and assumptions. The "white male effect" describes the finding that a cluster of well-educated white men in a survey sample rated risks as lower than other participants of both sexes and other races. The researchers suggest that "white males see less risk in the world because they create, manage, control, and benefit from so much of it" (Flynn et al. 1994). It has also been found that lower than average perceptions of environmental risk are held by white males with conservative political views (McCright and Dunlap, 2011).

Researchers have expanded on this observation to explain the prevalence of 'climate change denial' among white males holding traditional conservative values in the United States (McCright and Dunlap, 2011). They suggest that this position is held as part of an effort to protect an elite identity against "charges of societal danger … levelled at activities integral to social roles constructed by their cultural commitments" and to defend the predominant social and economic system."

The incorporation of stable attitudes and values into judgements about risk has been explored through the lens of the affect heuristic. 'Affect' is described as a general positive or negative feeling that is linked, through experience and learning, with an activity (Finucane et al., 2000; Poortinga and Pidgeon, 2005). The affect heuristic is the decision-making process by which "images, marked by positive or negative affective feelings, guide judgement and decision making" (Finucane et al., 2000). The affect heuristic suggests that general affective images of an activity are prior to, and direct, judgements of risk and benefit. This reverses the model that cognitions or beliefs build evaluations or general preferences, asserting that instead broader attitudes guide the formation of more specific beliefs. Psychologists now are considering that risk perceptions combine analysis and feelings in a 'risk-as-value' approach that "motivates individuals and groups to achieve a particular way of life" (Finucane and Holup, 2006: 144).

Summarizing the importance of understanding the role of affect and of values in risk perception, Finucane and Holup (2006: 145) observe: "research suggests that analytic and affective processes work in partnership to identify and prioritize experiences that are valued positively (and thus pursued) and experiences that are valued negatively (and thus avoided). Together, dual processes comprehensively govern the valuation of risk information in order to maintain a particular way of life."

A similar elaboration of the influence of trust on risk judgements gives insights into the political nature of trust relationships on risk management issues. Analysis of early findings that trust in risk managers is related to lower perceptions of risk suggested that increasing trust might reduce perceived risk (Slovic, 1991). Some researchers suggested that trust consists of characteristics, or 'dimensions of trust' including expertise, reliability, competence and care, and honesty and fairness, which are assumed to be universal, apparent to all observers, and thus generally considered 'trustworthy' (Cvetkovich and Nakayachi, 2007). This approach has led to risk communicators and risk managers to aim to increase trust in institutional sources of information and thus to reduce perceived risk, by conveying these qualities in risk communication and building trust through participation (Kasperson et al. 1999).

Other researchers argue that trust in risk information and managers and risk perceptions are reflections of more general attitudes towards a technology or risk management situation. Instead of a constellation of psychological attributes of a trusted risk manager, trust is characterized as a complex judgement of a risk context and the relationships among the stakeholders involved. The type of trust involved is 'social trust' (rather than personal trust), or a willingness to cooperate based on two "context-specific judgements" (Cvetkovich and Nakayachi, 2007). The first judgement assesses the saliency of values that apply to the problem at hand; the second assesses the "perceived agreement or similarity between self and the other person about what is important, that is, salient value similarity." This trust is context-specific; in situations of high concern people tend to trust risk managers with values similar to their own, and whom they perceive to be acting in their best interest.

In the light of this value-based understanding of risk, risk perception appears as a broad, contextual consideration of the important aspects of a technology or activity, such as the benefits of the activity and their distribution; risk and technology issues are seen as intrinsically political and social relational. Members of the public are "less concerned with making choices about which risks they are willing to tolerate than they are with grasping which political interests lie behind the promotion of particular choices" (Priest et al., 2013).

Social impacts and implications of risk judgements.

Judgements about risks are complex determinations made by individuals in the context of their knowledge and understanding, their attitudes and values, and their social relationships. As such, risk judgements often become collective judgements and social phenomena, subject to many interactive processes of information dissemination and interpretation that themselves occur within broader social and institutional contexts. It is through some of these processes that a risk can become a 'risk issue'; that is, a matter related to a risk that is highly salient within the public, or within a particular group of stakeholders (Leiss, 2001). This may develop from factors inherent in the risk itself (such as a risk source of particular concern or the involvement of a vulnerable group), or it may relate to broader factors such as concerns about risk management practices, or wider debates about a technology.

The Social Amplification of Risk.

Kasperson et al. (1988) noted that apparently minor risk or risk events, as assessed by technical experts, sometimes produce massive public reactions, accompanied by substantial social and economic impacts.

The social amplification of risk framework (Kasperson et al, 1988; Pidgeon et al., 2003) draws on communications theory to map out factors that contribute to people's interpretation of a risk and the movement through society of beliefs about risks and risk events. The basic principle is that "hazards interact with psychological, social, institutional and cultural processes in ways that may amplify or attenuate public responses to the risk or risk event" (Kasperson et al, 1988:178). Social amplification itself is "the phenomenon by which information processes, institutional structures, social-group behaviour, and individual responses shape the social experience of risk, thereby contributing to risk consequences" (Kasperson et al, 1988: 181).

Amplification occurs when these processes combine to heighten awareness and response to a risk, as is often seen with technological activities or chemical risk events; attenuation is seen with such well-documented health risks as indoor radon or aflatoxin (a carcinogen) in peanut butter, about which people are generally unconcerned. The steps of amplification include filtering of signals for attention; processing of risk information and attaching social values to it; interacting with cultural and peer groups to interpret and validate signals; formulating behavioural intentions to tolerate or take action against the risk or risk manager; and engaging in group behaviour to accept, ignore, tolerate, or change the risk.

Individuals may attend to certain sources of information on a risk that they trust, which may have the effect of reducing uncertainty for the individual and of polarizing opinion in society into separate and often conflicting camps (Eiser, 2004). In the case of amplification, one possible outcome of increased concern and salience about an issue is stigmatization.

Stigma.

One characteristic that emerged was that of stigma, defined as "a mark placed upon a person, place, technology or product, associated with a particular attribute that identifies it as different and deviant, flawed, or undesirable (Kasperson et al. quoted in Peters et al. 2004). Stigma is intensely negative imagery that is strongly associated with something that is socially disapproved; it can generate fear and anger, and is associated with both affective and cognitive responses (Peters et al. 2004). Stigma can be associated with substances or products. Negative imagery is associated with chemicals; the word 'chemical' is interpreted as a synthetic substance, rather than as a fundamental component of nature, and associations with it are mostly negative, eliciting responses like 'dangerous, poison, or toxic'. Stigma is often associated with technologies, or with places or communities in which technologies perceived as dangerous or unacceptable are located (Gregory and Satterfield, 2002; Miller and Sinclair, 2012).

Stigmatization often occurs as a result of media coverage, and associated risk amplification (Slovic, 2000), in many cases following an accident or critical event that serves as a 'signal' that the technology involved holds "abnormal risk" (Gregory and Satterfield, 2002).

Aboriginal perception of risk

Aboriginals make risk judgements according to the same basic principles as any other social group or community; that is, they rely largely on qualitative factors about a risk, and interpret these through the lens of their knowledge of and relationship with the risk source and their social and cultural values. As has been observed in many risk perception studies in many countries, overall attitudes about an activity are driven by judgements of its value and benefits.

However, Aboriginals' perceptions of risk, and judgements of risk sources, often differ from mainstream risk judgements, because many Aboriginal cultural assumptions and values, as well as material conditions and interactions with the environment, are different from those of the mainstream Canadian society. In order to understand the perceptions of risk by Aboriginal individuals and communities, it is necessary to be familiar with the cultural context that shapes those perceptions.

It is important to note that there are many Aboriginal groups in Canada, including the Inuit, Métis and many First Nations, which include communities both on and off-reserve from British Columbia to the Maritimes, as well as the Territories and Nunavut. These societies, nations and communities have long histories grounded in the way the communities lived in their traditional lands within these very diverse geographical regions; there is therefore no single 'Aboriginal' perspective.

Despite the diversity of Aboriginal culture in Canada, many North American Aboriginal cultures share a set of general assumptions and values that differ from key characteristics of Western culture. There are a number of cultural and social factors that form the context within which risks and risk sources are perceived and judged.

Relation to the land.

Land – nature as a spirit, the environment as providing foods and other material that communities use to survive, and territories that are traditional for individual communities – is central to Aboriginal activities, culture and identity. Nature, and the earth, is sacred; people and communities are part of Creation generally, and nations and communities are tied to specific traditional territories in which they carry out traditional hunting and other cultural practices.

Nature, physically and literally, embodies the sacred; the whole of creation, the land itself, is alive. 'Mother Earth' is meant literally as humans' mother; water is Earth's blood, rocks and minerals her bones, and plants her hair (Paper, 1990). Sharing a creator, humans are related to all other forms of life and can communicate with them; humans can take animal form, and animals can change into human form. Other species were regarded as 'people' with their own qualities and purpose within creation, and with whom humans relate as kin (Deloria, 1992). For Aboriginal cultures, humans are part of creation and are not superior to the rest of life, but were placed on earth "to be caretakers of all that is here' (Clarkson et al. 1992). This is closely tied to the traditional use of the land, which imparts a sense of the sacred into community relations with the land: "Every location within [a tribe's] original homeland has a multitude of stories that recount the migrations, revelations, and particular historical incidents that cumulatively produced the tribe" (Deloria, 1992: 122). While there is "great unanimity" among Aboriginal nations about the natural world and humans' behaviour in it, they are also distinct because they live in different local ecosystems; knowledge and values are not seen as universal (Henderson, 2000: 259 - 264).

Beyond the spiritual meaning of Nature, the land matters to Aboriginals in very material ways. Traditional uses of land maintain culture and strengthen communities, as many Aboriginal communities still hunt, fish, and harvest local plants which have been used by the people for many years. Carrying out traditional practices on ancestral lands and sacred places is fundamental to their identity and their survival as a people. Traditional foods "are those culturally accepted foods available from local natural resources that constitute the food systems of Aboriginal peoples. The concept of food system includes sociocultural meanings, acquisition and processing techniques, use, composition and nutritional consequences for the people using the food.

Of importance to understanding the role that culture plays in determining food choice in Aboriginal communities is that the activities required to procure traditional food are not merely a way of obtaining food but, rather, a mode of production that sustains social relationships and distinctive cultural characteristics. These practices are vital for the maintenance of traditions and cultural cohesion" (Willows, 2005). As Simpson (2003) notes:

> From a social perspective, being out on the land strengthens our relationship to our extended families and deepens our spiritual understanding of life and our place in it. Consuming traditional foods revitalizes our cultures, our languages and our ceremonies and it reinforces our sovereignty within our families, communities and Nations. Gathering rice, berries, and plants requires our people to remember or seek out Traditional Knowledge in order to understand how to harvest these items in a respectful and traditional way.

Social order.

Many traditional Aboriginal cultures have a different social organization and decision-making tradition than Western Culture. Decision-making is often community-based, inclusive and more collaborative than Western expert and specialist-driven processes. Elders are highly respected, in part for their deep knowledge of the environment and of the traditional territories (Friendship and Furgal, 2012).

Knowledge.

Knowledge within traditional Aboriginal cultures is more observational and experiential than analytical and technological, as Western knowledge is. Members of Aboriginal communities are likely to rely on sensory methods to judge the state or quality of elements in the environment. Much traditional knowledge is historical and transmitted orally, passed on by Elders (Friendship and Furgal, 2012).

Marginalization.

For a complex set of reasons related to social and political factors, including the colonial histories of Aboriginal people in Canada, the health status of Aboriginal communities in general is lower than the general population (Driedger et al., 2013). Housing on many reserves is below the standard expected in the rest of the country; many Aboriginal communities do not have reliable safe drinking water supplies (Patrick, 2011); and "access to and legitimacy of health services has been, and continues to be, a real issue" (Driedger et al. 2013). Many Aboriginals feel their health is a lower priority than is that of the mainstream population, and that their lives 'are less valued' than are those of other Canadians.

Differences in worldviews and values, knowledge and decision-making traditions, combine with social and political factors to create a lack of trust in Canadian authorities, experts and expertise. The combination of social marginalization and the use of traditional knowledge results in a lack of understanding of, and trust in scientific knowledge and dominant Western governance and decision-making. This lack of understanding is mutual, as scientists and authorities often do not understand Aboriginal values and perspectives, and consequently do not recognize that their own styles of knowledge and communication are not in accordance with those they are attempting to reach.

Perception of risk in Aboriginal culture and communities.

These cultural assumptions, values and priorities shape the perception of risks by Aboriginal individuals and communities. Several dimensions of risk perception can be recognized as particular to Aboriginal cultures; risks appear as events or circumstances that threaten key values or the viability of important cultural activities. Because of the centrality of nature, and of the use of traditional lands, to the maintenance of culture and community, an event that reduces the ability of the people to carry out their traditional activities on the land is a serious risk. Such threats could be changes in the environment, the wildlife or plants that live in it, access to traditional areas, or contamination that makes the use of traditional foods unsafe. The ability to continue to use the local natural environment is so central to Aboriginal cultural survival that risk to the environment is often simply perceived directly as a threat to culture and to the maintenance of the traditional way of life.

The deep connection between the land and the people leads to a belief that risks to the environment cannot be kept separate from the people: with humans and the rest of nature are united in a single system; "whatever happens to the animal life . . . will also happen to the Anishnawbe" (Morrisseau, 1991: 40). "Elders all over North America know that when the earth is sick, the people will also be sick, and this rings true in Indigenous Territories throughout Canada" (Simpson, 2003). There is a strong interaction between cultural perceptions of the benefits and risks of using or consuming foods and water, as well as with impacts on health and on the community of exposure to risks in the environment.

First, the contamination of traditional foods or water sources leads to complex situations of competing risks and benefits. As there are health and cultural benefits to eating ‘country foods’ - wild foods hunted or gathered in the traditional way - contamination of these foods causes health risks if they are consumed, and cultural risks if they must be avoided. Reducing consumption has a greater impact than it might in mainstream society; substitutions are less viable, because the hunting itself is integral to the process, and because healthy and affordable alternatives may not be available in remote communities. When people fear that traditional foods are contaminated, they lose confidence in the environment and in the traditional activities involved in gathering them (Indian Affairs and Northern Development, 2003: 74).

This situation has been observed with the discovery of high levels of mercury in some fish species in the North (El-Hayek, 2007), where the risks of mercury in fish must be balanced against the nutritional value of the fish, particularly in a population that relies heavily on fishing and hunting for food, as well as against the cultural values of fishing and eating traditional foods.

In some instances, the cultural benefits of using certain traditional foods or water may override risks, particularly if the risks are not readily apparent. The ‘values and benefits of the connections with elements of the natural world outside of nutritive contributions’ (Friendship and Furgal, 2012) can lead to the consumption of food or water that is not safe. Many individuals, particularly elders “who have spent a large part of their lives outdoors” (Martin et al., 2007) prefer to drink water from creeks, lakes or rivers rather than bottled water or treated tap water: despite the presence of bacterial contaminants, ‘raw’ water was considered to be “clearer and less contaminated’ than water from household tanks, and tastes better, because it does not taste of chlorine (Martin et al. 2007).

Second, the means of identifying and perceiving a risk is different within Aboriginal culture than by scientific methods. Aboriginals may rely on historical knowledge, personal experience and observation, and sensory methods to detect contaminants in food or water, for example. Chemical or bacterial contaminants may be detectable only with technological sampling and testing, and not be apparent to the senses. There is concern about health risks from environmental contaminants, and anxiety is increased by the lack of familiarity with many contaminants and by the uncertainty of receiving information from scientists that does not accord with sensory perceptions or with traditional means of assessing the environment. Many residents of reserves are concerned about the safety of drinking water in their communities. Women on reserves were found in one study to be more concerned about the safety of drinking water than men. The researchers "suspect that this is partly a reflection of the culture, given First Nations women are viewed as guardians of water, possessing greater traditional learning and knowledge of the natural resource"; women with children under 15 were also more concerned (Spence and Walters, 2012).

Uncertainty about the safety of traditional foods and water – "not being aware of whether water has ever been contaminated during the year" (Spence and Walters, 2012) - increased concern about the safety of the water. Many contaminants are not only invisible but are the products of a technological society with which remote Aboriginal communities are not familiar, leading to misunderstandings, uncertainty and anxiety (Indian Affairs and Northern Development, 2003). There may be a 'resistance' to information about invisible contaminants that cannot be tasted or smelled, which increases uncertainty in interpreting the safety of food and the possible presence of contaminants, and creates conflicts between different sources of information and modes of understanding. People may not 'go against the knowledge of Elders when choosing between science and traditional knowledge' (Friendship and Furgal, 2012). Incidents of contamination may require consultation with technical experts who refer to a different system of knowledge: "They must rely on individuals using different modes of understanding, communication and inquiry, and there are often competing messages about the nature and extent of the risks by different experts" (Indian Affairs and Northern Development, 2003).

These complex factors make communicating about risks difficult with Aboriginal communities. Trust is further eroded with the awareness that much of the contamination of the environment, and traditional foods and water, is the result of Western industrial activities. As Simpson (2003) notes, "Colonization, genocide and colonial policies aimed at destroying Indigenous Nations and disrupting our physical and intellectual connections to the land brought tremendous tragedy, sickness and dependency to our peoples. Industrial activities such as mining, deforestation, road building, hydro -electric development, and the contamination of the environment with toxic chemicals continue to threaten the ability of Indigenous communities to rely on our traditional foods systems for our health and well-being and the health and well-being of our families."

PERCEPTIONS OF RISK FROM NUCLEAR TECHNOLOGY AND NUCLEAR WASTE

General levels of support: survey research.

Many surveys provide information on general attitudes to nuclear technologies and applications; some of these are general risk perception studies (Krewski et al., 2006); others include questions on nuclear technologies in general public opinion surveys (for example the Eurobarometer surveys discussed by Greenberg, 2012); while others are dedicated studies of levels of opinion on nuclear technologies (Kim et al., 2014). These offer a broad, high-level picture of public opinion on nuclear technologies over time, and relative to other issues, social concerns, and risk sources. However, the general surveys provide little depth on any issue and do not offer interpretation and explanation of findings. It is also difficult to compare information from several surveys as the questions asked and the analyses performed on the data are specific to each study.

In the United States, there is fairly stable support for the use of nuclear energy, with benefits perceived as greater than risks (Jenkins-Smith, 2011). Support for the increased use of nuclear power in the U.S. fluctuated between 44% and 52% from 2005 to 2010 (Greenberg, 2012). The Eurobarometer survey of 2005 found an average of 37% of the populations of the EU countries favored nuclear power and 55% were opposed; however, there was a wide range in approval among countries. Several surveys reported a steady increase in positive opinion in Europe and the United States up to 2010, with the populations evenly split between support and opposition. An international opinion survey found that an average of 38% favored the use of nuclear energy, with a majority of respondents supporting the technology in India and the US. While only 34% of respondents to this survey approved of the construction of new nuclear power plants, approval was higher in the US (44%) and the UK (43%). It has been found in a number of studies that nuclear waste is perceived as a higher risk than nuclear power (Sjöberg, 2004; Whitfield et al., 2009).

The events at the Fukushima plant in Japan caused levels of support to drop in many countries (Greenberg, 2012). The international survey found that those who opposed nuclear power were most influenced, with 26% of those opposed to nuclear power strongly influenced by the Fukushima events in the US and 20% in the UK. As is discussed in more detail below, the effect of these events on individuals' perceptions of the risks of the technology depended on their pre-existing broader attitudes (Yeo et al., 2104).

Many studies ask respondents about the level of their support or opposition to nuclear technologies; one study of data collected in 2005 by the International Atomic Energy Agency (IAEA) distinguished between strong and reluctant acceptance of nuclear power, and opposition to the technology. ‘Reluctant acceptance’ was defined as “acceptance of the use of nuclear energy without a friendly attitude towards it because of a high level of dependence on nuclear energy, and a lack of alternative energy sources within that country” (Kim et al., 2014). Researchers were able to classify the 19 countries involved in the survey into four groups according to the levels of support and opposition. Group 1 countries had a high level of acceptance and a high level of strong acceptance; Canada is in this group, along with Australia, China, India, South Korea, Mexico and the US (Kim et al., 2014).

There have been a number of findings on attitudes towards different aspects and applications of nuclear technologies: even when there is general support for the use of nuclear energy, there is commonly opposition to the local siting of a plant (Whitfield et al., 2009). Advocates of nuclear energy have anticipated that since nuclear power is a sustainable means of generating electricity that does not emit carbon dioxide, concern about climate change might change attitudes and revive the technology; however, that appears not to be occurring (Whitfield et al.,2009; Bickerstaff et al., 2008).

Finally, Krewski et al. (2006) included nuclear power plants in a list of hazards that were ranked by respondents to the survey. One-third of the participants in this survey considered that nuclear power poses a high health risk, compared to 6 % who considered medical x-rays as being a high risk (Slovic, 2012).

Factors in attitudes to nuclear technologies.

Qualitative factors related to radiation.

As noted above, studies within the psychometric paradigm have described a number of qualitative factors that are associated with risk perceptions. Many of these factors apply to public perceptions of radiation and nuclear power, which differ from experts in fields related to radiation and nuclear technologies (Hardeman et al., 2004).

It is useful to understand the 'risk profile' that is presented by radiation and nuclear technologies; however, it should also be noted this perspective leaves out contextual factors such as social dynamics and personal and political values, which are the most influential factors shaping attitudes to risk and acceptability.

Perceptions of the risks of radiation follow the pattern of qualitative associations (Ramana, 2011). The following are the key factors that are associated with non-experts' perceptions of the risks of radiation from various sources.

Risk of different sources of radiation: industrial, medical and natural

Radiation from nuclear power, and particularly nuclear waste, is perceived as high risk; nuclear technologies ranked very high on the 'dread' and 'unknown' scales created by Slovic (1987). Nuclear waste and nuclear weapons were considered to be the most serious of five nuclear and environmental hazards presented (Whitfield et al., 2009). MacGregor et al. (2002) consider that the perceptions of risk from radiation from all sources are disproportionate to the exposures that actually occur; these perceptions are related rather to concerns about the consequences of exposure to radiation and about risk management.

Other man-made sources of radiation, including medical x-rays, are seen as low risk. It is also a common finding that people are not concerned about radiation from natural sources, even when it may pose a relatively high health risk, such as radon gas in people's homes (Slovic, 2012; Hardeman, et al., 2004).

Risk-benefit relationship

Slovic (2012) attributes some of the reason for the high perceived risk of nuclear power and nuclear waste to the perception that they do not offer social benefits; this same balance explains the lower overall risks perceived from other technologies that use radiation.

Representative surveys of the general public in the United States, Sweden, Canada, Norway, Belgium, and Hungary have consistently shown that people view nuclear power and nuclear waste as extremely high in risk and low in benefit to society, whereas medical x-rays are seen as very beneficial and low in risk.

Radiation is 'unknown'; invisible and complex to detect

Most members of the public "have a modest understanding of facts related to nuclear energy" (Jenkins-Smith, 2011); conclusions differ on the impact of that level of knowledge on risk perceptions. Jenkins-Smith (2011) found that the more inaccuracies a respondent provided the greater was the perceived risk and opposition to nuclear power. On the other hand, efforts to provide information on nuclear power did not change attitudes to the technology (Ramana, 2011) or changed them slightly (Slovic, 2012).

In terms of the characteristics of radiation and nuclear power as hazards, radiation is invisible and undetectable by the senses; special instruments are required to detect the type and amount of radiation that may be present. This means that it is not possible to be certain that there is no radiation present, or that one is not exposed, and that individuals must rely on experts to measure the radiation and interpret the significance of the risk.

Involuntary exposure

As with many large scale industrial facilities, nuclear power plants may expose those in the vicinity to emissions from routine operations, as well as from spills, leaks and other accidents; there is little possibility for people to reduce or avoid this exposure.

Effects delayed and long-term; may affect future generations

The health effects of exposure to radiation, except at very high levels, are expected to be in cancer that appears years, or decades, after the exposure; cancer is itself a highly feared health impact. Genetic damage from some exposures may also result in adverse impacts on offspring, thus resulting in effects on children and on future generations.

Catastrophic potential

As seen in several severe accidents and disasters, the impact of an incident at a nuclear power reactor is catastrophic; the concern for potential consequences outweighs the consideration that such events are infrequent and have a very low probability of occurring.

These effects include both severe impacts on human health and devastation of the environment for large areas around an accident site. The Chernobyl disaster resulted in a number of immediate deaths and the more or less permanent evacuation of an entire region, displacing many residents and resulting in concerns for heightened frequencies of thyroid cancer in children. The events at the Fukushima plant in Japan following the tsunami in 2011 also illustrated the potential for impacts that are severe, wide-spread, and long-term.

Uncontrollable

When accidents occur with nuclear technologies, the impacts are not easily managed or mitigated, even by experts. The damaged reactor at Chernobyl must be encased in concrete to contain the radiation that it continues to emit, decades after the accident; and international experts were not able to bring the situation at the Fukushima reactor under control after it was damaged by the Tsunami.

Tampering with nature

A later elaboration of the psychometric paradigm has been found to improve the explanation of risk perceptions. Tampering with nature includes 'interference with nature' and 'human arrogance and immorality' (Sjöberg, 2000). When included in a study of perceptions of risk from nuclear power this factor was also associated with a fear of long-term consequences and 'a warning of worse things to come' (Sjöberg, 2000).

Trust in Management

As has been found in general risk perception research, trust in those managing nuclear technologies is a strong factor in support for the technology (Whitfield et al.; MacGregor et al.) found that a majority in the US do not think the risks of radiation are regulated adequately. They do not believe that the government has done all it could to protect them, and do not think that decisions about health risks should be left to experts.

In addition to these qualitative factors that have been associated with the perception of various hazards, it can be seen that the broader effects of stigma and social amplification apply to nuclear issues.

Imagery.

Nuclear power originated in military applications and was strongly associated with nuclear weapons through the 1980s. This negative imagery has persisted, and is more recently combined with images of the effects of the accidents and Chernobyl and Fukushima, evoking associations of 'disaster' and 'bad' (Slovic, 2012).

Associated with the factors of invisibility and tampering with nature, nuclear accidents and the emission of radiation appear more as 'contamination' than damage; they 'penetrate human tissue indirectly rather than wound the surface . . . invisible contaminants remain a part of the surroundings – absorbed into the grain of the landscape and the tissues of the body" (Slovic, 2012 quoting Erikson, 1990). These images are associated with industrial applications of radiation, but not with natural sources or medical applications.

Signal value and amplification

Nuclear power and related technologies are highly salient, and incidents and other events receive a great deal of media coverage and commentary. Yeo et al., (2014) suggest that perceptions are strongly influenced by media coverage of risk issues.

As evidenced by the increased concern reported following the Chernobyl and Fukushima events, nuclear plant accidents are subject to social amplification, and generate broader social impacts. The Fukushima events resulted in large public demonstrations calling for the closure of another nuclear power plant located close to a fault line (Ramana, 2011).

Stigma.

A large amount of research has been conducted on the potential for nuclear technologies, particularly nuclear waste facilities, to stigmatize a region (Ramana, 2011). Much of this was related to impacts that a proposed nuclear waste facility located at Yucca Mountain in Nevada could have on broader social and economic conditions in the state (Slovic, et al. 1991). This phenomenon has been observed in the Fukushima prefecture in Japan; produce from the affected region is avoided, tourism to the region has dropped, and school children from the area have been bullied by classmates (Slovic, 2012; Ramana, 2011).

Demographic characteristics

The effect of demographic factors on risk perceptions has been considered in many studies of perceptions of nuclear technology, and results are variable. They are generally found to have little explanatory power on perceptions of risk directly, though they do on a number of factors that influence the perception of risk (Whitfield et al. 2009). Others have found however that women are less supportive than men of the use of nuclear power (Stoutenborough et al. 2013), and to be more likely to perceive very high risks (Sjöberg, 2004).

General levels of education have been associated with higher perceptions of risk (Sjöberg, 2004) and with lower levels of perceived risk (Whitfield et al., 2009). However, while it is generally acknowledged that members of the public are not well informed on radiation or nuclear power (Ramana, 2011; Stoutenborough et al., 2013), it is not clear that this factor affects the perception of risk from nuclear technologies or support for their use.

Worldviews, values and political attitudes.

Most researchers of attitudes to nuclear power and nuclear waste disposal advise that the focus of attention should not be on the psychological aspects of perceptions or cognitions about risk, or about emotions, but on the broader attitudes that members of society hold in the context of political systems and processes and of their worldviews and values (2004; Yim and Vaganov, 2003; Kim et al., 2014; Sjöberg, 2003). Broader attitudes shape beliefs (Sjöberg 2000) and influence the interpretation of information (Yeo et al., 2014; Yim et al., 2013) rather than the other way around. Whitfield et al. (2009), in their study on the values-beliefs-norms model of attitude structure, conclude that:

> [T]he individual decisionmaker is neither an isolated, cold, calculating maximizer of the rational actor paradigm, nor is the "cognitive cripple" ruled by incoherent thinking once believed in the psychology of risk. Instead, the decisionmaker exhibits a rich combination of cognitive insight, social and emotional intelligence and cultural awareness, all anchored by fundamental values showing concern for others and the environment.

Within various theoretical frameworks and disciplinary methodologies, researchers are describing the values and beliefs that underlie, and shape, individuals' attitudes to nuclear power (Whitfield et al., 2009). Certain values and attitudes are associated with approval of nuclear power, and lower perceptions of risk from nuclear power, while others are associated with opposition to nuclear power and a higher perception of risk.

Whitfield et al. (2009) argue that "attitudes towards nuclear power are driven directly by the perceived risk of the technology and the levels of trust in the institutions responsible for managing it." As has been noted in research focusing on social trust, people show greater trust in those organizations with which they identify, and that share core values.

However, there are other direct and indirect links that explain this association. The perception of risk is affected by both education and by trust in organizations that manage the risk; and this trust is "a function of generalized beliefs or worldview about human impacts on the environment." The following are the important influences on attitudes to nuclear power:

- Individuals with more traditional beliefs have greater support for nuclear power:
    - Traditional beliefs include importance of family, patriotism, and stability, and are associated with less concern for the environment
- Those with more altruistic values are more opposed:
    - Altruism is "a concern for the welfare of other humans and other species" and is associated with higher levels of environmental concern and perceptions of ecological risk
    - Belief that nuclear technology 'interferes with natural processes' is predictive of opposition to nuclear power. 'Tampering with nature' associates a moral judgement of human arrogance with the technology (Sjöberg, 2000).
- Trust in those responsible for managing nuclear power is a major driver of support for nuclear power:

- Those showing greater trust in nuclear organizations are those with “less concern for the biosphere”
- Those who are more altruistic and have greater concern for the environment (with higher New Environmental Paradigm scores have less trust in nuclear organizations.
- Trust in ‘inspection authorities’ (in this case the IAEA inspections) is important for those who are ‘reluctant supporters’ of nuclear power (Kim et al. 2014), but this trust does not inspire strong support.
- Trust in science – a belief that science has solved the problem of nuclear waste disposal - was found to correlate with perceived risk (Sjöberg 2004).

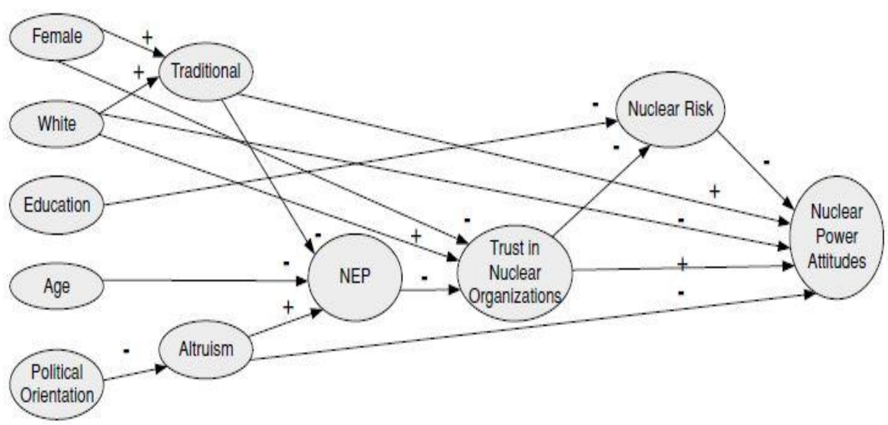

Figure 3. Whitfield et al., 2009. Stern-Dietz (S-D) values-beliefs-norms model of environmental decision making applied to nuclear attitudes. The direction of the association is shown as positive (+) or negative (-).

These attitudes and values have often been represented as basic political orientations, and associated with attitudes towards nuclear power. Yeo et al. (2014), for example, observe that conservatives are more supportive of nuclear power than liberals.

Decision making on nuclear issues.

While studies interested in attitude formation focus on psychological and cognitive processes, it is clear that people use a number of conscious and deliberate strategies in pulling together information and personal values and priorities in making decisions. This is closer to a policy analysis approach to understanding differences of opinion and in political priorities; Whitfield et al. (2009) describe the decision process employed by the public as 'social and deliberative'. People's attitudes to a technology are related to their valuing of the benefits they perceive from a particular application of the technology, in relation to its risks, in the context of their confidence in the motivations and competence of those who are responsible for managing it.

Sjöberg (2003) argues that people weigh a range of contextual factors when deciding on an issue of the use of technology. 'Substitutability' of technology was the predominant factor he found in a study of support or opposition to the continuation of nuclear power. Sjöberg argues that in Sweden, where nuclear power generates half of the country's electricity, people will become more accepting of the technology as they realize that there are currently no viable substitutes for the technology. Similarly, people in Japan are 'anxious about nuclear power' but also recognize that it is necessary (Tanaka, 2004; note that this study was conducted before the Fukushima events).

Pidgeon et al (2008) found that there was some support in the UK for increasing the use of nuclear power if it would help address the adverse impacts of climate change – but they emphasize that this response was highly conditional on the provision that the technology "would help"; and that the majority of the population remains opposed to the technology. Bickerstaff et al. (2008) similarly positioned nuclear power as a response to the impacts of climate change and found that the proposition was interpreted as a risk-risk scenario, in which people felt they could 'reluctantly' accept nuclear power if it would help offset the effects of climate change. Pidgeon et al. (2008) and Bickerstaff et al.

(2008) caution that attempts to reframe nuclear power as an environmentally advantageous technology relative to fossil-fuel energy sources appears opportunistic and manipulative and will likely fail.

Nuclear Waste.

The risks of nuclear wastes are commonly perceived to be even greater than those of nuclear power generation (Bickerstaff et al., 2008). In fact the problem of nuclear waste is often cited as a source of the concern about nuclear power, and members of the public state that they would give greater support to nuclear energy if the high-level waste storage and disposal issues were resolved (Jenkins-Smith, 2011). Because of this it is more difficult to find a location and construct a nuclear waste repository than a nuclear power plant (Tanaka, 2004). There is long history of opposition to attempts to site a nuclear waste facility in many countries, in most cases related to political contexts with the approval and use of nuclear power, with a number of failed efforts to site repositories and to change public opinion on them (Solomon, 2010).

Less research has been conducted on public judgements of nuclear waste than of nuclear power (Jenkins-Smith, 2011), although the studies on stigma carried out in the 1980s and '90s focused on the potential impacts of a nuclear waste repository on the society and economy of the state of Nevada. Nuclear waste is perceived to be highly stigmatizing, in terms of psychological effects, moral objections to nuclear power and water, and economic consequences (Marshall, 2005).

An early study of attitudes to a high-level nuclear waste repository in the US (Flynn et al., 1993) shows large differences between the public and members of the American Nuclear Society. A majority of the public believed there would likely be risks associated with the facility (such as earthquakes, accidents during operations, or sabotage or terrorist attacks); the strongest beliefs were that the buried based would not be contained to prevent underground water supplies, and that regulators “can [not] be trusted to provide prompt and full disclosure of any accidents or serious problems.” Imagery about nuclear waste was very negative, evoking thoughts of death and destruction.

Opinions of members of the America Nuclear Society were almost the inverse of the public opinions; however, both groups agreed that there would be accidents associated with the transport of wastes to the disposal site (Flynn et al., 1993).

Research on initiatives to manage nuclear waste in many countries has described a fairly consistent range of social and ethical concerns that have made siting a nuclear waste facility a very contentious and usually unsuccessful undertaking. People are concerned that there will be an accident, or that spills or leaks will contaminate surrounding land; accidents associated with the transportation of wastes to the facility are also a major concern (Marshall, 2005). Although the siting process in many countries involves inviting communities to volunteer to host a facility, through local political processes and plebiscites, many have questioned the objectivity of the information provided to the community and, particularly when financial compensation is offered, whether the consent is genuine or is a result of political or financial pressure. This concern is underscored by the fact that communities that are considered as potential waste facility sites are often remote and economically disadvantaged, so that residents may feel unable to reject a facility that they would otherwise oppose because of the promise of compensation and employment (Marshall, 2005).

In addition to these concerns about regional or social inequities in siting a nuclear waste facility, the very long time that the wastes remain hazardous and will require monitoring or management raises issues of intergenerational justice (Marshall, 2005). The consent for a facility that is expected in a democratic society can only be obtained from the present generation, yet many future generations who cannot give, or refuse, consent will also be affected by, and perhaps at risk from, the facility.

There is frequently some skepticism about the public participation in siting processes, partly as a result of the legacy of secrecy associated with historical nuclear technology decision-making, and partly due to challenges in mutual lack of comprehension between public and technical perspectives. There is often "public unease" about experts' claims of knowledge about long-term safety (Marshall, 2005), and a lack of trust in the nuclear industry and other risk management authorities.

A contrasting perspective is offered by the example of the successful process to agree to the development of a low-level nuclear waste facility in Port Hope, Ontario, which was driven by collaborative processes between the community, governments and the owners of the uranium refinery that had produced the wastes in activities from the 1930s to the 1970s (porthope.ca). Other factors that contributed to the success of the process were the familiarity with local people with refinery operations, the conviction that existing wastes should be dealt with, and the attention paid to the development of a 'comprehensive solution' that protected property values (NEA, 2003).

Attitudes of the general public to a proposed facility may not be easy to determine through a participatory siting process. This is because those who are more active in such processes – described in one study (Sjöberg, 2003a) as stakeholders – have stronger views and more extreme positions than members of the general public who are less active in such processes. Although stakeholders in a siting process in Sweden were not generally more risk-averse than others, they did have stronger concerns and more extreme views about the issue of nuclear waste disposal (Sjöberg, 2003a). Active stakeholders, both supporters and opponents of the project, had stronger opinions on risks and on benefits than the general public. Opponents perceived greater personal risk, expressed as a perception of damage to nature and new and unknown risk, and expected lower benefits from new business and government economic support associated with a facility. Supporters agreed that there would be benefits from the project and did not agree with the negative, risk statements. Stakeholders who were opposed perceived more risk, and less economic benefit, than non-stakeholders; stakeholders who supported a facility perceived less risk and more economic benefit than non-stakeholders (Sjöberg, 2003a).

More recent research has found that people generally prefer the centralized storage of nuclear wastes and are not comfortable with indefinite storage on the reactor site. The public expects very high levels of monitoring and environmental surveillance of interim storage, and is concerned about transportation of the wastes (Greenberg, 2012). Concerns about uncertainty, and skepticism about the adequacy with which it can be addressed through technical calculations and design, pertain to the uncertainty about future social and political conditions that will affect the way that the facility continues to be monitored or operated. Significant changes in social and political structures and conditions are inevitable but their nature is impossible to predict, and it is impossible even to be assured that facility warning information and symbols will be understood by people living in the area in hundreds or thousands of years (Marshall, 2005).

Opinions are also shaped by perceptions of benefits, and by policy and facility design factors. For example, a design that permits retrieval of the waste is generally preferred; and many people who had been opposed or neutral to the siting of a facility would support it if it were co-located with a research laboratory, which would both study improved ways to manage nuclear wastes and also reduce the stigma of the repository (Jenkins-Smith, 2011). Compensation to a community may increase support for hosting a facility – but only among those who were not previously opposed; such an offer actually decreased support among those who already opposed the project, to whom it appeared to be a bribe.

Some siting processes and related studies have found that communities that are close to a site appreciate the benefits of improved roads that the construction and operation of a facility would bring, and that communities that are closer to a site have higher approval (Jenkins-Smith, 2011). A positive siting process can reduce opposition and build support, as shown with the process to establish a repository in New Mexico (Jenkins-Smith et al., 2011). Greater success has been had in Scandinavia, with successful participatory processes and waste management (Solomon, 2010); Solomon recommends a greater role for social scientists and considerations of ethics and public policy processes in future research and siting processes.

Aboriginal perceptions of nuclear waste disposal

Farrugia-Uhalde noted in 2003 that there was very little research on Aboriginal attitudes to nuclear waste disposal (despite the fact that territory claimed and used by Aboriginal communities has been a major focus for the location of nuclear waste repositories that have been evaluated in Canada). In one of the few studies of Aboriginal perspectives on nuclear waste disposal, Hine et al. (1997) found that Aboriginal survey respondents were significantly more strongly opposed to a repository than the non-Aboriginal respondents.

Aboriginals expressed lower levels of trust in the regulators of the technology, and in science and technology than non-Aboriginals, and associated greater costs with the repository than others. Hine et al. (1997) suggest that the Aboriginals' "commitment to future generations" and to their responsibilities of stewardship of the earth explain much of the opposition to a nuclear waste repository, and is a major factor distinguishing Aboriginals' perspective on the facility from that of non-Aboriginals. This study also found that financial benefits that may be offered as a trade-off against the risk of a repository did not offset the opposition to the project among Aboriginals; this may be due to the very high level of risk perceived from the repository (Hine et al., 1997).

Farrugia-Uhalde (2003) reviews Aboriginal opinion on nuclear waste disposal by North American Aboriginals through an analysis of submissions made to the Seaborn Panel reviewing the concept for the disposal of high-level nuclear wastes. She found that the major issues that Aboriginal participants noted concerned respect for treaty and Aboriginal rights, spiritual and cultural values, the Aboriginal role in decision-making, and the lack of involvement of, and communication with, Aboriginals on the disposal concept.

Aboriginals recognize the risk posed by a possible nuclear waste repository as both a grave violation of the sacred earth and a threatened degradation of a culture. The notion of building a waste repository with potential effects for 100,000 years on the usual five-year planning horizon may be unimaginable to a people accustomed to making decisions with the seventh generation in mind. Other expressions of risk allude more specifically to the violation, by some more complex technologies, of a principle of nature as a threat in itself. A Lakota Sioux elder (quoted in Gowda, 1999: 138) warned that "the atomic force that binds the nucleus together is a sacred force; splitting the atom and transmuting matter is viewed as an intrusion in the realm of God and invites retribution." Placing toxic substances in nature is considered an affront to the sacred.

In addition to these cultural concerns Aboriginal interveners noted their concerns with deep geological disposal as a waste management option, and preferred the option of storing the waste above ground to facilitate monitoring and risk management.

Haalboom (2014) has noted in a recent analysis of Aboriginal participation in governance arrangements of uranium mining in northern Saskatchewan that perceptions of risk are described in terms of a lack of understanding of technical matters, often addressed through the provision of technical information. Haalboom (2014: 12) argues that this risk frame is "not benign" but rather renders "the development process as controllable, calculable and predictable, and those pursuing it as environmentally and socially responsible." Aboriginal participants counter by noting failures of technology and asserting their knowledge of local conditions, often making the dispute over 'techno-scientific' information central to the debate and controversy. While the governance process and provision of information are intended to engender trust with these Aboriginal communities, this dynamic does not achieve that trust.

SUMMARY: UNCERTAINTY AND ACCEPTABILITY

In the light of the observations that have been made through several decades of research on risk perception, particularly on the social and political dynamics that shape complex attitudes of the public and experts to technologies, perceptions of the risks they pose and benefits they offer, and trust in managers, several concluding observations may be made. These observations relate to the role of uncertainty in the controversy over the debate on nuclear waste disposal, and to the issue of the ultimate support of local communities and the public for a nuclear waste repository.

Uncertainty.

The public is concerned with uncertainty in the performance and safety of proposed facility, but their interest in it is not the same as experts'. The reason for this can be found in some of the factors that influence risk perception, as well as in more social and political attitudes and priorities.

First, non-experts tend to be less concerned with the likelihood that an adverse consequence will occur than they are with the significance of the consequence itself. This is clearly true of nuclear power, with the very rare but undeniably catastrophic accidents that have occurred, notably Chernobyl and Fukushima. With respect to nuclear waste, people recognize that there are a number of very serious impacts that could occur with a technology that must keep long-lived hazardous wastes contained and 'safe' for hundreds or thousands of years. A large part of the concern with the attention to consequences is the value of the people or ecosystem elements that could be affected.

Second, when non-experts think of uncertainty they are likely to think of the possibility that something may occur, even of various degrees of possibility; they are less likely to be interested in calculating and comparing detailed quantitative probabilities. There will inevitably be significant uncertainty with the long-term responsibility of containing nuclear waste; this recognition, combined with the serious consequences that could affect a highly valued environment, renders redundant the quantification and comparison of uncertainties related to certain functions of the facility.

Third, uncertainty may relate to people's lack of familiarity with a very complex technology, and to concern with the prospect of deep burial, out of sight, of materials whose hazardous properties are invisible. This requires that people delegate the management and oversight of the technology to experts and professional risk managers, as non-experts have very little means of evaluating the performance of the facility themselves. However experiences with processes to assess proposed facilities often make it clear that the experts involved do not share the values of many in the public with respect to the use of nuclear power and the siting and operation of the waste disposal facility; these experts therefore do not have the trust of those groups. Furthermore, there is skepticism that science, and risk managers, are capable of predicting and preventing the adverse consequences that may occur.

Two crucial things are known about a proposed nuclear waste facility: it holds the potential for serious harm to the environment due to the toxicity of the waste material and the long time-period over which it must be managed; and the combinations of events – including social and political changes – that might occur in tens or hundreds of years to cause such harm are unknowable. The uncertainties pertain to 'unknown unknowns' that may occur over such long time-frames that they are essentially irreducible; efforts to quantify them suggest a focus on the wrong issue, and an investment of greater confidence in the process and results of quantification than is deserved.

The presence of such 'large unknowns' and disputes over the meaning of uncertainties is characteristic of amplified risk controversies: Leiss (2003) notes that in risk controversies "incomplete hazard characterization," uncertainty over the range of adverse effects the public should be worried about" can be "compounded by the propensity of spokespersons for industry, often seconded by their governments counterparts, either to downplay or deny the scope of the hazards." Addressing risk controversies requires attention to the social and political dimensions of the controversy, or 'risk issue', as a separate managerial competence.

Acceptability and Tolerance.

The concept of 'acceptability' used in relation to the public attitude to the proposed facility refers to a judgement made collectively, or by a majority of the public, that the waste disposal technology can be accepted by the community at that site. It is clear that in most efforts to site a nuclear waste facility such acceptance is not achieved, and where community support has been achieved it is the result of long and carefully conducted processes of consultation with the community in which priorities for addressing risks and benefits are established.

There are a number of critical factors in the development of community support for a facility that are not reflected in the relatively simple term of 'acceptability'. Risk management principles developed by the Health and Safety in the UK make a distinction between acceptability and tolerability that is relevant to the context of nuclear waste disposal (HSE, 1992; HSE, 2001).

In this usage, an acceptable risk is one that is deemed to be low enough that no management is required to reduce it. This is not the kind of support that has been achieved in nuclear waste facility siting processes, or indeed in most applications of complex technology.

The type of support that has been achieved is better reflected in the concept of tolerance: a tolerable risk that is one that is *managed*, and is tolerated at the managed level *in light of the benefits received*. This concept may be more appropriate to the evaluation of public support for a nuclear waste disposal facility, as it retains the notion of negotiated trade-offs and ongoing relationships and responsibility. As the desired outcome of a community siting process, it directs decision-makers' attention to the important relationship between risks and benefits, and to the responsibility of risk managers to attend to that dynamic, ensuring that benefits are received and valued, by those bearing the risks, and that risks are managed to an appropriate level.

The toleration of a risk is conditional – as is the 'reluctant acceptance' of nuclear power as a response to climate change – on both the reception of benefits and on the appropriate control of the risks. The risk is not simply accepted as low enough that it is not a concern, a handing of the issue over to risk managers for them to manage as they see fit.

This conditionality means that the performance of risk managers will be scrutinized; they will not be trusted blindly to manage a nuclear waste facility. The trust that the public will place in risk managers will be "critical trust" (Walls et al., 2004), an "active trust' in which "self-confident and active citizens assess the claims of experts and institutions" (Walls et al, 2004; Taylor-Gooby, 2006). Active, or critical, social trust incorporates critical attention to, or monitoring of, activities and institutions as an essential complement to the delegation of responsibility for risk management; it functions both to manage the social complexity and to monitor the competence of those entrusted to manage the risk and ensure that they remain aligned with social values and expectations.

With this in mind, it is to be expected that achieving tolerance of the risks of a nuclear waste disposal facility will require that the public receive, and acknowledge that they receive and value, benefits from the facility; it will also require that they have evidence that facility proponents, designers and managers share their concerns about the hazards and their valuation of the environment that may be at risk and plan and manage the facility with those values in mind. Continued tolerance of a nuclear waste facility will require that management facilitate public scrutiny of the facility and its management through being open, with stakeholder participation, provision of relevant information and reliable notification of any problems that occur.

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Chapter 25

William Leiss, Tom Isaacs, Greg Paoli, and Maurice Dusseault

Report of the Independent Expert Group on Risk Perceptions of the Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario

Submitted to:

The Joint Review Panel for the Deep Geologic Repository Project for Low and Intermediate Level Radioactive Waste (DGR)

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You may obtain a separate PDF file of the Original Report from The Canadian Environmental Assessment Agency at:

http://www.acee-ceaa.gc.ca/050/documents/p17520/99177E.pdf

TABLE OF CONTENTS

Section I: Introduction

This Report was prepared in response to a communication, dated 6 March 2014, from the Deep Geologic Repository Joint Review Panel (JRP). In this communication the JRP asked the Independent Expert Group (IEG) to consider the following issues:

1. "…[T]he Panel expects that there be a comparison of *risk perception* (and thus, risk acceptability) among the four options…. [T]he Panel suggests that the Expert Group focus on uncertainty. This is because the technical risk analysis of the four options will have a direct link with the analysis of the effects of the technical uncertainty on risk perception."

2. "Many submissions [to the JRP] presented comparative risk perceptions and risk acceptability among status quo, enhanced surface storage and deep geologic repositories. These submissions, together with information in the published literature and the Expert Group's analysis and professional judgement should be used to produce a relative risk perception/acceptability score for the four options."

3. "…[T]he Panel would encourage the Expert Group to comment on how risk perception among Aboriginal peoples might better be acknowledged and incorporated."

4. “The Panel expects that the analysis then go forward with further consideration of the *perception* of each of the four options, as influenced by the relative degree of technical uncertainty associated with the primary uncertainty issues listed above.”

5. "The Panel maintains that use of a combination of evidence provided by submissions as well as published literature is sufficient to discriminate among the options if the Expert Group focusses, as is suggested above, on the effects of relative uncertainty on risk perception and risk acceptability."

In this supplementary Report the Independent Expert Group has sought to respond in detail to the issues and perspectives on risk perception and risk acceptability raised by the JRP. We have done so in the following way: First, we have commissioned a full background study of the published literature on all of the general topics raised in the JRP letter (risk perception, acceptable risk, and uncertainty as a factor in risk perception). Since there is a large literature on the recent treatment of these subjects, dating back to the 1970s, the background study is extensive; therefore, we have given a short summary of the study in Section II below, and have placed the complete study in Chapter 24.

Second, in Sections III and IV we have provided an overview of our understanding of risk perceptions of the four options, currently being discussed, for managing low- and intermediate-level nuclear waste in Ontario. These risk perceptions treat separately the views of Aboriginal interveners in this discussion, on the one hand, and all other interveners, on the other. Our selection of material in our two overviews was made using a software-based search routine of all the submissions made to the JRP as well as the transcripts of hearings conducted by the Panel. Finally, in Section IV we present our Observations and Conclusions with respect to the issues and perspectives raised by the JRP in its letter of 6 March 2014.

SECTION II
RISK PERCEPTION OF NUCLEAR WASTE DISPOSAL: EXECUTIVE SUMMARY OF THE BACKGROUND STUDY

Risk Perception.

Risk perception has been studied from the point of view of decision-making under conditions of uncertainty, qualitative factors associated with risk sources, demographic and psychological factors, and broader contextual factors relating to individuals' social values and their trust in risk managers. There are findings relevant to perceptions of risk from radiation, nuclear power and nuclear waste disposal at all levels studied in the field.

Radiation from industrial sources is commonly found to be considered a very high risk by non-experts, associated with the possibility of accidents with fatal and catastrophic consequences, with little attention to the low probability that such accidents will occur. Risks from nuclear power are perceived to be unfamiliar and not observable, imposed on the public and not easily avoided or reduced. There is also a sense that nuclear power is immoral, as it is seen to interfere with nature.

Nuclear power is often identified in terms of its high risk without consideration of its benefits, as individuals – experts and non-experts alike – frame an activity as predominantly a risk or a benefit and downplay the significance of the other side of the balance. The framing of nuclear power as a risk is associated with a more general negative perception of large-scale industries that impose risks on the public, while producing benefits that are diffuse and may not be experienced directly. This framing process is also seen in situations of higher risk that are tolerated because people experience, and value, benefits from the activity or use of a substance.

While commonly observed perceptions of risk from nuclear power and nuclear waste correlate strongly with a range of qualitative factors associated with the risk source, as well as demographic and psychological factors that influence individuals' judgements, the most important factors that influence perceptions of nuclear power are people's broader attitudes and values. These general attitudes and values shape more specific perceptions of risk from an activity, and the response people have to information on the activity as well as the trust they have for risk managers. Perceptions of the risk of an activity are associated with certain 'worldviews', political values and belief systems, and are stable components of a person's general social orientation and outlook. People who hold 'ecological' values, for example, are more likely to perceive technology to be a risk and to oppose large industrial technologies such as nuclear power.

These value systems also shape the trust that individuals have in information, information sources and risk managers. Particularly where a risk judgement relates to an issue of high value or political concern, people trust managers whose values are similar to their own, and who can be trusted to act in their best interest. Judgements about risk are complex determinations made in the context of individuals' knowledge and experience, their attitudes and values, and their social relationships. They are thus partly social phenomena, subject to interactive processes and broad social impacts. Judgements about a risk often become 'amplified'; that is, they may become the focus of heightened interest and concern, through processes of information interpretation through the filtering of information through personal values and social interactions, such that they result in 'ripple' effects that can affect society more broadly. One such effect is that of stigma, in which very negative imagery associated with a risk or activity is attributed to related activities or to an area in which a facility perceived as dangerous or undesirable is located. Stigma effects have been seen frequently in relation to nuclear waste facilities, when the location of a facility is seen to have adverse impacts on the local economy when other businesses perceive the area as undesirable.

Nuclear power, and in association nuclear waste disposal, are highly charged issues that engage people's values and social priorities. People are concerned about the risks of accidents, and often do not trust the organizations that manage it. These attitudes and value priorities persist when possible advantages of nuclear power are discussed, so that people may negotiate a 'conditional' or 'reluctant' acceptance of nuclear power if, for example, it may be advantageous in offsetting the effects of climate change.

Perception of risk within Aboriginal cultures.

The cultural values and priorities that shape risk judgements of Aboriginals, while they vary among different Aboriginal cultures and communities, are distinct from mainstream Western culture. The dominant priority is the cultural value of the land, generically as a spiritual entity and principle, and specifically as traditional territory to which a community is tied through history and material practices such as traditional harvesting. The integrity of the community and its culture depend on the continuation of traditional relationships with, and practices in, its territory, placing a primary focus in risk judgements on potential effects of a nuclear waste repository on the continuing integrity of the land.

Aboriginal communities may also have a different social structure than mainstream society, with a more participatory and inclusive means of decision making that reflects high degree of respect for community elders. They often have a traditional, more experiential approach to knowledge and to understanding the world that may be inconsistent with Western traditions, and particularly with science.

Perceptions of Nuclear Waste.

Nuclear waste is commonly perceived as a very high risk, even higher than nuclear power. This is partly because no benefits are perceived with nuclear waste, and there are concerns that communities that host a nuclear waste facility may be subject to stigmatization. Nuclear waste remains hazardous for a very long time, requiring monitoring and management processes that are unprecedented in human history. People often frankly reject scientific claims that the risks can be assessed and managed for such a long period into the future, and that a facility can be designed to contain the wastes for that long a period. Because of the timeframe nuclear waste facilities appear to place an inequitable burden of risk, and responsibility for management, on future generations, who cannot consent to the facility.

Aboriginal communities in particular may consider the placing of toxic waste in the earth to be an affront to the sacred, and, in the context of the multi-generational perspective that many Aboriginal cultures take in their actions on the environment, they may be more averse to the long-term threat posed by the wastes.

Efforts to site a nuclear waste repository have frequently been contentious and sometimes fail. More recent efforts in several countries have focused on the selection of a site through a participatory process within volunteer communities, resulting in successful attempts to site a nuclear waste facility. Financial benefits, such as stable employment opportunities and increased commercial property tax revenues, are of course available to communities which agree to host a facility. Such benefits are regarded as appropriate by those who support nuclear facilities, but may be interpreted as exerting inappropriate pressures on smaller or remote communities by those who do not.

Conclusions on the Concepts of Uncertainty and Acceptability.

Experts make an effort to quantify and compare the uncertainties in various facility components and designs, and of different event scenarios, as a core consideration in a decision on the location and management of a repository that must contain nuclear wastes for thousands of years. Non-experts, however, are not interested in quantifying uncertainties, and are more likely to refer to unknowns, asserting that many factors are simply unknowable over such long time-periods. Instead of quantifiable uncertainties, non-experts are more concerned with the consequences that are possible. In addition, they are concerned about the need to delegate responsibility for designing, operating and monitoring such a facility to experts who often do not share their concerns for the risk or their value for the environment that is vulnerable to the risk.

The determination by a potential host community that a facility is acceptable is often seen as the desired endpoint of a participatory process. The background report argues, however, that acceptability suggests an unrealistically simple concept of a generalized consent to proceed. The importance of the recognition of benefits and of the 'conditional' acceptance that has been observed among those who do not support nuclear power, suggests that agreement to host a facility is a more complex decision. The concept of tolerability has been used in other risk management contexts to express a risk that is actively managed to a level that is deemed appropriate in light of the benefits that are received from the activity. This multi-dimensional concept directs attention to the conditional or reluctant acceptance that may be granted by community members who acknowledge the value of a facility while they still have concerns about it. It reminds decision-makers and participants that ongoing attention to benefits and to risk management is an integral part of the decision-making and future management processes.

SECTION III
POSITIONS ON THE PROPOSED PROJECT EXPRESSED BY NON-ABORIGINAL

INTERVENERS TO THE JOINT REVIEW PANEL

Submissions to the Joint Review Panel were made by individual members of the public, Environmental Non-Governmental Organizations (ENGOs), community associations, and others; most are based in Canada, and a few were based in the United States. Individuals and representatives of groups also made oral interventions during public hearings before the Panel. Submissions made on behalf of Aboriginal Peoples, as well as oral interventions made at public hearings by representatives of Aboriginal Peoples, are considered separately in Section IV.

The record of submissions and hearings transcripts were searched for statements and expressions of views relevant to the perceptions of risk associated with the management of low- and intermediate level (LILW) nuclear waste in Ontario in general terms. These documents were also searched for statements and expressions of views relevant to perceptions about various methods of storage and disposal of such wastes and, in particular, to the proposal to construct a Deep Geological Repository (DGR) at the Western Waste Management Facility (WWMF) on the Bruce Nuclear site.

In this Section we present what we believe is, in an informal sense, a representative sample of these views. However, since we did not conduct a rigorous analytical examination of the documentation available to us, the generalizations that are made in the following paragraphs should be regarded as being examples rather than systematic patterns; thus individual exceptions could be found which are not encompassed in these generalizations. This snapshot, therefore, should not be taken as a complete account of the views expressed.

In general, the views expressed to the Panel in submissions and oral interventions reflected a wide spectrum of public opinion on the substantive matters under discussion. So far as the main issue – the need to provide for safe storage of nuclear LILW – was concerned, views ranged from strong support for the specific DGR proposal now under consideration, on the one hand, to a refusal to entertain storing the waste "anywhere on the planet," on the other. So far as the subsidiary issue – what specific management option for storage and disposal of this waste is the preferred one – was concerned, views ranged across all a wide variety of potentially feasible options: "as-is" at the existing WWMF, a concept of "hardened" surface storage, the proposed DGR at Bruce, and storage in a suitable facility "somewhere else" in Ontario.

It must be emphasized that our primary interest in examining these materials was not in discerning the spectrum of proposal solutions for the management of LILW nuclear waste in Canada, as expressed by interveners to the Joint Review Panel. Rather, we have sought to understand the public perception of risks in Canada that is associated with the accumulation and management of nuclear waste, and of the four options discussed in our earlier report, in accordance with the directive in the JRP Letter. The background study we commissioned on this subject (Section II and Appendix A) was designed to provide us with some analytical tools in this regard, which we could utilize in examining the submissions and interventions by members of the public.

Many of the published academic studies on public perception of risk are based on exercises using hypothetical settings or questions in order to elicit the underlying structures in people's reasoning about risk situations, structures that otherwise remain tacit and unarticulated. Sometimes these are called "mental models.") The results, as presented in the Background Study, reveal quite stable patterns of thinking about risk across populations and countries, on the basis of which robust inferences can be made about how any random cross-section of the public might be expected to react to a new situation, presented to their communities, involving a complex technology that is intended to deal with a complex problem in risk management.

This is exactly the situation in the Bruce Peninsula, where a network of small communities near the shores of Lake Huron in Ontario have been presented, for the first time in Canada, with a proposal to inter hazardous radioactive materials in an engineered facility deep underground in close proximity to their homes and businesses. Few phenomena in nature are complex as the electromagnetic spectrum, along which are found both enormous benefits (the combination of visible light and invisible radiation from the sun, and the electromagnetic fields that make wireless technologies, including cellphones, possible) as well as lethal threats (poisoning from radioactive particles). And the long periods of radioactive decay require complex technologies to contain those dangerous products, involving (in the DGR proposal) the combined capacities of both engineered and natural barriers.

Those responsible for designing the technology needed to respond to a particular challenge – in the present case, storing nuclear LILW – are required to use the tools of formal risk assessment to make the case that they can do so safely. This task involves the following steps, among others:

1. Describing the nature of all the hazards (potential harms) completely;

2. Specifying all the pathways of possible exposure, for humans and the environment;

3. Estimating, quantitatively, the probability (P) or likelihood of exposure for each pathway;

4. Estimating, quantitatively, the consequences (C) or impacts in those possible exposures;

5. Estimating, quantitatively, the uncertainty ranges for those estimates, at the 95% confidence interval;

6. Constructing an elaborate algorithm to summarize across all pathways an overall estimation of risk (R = P x C);

7. Presenting options for controlling risk within acceptable parameters (for example, dose limits for exposure to radioactive substances);

8. And so forth.

This is the kind of language used in the technical "discourse on risk" for formal risk assessments. [The benefits associated with successfully storing radioactive waste safely – which are the benefits derived from continuing to use nuclear energy to generate electricity – are assumed in this scenario. In this case the risks of handling radioactive materials are thought to be "outweighed" or exceeded by the associated benefits by a very substantial margin, and taking any such risks can be justified only by the level of benefits.]

This is not at all the language used in most of the public discourse on risk on storing nuclear LILW. The contrast here may be seen if we summarize the general themes found in the submissions and hearings, which are illustrated in the following paragraphs. We wish to emphasize strongly the point that, in making this list, we are in no way suggesting or implying that the modes of reasoning used in the public discourse are incorrect or inappropriate, or are less compelling than those found in the technical discourse. What is important to note is what is *not* articulated, as well as what is clearly expressed. These general themes are as follows:

A. Risks associated with handling and storing radioactive wastes are considered entirely separately from any benefits derived from nuclear power: In other words, for those opposed to the DGR proposal (for whatever reason), risks and benefits are never mentioned together.

B. Risks associated with handling and storing radioactive wastes are considered only as a discrete problem, and are not framed on a comparative basis with the risks of alternatives to nuclear power for electricity generation (for example, coal-fired generation stations).

C. Opponents to the DGR proposal do not, for the most part, place their opposition in the context of more general set of social values, but rather treat this issue in isolation (in contrast with the Aboriginal perspective, as described in Section IV).

D. When comparing different options for managing nuclear wastes, interveners usually do not express the comparison in terms of their perception of relative risks, preferring instead to make certain general observations (for example, criticizing the DGR as exemplifying the maxim, "out of sight, out of mind").

E. Probability or likelihood of harm is never quantified.

F. Consequences of adverse effects are never quantified.

G. Uncertainty is never quantified, and is usually treated as equivalent to "unknown."

As a generalization, and acknowledging explicitly that there are many individual exceptions to it, one is obliged to conclude that the two discourses about risk – the technical and the public – have very little in common. Although they are both referring to the same managerial issues and technologies pertinent to nuclear waste, they have fundamental differences in the way that conclusions about those issues are arrived at and the kinds of reasoning used to support those conclusions. These differences are well-illustrated in the following extracts from the materials in submissions and hearings, which are referenced only with the number citations in the NWMO files; no quotation marks are used, but they are all direct quotations from the record. [We wish to emphasize strongly the point that, in making this list, we are in no way suggesting or implying that the modes of reasoning used in the public discourse are incorrect or inappropriate, or are less compelling than those found in the technical discourse.]

Risk Perception:

- …[M]embers of our community, after five generations in the Hamlet of Inverhuron, will be forced to leave due to the impact of noise, pollution, a feeling of insecurity due to possible accident or malfunction of the deep repository and the lowering of property values due to stigma. (846)

- The risk perception of those who would buy agricultural goods, visit, or purchase a cottage in the area may be shaped by the notion that Kincardine is a nuclear oasis. The research that OPG has done around stigma, because it is limited to the local study area and immediate municipalities, is unable to capture these complexities. (1363)

- …[T]he DGR does represent a hazard with perceptions of high risk consequences*. All the cards and letters sent to CEARIS from ordinary Canadians and Americans, from Michigan to California, from service organisations like the Provincial Council of Women of Ontario, speak of the dangers of storing these wastes so close to the lake. ...* (944)

Risk Acceptability:

- The radioactive threat to the Great Lakes -- 20% of the world's surface fresh water, and drinking water supply for 40 million people -- is unacceptable on its face and must be cancelled immediately. You cannot risk such an environmental and health disaster. (524)
- I am therefore skeptical of the phrase "acceptable risk" when the likelihood of an incident is low, but the consequences if it does occur are shattering. (1380)
- Lake Huron is not only one of our treasured Great Lakes, but it provides fresh water, recreational opportunities, habitat for a large diversity of eco systems and species, and living space for millions of people on both sides of the US/Canadian border, which are all at risk should containment of the proposed repository fail, due to human error, systems failure, geologic conditions, or other catastrophic events. These unacceptable risks will not be confined to the life of the waste site, but will last for many thousands of years, (75)

Adverse Consequences:

- [T]he effects of the event are unbounded: *especially with a time frame extending into the hundreds of thousands of years*. (944)
- The site fault: Did OPG also mention the fault in the area that the DGR would be built on? A small earthquake could very well widen this fault and thereby weaken or breech the integrity of the DGR. Result? Game over for 40 million people who rely on the fresh water from the Great Lakes. And possibly for the children who will be at risk for nuclear-waste induced illnesses, deformities and cancers. (1104)
- I am here today because I feel that the proposal of a Deep Geological Repository no further than 1.2 kilometers away from Lake Huron, the second-largest of the Great Lakes, is a mistake. I feel that this is an unsafe and unreliable venture in which the potential for accidents is being grossly downplayed. (1653)

Probabilities:

- Since radioactive waste has to be kept completely contained for such a long time that it might as well be forever, not only does Murphy's Law become inescapable, but many of the scientific tools we habitually use become useless. Probabilities no longer apply, because everything that has more than an infinitesimal probability is going to happen sooner or later.

- Mathematical models of the containment system no longer apply, because they can't possibly take into account everything that might happen over such a long-time period accurately enough to make reliable predictions. Worst of all we cannot do scientific experiments to test and improve these models, or any proposed containment system, because such experiments would require millions of years to produce valid results. (1403)

- No increase in radioactivity exposure during the construction and long-term operation of the proposed DGR is acceptable. OPG states in their documents that the DGR "is not likely to result in any significant residual adverse effects to human health or the environment, including Lake Huron and the Great Lakes". "Not likely" is not a reassuring answer and presents too much uncertainty. How will a DGR for nuclear waste beside our drinking water result in a healthy outcome for ourselves and future generations? Where is the Precautionary Approach? (1373)

- Since radioactive waste has to be kept completely contained for such a long time that it might as well be forever, not only does Murphy's Law become inescapable, but many of the scientific tools we habitually use become useless. Probabilities no longer apply, because everything that has more than an infinitesimal probability is going to happen sooner or later. (1403)

Uncertainties:

- Because of the long-term and possibly unrecoverable consequences of an accident or leak resulting from faulty or unforeseen research, **no ambiguities or uncertainties** should be acceptable concerning the burial of nuclear waste. **Anything less than that is risk-taking.** (1051)

- In summary OPG's proposed DGR increases the likelihood – albeit a very tiny likelihood- that Lake Huron waters could be contaminated by radionuclides at some point over the next 60 to 1,000,000 years. OPG has advanced extensive explanations in its proposals and responses to information requests to argue that the likelihood is very small. Nevertheless, uncertainties remain that cannot be eliminated or even reduced at present. (1374)

- The areas of uncertainty are around the characterization of the geology, the effectiveness of the containers (none proposed, in this case), the estimates of corrosion and gas buildup, the reliability of the computer models, etc. These are all areas of uncertainty in this case, as in others…. The preferred alternative is that which reduces these uncertainties, and retains the option of pursuing a sounder and more secure option in the future. That means continued storage at site, in engineered containers which can be monitored, performance can be measured, and the containers can be replaced or re-encapsulated if needed - as needed - at some point in the future. (1395)

- Therefore, I am deeply concerned for the danger caused by burying this low and mid-level radioactive waste because over such a long-design life, we don't know what will happen. The DGR risks the contamination of Lake Huron and all of Canada's heartland. Water from Lake Huron feeds into Lake Erie and Lake Ontario, so tens of millions of human beings downstream will also be affected. (675)

- As such, key questions include, how such material would be able to re-enter the human environment? What conduits are available, in terms of permeable rock formations, fault zones, fracture zones (which may have no fault movement along them), and deep groundwater circulation? There is further uncertainty as to how the nuclear waste will interact with the barriers (i.e., corrosion of the barriers, the releasing of gases), seismic or glacial activity, and how radioactive material will react in a closed environment. Again, we must ask - where is proof of safety? (1395)

Preferred Location "far away":

- Is it necessary to take ANY risk, when a DGR can simply be located somewhere else far away from the Bruce Nuclear Power Plant, and far away from Lake Huron or any of the Great Lakes, where these risks are not present? (713)

- The storage dump should be located in granite, in an area which is not subject to earthquakes, and away from our fresh water, and away from densely populated areas. (985)

- So the best possible scenario would be OPG abandoning the present site for a less risky site in the Canadian Shield, in order to guarantee that we keep the Great Lakes and all the interconnected waterways free of the possibility of nuclear waste contamination. This will be of ultimate benefit to the vast majority of Canadians and our American neighbors, whom also have a very great stake in the continuing good health of the Great Lakes. (1104)

- International experts agree that radioactive waste is best stored far from people, animals and water sources. Ignoring this broadly held and logical conclusion, the plan to construct the DGR in our region, the home of many picturesque small towns, an area reliant on agriculture and a vacation destination for tourists, defies responsible planning principles. (1370)

"Out of sight, out of mind":

- Spend money thoughtfully and usefully, and in the next 40 to 100 years figure out a useful way to use this waste. Figure out one solution for all nuclear waste -- low, intermediate, and high level. Never in life can you bury your problems and think that they will not resurface. Nuclear waste is no different. Out of sight is not out of mind. (683)

- And therefore, we would recommend that in the absence of permanent safe solutions, society can best meet its obligations to protect the biosphere from existing nuclear waste through longer term management based on surface or near surface monitored and retrievable storage. In other words, in sight and in mind with visible institutional controls and monitoring, that in fact, the average public could take an interest and have some ownership in as well to ensure that we have adequate funding, adequate care. (1631)
- In summary, the risk of burying low- and intermediate-level nuclear waste "out of sight" and potentially "out of mind" of future generations is simply an unacceptable risk to take. It is prudent to assume, based on other precedents, that breaches of containment will occur…. Continuous surface or near-surface containment with institutional monitoring and retrieval capability is the precautionary route to take. (1273)

Preferred Option "As Is":

- If it is safely stored now, as you say it is, continue to do it that way. Why rock the boat into the unknown with the concurrent risks of leaks and disaster. Fortify even further the storage currently and in the future above ground at-site. Hopefully, it can be recycled some *way,* without trying to bury it to eternity with all the unforeseen risks below the surface of the ground, with accompanying negligence in building materials and workmanship of the DGR over time, and old age of the structure deteriorating with time as all structures (natural and man-made) ultimately do, in addition to all the inherent transportation risks. (1389)

- So there's a few factors. If you're going to do surface or accessible, retrievable waste storage, you have to keep a population aware that this is happening. And as Dr. Harvey said, you have to have monitoring, you have to know it, you have to be able to repair it and so on. That is easier -- "easier" -- than something that is deep underground that you then have difficulties retrieving without causing more damage. (1593)
- This process is flawed and on OPG's own evidence, the status quo is the preferred option before you today. It will remain the preferred option until science can prove the same certainty as safety as the status quo has proven over the past 40 years. (1685)

"Abandonment":

- The concern is institutional control and the lack of possibly institutional control in abandoning a site of this nature. How are you going to alert future generations? How are you going to avoid any intrusion if the site is not being monitored, abandoned forever, which is one of the major problems with this DGR proposal is abandonment. You cannot abandon something of this nature and ensure that if there is a problem where is the control? What if there is impairment in institutional control? What if there's no funding anymore to provide this? What if there is no memory of what this was, retained? How is this going to be looked after considering the long-lived radionuclides? So that is one of the major problems with the concept of the DGR and in this particular case, that abandonment phase. (1593)

- Nuclear waste must never be abandoned. It must be kept in engineered facilities where it will always be monitored -- forever be monitored and retrievable should containment fail. There must be zero tolerance for the escape of radiation from the storage facility. We have no right to impoverish or imperil the lives of our children and grandchildren and all future generations with any increase in exposure to ionizing radiation. (1606)

Deep Geologic Repository:

- Imagine when an earthquake starts breaking your underground cavern apart. Who will go down there to retrieve the nuclear waste and bring it to the surface as the walls break apart, water flows in and the sealed containments crack apart? Will you? I doubt anyone will be able to stop such a calamity. The waste will go into the Great Lakes. It will flow out into the ocean. It will kill the life in the lakes, the people near the lakes, and it will stop people from enjoying the lakes, making a living from the lakes, and transportation on the lakes. (1152)
- It only makes sense that placing medium level waste in sealed containers, far underground in structurally sound rock and monitoring them makes more sense than having it near the surface where acts of terrorism or acts of nature i.e. tornadoes, floods etc, could cause the release of the waste to more readily affect the public safety. (1361)

- In one-on-one conversations, several persons mentioned the need to support a DGR, especially after the events of the Goderich F2 tornado and, therefore, we agree with the assertion of OPG that a DGR is more secure than the current aboveground storage for the existing waste and the waste to be generated in the future. (1618)

- Nothing is immutable, not even rocks. Containers of this waste will inevitably corrode. Cracks and fissures will develop in the rock formations and widen over time. Water and gas contaminated with radionuclides will flow through the cracks and penetrate the barriers in the repository. Chemical and microbial processes and interactions will occur that could further erode the barriers. Climate change, glaciation, and earthquakes could severely destabilize the repository. And then, there is the possibility of accidental and even intentional intrusion into the repository. (1387)

These excerpts illustrate many of the general points about risk perception that are referenced in the Background Study:

1. Public risk perceptions especially where risks are thought to be high, tend to be strongly influenced by the factors listed under the categories of "dread" and "unknown" risks.

2. Where modern technologies are concerned, risks are uppermost in most people's minds, and people are not strongly influenced by the benefits derived from those technologies (page 6).

3. Many studies show that "people's perception of the risk level of an activity is related to their trust in the authorities who manage it" (page 7), and this influences judgements about risk for projects with heavy involvement by industry and government.

4. Risk judgements are influenced by "broader social and political attitudes and values" which are relatively stable over time and thus are not change with new information (page 10).

5. The process whereby attention becomes focussed over protracted time-frames on particular risks, through small group interactions and media coverage, can result in an amplification of perceived risks (page 12).

Note IR EIS-12-513a – Keyword Searches

A specialized software program, dtSearch Desktop version 7.72, was used to perform global searches throughout all items on the CEAA Registry posted up to the end of February 2014, up to and including CEAA Registry Doc# 1831. Items posted on the CEAA Registry with specific comments on the Environmental Impact Statement Guidelines were not included.

For each of the four options identified in IR EIS-12-513, combinations of specific keywords were used to find any references to the risk perception and/or acceptability of risk associated with the primary uncertainties specified by the Panel (*JRP Letter Reference*), for the public and Aboriginal groups in submissions and interventions during the public hearing/meeting sessions. Boolean searches were used to find structured groups of keywords linked by connectors such as *and*, *or*, *w/30* ["*apple w/30 pear*" means that "*apple*" must occur within 30 words of "*pear*"]. As an example, one of keyword combinations used to find references to *risk perception* and *acceptability of risk* for the *proposed DGR* with respect to *accidents* was:

(DGR or deep geologic reposit*)* *w/30* *(uncert* or probab* or risk* or likelih* or conseq* or impact* or permiss* or communit* or accept*)* *w/30* *(accid* or incid* or event* or malfunc* or fire* or Chern* or Three Mile* or Fuku*)*.

Results of all searches with respect to risk perception/acceptability were grouped into: (Public or Aboriginal Input) x (4 Options) x (9 primary uncertainties identified in the JRP letter)

SECTION IV
POSITIONS ON THE PROPOSED PROJECT EXPRESSED BY ABORIGINAL INTERVENERS TO THE JOINT REVIEW PANEL

Representatives of several different Aboriginal groups made submissions to the Panel on the proposal to construct a deep geological repository (DGR) at the Bruce Nuclear Generating Station. These include the Saugeen Ojibway Nation (SON, whose lands are on the shores of Lake Huron north of Kincardine), the Historic Saugeen Métis (HSM, whose territory is on the Lake Huron shoreline from Tobermory to south of Goderich), the Métis Nation of Ontario (MNO, representing Metis communities throughout Ontario), the Mnidoo Mnising First Nations (representing six First Nations in the Manitoulin Island area), as well as a 'global representative' for Traditional Indigenous Human Rights. While there is considerable overlap in the type of information provided by each group, they expressed a range of positions on the DGR proposal and on the decision-making process.

The transcripts and submissions to the Joint Review Panel that are cited here are on the public record of the review, and were collected by the Nuclear Waste Management Organization (NWMO), the agency responsible for managing the review. They are referenced by the document number assigned by the NWMO.

Identity and assertion of rights

Most of the Aboriginal submissions began with a statement of the history of their First Nation or community and an assertion of its legal right to its territory and to the pursuit of traditional hunting and harvesting activities in that territory. The SON describes itself as "an unceded First Nation" (NWMO, 894) that claims certain rights to their traditional territory, while the HSM asserted its rights over the lands and waters of the proposed DGR site. The HSM and the SON described the historic relationship of their Nations and communities with the Government of Canada, including the general right of Aboriginal communities to harvest foods in their traditional territories as set out in the Constitution Act (NWMO 1675), and more specific treaties and other agreements; there were several mentions of the Crown's 'duty to consult' (NWMO 1270). The SON described the recent legal decision that permitted their communities to rebuild their commercial fishery, which had been set back with earlier legal disputes (NWMO 1461).

Expectations for process

Related to the assertion of rights over traditional territories and claims of responsibilities of the federal government, most Aboriginal interveners stated that the proponent and project reviewers have an obligation to consult with them extensively on this proposal. Many submissions referred to a "history of exclusion," previous failures of government to consult with them on the installation of industry on their land, including the initial construction of the Bruce nuclear power stations, and more recently the location of wind farms, which took place without their consent (NWMO 894; 1741). They also recounted the process that was followed by OPG and the Canadian Nuclear Safety Commission, which was marked in many instances by problems in establishing proper notification and consultation procedures.

Some positive relationships were mentioned, including a strong working relationship between the HSM and OPG, with good efforts by OPG to notify them of the proposal to build a nuclear waste repository, helping them understand the facility and including them in planning discussions and the review process (NWMO 1675). Many individuals from HSM communities have been employed by the generating station and they appreciate the respectful process that OPG follows with them. Submissions by the SON noted that OPG has made a commitment that it will not begin construction on the project without support from the SON communities (NWMO 1427).

Cultural values

Most of the submissions made by Aboriginal interveners included a statement of the cultural context that shapes the perspective of the First Nation or community to the land, and to its traditional territory specifically. The HSM stated that no individual owns the land: rather, the people are the caretakers of the land; the land provides for them, and they in turn are responsible for protecting the land. It was often stressed that the most fundamental principle is the critical relationship of the people with their territory: An SON representative stated that they are 'inextricably linked to the lands and waters, and that "our waters are who we are as a people" (SON; NWMO 1741).

Several submissions mentioned the importance of spiritual beliefs in the decision. One intervener said that "when we allow anyone to poison Mother Earth what we are really saying is that it is OK to poison our Children and Grandchildren and all future generations (David Eagle, NWMO 1156). The Mnidoo Mnising Elders Circle (NWMO) 1383) stated that the care and protection of mother earth are part of Anishinaabe sacred teachings and are their 'foremost priority'. Another (SON, NWMO 1704) stated that it is "offensive" that scientists could assert that because there are no radiological reasons for Aboriginal people to change how they value plant and animals they harvest:" this statement ignores the incompatibility of waste in the rock, the first order of Creation: "If our people come to believe that it is no longer right to consume the plants, fish or animals for food or spiritual reasons, this cannot be mitigated by demonstrating that there are no new radiological effects." For example, if sweetgrass is perceived as being less 'pure' because of concerns that it may have been affected by radiation, it may not be viable for spiritual purposes (NWMO 1704). It was also noted public hearings do not offer an appropriate context for addressing such matters (SON; NWMO 1741).

These statements illustrate Aboriginal values and the type of knowledge that is credible among Aboriginal people, which are distinct from mainstream culture and particularly from scientific knowledge. It was mentioned by several interveners that cultural teachings are passed down from generation to generation (SON, NWMO 1741). The Mnidoo Mnising Elders Circle representative (NWMO 1383) stated that the elders "provide appropriate teachings that reflect our cultural[ly] sensitive manner," and which is an essential link from the past to the future, completing the cycle of life."

Specific concerns related to the proposed repository

Aboriginal interveners stated that the DGR project could damage the land that they live on, which would in turn damage their rights, interests and way of life. Several Aboriginal interveners stated that they are concerned that a repository could change the relationship of the people to their territory, threatening the ability of the land to sustain them and undermining the culture and identity of the people (e.g., NWMO 894). A major concern is for the waters and the fisheries, both the sustenance fishery and the recovering commercial fishery. The SON (NWMO 1461) stated that the disposal facility "within hundreds of meters of spawning grounds" posed "a significant new threat" to the fish they rely on for food and for the commercial operation.

These activities could be damaged physically by the industrial activity or by contamination from the waste, as well as by stigma effects that reduce the market value of the fish and the commercial fishery and related tourism industry; it was stated that efforts to rebuild the commercial fishery likely could not 'withstand the blow of stigmatization' (NWMO 1704). There were also concerns that transmission lines crossing the territory could 'impinge on' migration routes of birds and animals, which could affect traditional harvesting activities.

In addition, many outlined concerns about adverse impacts that the proposed repository could have on their lands and waters; the HSM stated that 'the most likely impact of a repository is to traditional harvesting territories as a result of an incident at the DGR (NWMO 1675) that could have 'severe adverse impacts' on sustenance harvesting for centuries into the future (NWMO 1270). There were a number of comments on the need to study the potential impacts of transporting waste to the facility, as well as challenges to the determination that transportation issues were outside of the scope of the EIS. Concerns were also raised about the threat of extreme events, such as severe weather, that have not been factored into the existing facility design. Many comments referred to the events at the Fukushima reactor in Japan caused by the earthquake and tsunami, with concerns expressed that the possibility could not be ruled out that similar events could happen at the repository site over the long waste management timeframe (e.g., NWMO 894, 1462, 1383).

There were a number of criticisms of the Environmental Impact Statement (EIS), relating to the process by which elements to be assessed were determined, and to the adequacy of the EIS itself. The MNO pointed out that they had been left out of the process to identify the Valued Ecosystem Components (VECs) that should be studied as part of the EIS; these were "incorrectly chosen" and so the EIS does not reflect Metis values for the land. The MNO provided a complete traditional land use study, but noted that this has not been incorporated into the EIS; they argued that they should be able to sit down with the proponent and explain their land use study and the way the information in it can be used (NWMO 1675).

Other submissions detailed deficiencies in the EIS. These deficiencies included the failure to assess an alternative site and a number of other technical aspects of the proposed facility and its design. It was also noted that central characteristics of the project have been left to be defined in later licensing stages of the approval process, rather than being included in the formal environmental assessment. The EIS has an incomplete waste inventory, as well as an undefined geoscientific verification plan, insufficient alternative means assessment and no analysis of different options for managing intermediate waste components. Concern was expressed that decommissioning waste from Pickering could be included in the facility, which would appear to be a change in the scope of the project (NWMO 1704).

On the social assessment side, the socio-economic effects are not known: there is an inadequate analysis of the potential impacts of stigma; it was stated that OPG does not understand the possible effects that stigma could have on the social and economic life of the communities. The more general community acceptance surveys are not reliable, as the area that was included in the surveys was too limited, not including people who did not live in the study areas (NWMO 1704; 1463). Larger nuclear power issues were also considered, as low- and intermediate-level nuclear wastes are products of nuclear power generation; interveners wanted to know how the construction of a low- and intermediate- level waste repository fits in with plans to manage spent fuel from power reactors.

Trust and uncertainty

Varying levels of trust were expressed in the different organizations involved in the project. The HSM expressed appreciation for the positive relationship it has with OPG (NWMO 1362), and the SON similarly appreciates that OPG has “recognized that the project must be developed in a way that has the support of the Aboriginal people who could be affected, and who must be part of the decision-making process” (NWMO 1427).

However, the SON has many questions that must be addressed, including potential uses for the wastes, transportation issues, a cumulative effects analysis, waste treatment options, and a consideration of the project in the context of broader nuclear waste management issues (NWMO 1704). Where there is mistrust, it results from a failure to consider other sites for the facility, last-minute changes to the design of the facility, the means by which community support was measured, and the refusal to discuss the connection between this project and used nuclear fuel disposal (NWMO 1704).

A fundamental lack of confidence in scientific assurances of safety was expressed by a number of interveners. The SON stated that OPG has failed to demonstrate the social or technical safety of the project: the consequences of the project “are not known and in many cases are not even considered” (NWMO 1461), and SON communities “do not have sufficient confidence in the completeness of scientific and technical estimates” of the project (NWMO 1427). The long time over which the waste must be contained ‘denies any real certainty for the future reliability of containment’ (NWMO 1675).

There was a basic lack of trust that the project will have no impacts on the water or the environment, the people’s health or their means of making a living: a Chief asked: “can we trust this project? Can we accept this project and can we agree to have this project as part of our future for all times?” As noted above, Aboriginal people need to know if the DGR will be technically safe, but they also need to know that it will be done in a way that is consistent with ‘spiritual and cultural teachings and does not cause harm to fundamental elements of who they are as a people" (NWMO 1741). The HSM stated that a conclusion that there are no potential impacts would indicate a failure to understand 'the potential nature of the Aboriginal rights that could be impacted' (NWMO 1675).

Support for the repository project

The SON and the HSM expressed conditional support for the project. Both noted that the ultimate goal is to find a way to manage nuclear wastes (NWMO 1427; 1362); the HSM stated that they "accept that nuclear waste must be addressed" (NWMO 1362), and acknowledged that "we are all responsible collectively to develop a safe storage for nuclear waste created here" (NWMO 1675). The SON "has committed to work with OPG to understand the project and achieve the goals of managing nuclear waste" (NWMO 1427), and notes that OPG acknowledges that SON communities must participate in the decision and support the project for it to proceed.

The HSM explained that they have received economic benefits of employment at the Bruce generating station and benefits from its activities, and looks forward to continuing involvement in working with OPG on the DGR. They noted that they have been living in the area alongside the nuclear power plant and don't have the same sense of stigma that others might (NWMO 1375).

Despite these statements of support for the goal of managing nuclear wastes, both the SON and the HSM noted a number of conditions that would need to be met for their clear approval of the project.

The HSM expect to be involved in monitoring the DGR 'as the project goes forward': given the significance of the threat posed to their constitutionally protected Aboriginal rights, they require a high degree of consultation (NWMO 1270). A clear and formalized understanding of the way that HSM concerns will be considered and integrated into long-term decision-making processes will need to be developed. ‘Agreements directly with Métis communities, or conditions stipulated in regulatory approvals, could be used to ensure that “the proponent is held accountable to the affected community” through all phases of the project, including construction, operation, monitoring and decommissioning” (NWMO 1270).

The SON stated that people will need the opportunity to decide their support for the project, which they believe will pose a ‘permanent’ risk to their land, water and people “regardless of how small we may now predict” the impact to be (NWMO 1704); under these circumstances there must be conditions for the acceptance of the project by the people. The people must “be asked for their agreement” and the project should proceed only “when the people most affected fully understand the project and when are supportive of it moving ahead” (NWMO 1704). The SON stated that some concerns regarding the transportation of nuclear waste through its territory must be addressed or the assessment will be ‘fundamentally incomplete” (NWMO 1463). They will ‘test and challenge every aspect [of the project proposal] to ensure ‘protection of their territory and their future. Projects in their territory that are acceptable would be those that do not subject their territory or people to undue risks or harms; that contribute to the long-term sustainability of the territory by improving the environmental, social, cultural and economic well-being of the people; and that ensure that the wastes are managed, monitored and regulated effectively with their appropriate participation.

SUMMARY AND CONCLUSIONS: ABORIGINAL PERSPECTIVES ON A NUCLEAR WASTE REPOSITORY

The positions expressed by Aboriginal participants in the review process echo the cultural values and perspectives on risk that are expressed in published literature on Aboriginal attitudes to technological risks, as described in Section 1 above. This enlarges an understanding of the importance of culture, social relations and political dynamics as shaping risk judgements within Aboriginal cultures, as in any culture or society.

In terms of perceptions of risk, the Aboriginal interveners all stressed the primary importance of their spiritual and material ties to their traditional territory, and their concern that adverse impacts of a DGR would undermine the traditional harvesting activities that strengthen those ties to the land and give the community its sense of identity and cohesion. While the Aboriginal interventions make it clear that they are able to address more technical aspects of risk and environmental assessment, it is also clear that their perspective places a stronger emphasis on the value of specific entities that are *at risk*, rather than on perceptions of the risk source and of the significance of its threat to human health more generally. This suggests that reassurances that any escape of radiation from the facility will be at low levels that have no implications for physical health may miss the point; the greater concern is for the undermining, by any means, of the spiritual and social value of the land and the traditional activities that are intertwined with it.

The respect for spiritual connections with traditional territory and for traditional teachings links to a traditional way of perceiving and knowing about the environment that is very different from modern Western scientific knowledge. Section 1 describes the 'gap' between experts and non-experts, which has been used to explain the different judgements that are reached through scientific reasoning and broader contextual reasoning used by most individuals on social situations that involve risk. The traditional aboriginal perspective is, like most non-experts', largely based in cultural and social assumptions rather than scientific principles and methods; however, it is more strongly connected to a coherent alternative body of knowledge, principles of reasoning, and respect for the traditional teachings of elders. Aboriginals may explain an attitude to a 'risk' in terms of a cultural value that is unrelated to the conventional scientific explanation. There may therefore be a greater need for scientists and other risk managers to understand traditional Aboriginal values and knowledge in an effort to communicate effectively and with mutual respect.

The social traditions of many Aboriginal communities place an emphasis on the necessity to establish relationships based on respect and a recognition of rights and responsibilities. Process considerations are very important for all societies studied by risk perception and technology acceptability researchers, but the expectation for a respectful approach to an Aboriginal community and the development of trusting relationships may be more particular within those cultures. Especially where a First Nation or community has experienced marginalization and threats to the continuation of its traditional activities, respect and support for those communities' efforts to protect their relationships of stewardship with their territories will be critical to the development of trusting relationships.

Aboriginal interveners stressed two key factors that determine the support of their community for a nuclear waste repository. These are an acknowledgement that there are benefits received, and valued, from the facility or the production of the waste; and the conditionality of support on the continued ability to participate in decisions and monitor the progress of the plans and the operation of the facility when it is built. This is consistent with findings on the acceptance of a risk when a benefit is received, and on experience in many countries with the conditions under which communities accept a hazardous facility.

These Aboriginal expressions of facility support are also consistent with the suggestion in Section 1 that a more productive operational focus is to achieve community tolerance rather than acceptance. The concept of tolerance incorporates an explicit consideration of the balance of benefits and risks, and of the active management of the risk to a level that is appropriate in light of the risk-benefit trade-off. While there is no sense that acceptability, and community acceptance, are interpreted by the JRP as though a community gives blind trust to the risk manager, the concept itself does little to clarify what the expectations for community acceptance might be. The concept of tolerability is a more robust concept that makes an explicit connection to the two primary conditions that are commonly expressed in risk acceptance debates, of benefits that justify the risk and of the management of the risk in accordance with that risk-benefit balance.

SECTION V
OBSERVATIONS AND CONCLUSIONS

Observations:
As the Background Study shows, earlier perspectives that appeared to find strong underlying differences between expert and "lay" perceptions of risk have been modified, suggesting that those differences were exaggerated. However, this does not affect the reality that, in countries such as Canada today, two very different *discourses* about risk will be heard formal decision-making processes, such as environmental review public hearings carried out under the terms of legislation and regulation.

Project proponents in these circumstances have an obligation to make a "safety case" using the technical terminology of risk assessment, and regulators expect that they will use a highly technical discourse competently. (One good example is the requirement to demonstrate that existing radiation dose limits, for both workers and the public, will not be exceeded.) Interveners at public hearings who are individual citizens or members of public-interest groups are not obliged to use a technical discourse about risk, although some may do so, and some have done so in the present case. Thus in any environmental review process using public hearings, two quite different discourses will be heard, and it can be expected that the two will have, for the most part, little in common.

Our earlier Report on comparing four options for managing low- and intermediate level nuclear waste, using the techniques of qualitative risk assessment, necessarily embodies a technical discourse. We were in fact asked to use in our assessment highly technical parameters such as advective gas and water flow, structural and mechanical impairments, waste container integrity, and radiological dose for workers. We made our expert judgements on these parameters under the assumption that there are very extensive and reliable bodies of accumulated knowledge which could justify such judgements. We find no comparable materials in the public discourses on risk, which illustrates the lack of commonality noted above. However, with respect to other parameters relevant to risk in this case, such as, for example, the possibility of seismic events or future glaciation in the region, there is an element of commonality between the two discourses; but for the most part the public discourse lacks the degree of elaboration necessary to estimate, even qualitatively, the *magnitude* of the risk.

The frequent reference in the public discourse to the proximity of the waste storage and disposal site to Lake Huron provides an excellent example of this point. When confronted with the possible Bruce DGR within visible proximity to the Lake, there is for many people almost an automatic assumption that the chain of events leading to a breach and to uncontrolled emission of radionuclides is a very short chain indeed: The physical distance to the water is on the order of one kilometer (700 m deep, 700 m to the lake shore). But from a pathway aspect, in technical terms, the probability of a breach is extremely low, the potential flow rate from a breach is very low, and the impact of any breach is massively reduced because of the dilution effect of a huge volume of water on a small volume of escaping material. *Both perspectives* are reasonable when considered in their own terms – but they are incommensurable.

Conclusions:

We can now apply the results of both our background study on risk perception, and our examination of materials from the submissions and public hearings, to the issues and perspectives posed by the letter from the Joint Review Panel dated 6 March 2014:

- "…[T]he Panel expects that there be a comparison of *risk perception* (and thus, risk acceptability) among the four options…. [T]he Panel suggests that the Expert Group focus on uncertainty. This is because the technical risk analysis of the four options will have a direct link with the analysis of the effects of the technical uncertainty on risk perception."

- "Many submissions [to the JRP] presented comparative risk perceptions and risk acceptability among status quo, enhanced surface storage and deep geologic repositories. These submissions, together with information in the published literature and the Expert Group's analysis and professional judgement should be used to produce a relative risk perception/acceptability score for the four options."

- "…[T]he Panel would encourage the Expert Group to comment on how risk perception among Aboriginal peoples might better be acknowledged and incorporated."

- "The Panel expects that the analysis then go forward with further consideration of the *perception* of each of the four options, as influenced by the relative degree of technical uncertainty associated with the primary uncertainty issues listed above."

- "The Panel maintains that use of a combination of evidence provided by submissions as well as published literature is sufficient to discriminate among the options if the Expert Group focusses, as is suggested above, on the effects of relative uncertainty on risk perception and risk acceptability."

RESPONSES FROM THE INDEPENDENT EXPERT GROUP

Non-Aboriginal Interveners:

1. Across the range of submissions as a whole, we find no discernible *pattern* of public views in which preferences among the four management options are systematically related to the perception of risks associated with the storage and disposal of nuclear waste.

2. Risk perception and risk acceptability are two completely different phenomena; they may be related to some extent, but if so, only indirectly. For example, a risk that is perceived to be very high will, generally speaking, be regarded as unacceptable; but this is true mainly for involuntary risks, whereas voluntary risk-taking often violates this rule, e.g., extreme sports.

3. According to our review of risk perception research, uncertainty (as a discrete concept) is not a significant factor in the perception of risk – except where uncertainty refers to what is "unknown" or unknowable, in which case it cannot be estimated in terms of magnitude.

4. Since in the public discourse uncertainty is almost never estimated as to magnitude (i.e., how much uncertainty, expressed qualitatively), there is no way to estimate relative uncertainty, and thus no possibility to discriminate among the options with respect to it.

5. With respect to the concept of risk acceptability, we find in the record of the public discourse few, if any, statements about what constitutes acceptable risk in the storage of nuclear waste (as opposed to statements about unacceptable risks), and thus no basis whatsoever for seeking to discriminate among the four options using this concept.

6. In the light of the foregoing, there is no possibility of assigning scores, on either a qualitative or a quantitative scale, to the four options with respect to either risk perception or risk acceptability.

Aboriginal Interveners:

1. Aboriginal perceptions of the risks associated with the storage of nuclear waste have been articulated within a comprehensive worldview, as shown in the Background Study, and the views expressed to the Joint Review Panel on the specific DGR proposal under consideration are consistent with that worldview.

2. As noted in Section IV, referring to the current proposal: "Aboriginal interveners stressed two key factors that determine the support of their community for a nuclear waste repository. These are an acknowledgement that there are benefits received, and valued, from the facility or the production of the waste; and the conditionality of

support on the continued ability to participate in decisions and monitor the progress of the plans and the operation of the facility when it is built. This is consistent with findings on the acceptance of a risk when a benefit is received, and on experience in many countries with the conditions under which communities accept a hazardous facility."

3. Further, as noted in Section IV: "These Aboriginal expressions of facility support are also consistent with the suggestion … that a more productive operational focus is to achieve community tolerance rather than acceptance. The concept of tolerance incorporates an explicit consideration of the balance of benefits and risks, and of the active management of the risk to a level that is appropriate in light of the risk-benefit trade-off."

4. We believe that these perspectives encompass a sophisticated understanding of many of the important dimensions of risk perception and risk acceptability.

CHAPTER 26:

GREG PAOLI, MAURICE DUSSEAULT, TOM ISAACS, AND WILLIAM LEISS

"Report of the Independent Expert Group on Additional Figures and Interpretation in Support of Qualitative Risk Comparisons among Four Alternative Means for Managing the Storage and Disposal of Low and Intermediate-Level Radioactive Waste in Ontario."

Submitted to the Joint Review Panel, 19 June 2014.

THIS IS A PUBLIC DOCUMENT

You may obtain a separate PDF file of the Original Report from The Canadian Environmental Assessment Agency at:

http://www.ceaa.gc.ca/050/documents/p17520/99322E.pdf

Note to the Reader: Only Section 1, the introduction to Section 2, and Figure 1 of this Report are included in this Chapter. The rest contains innovative color graphics that are not easily viewed in an E-book format. To see the rest of the Report, please access the PDF file on the CEAA website (URL just above) and download it onto a computer with a sufficiently large screen for ease of viewing.

I strongly recommend that, if you are interested in seeing the complete Report, you access and download the PDF file as soon as possible. This is because many agencies of government which have responsibilities for a continuing series of large-scale projects may periodically remove earlier materials from their websites.

SECTION 1
APPROACH TO THE TASK

This report responds to the following information request received from the Joint Review Panel (JRP).

"a) Provide an indication of the log-log scale on the risk assessment plots, both Relative Risk and Absolute Risk, for the 12 key features (or pathways of harm) for comparison among the 4 alternatives for the near term (<100 years) and long term (>100 years) in order that the reader may distinguish negligible, low, moderate, high or very high risk assessments on these scales.
b) Provide a table and/or figure with accompanying explanatory narrative that summarizes the overall relative risks of the four identified options for the long- term management of low and intermediate level waste, over both timeframes (<100 years and >100 years). Include this summary in OPG's separate submission to address the Panel's follow-up comments on the comparison of risk perception among the four options."

In response to part (a) of the request, we have provided the same relative risk and absolute risk plots with labelling to explicitly clarify that both the likelihood and consequence dimensions of the risk assessment plots have a logarithmic scale. These re-labeled plots are included as Appendix I of this report.

We have not provided categorical labels (such as negligible, low, moderate, high, etc.) on either the likelihood or consequence scales, and have not provided a categorical indication of the level of risk (which requires simultaneous consideration of both consequence and likelihood). The rationale for not providing categorical indications of likelihood, consequence, or risk is as follows:

- Categorical labels for probability estimates are known to be an unreliable means of communication of probability due to the high level of variability in public interpretation of words such as “unlikely”, “likely”, “remote”, “rare”, “common”, “uncommon”, “negligible”, “improbable”, “inevitable”, etc.

- Categorical labels for consequences suffer from similar variability in interpretation and necessarily impose a societal valuation on the seriousness of various consequences through the assignment of labels such as “negligible”, “low”, “moderate”, and “high”. The assignment of such labels is normally considered to be the domain of risk management, as opposed to risk assessment, in the usual conceptual separation of these activities in the development of public policy. In addition, we believe that the stakeholders involved would have, and have expressed, highly variable evaluations of the seriousness of various consequences described in our earlier report.

- Given the above lack of definition and consensus on the significance of various consequences, the IEG is not in a position to apply categorical labels on consequences.

- Due to the inability to provide categorical assessments of likelihood and consequence, we are similarly unable to assign categorical labels to the concept of risk as the combination of likelihood and consequences.

In response to part (b) of the request, we have provided additional figures which provide an overall perspective on the relative risks of the four disposal options, for both timeframes previously assessed. The following section includes an explanation of these figures. This document assumes that the reader is familiar with the previous IEG report.

SECTION 2
ADDITIONAL FIGURES RELATED TO QUALITATIVE RISK COMPARISON

To provide an overall perspective on the array of risks posed by the four disposal options, we have provided two figures, one for each of the two timeframes. In viewing and interpreting these figures, the following concepts should be carefully considered:

1. The likelihood of the various accidents and events associated with the waste disposal options varies over many orders of magnitude. The horizontal axis of the figures should be understood in logarithmic terms.

2. The consequences associated with the various pathways of harm are highly variable in their nature, the receptors involved (e.g. public, worker, environment) and the magnitude of the consequences. Although the consequences have not been given quantitative meaning in this exercise, they should also be understood to vary over several orders of magnitude. As such, the vertical axis of the figures should also be understood in logarithmic terms.

3. Due to the use of a logarithmic scale, it is not strictly possible to represent zero on the likelihood or consequence scales. However, in some cases, the likelihood or consequences are considered to be essentially zero. In these cases, the associated icons have been placed directly on top of the axis. For example, the location of the Public Health and Safety (PSH) icon in the post-100-year timeframe (**Error! Reference source not found.**) indicates that events impacting public health and safety for the closed deep geologic repositories would have essentially zero probability and zero consequence.

Similarly, the icon for impact of glaciation (GLA) in the post-100 year timeframe is placed on the x-axis to indicate that there is essentially zero consequence associated with this pathway for the closed deep geologic repositories.

4. Risk, from a technical perspective, is generally understood to integrate the concepts of likelihood and consequence. As such, an increase in either likelihood or consequence is understood to increase the level of risk. With this concept, the risk associated with the various combinations of exposure pathways and disposal options should be understood to increase as the icons are vertically higher in the diagram or as they are further to the right of the diagram. The lowest risks are found in the bottom left corner of the diagram, and the highest risks are found in the top right of the diagram (
5. Figure 6). In addition, by virtue of the logarithmic scales of both consequence and likelihood, the risk continuum represented by the figure should also be understood to span many orders of magnitude.

6. The figures in this report are the result of attempting to combine a series of individual pathway-specific relative risk estimates and absolute risk estimates from the previous IEG report. The IEG did not systematically consider the relative likelihood or consequences of different pathways during the original assessment process. Due to the qualitative nature of the assessment exercise, there is significant uncertainty about the correct icon location in both the likelihood and consequence dimensions such that small variations in the relative locations of icons should not be interpreted as representing a significant difference between their likelihood and/or consequence. Icons appearing close together in a region of the figure can be interpreted as carrying similar levels of risk, including the possibility that the apparent difference in likelihood or consequence could be non-existent

or even reversed. As a result, the overall relative risk assessment is most reliable for comparing options that are significantly different in terms of likelihood and/or consequence.

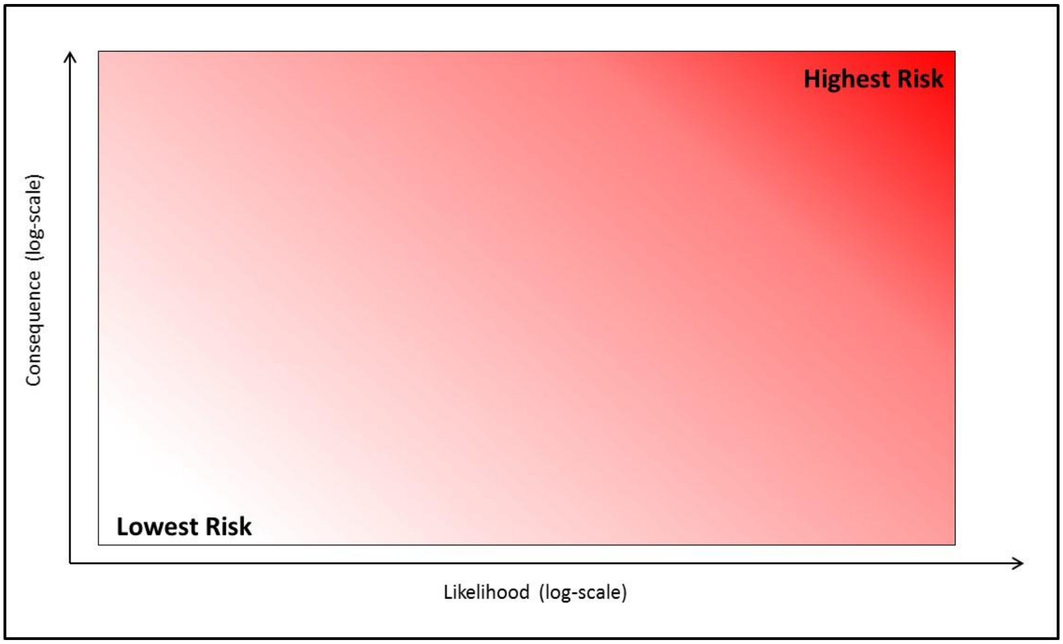

Figure 6. Visualization of the risk continuum based on likelihood and consequence