NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

November 2003

NWMO BACKGROUND PAPERS
1. GUIDING CONCEPTS

THE RISK-BASED APPROACH TO LONG-TERM MANAGEMENT OF HIGH-LEVEL NUCLEAR WASTE IN CANADA

COMMISSIONED COMMENT

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NWMO Background Papers

NWMO has commissioned a series of background papers which present concepts and contextual information about the state of our knowledge on important topics related to the management of radioactive waste. The intent of these background papers is to provide input to defining possible approaches for the long-term management of used nuclear fuel and to contribute to an informed dialogue with the public and other stakeholders. The papers currently available are posted on NWMO's web site. Additional papers may be commissioned.

The topics of the background papers can be classified under the following broad headings:

1. **Guiding Concepts –** describe key concepts which can help guide an informed dialogue with the public and other stakeholders on the topic of radioactive waste management. They include perspectives on risk, security, the precautionary approach, adaptive management, traditional knowledge and sustainable development.
2. **Social and Ethical Dimensions** - provide perspectives on the social and ethical dimensions of radioactive waste management. They include background papers prepared for roundtable discussions.
3. **Health and Safety –** provide information on the status of relevant research, technologies, standards and procedures to reduce radiation and security risk associated with radioactive waste management.
4. **Science and Environment –** provide information on the current status of relevant research on ecosystem processes and environmental management issues. They include descriptions of the current efforts, as well as the status of research into our understanding of the biosphere and geosphere.
5. **Economic Factors** - provide insight into the economic factors and financial requirements for the long-term management of used nuclear fuel.
6. **Technical Methods** - provide general descriptions of the three methods for the long-term management of used nuclear fuel as defined in the NFWA, as well as other possible methods and related system requirements.
7. **Institutions and Governance** - outline the current relevant legal, administrative and institutional requirements that may be applicable to the long-term management of spent nuclear fuel in Canada, including legislation, regulations, guidelines, protocols, directives, policies and procedures of various jurisdictions.

The Risk-based Approach to Long-term Management of High-level Nuclear Waste in Canada

A paper prepared at the request of the
Nuclear Waste Management Organization
(http://www.nwmo.ca/)

by

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Summary

This paper deals with broad issues involving how Canada will manage its high-level nuclear wastes in the future. These wastes are the solid-fuel bundles, each containing originally about 19 kilograms of processed uranium, which have been used in CANDU reactors to generate electricity, before being removed again and replaced with fresh bundles. The used fuel bundles contain materials that will remain radioactive for as long as one million years or more. Such wastes represent significant risks to human health and the environment, and therefore they must be managed in a way that minimizes those risks. The purpose of this paper is to give a brief overview of an approach to the disposition of such wastes that is based on the principles of risk assessment and risk management; it is called, for short, the "risk-based approach." The paper has the following objectives: (1) to outline the general characteristics of the risk-based approach, as it is used in Canada and elsewhere today, for many different types of health and environmental hazards; (2) to discuss in particular certain key issues within this approach, especially uncertainties; and (3) to comment on the important issues of trust, believability, and procedural fairness that are essential to the building confidence among members of the public in the risk-based approach.

November 10, 2003

This paper has the following sections:

A. Introduction: What is high-level nuclear waste (HLNW)?
B. The risk-based approach: Structure and illustrations.
C. Uncertainties and variability.
D. Procedural fairness and public trust in the matter of HLNW.

A. Introduction: What is high-level nuclear waste (HLNW)?

High-level nuclear waste is produced in a number of ways, for example: in power plants generating electricity using uranium fuel, as a byproduct of the manufacture or dismantling of nuclear weapons, and in the disposal of medical equipment containing radioactive materials. In Canada the first-mentioned of these (used uranium fuel bundles from nuclear power plants) makes up almost the entire inventory of HLNW that we are required to manage, and so these wastes will be the focus of the discussion in the remainder of this paper.

It should be noted, however, that many countries in the world have sources of HLNW, and in most cases these are almost entirely composed of wastes similar to what we have in Canada. As of 1995, there was information available on the various approaches being taken to HLNW in various countries in Europe and North America (Belgium, Canada, Finland, France, Germany, Netherlands, Sweden, Switzerland, United Kingdom, United States).[2] Of course, this is not a complete list, since other countries – for example, South Korea and China – have nuclear-power plants, and still others (China, Israel, Iran, India, Pakistan, North Korea) have or may have active nuclear weapons programs.

Closest to home, the United States has large quantities of both spent fuel from nuclear-power plants and various types of extremely hazardous radioactive wastes from weapons programs. Long-term management of these wastes is, of course, a very active matter of planning and debate there. Most of the current debate is focused on the Yucca Mountain site in southwestern Nevada, which is currently the designated future location for permanent underground storage.[3] Even the most minimal search for information on HLNW, using either the Internet or conventional library research, will indicate that there is intense and long-standing public and expert controversy about all aspects of this subject. This controversy is to be expected, given both the nature of the risks posed by HLNW and by one of the unique characteristics of those risks, namely, the extremely long time-frame (up to a million years) during which the radioactivity hazards will exist.

At present the largest portion of HLNW in Canada, represented by spent fuel bundles from our CANDU reactors, is kept in monitored storage under water in large tanks at each of our nuclear-power stations. (Ontario has 19 of these reactors; New Brunswick and Québec have one each.) A significant element in the public controversies, both in Canada and elsewhere, has to do with different views on the best choices among options for longer-term storage or disposal of these wastes. Public discussions in Canada on the choice of options for the long-term management of HLRW have been going on for over a quarter-century. Following is a list of these longer-term options, separated into three types, treatment, storage, and disposal:[4]

1. Treatment:
   a. Reprocessing and recycling (first extracting useful plutonium and uranium from spent fuel, then sending remaining wastes to storage or disposal);
   b. Reprocessing and transmutation (no technology currently available).

2. Storage (retrievable):
   a. Wet: continued storage in surface pools;
   b. Dry: above-ground storage in dry canisters.

3. Disposal (permanent, non-retrievable storage):
   a. Sent to outer space using rockets;
   b. Entombment in ice sheets;
   c. Entombment on the ocean seabed;
   d. Entombment in land-based geological formations (deep underground storage – 300m or more – in clay, plutonic rock [granite], salt, shale, or volcanic tuff).

A strong preference for one of these options has been expressed by expert communities in Canada – namely, disposal in land based-geological formations (plutonic rock in the

Canadian Shield). However, to date Canada has never undertaken a detailed, credible and comparative technical assessment of *all* feasible options for long-term management of HLNW.

The most recent comprehensive discussion of issues around long-term management of HLNW in Canada will be found in the "Seaborn Report," the report of an official federal panel, active in the period 1989-1997, which issued its final report in February 1998 (see endnote 2). Its summary conclusions are as follows:[5]

> "From a technical perspective, safety of the AECL concept [deep disposal in plutonic rock] 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."

In recommending future steps to the federal government, the panel specifically called for a process of "developing and comparing options for managing nuclear fuel wastes." As we shall see, this demand for a comparative assessment of feasible options is not only consistent with the risk-based approach, but is in fact the only type of assessment that is consistent with this approach.

B. The risk-based approach: Structure and illustrations.

There is clearly an imperative to explain what meaning we assign to risk for the purposes of managing risk. The most useful and comprehensive notion of risk can be built upon the concepts first outlined by Kaplan and Garrick (1981). They proposed that risk is a multi-dimensional entity comprising the answers to three questions:

- What can go wrong?
- How likely is it?

- What are the consequences?

The answers to these questions, which effectively amount to an assessment of risk, combined with a need to specify a time-frame, and with consideration of some essential human issues that have been well described by Ortwin Renn, can lead to a functional notion of the kind of risk that we attempt to assess and to manage.[6]

The core of the risk management approach itself is *risk assessment*. This is a highly technical exercise which begins in the basic sciences of chemistry, biology, and physics, and then runs through the applied disciplines of toxicology, epidemiology, engineering, medicine, pharmacology, and many others, depending on the depth of evidence available for assessment. (In many cases a more pragmatic qualitative risk assessment may be necessitated by the absence of substantial evidence.) What comes out is a *hazard characterization*, which seeks to provide a comprehensive understanding of exactly what kinds of harm can result, to humans, other species, or the environment generally, with respect to the impacts of a natural hazard or a technology. Here the most important guide is the *dose-response relation*: Since everything in the world is harmful at some level (including the staples of life, water and oxygen), what is the harmful dose? This is what distinguishes hazard – the potential to cause harm – from risk, defined as the chance of harm occurring.

Now add *exposure*, another key ingredient: If a harmful dose is present somewhere, but you are not, then you are not at risk. But often we don't know whether or not that is the case; all we know is that there is a certain *probability* that some among us may encounter a harmful dose. This is risk, namely, the chance of harm. For example, we know that all long-term smokers are "at risk" of contracting lung cancer (and hundreds of other types of harms to health), but only 12-17% of them will actually contract this particular deadly disease in Canada.[7] Thus this notion of risk is a prediction or expectation, called a *risk estimation*, which involves the following factors:

- a hazard (the source of danger),
- exposure to the hazard (at a certain dose),
- uncertainty of occurrence and outcomes (expressed by the probability or chance of occurrence),
- adverse consequences (the possible outcomes),
- a time frame for evaluation, and
- the perspectives of those affected about what is important to them.

In summary: Risk is the predicted or expected chance that a set of circumstances over some time frame will produce some harm that matters.[8] Risk estimates include, importantly, the careful characterization – and quantification, where appropriate – of both uncertainty and variability. These two concepts will be discussed in the following section.

C. Uncertainties and variability.

Risk situations form part of a seamless continuity bounded by *what is known with a reasonable degree of certainty*, on one side, and *the sphere of the (currently) unknown*, on the other. A risky situation as such is one that is expressed as a range of probabilities, within which there are one or more aspects of uncertainty, low or high:

What is (now) known	***What is "at risk"***	***What is (now) unknown***
Basic chemical, physical, and biological processes, theoretically described and /or experimentally validated	**Probable outcomes:** High ⟸⟹ Low Uncertainties Low ⟸⟹ High	Undiscovered or unvalidated chemical, physical, and biological processes / relations

This is a continuum, not an array of three independent categories. At the border where the category of the known shades into that of the "at risk," a physical process has been described and validated: A single particle of alpha radiation *can* initiate the long process resulting in a fully-developed case of lung cancer, by causing unrepaired genetic damage in a single cell of lung tissue in an organism. (This is a well-characterized hazard, in other words.) Now, let us say, we encounter the case of a person who *may have been* exposed – with a high degree of probability – to some amount of alpha radiation. What cannot be known, but only estimated (with varying degrees of uncertainty), is the probability that this particular person will go on to develop lung cancer. We can reduce, but not eliminate, some of these uncertainties if we know something about the genetic variability of the whole population, the genetic profile of the individual in question, and the relationship between genetic variation and the toxic dose of alpha radiation. But some uncertainties will always remain, because that is the very essence of risk itself.

On the other side of the schematic above is the border where the category of the "at risk" shades into that of the presently unknown. On the left-hand side of the border, risk can be estimated, but only within very large uncertainty parameters. This would be the case, for example, where exposure is very poorly characterized or where what is called a "surrogate" measure of exposure has been used. For example, in many epidemiological studies investigating a possible association between childhood leukemia and extremely-low-frequency electric and magnetic fields (from electrical wiring and appliances in the home), domestic wiring codes were used as a surrogate to estimate exposure, because no direct measure of the strength of the fields in actual homes – and duration of exposure to those fields – was undertaken. (More recently direct measurements have been taken using portable equipment.)

On the other side of this border, "what is (now) unknown," reside the basic physical, chemical, and biological processes which remain undiscovered at present. For example, before 1984 the existence of the so-called "prion particle" (an infectious protein) was not known, and therefore the risk of prion disease, such as contracting the neurological disorder known as Creutzfeldt-Jakob Disease from transmission of infected tissue, could not even be estimated, as it now can be.[9] Since the process of scientific discovery is ongoing, we can expect that in the future a continuous stream of entirely new risks (or risk factors) will be uncovered and characterized – and that existing risk factors will be re-evaluated through new studies. But in all of the risk characterizations some uncertainties will remain, because uncertainty is an integral part of risk itself.

This perspective on the risk-based approach differs fundamentally from the one set out in the paper by Kristin Shrader-Frechette. She writes: [10]

> "According to basic Bayesian probability concepts, scientific phenomena may exhibit certainty, risk, or uncertainty. Situations of certainty have probability 1…. Cases of risk have some numerical probability (greater than 0 but less than 1)…. Cases of uncertainty cannot be defined in terms of probabilities, because of incomplete evidence and multiple unknowns."

One can see that in part the difference between my scheme and Shrader-Frechette's is a matter of terminology. But there is a more important difference as well, one that has to do with the use of the concept of risk itself. The simple fact that, as Shrader-Frechette herself says, a risk situation may lie anywhere along the continuum between the values of 0 and 1, means that there is some uncertainty as to where in fact it lies.

However, these values are by no means arbitrary, in the cases of well-characterized risks, and in many cases are quite precise, although those values always also *incorporate* many types of uncertainties. For example, as referred to above, the number of long-term smokers in Canada who will contract lung cancer lies between 14% and 17% of the total set. However, we cannot (yet) predict *which* persons in the smoker cohort will be the victims – although we now suspect that genetic profiles will turn out to be important, in the future, in making predictions about which persons within the cohort are much more likely than others to fall victim to this specific disease. (We already know that women smokers have between two and four times the lung cancer risk compared with men.)

The important point is this: From the standpoint of society's interest in minimizing life-threatening risks from self-administered substances, *we do not need to know which individuals will be the victims*! And what we do need to know is given to us by the risk estimation: namely, that there is a significant association between smoking and lung cancer risk. Armed with this insight, we are then motivated to design smoking cessation and other behavioural modification programs to attempt to reduce the number of smokers, i.e., potential victims. And moreover: It is *only* the careful estimation of risk, achieved by many decades of painstaking research in toxicology and epidemiology (as well as bitter battles with tobacco interests who sought to deny the research results), that grants us this knowledge about the link between smoking and cancer. Without it we would be blind, deaf and dumb – as we were before 1950, when the pioneering research by Sir Richard Doll starting being published.

Uncertainty pervades our estimates of risk.[11] We should have differing levels of confidence in our estimates of probability depending on the quality of the evidence relied upon. The existence of uncertainty in probability estimates of risk is unavoidable, even if it is not commonly expressed. This creates an interesting dilemma for risk ranking:

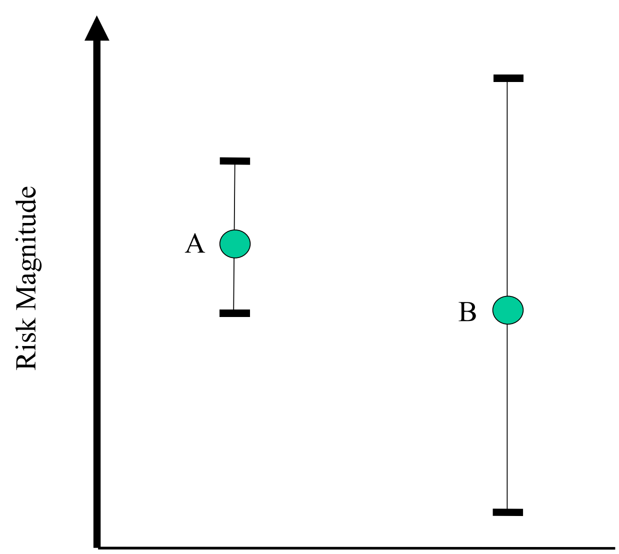

Figure 1: Risk Comparisons Considering Uncertainty (Confidence) Intervals

One might ask: Which risk has a greater probability, risk A or risk B? The large size of the confidence intervals shown may seem pessimistic, but such wide confidence intervals are very common for estimated low level risks. This raises the challenge that we should really be ranking probability distributions rather than point estimates of probability. If we demand higher confidence (say 99%), the size of the confidence interval and the potential for greater ambiguity created by overlapping confidence intervals will inevitably increase. Some might not see a dilemma in this choice because they would regard the central point of each distribution as the best estimate of the risk magnitude and use that for ranking. However, someone inclined towards avoidance of the largest likely disaster could logically argue that B has potentially worse consequences than A, making it the larger risk to be avoided.

What Figure 1 illustrates is only one of many different types of uncertainties that accompany all risk estimates. An authoritative U. S. report contains an excellent summary of the more general types:[12]

> "Much attention has been recently given to quantitative, analytic procedures for describing uncertainty in risk characterizations…. Uncertainty commonly surrounds the likelihood, magnitude, distribution, and implications of risks. Uncertainties may be due to random variations and chance outcomes in the physical world, sometimes referred to as *aleatory uncertainty*, and lack of knowledge about the world, referred to as *epistemic uncertainty.* Sometimes, scientists may not know which of two models of a risk-generating process is applicable. Such situations are sometimes referred to as presenting *indeterminacy.*"

The authors of this report do not confine themselves to these more technical aspects of uncertainty within risk characterization. They also note the importance of having experts understand (1) the uncertainties that matter to people, (2) the impact uncertainties have on the social and political factors in risk management, and (3) how the treatment of uncertainties impinges on the process of societal decision-making. I shall return to these themes in the final section of this paper.

I want to give a further illustration, supporting the main contention here – namely, that uncertainties lie *within* risk estimates and not "outside" them, as Shrader-Frechette claims. What are called quantitative or probabilistic risk assessments (QRA or PRA) always seek to specify, and describe in detail, the sources of uncertainty in the estimates of risk. For example, in a volume dealing with health effects of exposure to radon in homes, the detailed breakdown of four principal sources of uncertainty includes:

1. Uncertainties in data in the lung-cancer risk model [based on data from uranium miners]: sampling variation, errors in the miner health databases (3 types of error), and in application of the model to occupants of homes (5 types of uncertainty);
2. Uncertainties arising from the exposure/dose model;
3. Uncertainties arising from the exposure distribution model (3 types);
4. Uncertainties in the demographic data used to calculate lifetime risk.

Adding up all the breakdowns within these four sources, no fewer than *fourteen* different sources of uncertainties are specified.[13]

In risk estimation, however, variability is just as important as uncertainty and may be regarded as another one of its sources: "Uncertainty represents ignorance about the values of model parameters, while variability represents the inherent variations in the values of parameters among individuals in the population of interest."[14] Only some of the relevant variability in our populations – such as male/female numbers – is actually well-known. Those aspects less well known or presently unknown (such as genetic variance), which are relevant for the distribution of risk in the population, represent other sources of uncertainty in risk estimates.

We derive a number of practical advantages from seeking to specify what are the different types of uncertainties and variability within a particular risk estimation. For example, we seek to manage risks by exploring options for risk reduction, once we have the risk assessment in hand. Knowing the differing types and levels of uncertainty enables us to identify which factors of hazard and exposure we should try to manipulate if we want to reduce risk.

D. Procedural fairness and public trust in the matter of HLNW.

In the risk analysis literature of the last decade a huge amount of attention has been devoted to the issue of trust and credibility.[15] Anyone who works in this area, either as an academic analyst or as a practitioner in government or industry, ignores the dimension of public trust at his or her peril. In the general area of risk management, the factor of public trust grows in importance with each passing year. Canadian authorities have recognized the importance of public confidence in the most recent assessment (1998) of issues about the disposal of high-level nuclear waste, as indicated earlier in this paper: "As it stands, the AECL concept for deep geological disposal has not been demonstrated to have broad public support."

Shrader-Frechette appears to believe that there is an inherent connection between a recognition of the right of public involvement in nuclear waste issues, on the one hand, and a rejection of the risk-based approach to nuclear waste management, on the other. She writes: "Because choosing successful policies for long-term management of waste and spent nuclear fuel presents a case of uncertainty, not risk or certainty, it is a decision for stakeholders and citizens, as well as experts." She argues further (p. 2):

> "… a waste-policy choice involves at least three goals or objectives: (i) making different kinds of scientific, mathematical, social, and cultural uncertainties as transparent as possible; (ii) clarifying alternative ethical and social norms (including assumptions and consequences) of different waste-policy options; and (iii) articulating just and equitable procedures for waste choices that both accommodate scientific findings and respond to democratic welfare, needs, rights, and duties – especially stakeholder rights to make decisions affecting them."

Very few analysts would find anything to disagree with in this statement; I for one certainly don't. The curious thing is, however, that none of what is stated there supports –

or is even relevant to – the associated contention that nuclear-waste policy is a case of "uncertainty, not risk."

For almost ten years now a sustained effort has been made to install the objectives of transparency, social values, and participatory rights firmly within the decision processes of a risk management approach. The best single source on this topic is still the 1996 volume issued by the U. S. National Research Council, *Understanding Risk: Informing Decisions in a Democratic Society*, the result of a deliberative process directed by an eminent group of risk experts. Chapter 6 in that volume, "Implementing the New Approach," contains many useful and practical directives which remain worthy of our attention. And indeed, the most recent official assessment of issues about the disposition of HLNW in Canada, the 1998 Seaborn Report, displayed in its evaluation a very fine sensitivity to all of the objectives specified above.

What remains for us in Canada is, as the Seaborn report recommended, to redo the assessment process in the context of a comparative risk assessment of an appropriate range of feasible options, including treatment, storage, and disposal. The panel which prepared the Seaborn report has already shown us how to do this fuller assessment while at the same time upholding the values of transparency, diversity of values, and public participation.

What we simply cannot do, in my opinion, is to contemplate abandoning the risk-based approach to undertaking a full assessment of HLNW management options. We have long experience in Canada already in developing and applying a risk management framework, especially for health risks.[16] Applying the risk-based approach to the issue of managing high-level nuclear wastes is essential *precisely because* this approach can provide such a clear articulation and specification of the relevant uncertainties. As explained above, these uncertainties are captured *within* a risk characterization, not outside it. And because those uncertainties have, in the case of HLNW, certain unique features – especially the nature of the decision time-frames –, only the risk-based approach can do the job which the Canadian public will need to have done.

Endnotes

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[1] About the author: William Leiss is a Fellow and former President (1999-2001) of the Royal Society of Canada. He is author, collaborator or editor of twelve books, including *In the Chamber of Risks: Understanding Risk Controversies* (2001), *Mad Cows and Mother's Milk: The Perils of Poor Risk Communication* (co-authored with Douglas Powell, 1997) and *Risk and Responsibility*, 1994 (all from McGill-Queen's University Press). Over a period of twenty years he has worked extensively in an advisory capacity with industry and with Canadian federal and provincial government departments in the area of risk communication, risk management, public consultation, and multi-stakeholder consensus-building processes. He has been an advisor on issues dealing with pesticides, toxic chemicals (chlorine, dioxins, and others), tobacco, prescription drugs, radio-frequency fields, genetic engineering, , and others. He was a member of the Senior Advisory Panel for the Walkerton Inquiry (2000-2002) and in 2000 was Chair of the Task Force on Public Participation for Canadian Blood Services. See: http://www.leiss.ca

[2] Canadian Environmental Assessment Agency, "Nuclear Fuel Waste Management and Disposal Concept: Report of the Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel" (B. Seaborn, Chair). Ottawa: Minister of Public Works and Government Services, 1998, Appendix K. Cited hereafter as "Seaborn Report."

[3] Go to http://www.ocrwm.doe.gov/ymp/index.shtml, which is the official U. S. government website. Any search of the Internet under "yucca mountain" will yield sources for a rich diversity of views. For one of many "oppositional" websites go to: http://yuccamountainfacts.org/

[4] This discussion is based on the Seaborn Report, Appendix L.

[5] Seaborn Report, pp. 2-3.

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[6] S. Kaplan & B.J. Garrick, "On the quantitative definition of risk," *Risk Analysis*, 1 (1981): 11-27; S. Kaplan, "The words of risk analysis," *Risk Analysis*, 17 (1997): 407-417; O. Renn, "Concepts of Risk: A Classification," in: S. Krimsky & D. Golding (eds.), *Social Theories of Risk* (Westport, CT: Praeger, 1992), 53-79.

[7] P. J. Villeneuve & Y. Mao, "Lifetime probability of developing lung cancer, by smoking status, Canada," *Canadian Journal of Public Health*, 85 (1994): 385-388.

[8] S. E. Hrudey, "Current needs in environmental risk management," *Environmental Reviews* 5 (1997): 121-129.

[9] R. M. Ridley & H. F. Baker, *Fatal Protein* (Oxford University Press, 1998).

[10] K. Shrader-Frechette, "Risk and Uncertainty in Nuclear Waste Management" (NWMO, 2003), pp. 1-2.

[11] The following two paragraphs and Figure 1 are based on the work of my colleague, Professor Steve E. Hrudey, Professor, Department of Public Health Sciences, Faculty of Medicine and Dentistry, University of Alberta.

[12] U. S., National Research Council, *Understanding Risk* (Washington, D.C.: National Academy Press, 1996), pp. 106-7; see generally the section, "The Analysis of Uncertainty," pp. 106-117.

[13] U. S., National Research Council, *Health Effects of Exposure to Radon* (Washington, D.C.: National Academy Press, 1999), Table 3-13, p. 100; see generally the sections, "Sources of Uncertainty" and "Analysis of Uncertainty," pp. 100-110. See also: S. N. Rai, D. Krewski & S. Bartlett, "A general framework for the analysis of uncertainty and variability in risk assessment," *Human and Ecological Risk Assessment,* vol. 2 (1996): 972-989; S. N. Rai & D. Krewski, "Analysis of uncertainty and variability in multiplicative risk models," *Risk Analysis,* vol. 18 (1998): 37-45.

[14] *Ibid.*, p. 158. Shrader-Frechette says (p. 2): "Mere 'variability,' however, is not uncertainty. Variability is simply the normal range of values that different members of a population exhibit, like differences in height among humans. In principle, such variability can be measured and hence is not uncertain." What does "in principle" mean? In fact, not all variability (and its implications for risk) can be or has been specified at present. The NRC report on radon (*ibid.,* p. 159) says: "For many factors, there is little basis for estimating variability." For example, we are beginning to accumulate scientific evidence about genetic variations among the population, and suspicions that such

variation may have large implications for the distribution of many types of risk, but there are as yet many unknowns. This is one of a number of sources of uncertainty within variability.

[15] The most recent article is W. Poortinga and N. Pidgeon, "Exploring the dimensionality of trust in risk regulation," *Risk Analysis*, vol. 23, no. 5 (October 2003): 961-972, which includes references to many other studies on this theme.

[16] Go to http://www.hc-sc.gc.ca/sab-ccs/mar1998_apph_hpb_risk_e.html for material on Health Canada's risk management framework.