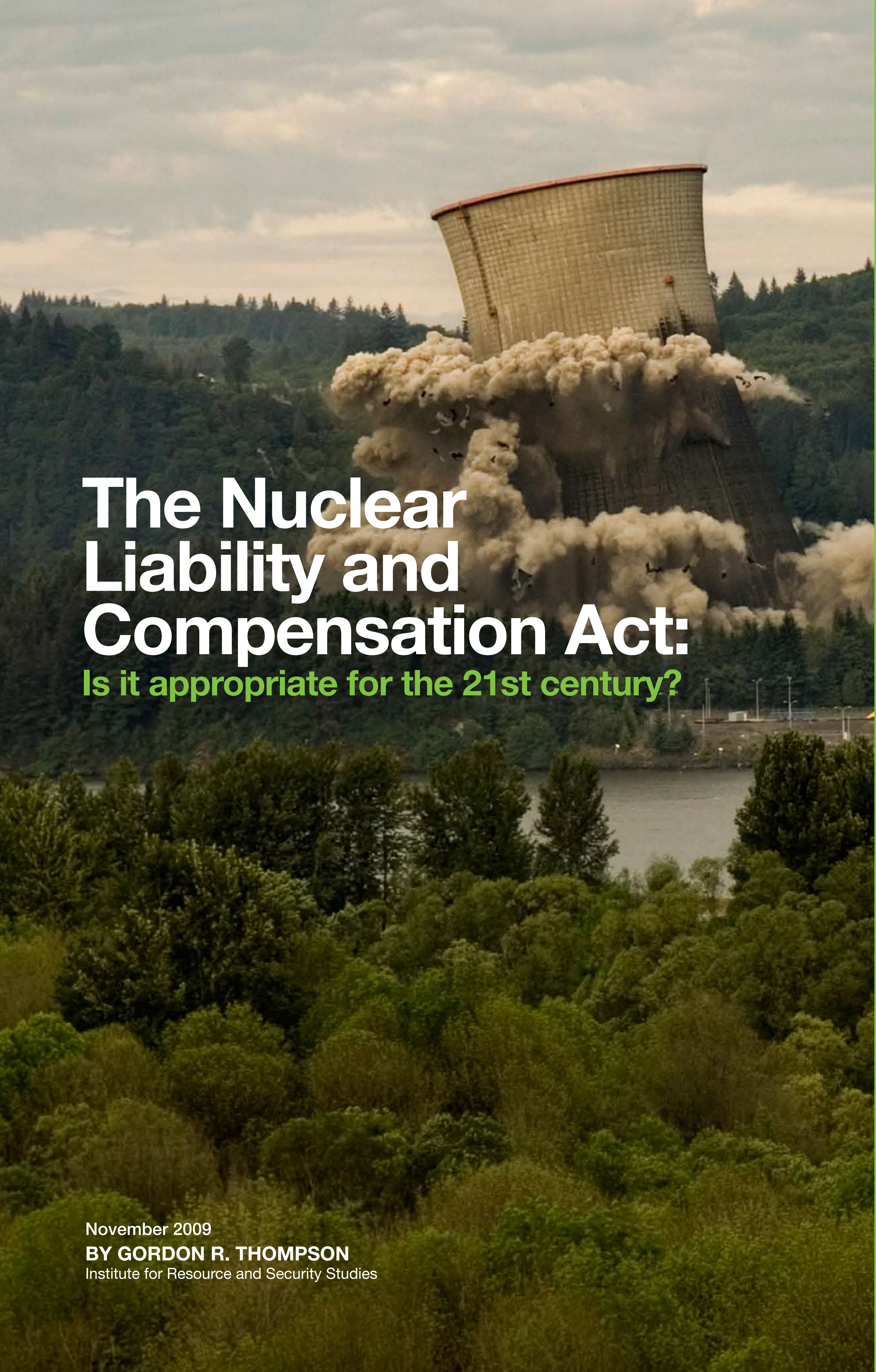

The Nuclear Liability and Compensation Act:

Is it appropriate for the 21st century?

November 2009

BY GORDON R. THOMPSON
Institute for Resource and Security Studies

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ABSTRACT

A bill has been introduced into Canada's parliament to create the *Nuclear Liability and Compensation Act* (NLCA), which would replace the existing *Nuclear Liability Act*. Both Acts pertain to civil liability for damage arising from an incident at a nuclear installation. This report assesses the proposed NLCA. In performing that task, the report focuses on the application of the NLCA to nuclear power plants (NPPs) in Canada. The report further focuses on potential incidents at NPPs where the incident involves an unplanned release of radioactive material to the environment or within a plant. Criteria used here to assess the NLCA are based upon three concepts that would play major roles in a properly-constructed 21st century policy framework for nuclear power. The concepts are: sustainability; the precautionary principle; and full accounting of costs (which includes the polluter-pays principle). This report's assessment of the NLCA identifies significant deficiencies. Options for improving the NLCA are set forth here.

ABOUT THE INSTITUTE FOR RESOURCE AND SECURITY STUDIES

The Institute for Resource and Security Studies (IRSS) is an independent, nonprofit, Massachusetts corporation, founded in 1984. Its objective is to promote sustainable use of natural resources and global human security. In pursuit of that mission, IRSS conducts technical and policy analysis, public education, and field programs. IRSS projects always reflect a concern for practical solutions to resource and security problems.

ABOUT THE AUTHOR

Gordon R. Thompson is the executive director of IRSS and a research professor at Clark University, Worcester, Massachusetts. He studied and practiced engineering in Australia, and received a doctorate in applied mathematics from Oxford University in 1973, for analyses of plasma undergoing thermonuclear fusion. Dr. Thompson has been based in the USA since 1979. His professional interests encompass a range of technical and policy issues related to sustainability and global human security. He has conducted numerous studies on the environmental and security impacts of nuclear facilities, and on options for reducing those impacts. For example, Dr. Thompson prepared a report in 2000 for the Standing Committee on Energy, Environment, and Natural Resources of the Canadian Senate, discussing the accident risk posed by the Pickering A nuclear generating station.

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Executive Summary

A bill has been introduced into Canada's parliament to create the *Nuclear Liability and Compensation Act* (NLCA), which would replace the existing *Nuclear Liability Act*. Both Acts pertain to civil liability for damage arising from an incident at a nuclear installation. Under the new Act, the liability of the operator of the affected installation would be limited to $650 million, compared to the limit of $75 million under the present Act.

This report assesses the proposed NLCA, focusing on its application to nuclear power plants (NPPs), and on incidents involving an unplanned release of radioactive material to the environment or within a plant. Damage from such an incident could substantially exceed other types of damage covered by the NLCA.

The NLCA is assessed here using three concepts that would play major roles in a properly-constructed 21st century policy framework for nuclear power. The concepts are: sustainability; the precautionary principle; and full accounting of costs (which includes the polluter-pays principle). Criteria based on these concepts are used here to assess the NLCA. The criteria are expressed as questions, as follows:

Criterion #1: Full accounting – information disclosure

Would the NLCA require Canada's nuclear industry and government to publish a full spectrum of information relevant to nuclear risk and nuclear insurance, including:

(a) an assessment of the risk of operating each NPP and other nuclear installation; and

(b) the insurance coverage of offsite and onsite damage that is provided for each NPP and other nuclear installation, premiums paid for this coverage, and reinsurance arrangements?

Criterion #2: Full accounting – damage coverage

Would the NLCA ensure that commercial insurance covers the full range of potential offsite and onsite damage arising from incidents at each NPP and other nuclear installation?

Criterion #3: Full accounting – accounting for risk costs as costs of production

Would the NLCA ensure that the risk costs of operating each NPP and other nuclear installation are accounted for as costs of production?

Criterion #4: The precautionary principle

Would the NLCA be compatible with coherent and consistent application of the precautionary principle in Canada?

Criterion #5: Sustainability

Would the NLCA be compatible with a transition of Canada's economy toward sustainability?

MAJOR FINDINGS

In regard to Criterion #1, the NLCA would not require Canada's nuclear industry and government to publish a full spectrum of information relevant to nuclear risk and nuclear insurance. Thus, the present situation would continue, in which the information published about nuclear risk is often incomplete or misleading, and there is a dearth of information about the operation of the nuclear insurance sector. This situation is incompatible with democracy, given the public-policy significance of nuclear risk and nuclear insurance.

In regard to Criterion #2, the NLCA would not ensure that commercial insurance covers the full range of potential damage arising from incidents at NPPs. The liability of commercial insurers would be limited to $650 million, and a substantial portion of that exposure would be reinsured by the Canadian government. Monetized damage to third parties could far exceed $650 million. Studies by the Canadian nuclear industry show that offsite health costs from some potential accidents at existing NPPs could exceed $50 billion. The industry says that such accidents have low probability. Yet, offsite health costs could exceed $1 billion for accidents that the industry concedes are "credible" because their probability is comparatively high. Moreover, there are reasons to doubt that accident probabilities are as low as the nuclear industry claims. Nuclear insurers assume much higher probabilities. Also, the potential for malevolent acts must be considered. Overall, the probability of an event causing offsite damage exceeding $50 billion is substantially higher than is shown by industry studies.

In the USA, a two-tier system of nuclear insurance provides about $11 billion of coverage for damage to third parties. The Price-Anderson Act governs this arrangement. In Germany, there is no limit on an NPP operator's liability for damage to third parties. Each NPP operator in Germany must provide security of 2.5 billion Euro toward its liability.

An unplanned release of radioactive material could cause economic damage to the operator of an NPP even if most of the released material is contained within the plant buildings. Studies by the nuclear industry show that accidents with a comparatively high probability could cause damage to the operator in excess of $650 million. For example, an industry study shows that one type of accident at the Darlington nuclear station with an estimated probability of 3 per 1,000 reactor-years (i.e., 48 percent over 40 years, at this 4-unit station) would cause damage between $790 million and $2,500 million to the operator. It appears that no insurance coverage of such an accident exists now in Canada or would exist under the NLCA. Although the damage would directly affect the operator, its costs would ultimately be borne by society at large. Insurance coverage of damage to the operator is provided in the USA.

In regard to Criterion #3, the NLCA would not ensure that the risk costs of operating each NPP are accounted for as costs of production. This report contains quantitative analysis to address that issue, and the findings are presented in Table ES-1. That table shows that risk costs would far exceed insurance premiums. There is no other mechanism to incorporate risk costs as production costs. Thus, most of the risk costs would be borne by the public at large, representing a large, implicit subsidy of nuclear power. For example, Table ES-1 shows that operation of an existing NPP in Canada creates offsite risk costs of 2.7 to 5.4 cent per kWh of electricity produced, plus additional onsite risk costs of 2.7 to 5.6 cent per kWh. Under the NLCA, the only evident accounting for these risk costs as costs of production would be through payment of insurance premiums amounting to 0.02 cent per kWh, to cover offsite damage to third parties up to a $650 million limit. Thus, the public now provides, and would provide under the NLCA, an implicit subsidy to NPP operators of 5.4 to 11.0 cent per kWh. In 2007, the total, implicit subsidy across all Canadian NPPs was $4.8 billion to 9.7 billion for the year. (Canadian nuclear generation was 88.2 billion kWh in 2007.) Such a large subsidy is a significant violation of the polluter-pays principle.

Table ES-1

Risk Costs of Nuclear Generation in Canada: Summary of this Report's Findings

Note: This table, with notes, appears in the body of the report as Table 9-8.

CATEGORY OF IMPACTS FROM UNPLANNED RELEASES OF RADIOACTIVE MATERIAL	Category of Risk Costs and the Insurance Premiums that are Paid to Provide Coverage of these Costs	Magnitude of Risk Costs and Insurance Premiums	
		For an Existing CANDU Plant	For a New Generation III Plant
Offsite Impacts	Risk Costs (2009 Can cent per kWh)	2.7 to 5.4	1.5 to 15.4
	Insurance Premiums Under the NLCA (2009 Can cent per kWh)	0.02	As for existing CANDU plant?
Onsite Impacts	Risk Costs (2009 Can cent per kWh)	2.7 to 5.6	Smaller amount than for existing CANDU plant
	Insurance Premiums Under the NLCA (2009 Can cent per kWh)	No explicit premium is evident	No explicit premium is evident

The analysis underlying Table ES-1 involves various uncertainties and assumptions. Other analysts might make different assumptions, yielding different findings. However, the assumptions made here are reasonable, and the findings are robust. Risk costs exceed insurance premiums by a factor of 270 to 550. Although limited information is publicly available regarding the premiums set by nuclear insurers, accessible data show that nuclear insurers make assumptions about nuclear risk that are consistent with the assumptions made here.

In regard to Criterion #4, the NLCA would not be compatible with coherent and consistent application of the precautionary principle in Canada. Underlying the NLCA is an assumption that consideration of the risk of unplanned radioactive releases from NPPs should, in the practical context of liability and insurance, be confined to comparatively small releases. That assumption is implicit in the choice of $650 million as a liability limit, and is confirmed by official sources. Yet, that assumption is contradicted by studies conducted by the Canadian nuclear industry, analogous studies conducted in other countries by industry and government, experience with the 1986 Chernobyl accident and the 1979 Three Mile Island accident, and a well-recognized potential for malevolent acts at NPPs. Those sources of information show that damage far in excess of $650 million is a realistic possibility. The NLCA ignores that possibility, and would, therefore, be incompatible with the precautionary principle. Moreover, the NLCA's liability limit has no basis in either systematic technical analysis or public debate, both of which are central to application of the precautionary principle. A relevant technical analysis – the Severe Accident Study – was initiated by the Canadian government in the late 1980s but never completed.

In regard to Criterion #5, the NLCA would not be compatible with a transition of Canada's economy toward sustainability. There are at least three major aspects of this incompatibility. First, the NLCA would violate the precautionary principle, thereby tending to suppress policies and actions flowing from that principle. As a result, opportunities to reduce the risk of NPP operation would be lost, and Canada would bear an unnecessarily high risk of a radioactive release with devastating impacts on the environment, economy, and society. Second, the NLCA would create a large, implicit public subsidy for nuclear power, thereby distorting decisions about public and private investment in systems for production and use of energy. In that way, the NLCA would suppress innovation in sustainable energy systems, and would inhibit market processes for cost-effective deployment of such systems. Third, the NLCA would continue the present climate of incomplete and often misleading information about nuclear risks and nuclear insurance. That climate is antithetical to the open, science-based, and participatory exchange of information that is necessary for Canada's transition to sustainability.

The polluter-pays principle was upheld unanimously by the Supreme Court of Canada in a 2003 decision. The precautionary principle has important roles in the *Canadian Environmental Assessment Act* of 1992 and the *Federal Sustainable Development Act* of 2008. Yet, the NLCA would violate both the polluter-pays principle and the precautionary principle. Thus, the NLCA would be incompatible with existing Canadian law, and may be incompatible with Canada's international commitments. Also, the NLCA would create subsidies for nuclear generation of electricity. One subsidy is implicit in the $650 million liability limit. Another subsidy would be the Canadian government's reinsurance of risk that the nuclear insurers refuse to cover. Both subsidies may be incompatible with Canada's existing laws and international commitments.

OPTIONS FOR IMPROVING THE NLCA

The preceding paragraphs identify significant deficiencies in the proposed NCLA. Options that could address those deficiencies, to varying extents, include:

Option #1: Disclosure of nuclear insurance data

The NLCA would require the timely publication of data on nuclear insurance coverage, premiums, reinsurance, and compensation.

Option #2: Full assessment of NNP risk

Voting by Parliament on the NLCA would be preceded by publication of a comprehensive assessment of the risk posed by NPP operation in Canada. As part of this option, the NLCA could provide for its own review at specified intervals, preceded each time by an updated NPP risk assessment.

Option #3: Full commercial insurance

The NLCA would prohibit nuclear reinsurance by the Canadian government.

Option #4: Increased liability limit

The NLCA would have a third-party liability limit much higher than $650 million, or no limit.

Option #5: Coverage of onsite damage

The NLCA would require NPP operators to have commercial insurance coverage for onsite damage, including loss of electricity production.

Option #6: Economic channeling

The NLCA would require economic channeling of liability, as under the Price-Anderson Act.

Option #7: Operator-pooled, second-tier coverage

The NLCA would require all Canadian NPP operators to participate in pooled, second-tier coverage via retroactive premiums, as under the Price-Anderson Act. A variant of this option would involve all US NPP licensees and all Canadian NPP operators participating in a common pool that provides second-tier coverage.

MAJOR RECOMMENDATIONS

The following recommendations are offered:

R1. The NLCA should not be enacted in its present form.

R2. The Canadian government should prepare a comprehensive assessment of the risk posed by NPP operation in Canada, the opportunities for reducing that risk, and the accompanying risk costs and risk-reduction costs.

R3. The Canadian government should prepare a legal analysis of the compatibility of the NLCA with Canada's existing laws and international commitments.

R4. The Canadian government should prepare a systematic study of options for improving the NLCA, to include the options outlined in this report.

R5. Parliament should sponsor a public event at which representatives of a wide range of stakeholders would discusses the analyses called for in recommendations R2 through R4, and would present their own analyses.

R6. A revised NLCA should be prepared, informed by the public event called for in recommendation R5.

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1. Introduction

A bill has been introduced into Canada's parliament to create the *Nuclear Liability and Compensation Act* (NLCA).[1] The new Act would replace the existing *Nuclear Liability Act*. Both Acts pertain to civil liability for damage arising from an incident at a nuclear installation. Under the new Act, the liability of the operator of the affected installation would be limited to $650 million, compared to the limit of $75 million under the present Act.

This report assesses the proposed NLCA. In performing that task, the report focuses on the application of the NLCA to nuclear power plants (NPPs) in Canada.[2] The report further focuses on potential incidents at NPPs where the incident involves an unplanned release of radioactive material to the environment or within the plant. Those foci reflect the fact that an unplanned release of radioactive material from or within an NPP could cause damage substantially exceeding the damage arising from other types of incident covered by the NLCA.[3]

In assessing the NLCA, this report indirectly assesses the existing *Nuclear Liability Act*. Applying the assessment criteria used here, the existing Act is equivalent to or weaker than the NLCA. Thus, deficiencies identified in the proposed NLCA are present to an equal or greater extent in the present Act.

CRITERIA FOR ASSESSING THE NLCA

The major purpose of the NLCA would be to facilitate the future operation of NPPs in Canada. Those NPPs could be existing or new plants.[4] Historically, national governments adopted legislation on nuclear liability because the private insurance sector was unwilling to extend coverage to NPPs. Governments took that action to facilitate the growth of what was then a new industry. Now, nuclear power is a mature technology that has been in use for half a century. If this technology is to remain in use over the coming decades, it should do so within a policy framework that is appropriate for the 21st century. The NLCA should be assessed in the context of such a framework.

Detailed articulation of a 21st century policy framework for nuclear power is a task beyond the scope of this report. It is clear, however, that three concepts would play major roles in such a framework. The concepts are: sustainability; the precautionary principle; and full accounting of costs (which includes the polluter-pays principle). Section 3 of this report outlines each concept, and sets forth criteria, pertinent to each concept, that are used here to assess the NLCA.

TYPES OF ANALYSIS USED HERE

This report's assessment of the NLCA according to sustainability and precautionary-principle criteria uses qualitative analysis. In applying full-accounting criteria, however, this report employs both qualitative and quantitative analysis. The quantitative analysis estimates the risk of operating an NPP, assigns that risk a monetary value, and determines the extent to which the monetized risk would receive insurance coverage under the NLCA. Monetized risk that is not covered by insurance can be designated as "uninsured risk cost" or as "externality cost".

It should be noted that the risk of operating an NPP has some attributes that cannot be quantified. Moreover, quantitative estimation of risk involves uncertainty and assumptions. Also, assigning a monetary value to a unit of quantitatively-estimated risk involves assumptions. In the quantitative risk analysis that is presented here, various assumptions and estimates are used. Some of these assumptions and estimates originate with the Canadian nuclear industry, and some are by the author. The findings should be viewed as illustrative in both cases. Other analysts might employ different assumptions, and their numerical findings would differ accordingly. Ultimately, assessment of the NLCA must be qualitative.

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[1] Becklumb and Dufresne, 2009; Henault, 2009. The current bill is designated as bill C-20. It is functionally identical to bills C-63 and C-5 that were introduced during the 39th parliament but not enacted.

[2] Throughout this report, the term "nuclear power plant" means a fission reactor and its associated equipment, including equipment to produce electricity. Future NPPs of the Generation IV type, if any operate in Canada, might also produce hydrogen, potable water, and/or process heat. At three sites in Ontario (Pickering, Bruce, and Darlington), NPPs are clustered in groups of four to make up "nuclear generating stations". In those instances, the individual NPPs are often described as "units".

[3] NPPs would be less dominant in terms of potential damage if a uranium enrichment plant, nuclear fuel reprocessing plant, or high-level radioactive waste repository became operational in Canada.

[4] There is discussion about building new NPPs in Canada. At present, no order has been placed for a new NPP.

DEFINING AND CATEGORIZING RISK

The term “risk” is used here to refer to the potential for, and impacts of, unplanned releases of radioactive material to the environment or within an NPP.[5] Such releases could occur as a result of accidents or malevolent acts, as discussed below. The releases would be “unplanned” in the sense that they would not be expected to occur during routine operation. Nevertheless, the potential for occurrence of unplanned releases is acknowledged by the nuclear industry and its regulators, in Canada and elsewhere.

A more precise term for the type of risk considered here would be “residual risk”. In that term, the word “residual” characterizes the risk that remains after the nuclear industry has complied with the requirements imposed by its regulators. In Canada, the primary regulator of the safety and security of NPPs is the Canadian Nuclear Safety Commission (CNSC). This report examines risk with two assumptions. First, construction and operation of NPPs in Canada consistently reflect good-faith efforts by the nuclear industry to comply with CNSC regulations. Second, CNSC personnel consistently make good-faith efforts to enforce CNSC regulations.

An unplanned release of radioactive material could occur as a result of an accident or a malevolent act. The Canadian Environmental Assessment Agency (CEAA) acknowledges the need to consider both types of incident in an environmental impact statement (EIS) for the construction of a new NPP. CEAA describes such incidents as “accidents and malfunctions”, which are defined as a category of events that includes accidents of a traditional type (events attributable to human error, natural phenomena, etc.) together with intentional, malevolent acts. Consideration of malevolent acts in an EIS for a commercial nuclear installation is a comparatively new development in the field of environmental assessment. CEAA has published EIS guidelines that contain a classification of accidents and malfunctions at an NPP.[6] The CEAA classification has been refined by this author, as shown in Table 1-1.

This report focuses on accidents and malfunctions in the first two rows of Table 1-1. Those rows pertain to an unplanned release of radioactive material from the reactor core or from spent fuel. Such events dominate the potential for damage that is relevant to the NLCA. The damage could occur within an NPP or in the surrounding environment. In addressing damage in the surrounding environment, this report focuses on potential unplanned releases to the atmosphere. The released material would be carried downwind in a radioactive plume, and some of that material would be deposited from the plume onto vegetation, buildings, the ground surface, etc.

SECRECY

The nuclear industry, and the bodies that regulate its safety and security, are prone to secretive behavior. Such behavior reflects a variety of motives. The nuclear industry has a legitimate need to protect trade secrets, but has also been known to hide embarrassing information that should be disclosed. Regulators have often chosen to not assess, or not disclose, the upper end of the range of risk associated with nuclear installations, reflecting a paternalistic view of the public’s ability to use such information. In recent years, as the potential for intentional, malevolent acts has become a salient issue, industry and regulators have become more secretive. This trend reflects the fact that each existing and currently-proposed NPP – in Canada and elsewhere – has a limited ability to ride out an attack by a well-prepared, sub-national group.[7]

The nuclear industry and regulators have two, broad motives for secrecy regarding the risk of malevolent acts at NPPs. First, they do not wish to encourage an attack. Second, they are reluctant to admit their failure, over several decades, to ensure that resistance to attack is a priority in NPP design. The first motive matches the public interest, but the second does not. While NPPs continue to operate, it is difficult to disentangle the two motives. Thus, excessive secrecy persists. As a result, public discussion of nuclear risk and nuclear insurance does not properly address the threat of attack. This report strikes a balance in discussing that threat. The report describes, in a general way, the risk of malevolent acts at NPPs, but does so without disclosing information that would assist potential attackers.

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[5] The term “risk” is often used to refer to the arithmetic product of: (i) a quantitative indicator of adverse impact; and (ii) the quantitative probability that the impact will occur. In this report, the term is used in a more general sense, to encompass a range of qualitative and quantitative information about the potential for an adverse outcome.

[6] CEAA at al, 2008. That document was prepared by CEAA and the Canadian Nuclear Safety Commission, in consultation with Fisheries and Oceans Canada, Transport Canada, and the Canadian Transportation Agency.

[7] A sub-national group of attackers is a group that can operate without support or direction from a nation-state.

STRUCTURE OF THIS REPORT

The remainder of this report has twelve sections. Section 2 describes the NLCA and the nuclear insurance sector in Canada. Section 3 develops criteria for assessing the NLCA, drawing upon three high-level issues related to nuclear power: sustainability; the precautionary approach; and full accounting of costs. Section 4 provides global and North American perspectives on nuclear liability and insurance. Then, Section 5 discusses the general problem of assessing the risk posed by NPPs, and Section 6 discusses options for reducing that risk. Section 7 examines the risk posed by NPPs in Canada. Risk-related costs are then discussed from two perspectives. Section 8 outlines the Canadian government's consideration of risk-related costs, while Section 9 provides this report's estimation of those costs. Section 10 discusses regulatory issues, secrecy, and their relevance to the NLCA.

Drawing upon all the preceding sections, Section 11 summarizes the major deficiencies in the NLCA that are identified in this report, and discusses options for correcting those deficiencies. Conclusions and recommendations are set forth in Section 12, and a bibliography is provided in Section 13. All documents cited in this report, whether in the footnotes to the narrative or in the report's tables and figures, are listed in the bibliography. Tables and figures, numbered according to the relevant section of the report, appear after Section 13. An appendix appears at the end of the report. This Appendix, which is especially relevant to Section 6, shows how NPPs could be designed to pose a comparatively low level of risk.

2. An Outline of the NLCA and Nuclear Insurance in Canada

The proposed *Nuclear Liability and Compensation Act* would replace the existing *Nuclear Liability Act*. Major provisions of the NLCA are outlined here, drawing upon a summary by the Parliamentary Information and Research Service and another summary by an advisor to Natural Resources Canada.[8]

Both the existing Act and the proposed NLCA make the operator of a nuclear installation exclusively liable for damage arising from an incident at the installation. The liability is "absolute", which means that a victim does not need to prove negligence in order to make a claim. The operator's exclusive liability is through "legal" channeling, which differs from the "economic" channeling that occurs in the USA under the Price-Anderson Act. The difference between these modes of channeling is discussed in Section 4, below.

A major difference between the NLCA and the present Act is the NLCA's higher limit on liability. Under the NLCA, the operator's liability would be limited to $650 million, compared to the limit of $75 million under the present Act. The $650 million limit could be increased by regulation, and must be reviewed every five years by the responsible minister. The rationale for a $650 million limit has been described by an advisor to Natural Resources Canada as follows:[9]

> *"The $650 million limit reflects a balance of considerations. First, it addresses foreseeable, rather than catastrophic Chernobyl-type accidents. Second, it reflects insurance capacity that can be available at reasonable costs. It puts Canada on par with liability limits in many other countries. And, finally, it is responsive to recommendations of the Standing Senate Committee on Energy, Environment and Natural Resources which, in 2001, recommended that the operator liability limit be increased from the current 75 million dollars to an amount in line with the Paris and Vienna Conventions of over 600 million dollars."*

There are various other differences between the NLCA and the present Act. For example, the NLCA is more explicit in stating that Parliament can appropriate funds for additional victim compensation beyond the $650 million limit, should that be necessary. Also, the NLCA would extend the claims limitation period to 30 years for bodily injury and death, while continuing the present 10-year claims limitation period for property damage.

The NLCA would expand the definition of compensable damage. Under the NLCA, compensable damage would include bodily injury, damage to property, and psychological trauma resulting from those effects. Also included would be economic losses arising from bodily injury, property damage, or psychological trauma, together with costs arising from loss of use of property. However, costs arising from an affected nuclear installation's failure to provide electricity would not be compensable. Costs of measures to repair or mitigate environmental damage would be compensable if the measures are ordered by a government agency.

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[8] Becklumb and Dufresne, 2009; Henault, 2009.
[9] Henault, 2009.

APPLICATION OF THE NLCA TO MALEVOLENT ACTS

The NLCA would not apply to an incident resulting from an act of war, hostilities, a civil war, or an insurrection. It would, however, apply to an incident arising from "terrorist activity", as defined in subsection 83.01(1) of the *Criminal Code*. That definition encompasses a wide range of incidents, with the following specific exception:[10]

> *"[Terrorist activity] does not include an act or omission that is committed during an armed conflict and that, at the time and in the place of its commission, is in accordance with customary international law or conventional international law applicable to the conflict, or the activities undertaken by military forces of a state in the exercise of their official duties, to the extent that those activities are governed by other rules of international law."*

APPLICATION OF THE NLCA TO ONSITE DAMAGE

According to the Parliamentary Information and Research Service, the NLCA would not apply to damage to a nuclear installation that experiences an incident, if the operator is responsible for that damage. It is not clear, however, that the NLCA would apply to this type of damage if the operator were not responsible. Such a situation could arise, for example, if the incident were caused by a natural event (e.g., an earthquake) or a malevolent act.[11]

It appears that there is no specific provision in Canadian law or insurance practice to address liability or compensation for onsite damage at an NPP that experiences an unplanned release of radioactive material. More specifically, this author has not identified such a provision. Apparently, Canadian operators of NPPs self-insure for onsite damage. This practice was established during a period of several decades when all the NPP operators were provincially-owned corporations. More recently, a private entity – Bruce Power – has become an NPP operator.[12] Bruce Power's insurance arrangements for onsite damage are unclear.

NUCLEAR INSURANCE IN CANADA

Three "pools" of insurance companies provide nuclear insurance in Canada. Each pool is approved under the existing *Nuclear Liability Act*, and has held that position since 1976. The pools are: Nuclear Insurance Association of Canada (NIAC); American Nuclear Insurers (ANI), a US pool; and Nuclear Risk Insurers (NRI), a UK pool. NIAC, the Canadian pool, consists of domestic insurance companies and Canadian subsidiaries or branches of foreign insurance companies. In Canada, NIAC is the primary insurer, and ANI and NRI are co-insurers.

A substantial fraction of NIAC's present coverage of NPP operators is re-insured with the Canadian government. In 2008, the government was providing $585 million of third-party liability coverage for Canada's 18 operating NPPs, which amounts to an average of $32 million per NPP, or 43 percent of the $75 million liability limit.[13]

Re-insurance by the Canadian government would continue under the NLCA, in order to "provide coverage for risks that insurers are unwilling or unable to cover".[14] For this purpose, the government would continue to operate the Nuclear Liability Reinsurance Account. Any deficit in that account would be paid from the Consolidated Revenue Fund. In other words, the Canadian government would provide nuclear reinsurance from general revenue.

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[10] Definition accessed on 19 October 2009 at: <http://www.canlii.org/en/ca/laws/stat/rsc-1985-c-c-46/latest/rsc-1985-c-c-46.html>.

[11] In such a situation, it might be argued that the operator had failed to ensure that the installation could ride out a foreseeable natural event or malevolent act, and was therefore responsible.

[12] Bruce Power operates, but does not own, the Bruce A and Bruce B nuclear generating stations in Ontario, and has proposed the construction of new NPPs.

[13] CNSC, 2008d, page 73.

[14] Henault, 2009.

The Canadian nuclear insurers have made it clear that they would not provide coverage under the NLCA without reinsurance by the Canadian government. At an October 2009 conference in Toronto, their representatives stated:[15]

> *"Insuring all of the heads of damage under the NLCA for the full Cdn. $650 million limit will be challenging. We understand that countries that are signatories to the Conventions face similar challenges.*
>
> *Insurers have expressed concerns with insuring a number of the new heads of damage under the NLCA. Of particular concern is environment impairment. However, there are also concerns with respect to economic loss, psychological trauma and terrorism.*
>
> *Fortunately, in Canada, the Federal Government already reinsures a portion of the exposure under the current NLA and has expressed a willingness to continue to reinsure a portion of the exposure under the NLCA. Without such reinsurance, it would be impossible to insure the full exposure under the NLCA."*

OPERATIONAL DATA ABOUT NUCLEAR INSURANCE: PREMIUMS, ETC.

There is a dearth of publicly-available operational data for the nuclear-insurance sector in Canada. No information about coverage of onsite damage at NPPs could be obtained for this report. Sparse information was obtained about premiums paid for third-party liability coverage, as discussed below. An attempt to obtain information about nuclear insurance was made in 2008 in the context of a proceeding (EB-2007-0707) before the Ontario Energy Board. Relevant interrogatories were submitted to the Ontario Power Authority (OPA) by a group of intervenors.[16] OPA provided no information in response to those interrogatories.

A research paper sponsored by the Canadian government states that a third-party liability premium of $125,000 per RY was paid in 1995 for the Darlington nuclear generating station.[17] That premium can be adjusted upward to 2009 $ by a factor of 1.36, using the CPI inflator published by Bank of Canada.[18] A further upward adjustment can be made by a factor of 650/75 to account for an increase in the liability limit from $75 million to $650 million. Those adjustments yield an estimated premium of $1.47 million (2009 $) per reactor-year (RY) for third-party liability coverage for a Canadian NPP under the proposed NLCA. That estimate is used in this report, in the absence of official data. In view of the extrapolation from 1995 data, we assume that terrorist-risk coverage is not included in this estimated premium.

After the attacks of September 2001 on New York and Washington, the NIAC insurers were unwilling to provide full coverage for third-party liability associated with terrorist incidents. Since 2003, the Canadian government has provided the bulk of that coverage through reinsurance. In 2006, for example, the Canadian government provided 80 percent of the terrorist-risk coverage for Canada's 18 operating NPPs for an aggregate premium of $280,000.[19] That amount is equivalent to a premium of $280,000/(18 x 0.8) = $19,400 per RY (2009 $). The latter premium can be adjusted upward by a factor of 650/75 to account for an increase in the liability limit, resulting in an estimated premium of $0.17 million per RY (2009 $) for terrorism-risk third-party liability coverage under the proposed NLCA.

The two preceding paragraphs yield an estimated total premium of $1.64 million per RY (2009 $) for coverage of an NPP under the NLCA.[20] Assuming a plant capacity of 0.88 GWe and a capacity factor of 0.9, that premium translates to an amount of 0.024 cent per kWh of nuclear generation (2009 Can cent).

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[15] Murphy et al, 2009.

[16] The group consisted of the Green Energy Coalition, the Ontario Sustainable Energy Association, and the Pembina Institute. The relevant interrogatories were numbered 91 through 99.

[17] Heyes and Heyes, 2000, page 93.

[18] It could be argued that the premium should not be adjusted for inflation, because the $75 million liability limit has remained unchanged. That argument neglects profit and administrative costs, and the insurers' expectations regarding claims below the liability limit. Without an inflation adjustment for the premium, this report's estimate of uninsured risk costs would rise slightly.

[19] Lunn, 2007.

[20] Given perfect forecasting and no profit or administrative costs, an insurance premium of $1.64 million per RY for coverage of $650 million would imply an event probability of 2.5 per 1,000 RY.

3. Issues Relevant to Assessing the NLCA: Sustainability, Precaution, & Full Accounting

3.1 Imperatives and Principles of Sustainability

During recent decades, citizens and governments have increasingly recognized the need to organize human affairs within the context of a finite Earth. One manifestation of that need is human-induced, adverse change in the climate.[21] Other signs of stressed ecosystems are also evident. The Millennium Ecosystem Assessment determined that 15 out of the 24 ecosystem services that it examined "are being degraded or used unsustainably, including fresh water, capture fisheries, air and water purification, and the regulation of regional and local climate, natural hazards, and pests".[22] By abusing ecosystems in this manner, we deplete renewable resources that are essential to human life. Non-renewable resources are also being depleted. For example, a growing body of analysis predicts a peak in world oil production within the next few decades.[23]

In our well-populated, competitive world, limits to the availability of resources and ecosystem services have implications for peace and security. For example, analysts are considering the potential for climate change to promote, through its adverse impacts, social disorder and violence.[24] It is increasingly evident that nations must cooperate to protect and share the Earth's resources. International agreements such as the Framework Convention on Climate Change reflect that imperative. National policies on a range of issues – including energy, agriculture, forestry, transport, minerals, and urban planning – must be consistent with global needs. Engineers must develop new design approaches, as shown in Table 3-1.

Policy choices made now will determine the opportunities available to future generations. The future implications of current policy choices have been examined by analysts convened by the Stockholm Environment Institute (SEI).[25] These analysts identified six possible worldwide scenarios for human civilization over the coming century and beyond. In some scenarios, the world faces chronic, unresolved problems and conflicts. In others, the world descends into barbarism. The most attractive scenario, with the greatest opportunities for future generations, is one that the SEI analysts described as a New Sustainability Paradigm.

The concept of sustainability was brought to wide public attention by the World Commission on Environment and Development in 1987. WCED discussed the concept in terms of sustainable development, to emphasize that sustainability is compatible with improvement in the conditions of life for poorer societies. Since 1987, the concept of sustainability has been widely endorsed by governments and other entities. Yet, there has been comparatively little progress in making the concept operational at the level of specific policies and plans. In an effort to address that problem, the Organization for Economic Cooperation and Development (OECD) initiated a three-year project in 1998, seeking to identify sustainability principles and indicators that can be used in policy making. One product of the effort was a report by the OECD Nuclear Energy Agency (NEA), published in 2000, that discussed commercial nuclear power in the context of sustainable development.[26]

THE NEA VIEW OF SUSTAINABILITY

In discussing the concept of sustainability, the NEA report took as its starting point the WCED definition of sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". The NEA report elaborated on that definition by suggesting that sustainability involves the passing on to future generations of a stock of capital assets, which could be human-made, natural, or human and social. Human-made assets include buildings, machinery, and infrastructure. Natural assets include the environment, and the renewable and non-renewable resources that it can supply. Human and social assets include education, health, scientific and technical knowledge, cultures, institutions, and social networks.

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[21] IPCC, 2007.
[22] MEA, 2005, page 1.
[23] GAO, 2007.
[24] Campbell et al, 2007.
[25] Raskin et al, 2002.
[26] NEA, 2000.

According to the NEA, "strong sustainability" involves the preservation of an asset in its present form. That approach is relevant, for example, to ecosystems that are essential and irreplaceable. Earth's atmosphere fits that category. An alternative approach is "weak sustainability", whereby the loss of one asset (e.g., an area of forested land) is offset by creation of another asset (e.g., development of a city on the formerly forested land). The weak-sustainability approach requires tradeoffs, which create the potential for conflicts within and between generations. The strong-sustainability approach is conceptually simpler, but is rarely encountered in its pure form. For example, human-induced emissions of CO2 to the atmosphere cannot be eliminated instantly, but must be reduced over time. With the best of intentions, we cannot pass on to the next several generations an atmosphere containing CO2 at the present concentration.

The NEA report contained a general discussion of nuclear power from the perspective of sustainability. That discussion addressed many of the relevant issues, including emissions of CO2 and other greenhouse gases. The NEA report did not, however, provide an analytic framework that could be used to assess the sustainability of a proposed program of nuclear power, or to compare the sustainability of that program and the sustainability of other strategies to meet energy needs.

The NEA report discussed the potential for an NPP to experience a large, unplanned release of radioactive material to the environment. Such a release would substantially degrade human-made, natural, human, and social assets in the affected locations. For example, contaminated land and buildings would be abandoned, and exposed populations would experience higher rates of cancers. Thus, the release could have significant, adverse effects on sustainability.

According to the NEA, the probability of a large, unplanned release is low. Thus, a conceptual and analytic framework is needed to assess the sustainability implications of potential events with large, adverse consequences and low probability. That issue is not unique to nuclear power. For example, capture and sequestration of CO2 is an energy option that could allow use of fossil fuels without adverse effects on Earth's climate. If a proposed project involves CO2 sequestration on a large scale, an assessment of the sustainability of the project should examine the probability and consequences of a large, unexpected release of sequestered CO2 to the atmosphere.

Analysts in the nuclear industry and its regulatory bodies address the potential for high-consequence, low-probability events by defining an indicator called "risk". They typically define that indicator as the arithmetic product of a numerical indicator of consequences and a numerical indicator of probability.[27] They frequently argue that equal levels of risk should be equally acceptable to citizens. That argument has been made so often that it has become dogma. Yet, the argument is not a scientific statement. It is, instead, a statement representing a particular set of values and interests.

The NEA report recognized that citizens may be more concerned about the potential for a high-consequence, low-probability event than about the potential for a low-consequence event with the same nominal level of risk. That concern can reflect a legitimate set of values and interests, skepticism about estimates of low probability, doubt that the complexity of consequences can be represented by simple indicators, and recognition that new phenomena can come into play when thresholds of consequence are exceeded.[28] The NEA report recommended that concerns of this type be heard, respected, and addressed by governments. Acceptance of that recommendation would require the abandonment of previous dogma about the acceptability of risk. Public-engagement processes and research could then be used to develop a new paradigm of risk and its acceptability.

CANADA'S COMMITMENT TO SUSTAINABILITY

Canada is officially committed to the principles of sustainability through the *Federal Sustainable Development Act*, which states at paragraph 5:[29]

> *"The Government of Canada accepts the basic principle that sustainable development is based on an ecologically efficient use of natural, social and economic resources and acknowledges the need to integrate environmental, economic and social factors in the making of all decisions by government."*

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[27] In this report, the term "risk" is used in a more general sense, to encompass a range of qualitative and quantitative information about the potential for an adverse outcome.

[28] There is evidence that the consequences of the 1986 Chernobyl reactor accident exceeded thresholds that brought new social and political phenomena into play. Many observers conclude that the accident undermined the legitimacy of the USSR government, contributing significantly to the breakup of the USSR. See, for example: Parsons, 2006.

[29] Accessed on 22 October 2009 at: <http://laws.justice.gc.ca/en/showtdm/cs/F-8.6>.

3.2 Prudence, Uncertainty, & the Precautionary Principle

A prudent citizen or public official will always give careful consideration to potential adverse outcomes of a proposed action. If the proposed action is the construction and operation of an NPP, two potential adverse outcomes will be particularly salient. One potential outcome, as mentioned above, would be a large, unplanned release of radioactive material from the plant to the environment. The second potential outcome would be the diversion of fissile or radioactive material from the plant by a national government or a sub-national group, for use in nuclear or radiological weapons. The organizations that construct, operate and regulate nuclear power plants will implement measures intended to prevent these outcomes. Nevertheless, a prudent observer will consider the possibility that the preventive measures will fail. In view of the severe, adverse impacts that would be associated with these outcomes, it would be imprudent to ignore the possibility of their occurrence.[30]

ASSESSING THE POTENTIAL FOR AN UNPLANNED RELEASE

The potential for a large, unplanned release of radioactive material is typically regarded by the nuclear industry and its regulators as a "safety" issue. An analytic art, known as probabilistic risk assessment (PRA), has been developed to estimate the probabilities and consequences of potential releases. The first PRA for an NPP was known as the Reactor Safety Study, and was published by the US Nuclear Regulatory Commission (NRC) in 1975.[31] A PRA for an NPP considers a range of scenarios (event sequences) that involve damage to the reactor core. The initiating events are categorized as "internal" events (human error, equipment failure, etc.) or "external" events (earthquakes, fires, strong winds, etc.). The core-damage scenarios that arise from these events are termed "accidents". PRAs typically do not consider initiating events that involve intentional, malevolent acts, although PRA techniques can be adapted to estimate the outcomes of such acts. The NRC adapted PRA techniques in developing its 1994 rule requiring protection of each NPP against attack using a vehicle bomb.[32]

A modern NPP has safety features – reactor shut-down systems, core cooling systems, etc. – with independent, redundant and diverse components. A core-damage accident at such a plant would, in many potential cases, involve a combination of independent failures that coincide, thereby overcoming the plant's safety features.[33] By contrast, during an intentional attack on an NPP, the plant's safety features would be challenged by a common factor – the attackers' intellectual and practical capabilities. Attackers with the motivation and resources to mount a significant attack would be likely to plan the attack with the specific intention of overcoming the plant's safety features and causing a large radioactive release.

Attacks on buildings in New York and Washington in September 2001 demonstrated that an attack on a civilian facility by a skilled, highly-motivated and well-resourced sub-national group is a credible event. Many observers agree that an NPP is a potential target of a future attack of this kind. Faced with this threat, risk analysts, regulatory bodies and plant designers must modify their approach. The traditional safety paradigm is insufficient. To understand the threat, risk analysts must think like skilled attackers. Regulatory bodies must capture those insights in appropriate rules and guidance documents. Resistance to attack must become an explicit objective in the design of an NPP.

A large, unplanned release of radioactive material from a nuclear power plant would be a comparatively rare event. Any estimate of the probability of such an event will be highly uncertain.[34] Many PRAs for NPPs have been performed, and the results are useful for various purposes. However, PRA estimates of the probabilities of accidental releases should not be regarded as definitive, scientific findings. Such estimates rely on numerous assumptions and judgments. There is no certainty that all of the relevant factors are captured by a PRA. Findings of very low probability cannot be validated by direct experience.[35]

At present, there is no statistical basis for a quantitative estimate of the probability of a large release caused by an intentional, malevolent act. It does not follow, as some have suggested, that malevolent acts should be ignored in risk analysis for NPPs. In a policy or planning context, risk analysts could use judgment to assign minimum probabilities to postulated acts. That judgment could be combined with technical assessments of the vulnerability of plants to the postulated acts. Those assessments would rely, in part, on PRA techniques.

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[30] See Table 1-1 for an additional perspective.

[31] NRC, 1975.

[32] NRC, 1994.

[33] In some core-damage accidents, a common cause – such as a powerful earthquake – would simultaneously overcome a number of safety features.

[34] Hirsch et al, 1989.

[35] There have been two core-damage accidents involving unplanned releases of radioactive material from commercial nuclear power plants. Those accidents occurred at Three Mile Island in 1979 (involving a small release) and Chernobyl in 1986 (involving a large release).

ASSESSING THE POTENTIAL FOR A DIVERSION OF MATERIAL

A second potential adverse outcome of operating a nuclear power plant is, as mentioned above, a diversion of fissile or radioactive material from the plant, for use in nuclear or radiological weapons. That possibility is typically regarded by the nuclear industry and its regulators as a "safeguards" issue. Canada and many other countries have safeguards agreements with the International Atomic Energy Agency (IAEA). The purposes of these agreements include the prevention of diversion of fresh or spent fuel from NPPs. If such diversion is successfully prevented, the fissile and radioactive material in the fuel will remain protected.

In the context of plant design, it is important to note that spent fuel could be diverted from some types of NPP with comparative ease. Heavy-water reactors, such as the Canadian CANDU design, are in this category because they employ on-line refueling. At those plants, prevention of diversion must rely heavily on administrative measures. By contrast, light-water reactors (LWRs) undergo batch refueling at intervals of one or more years. Thus, diversion of spent fuel from an LWR plant is comparatively difficult. Note that most (80 percent) of existing NPPs worldwide are LWRs.

Diversion of spent fuel from a Canadian NPP for malevolent use is a comparatively unlikely event, given the present social and political environment in Canada. The same cannot be said for every location in the world where a Canadian-supplied CANDU plant is operating.[36] A diversion event at such a plant could potentially be significant in terms of Canadian liability. Thus, the nexus between the NLCA and the risk of diversion should be examined. This report does not undertake that task.

THE PRECAUTIONARY PRINCIPLE (PRECAUTIONARY APPROACH)

The preceding discussion addresses two potential adverse outcomes of operating a nuclear power plant – an unplanned release of radioactive material, and a diversion of fissile or radioactive material. The probability of either outcome is highly uncertain. Yet, either outcome would be significant from the perspective of the sustainability of nuclear power. In a policy or planning context, citizens and policy makers must grapple with this conjunction of uncertainty and significance. The precautionary principle offers guidance in such situations. This principle has been much discussed, and is incorporated in laws and regulations in Canada and elsewhere. It is discussed in Canadian government guidelines for the preparation of an EIS for a new NPP. Those guidelines tend to use the terms "precautionary principle" and "precautionary approach" interchangeably, and they introduce the concept as follows: [37]

> *"One of the purposes of environmental assessment is to ensure that projects are considered in a careful and precautionary manner before authorities take action in connection with them, in order to ensure that such projects do not cause significant adverse environmental effects. The Precautionary Principle informs the decision-maker to take a cautionary approach, or to err on the side of caution, especially where there is a large degree of uncertainty or high risk."*

In the *Canadian Environmental Assessment Act* of 1992, the concept of precaution appears twice in the Purposes section.[38] First, at 4 (1) (a), the Act states that one of its purposes is "to ensure that projects are considered in a careful and precautionary manner before federal authorities take action with them, in order to ensure that such projects do not cause significant adverse environmental effects". Then, at 4 (2), the Act states that federal government entities shall, in administering the Act, "exercise their powers in a manner that protects the environment and human health and applies the precautionary principle".

The Act further states, at 4 (1) (b), that one of its purposes is "to encourage responsible authorities to take actions that promote sustainable development and thereby achieve or maintain a healthy environment and a healthy economy". Thus, the Act seeks to promote principles of sustainability and of precaution. That general commitment has been applied to specific cases by panels convened under the Act.[39]

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[36] For additional information and analysis, see: Thompson, 2008b.
[37] CEAA et al, 2008, Section 2.5.
[38] Justice Department, 2007.
[39] Gibson, 2000.

In April 2007, the Canadian government issued the Cabinet Directive on Streamlining Regulation.[40] That directive sets forth six objectives for regulation by the federal government. The third of those objectives states that the government will:

> "Make decisions based on evidence and the best available knowledge and science in Canada and worldwide, while recognizing that the application of precaution may be necessary when there is an absence of full scientific certainty and a risk of serious or irreversible harm".

One application of that objective would be to anthropogenic climate change. In that instance, the harm would be serious and irreversible if no action were taken to reduce emissions of greenhouse gases. Yet, there might not be full scientific certainty about the extent to which emissions should be reduced. The above-stated objective would call for early action, without waiting for full scientific certainty.

In the context of this report, serious and irreversible harm could arise from the taking of an action. The action would be the operation of an NPP, if the design of the plant created a significant potential for an unplanned release of radioactive material, or for diversion of fissile or radioactive material. In this instance, the above-stated objective would favor the blocking of the plant's operation, even though the potential for harm could not be characterized with full scientific certainty as to consequences and probability.

Canada's *Federal Sustainable Development Act* of 2008 gives the precautionary principle a prominent role in planning for sustainability. Paragraph 9 of the Act calls for the development and periodic updating of "a Federal Sustainable Development Strategy based on the precautionary principle".[41]

3.3 Full Accounting of Costs

The concept of sustainability introduces new categories of cost into analyses of the costs and benefits of potential actions. In considering the costs and benefits of a large energy project, such as an NPP, it is no longer sufficient to consider a narrow range of costs, as was typically done in the mid-20th century. It is now necessary to consider costs over the full life cycle of a project, together with costs arising from the environmental and social impacts of the project.

An essay placed on the Canadian Nuclear Association's website describes the importance of a full accounting of costs. It calls for a life-cycle perspective and the internalizing of costs that were previously neglected. It states:[42]

> *"Nuclear energy should argue vigorously for a level playing field, where the costs of external impacts are internalized in the costs of energy sources, and where sustainable development considerations are given adequate weight."*

Maintaining a level playing field requires that a full spectrum of information about the costs of any large energy project is publicly available. Democracy and the functioning of energy markets both require the publication of all relevant costs, with minor exceptions to protect privacy.

Part of full accounting is to ensure that costs are properly attributed. An important mechanism for such attribution is the polluter-pays principle. This principle is defined by Environment Canada as follows:[43]

> *"Polluter Pays Principle (*Principe du pollueur-payeur*)*
> *A principle under which users and producers of pollutants and wastes*
> *should bear the responsibility for their actions. Companies or people*
> *that pollute should pay the costs they impose on society."*

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[40] Government of Canada, 2007.
[41] Accessed on 22 October 2009 at: <http://laws.justice.gc.ca/en/showtdm/cs/F-8.6>.
[42] Morrison, 2000.
[43] Accessed on 17 October 2009 at: <http://www.ec.gc.ca/cppic/en/glossary.cfm?view=details&id=178>.

The Supreme Court of Canada unanimously upheld the polluter-pays principle in a 2003 decision. The decision supported the Quebec Minister of Environment against Imperial Oil. In its decision, the Court stated that the polluter-pays principle "has become firmly entrenched in environmental law in Canada". The Court explained the principle as follows:[44]

> "To encourage sustainable development, that principle assigns polluters the responsibility for remedying contamination for which they are responsible and imposes on them the direct and immediate costs of pollution. At the same time, polluters are asked to pay more attention to the need to protect ecosystems in the course of their economic activities."

3.4 Criteria for Assessing the NLCA

Sections 3.1 through 3.3, above, describe three concepts that would play major roles in a properly-constructed 21st century policy framework for nuclear power. The concepts are: sustainability; the precautionary principle; and full accounting of costs. From these concepts, one can articulate criteria for assessing the NLCA. Five criteria are set out here, expressed as questions. The first question, about full accounting, has a simple, factual answer. Questions two and three, also about full accounting, can in part be answered through quantitative analysis. Questions four and five, about the precautionary principle and sustainability, require qualitative answers.

In this report, the NLCA is assessed according to the extent to which it would respond to the content of each question. The questions follow.

Criterion #1: Full accounting – information disclosure

Would the NLCA require Canada's nuclear industry and government to publish a full spectrum of information relevant to nuclear risk and nuclear insurance, including:

> (a) an assessment of the risk of operating each NPP and other nuclear installation; and
>
> (b) the insurance coverage of offsite and onsite damage that is provided for each NPP and other nuclear installation, premiums paid for this coverage, and reinsurance arrangements?

Criterion #2: Full accounting – damage coverage

Would the NLCA ensure that commercial insurance covers the full range of potential offsite and onsite damage arising from incidents at each NPP and other nuclear installation?

Criterion #3: Full accounting – accounting for risk costs as costs of production

Would the NLCA ensure that the risk costs of operating each NPP and other nuclear installation are accounted for as costs of production?

Criterion #4: The precautionary principle

Would the NLCA be compatible with coherent and consistent application of the precautionary principle in Canada?

Criterion #5: Sustainability

Would the NLCA be compatible with a transition of Canada's economy toward sustainability?

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[44] Ferrara and Mesquita, 2003.

4. Nuclear Liability from Global & North American Perspectives

In assessing the NLCA, it is important to view the relevant issues from both global and North American perspectives. The global perspective is important because Canada's economy is integrated with the global economy, and Canada's nuclear industry is part of that integration. The North American perspective is important for two reasons. First, the potential for cross-border effects from nuclear incidents irrevocably links the nuclear liability regimes of the USA and Canada. Second, the nuclear liability regime in the USA offers lessons that should be considered in updating Canada's regime.

In taking a global perspective, the first step is to examine the prospects of nuclear power over the coming decades.

SCENARIOS FOR FUTURE USE OF NUCLEAR POWER WORLDWIDE

Nuclear power is in a transitional phase. Annual, worldwide capacity additions peaked in 1985 and have been modest since 1990.[45] If construction of nuclear power plants does not resume, total capacity will decline as plants are retired. Observers view this situation in widely differing ways. Some call for a nuclear power "renaissance" in which nuclear generating capacity rises substantially. Others prefer or expect a scenario in which nuclear capacity declines, leading to eventual disappearance of the industry.

The most ambitious visions of the nuclear renaissance are exemplified by a "technology roadmap" issued under the auspices of the US Department of Energy in 2002.[46] The roadmap proposed the development and use of a range of "Generation IV" nuclear fission reactors that would push against engineering limits in a variety of respects. Some reactor types would produce hydrogen as well as electricity, thereby providing fuel for use in vehicles and other applications. Reactors would be deployed in such large numbers that uranium reserves would become depleted during the latter part of the 21st century. To prepare for that eventuality, large-scale reprocessing would begin during the next few decades, and breeder reactors would be deployed beginning in about 2030.

A less extreme but still highly ambitious vision of the nuclear renaissance is contained in a study published under the auspices of Massachusetts Institute of Technology in 2003.[47] The authors saw no need for reprocessing or breeder reactors during at least the next 50 years. They offered an illustrative scenario for expansion of nuclear capacity using "Generation III" reactors whose designs would involve a comparatively small evolutionary step from the designs of present reactors. In the scenario, annual worldwide production of nuclear-generated electricity would rise by a factor of 4 to 6 between 2000 and 2050.

Many observers doubt the merits of nuclear power, and seek or expect a decline in its use.[48] Some argue that nuclear power can and should be phased out, even during an effort to dramatically reduce greenhouse gas emissions from electricity generation.[49] Others argue that scenarios for expansion of nuclear capacity are implausible, and that the commercial nuclear industry is in evident decline.[50]

THE ECONOMICS OF NUCLEAR POWER

Current trends suggest that the nuclear industry will decline over the coming years, rather than experience a renaissance. The major trend that suggests this outcome is a rapid, steep rise in the projected costs of generating electricity from new NPPs. Alternative options for meeting electricity needs and reducing greenhouse gas emissions are less costly.[51] Nevertheless, a number of national governments are committed, at least nominally, to the construction of new NPPs in their countries. A continued commitment to this goal would oblige governments to provide direct or indirect subsidies to new NPPs. If governments do provide such subsidies, they will continue a longstanding practice. A recent study has concluded:[52]

> *"There are numerous ways by which governments have organized or tolerated subsidies to nuclear power. They range from direct or guaranteed government loans to publicly funded research and development (R&D). Direct ownership of subsidized nuclear fuel chain facilities, government funded nuclear decommissioning and waste management, generous limited liability for accidents and the transfer of capital costs to ratepayers via stranded cost rules or special rate-basing allowances are all common in many countries."*

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[45] IAEA, 2006.
[46] NERAC/GIF, 2002.
[47] Ansolabehere et al, 2003.
[48] Romm, 2008.
[49] Makhijani, 2007; Greenpeace International, 2007.
[50] Schneider et al, 2009.
[51] Cooper, 2009.
[52] Schneider et al, 2009, page 7.

Given this history, any assessment of the NLCA should pay close attention to its possible role in subsidizing nuclear power in Canada. If the NLCA would provide a subsidy, its proponents should acknowledge and justify that subsidy.

THE NUCLEAR LIABILITY REGIME IN THE USA

Much of law and practice around the world regarding nuclear liability and compensation can be traced back to the development of commercial nuclear power in the USA in the 1950s. Initially, the private sector was only willing to become involved in nuclear R&D if the US Atomic Energy Commission would include “hold harmless” clauses in the applicable contracts, thus channeling liability to the State. Beginning in 1954, however, the US government shifted third-party liability to the emerging nuclear industry. That move acted as a brake on private nuclear investment, because the insurance sector could not provide insurance on a normal commercial basis. In response, the Price-Anderson Act was passed in 1957, channeling liability to the operator while limiting that liability.[53]

The Price-Anderson Act introduced “economic” channeling, which differs from the “legal” channeling that prevails in Canada. The difference has been described as follows:[54]

> *“In regimes of legal channelling, the operator is the only party which victims may legally hold responsible for a nuclear accident, i.e. no civil lawsuits may be initiated against any other party (suppliers, designers, constructors, etc.) and on any other civil basis than the channelling legal basis. Ordinary tort law is, in other words, set aside. This is so, even when the operator did not even remotely contribute to the nuclear accident. Moreover, unless a contract expressly states otherwise, the operator does not have a right of recourse against these other parties and fully bears the financial liability burden of a nuclear accident vis-à-vis third parties.*
>
> *In systems of economic channelling, victims can initiate civil lawsuits both against the operator and against any of the other parties involved (suppliers, designers, etc.) in line with ordinary tort law. However, the operator, whose insurance needs to cover the other parties´ third party liability as well (i.e. an “*omnibus coverage*” or “*umbrella insurance*”), ultimately needs to indemnify these parties. The result is similar to legal channelling in that the operator bears the financial liability burden of the nuclear accident vis-à-vis third parties. However, economic channelling leaves the legal reality unscathed and does not set ordinary tort law aside, whereas legal channelling distorts the underlying legal construction and sidesteps ordinary tort law. The functioning of economic channelling is best illustrated by the Three Mile Island accident of 1979, where all defendants – the operator, the designer and the constructor of the plant – were represented by a single law firm.”*

In the late 1950s, US firms began exporting nuclear technology and materials to the emerging nuclear industry in Europe. They became concerned about their potential liability for damage arising from a nuclear incident in Europe. That concern was resolved by successfully promoting legal channeling as the basis of the 1960 *Convention on Third Party Liability in the Field of Nuclear Energy* (Paris Convention), which determined nuclear liability regimes in Europe. US nuclear suppliers also successfully promoted legal channeling as the basis of the 1963 *Vienna Convention on Civil Liability for Nuclear Damage* (Vienna Convention). Western European nuclear suppliers subsequently promoted legal channeling as the basis for nuclear liability regimes in Eastern Europe, to facilitate their exports to that region. This history has been summarized as follows:[55]

> *“Put simplistically, legal channelling was introduced in the legal systems of Western Europe by the Paris Convention under US pressure and in the legal systems of Eastern Europe by the Vienna Convention under Western-European pressure.”*

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[53] Ameye, 2009.
[54] Ameye, 2009.
[55] Ameye, 2009.

In the USA, economic channeling continues as the basis of the Price-Anderson Act. That Act was most recently amended in 2005. It holds the operator liable for third-party damage up to $300 million. For a single-unit NPP site, the average annual premium for insurance of that amount is currently about $400,000.[56] If damage exceeds $300 million, a second tier of insurance is provided via a retroactive premium levied on each licensed NPP in the USA. The retroactive premium is adjusted for inflation. In 2005, its maximum value was $15.8 million per year per NPP, and the maximum cumulative value was $100.6 million per NPP.[57] At present, 104 NPPs are licensed in the USA. Thus, the second tier of insurance amounted to $10.5 billion in 2005.[58]

As a separate matter, the US Nuclear Regulatory Commission (NRC) requires each licensee of an NPP in the USA to obtain insurance coverage for onsite damage. The minimum required coverage is currently $1.06 billion per NPP site, and actual coverage is $2.75 billion. This coverage does not include loss of electricity production. The coverage is provided by Nuclear Electric Insurance Limited (NEIL), a mutual insurance system created by a group of NPP operators.[59] NEIL also provides separate coverage of loss of electricity production. The covered amount is up to $4.5 million per week, with a maximum claim of $490 million.[60]

LIABILITY ACROSS THE CANADA-USA BORDER

An incident at a Canadian NPP could cause significant damage in the USA, and vice versa. The NLCA would allow the Canadian government to enter into an agreement with the US government, whereby parties in each country have access to the liability and compensation regime in the other country.[61] At present, the law regarding cross-border claims is unclear. An injured party in the USA could make a claim in a US court against the operator of a Canadian NPP that experienced an incident, or against a supplier to that operator. If the US court accepted the claim, it could seek enforcement of the claim in Canada. Enforcement would pose a challenge to the relevant Canadian court, a challenge that has been described as follows:[62]

> *"A Canadian court may be unwilling to enforce a very large US judgment for damages where doing so would frustrate the purpose of the* Nuclear Liability Act *by draining the available pool of funds for claimants, if US plaintiffs would be substantially or fully compensated and Canadians would be left with little to no compensation. However, the political acceptability of such a situation of under-compensation in the US would be so difficult that, as a practical matter, the Canadian government would be forced to make up the difference. If Canada can afford to provide some $4 billion to protect the domestic automobile manufacturers, it seems unlikely that it could limit payment to victims of a nuclear incident, on either side of the border, to a mere $75 million."*

It has been suggested that Canada could resolve this problem by becoming a party to the 1997 *Convention on Supplementary Compensation for Nuclear Damage* (CSC). The USA ratified the Convention in 2008, but it has not yet entered into force. If Canada ratified the Convention and it entered into force, then a US party injured by an incident at a Canadian NPP could not, apparently, sue in a US court.[63]

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[56] WNA, 2009. Given perfect forecasting and no profit or administrative costs, an insurance premium of $400,000 per RY for coverage of $300 million would imply an event probability of 1.3 per 1,000 RY.
[57] These amounts include a 5 percent allowance for legal costs.
[58] Faure and Borre, 2008.
[59] Faure and Borre, 2008.
[60] NEIL PowerPoint presentation at the Nuclear Inter Jura Congress, Toronto, 5-9 October 2009.
[61] Henault, 2009.
[62] Roman et al, 2009.
[63] Roman et al, 2009.

NUCLEAR LIABILITY REGIMES OUTSIDE NORTH AMERICA

Outside North America, there is a patchwork of nuclear liability regimes at the national level. A coherent, international structure is gradually emerging that links these national regimes and establishes a common approach. At the center of that structure are the Paris Convention and the Vienna Convention, as mentioned above. These conventions were developed under the aegis of NEA and IAEA, respectively. Their territorial scope is linked by the 1988 *Joint Protocol*. They have been amended in various respects. The CSC is a related, stand-alone convention, developed under the aegis of IAEA.[64]

In 2004, parties to the Paris Convention signed a set of amending Protocols, upgrading the Convention's level of compensation. The 2004 Protocols expand the scope of damage that is compensable, extend the time horizon of compensable personal injury or death from 10 years to 30 years, and raise the liability limit. The new liability limit for each incident is 1,500 million Euro, supported by three tiers of compensation. The first tier is 700 million Euro of operator liability, nominally met by commercial insurance.[65] The second tier is 500 million Euro of public funds provided by the government of the country in which the nuclear incident occurs. The third tier is 300 million Euro of public funds provided by the governments of other parties to the Paris Convention.[66]

The 2004 Protocols are not yet in force. A major reason is that NPP operators have had difficulty obtaining insurance coverage for a liability of 700 million Euro.[67] This difficulty came to public attention in the UK in September 2009. Press reports disclosed that nuclear insurers in the UK were refusing to cover the 700 million Euro of operator liability required by the 2004 Protocols. The insurers especially objected to the scope of damage and the time horizon specified by the Protocols. It appears that this problem will be resolved by the UK government covering a substantial portion of the operator liability, for both existing and new NPPs.[68]

Germany is a party to the Paris Convention, but has no limit on the operator's liability. Each NPP operator in Germany must provide security of 2,500 million Euro, of which 256 million Euro is provided by insurance. The remaining security is provided collectively by all of the NPP operators in Germany. In this collective arrangement, the directly-affected operator bears the primary burden of liability, and the others provide backup.[69]

As an indication of nuclear-insurance premiums in Europe, consider the case of EDF, the French NPP operator. EDF has current liability of 91 million Euro, covering 31 million Euro of this liability through insurance and the remaining 60 million Euro through its own reserves. To provide 31 million Euro of insurance coverage for 58 NPPs in 2008, EDF paid an annual premium of 6.4 million Euro.[70] Thus, the premium was 110,000 Euro per RY. Given perfect forecasting and no profit or administrative costs, an insurance premium of 110,000 Euro per RY for coverage of 31 million Euro would imply an event probability of 3.5 per 1,000 RY.

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[64] Faure and Fiore, 2008; WNA, 2009.

[65] Under the 2004 Protocols, a country's government could meet the operator's first-tier liability of 700 million Euro, or some portion of that liability, from public funds.

[66] Faure and Fiore, 2008; WNA, 2009.

[67] Faure and Borre, 2008.

[68] Pagnamenta, 2009.

[69] Faure and Borre, 2008.

[70] Faure and Fiore, 2008.

5. Assessing the Risk Posed by Nuclear Power Plants

There is a large body of technical literature addressing the risk posed by NPPs. Much of this literature assesses the potential for, and consequences of, an atmospheric release of radioactive material following accidental damage to nuclear fuel. The fuel could be in the reactor core, the spent-fuel pool, or elsewhere in the plant. Such literature typically falls under the rubric of probabilistic risk assessment, as described in Section 3.2, above.

In the PRA field, the events that initiate an accidental release are categorized as "internal" events (human error, equipment failure, etc.) or "external" events (earthquakes, fires, strong winds, etc.). PRAs typically do not consider initiating events that involve intentional, malevolent acts, although PRA techniques can be adapted to estimate the outcomes of such acts.

PRAs for NPPs are conducted at Levels 1, 2 and 3, in increasing order of completeness, as discussed below. A thorough, full-scope PRA would be conducted at Level 3, and would consider internal and external initiating events. The findings of such a PRA would be expressed in terms of the magnitudes and probabilities of a set of adverse environmental impacts, and the uncertainty and variability of those indicators. The adverse impacts would include:

(i) "early" human fatalities or morbidities (illnesses) that arise during the first several weeks after the release;

(ii) "latent" fatalities or morbidities (e.g., cancers) that arise years after the release;

(iii) short- or long-term abandonment of land, buildings, etc.;

(iv) short- or long-term interruption of agriculture, water supplies, etc.; and

(v) social and economic impacts of the above-listed consequences.

The magnitudes and probabilities of such adverse impacts would be estimated in three steps. First, a Level 1 PRA analysis would be performed. In that analysis, a set of event sequences (accident scenarios) leading to fuel damage would be identified, and the probability (frequency) of each member of the set would be estimated. The sum of those probabilities across the set would be the total estimated fuel-damage probability.[71] Second, a Level 2 PRA analysis would be performed. In that analysis, the potential for release of radioactive material to the atmosphere would be examined across the set of fuel-damage sequences. The findings would be expressed in terms of a group of release categories characterized by magnitude, probability, timing, isotopic composition, and other characteristics.

Third, a Level 3 PRA analysis would be performed, to yield the impact findings described above. In that analysis, the atmospheric dispersion, deposition and subsequent movement of the released radioactive material would be modeled for each of the release groups determined by the Level 2 analysis. The dispersion modeling would account for meteorological variation over the course of a year. Then, the adverse environmental impacts of the released material would be estimated, accounting for the material's distribution in the biosphere.

If done thoroughly, this 3-step estimation process accounts for uncertainty and variability at each stage of the process. A thorough, full-scope, Level 3 PRA is expensive and time-consuming. It yields estimated impacts expressed as statistical distributions of magnitude and probability, not as single numbers. Even after such a thorough effort, there are substantial, irreducible uncertainties in the findings.[72]

EMPIRICAL VALIDATION OF PRA FINDINGS

Direct empirical evidence for the validity of PRA findings is limited. Worldwide operating experience of commercial nuclear power plants through 2008 is about 13,400 RY, and Canadian experience is about 580 RY.[73] Two events involving substantial damage to a reactor core have occurred worldwide while that experience was accruing. At Three Mile Island Unit 2 in 1979, the reactor core was severely damaged but there was a comparatively small radioactive release to the environment. At Chernobyl Unit 4 in 1986, a substantial fraction of the core inventory of radioactive material was released to the atmosphere. This limited experience allows one to estimate the probability of a core-damage accident as 1.5 per 10,000 RY, and the probability of a large atmospheric release as 0.7 per 10,000 RY.[74]

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[71] The term "core-damage frequency" (CDF) is often encountered. This term refers to the annual probability of severe damage to nuclear fuel in a reactor core.

[72] Hirsch et al, 1989.

[73] Extrapolated from Table 1 of: IAEA, 2006.

[74] 2/13,400 = 1.5 per 10,000; 1/13,400 = 0.7 per 10,000.

NUREG-1150

The “high point” of PRA practice worldwide was reached in 1990 with publication by the NRC of its NUREG-1150 study, which examined five different nuclear power plants using a common methodology.[75] The study was well funded, involved many experts, was conducted in an open and transparent manner, was done at Level 3, considered internal and external initiating events, explicitly propagated uncertainty through its chain of analysis, was subjected to peer review, and left behind a large body of published documentation. Each of those features is necessary if the findings of a PRA are to be credible. There are deficiencies in the NUREG-1150 findings, which can be corrected by fresh analysis and the use of new information. The process of correction is possible because the NUREG-1150 study was conducted openly and left a documentary record.

PRA practice in the USA has degenerated since the NUREG-1150 study. Now, PRAs are conducted by the nuclear industry, and the only published documentation is a summary statement of findings. NRC formerly sponsored independent reviews of industry PRAs, but no longer does so. Thus, PRA findings have lacked credibility for at least a decade. In other countries, including Canada, PRA practice has experienced similar degeneration.[76]

Figures 5-1 through 5-3 show some findings from the NUREG-1150 study that are relevant to this report. The findings are for a pressurized-water-reactor (PWR) plant at the Surry site, and a boiling-water-reactor (BWR) plant at the Peach Bottom site. These plants typify many of the “Generation II” plants in the present worldwide fleet of nuclear power plants. Using the Livermore seismic estimates, the NUREG-1150 findings for these two plants are roughly comparable with the experience-derived probability estimates mentioned above — a core-damage probability of 1.5 per 10,000 RY, and a large-release probability of 0.7 per 10,000 RY.

THE POTENTIAL FOR MALEVOLENT ACTS AT NUCLEAR POWER PLANTS

CNSC has established criteria for the design of new NPPs. These criteria, expressed in the document RD-337, include resistance to attack as a design objective.[77] To date, CNSC has not specified the threats that will be considered in applying the design criteria. CEAA guidelines for an EIS for a new NPP require the consideration of accidents and malfunctions that include malevolent acts.[78] This author has commented upon those guidelines.[79]

A consultant to CNSC has examined potential modes and instruments of attack on an NPP, and has recommended an approach to incorporating these threats in the design criteria for new plants.[80] Among the instruments of attack considered by the consultant were a large commercial aircraft, an explosive-laden smaller aircraft, and an explosive-laden land vehicle. Table 5-1 describes some potential modes and instruments of attack on an NPP, and also describes the defenses that are now provided at US plants. There is no defense against a range of credible attacks. Defenses at Canadian plants are no more robust than at US plants.

Among the instruments of attack mentioned in Table 5-1 is a large commercial aircraft. In September 2001, aircraft of this type caused major damage to the World Trade Center and the Pentagon. However, such an aircraft would not be optimal as an instrument of attack on a nuclear power plant. Large commercial aircraft are comparatively soft objects containing a few hard structures such as turbine shafts. They can be difficult to guide precisely at low speed and altitude. A well-informed group of attackers would probably prefer to use a smaller, general-aviation aircraft laden with explosive material, perhaps in a tandem configuration in which the first stage is a shaped charge. Table 5-2 provides some information about shaped charges and their capabilities.

There is no statistical basis for a quantitative estimate of the probability that am NPP will be attacked. However, if a given attack scenario is postulated, one can apply PRA techniques to estimate the conditional probabilities of various outcomes. NRC took that approach in developing its vehicle-bomb rule of 1994.[81]

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[75] NRC, 1990.

[76] In Canada, it appears that PRAs are no longer available for independent review. To illustrate, Greenpeace Canada requested a copy of the PRA for the Pickering B units. CNSC has refused to order Ontario Power Generation (OPG) to provide this PRA. In so doing, CNSC has accepted OPG's argument that the PRA should be available only to OPG personnel on a “need to know” basis. See: CNSC, 2008b. This approach, although it may be well-intentioned, will inevitably create an entrenched culture of secrecy that will suppress a clear-headed understanding of risks. A more sophisticated approach could allow independent review of the PRA without disclosing information that would assist malevolent actors.

[77] CNSC, 2008a.

[78] CEAA et al, 2008.

[79] Thompson, 2008a.

[80] Asmis and Khosla, 2007.

[81] NRC, 1994.

RADIOACTIVE RELEASES FROM STORED SPENT FUEL

At NPPs in the USA and elsewhere, large amounts of spent fuel are stored under water in pools adjacent to reactors. All US pools currently employ high-density racks, to maximize the amount of spent fuel that can be stored in each pool. This practice has been adopted because it is the cheapest mode of storage of spent fuel. Unfortunately, the high-density configuration would suppress convective cooling of fuel assemblies if water were lost from a pool.

Several reputable studies have agreed that loss of water from a pool would, across a range of water-loss scenarios, lead to spontaneous ignition of the zirconium alloy cladding of the most recently discharged fuel assemblies. The resulting fire would spread to adjacent fuel assemblies and propagate across the pool. Extinguishing the fire, once it had been initiated, would be difficult or impossible. Spraying water on the fire would feed an exothermic reaction between steam and zirconium. The fire would release a large amount of radioactive material to the atmosphere, including tens of percent of the pool's inventory of cesium-137. Large areas of land downwind of the plant would be rendered unusable for decades. Loss of water could arise in various ways as a result of an accident or an intentional, malevolent act.[82] Fortunately, measures are available for dramatically reducing the risk of a fire in a spent-fuel pool, as discussed in Section 6, below.

As discussed in Section 7, below, three designs of NPP are being considered for construction in Ontario. Two of these plant designs – the AREVA and Westinghouse designs – are PWR plants. It appears that both vendors envision the equipping of each plant's spent-fuel pool with a set of high-density racks.[83] That practice would bring with it the potential for a large atmospheric release of radioactive material (especially Cesium-137) from the pool.

This author is not aware of any study on the potential for an accidental release of radioactive material from spent fuel stored at an NPP employing a CANDU reactor. Absent such a study, the potential remains unknown.

CNSC POSITION ON NPP RISK

CNSC has articulated safety goals for a new NPP, as shown in Table 5-3. The safety goals were first set forth in a 2007 draft document. Revised safety goals were then adopted by CNSC in 2008. As shown in Table 5-3, the safety goals that were ultimately adopted by CNSC represent a significant retreat from the draft goals set forth in 2007. A logical explanation for that retreat is a CNSC determination that compliance with the 2007 goals could not be demonstrated for new plants of the types being considered for construction in Canada.

Thus, CNSC's current position is that the probability of a large release of radioactive material to the environment from a new NPP in Canada "is less than" 1 per 1 million RY. Apparently, that probability does not account for malevolent acts. CNSC has not specified whether the stated probability is a mean value or some other expression of the probability density function. In this report, it is assumed that CNSC's stated probability is a mean value. It would also be reasonable to assume an uncertainty factor of 10.[84] Given those assumptions, CNSC's current position would be that the 95th percentile probability of a large release from a new plant would be 1 per 100,000 RY. The 95th percentile value can be regarded as a "high confidence" estimate.

The discussion in the preceding paragraph refers to new NPPs. In the context of life extension of an existing plant, CNSC requires a licensee to conduct an Integrated Safety Review, whose purposes include "determination of reasonable and practical modifications that should be made to systems, structures, and components, and to management arrangements, to enhance the safety of the facility to a level approaching that of modern nuclear power plants [emphasis added], and to allow for long term operation".[85] CNSC does not articulate numerical safety goals for existing plants.

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[82] Alvarez et al, 2003; National Research Council, 2006; Thompson, 2007.

[83] Thompson, 2008a.

[84] In this report, the term "uncertainty factor" is used to designate the ratio of the 95th percentile value to the mean value of a probability density function.

[85] CNSC, 2008c, page 4.

6. Options for Reducing the Risk Posed by Nuclear Power Plants

There are numerous opportunities for reducing the risk posed by an NPP. Those opportunities are, in principle, substantially greater for a new NPP than for an existing plant. The design of the new plant could benefit from new technical knowledge. The safety and security criteria that the plant must meet could be more stringent than the criteria to which existing plants were designed. In practice, however, the new plants being considered for construction in Canada would not pose a substantially lower risk than do the existing plants, for reasons discussed below.

TRENDS IN CONSTRUCTION, SAFETY AND SECURITY OF NUCLEAR POWER PLANTS

Nuclear power is in a transitional phase, moving toward an uncertain future. Annual, worldwide capacity additions peaked in 1985 and have been modest since 1990.[86] If construction of NPPs does not resume, total capacity will decline as plants are retired.

During the nuclear industry's start-up phase (1956-1970), capacity additions worldwide averaged about 1 GWe per year. In the decade 1971-1980, worldwide capacity increased at an average rate of about 12 GWe per year, increasing to an average rate of 20 GWe per year during the period 1981-1990. During the period 1991-present, the rate of capacity addition has been much lower, averaging about 4 GWe per year, with an even lower rate since 2000.[87]

This construction history has left the world with a fleet of existing NPPs that are mostly in the "Generation II" category. The basic designs of these plants were laid down more than three decades ago. At that time, risk goals were less demanding than the goals now articulated by CNSC.[88] There was, for example, less concern by industry and regulators about the potential for malevolent acts.

During the 1970s and 1980s, plant vendors and other stakeholders identified innovative design options that could have reduced the risk of NPP operation to a level substantially below the level posed by the Generation II designs. Some of those design options – such as ASEA-Atom's PIUS design – are discussed in the Appendix to this report.

The nuclear industry did not adopt innovative designs such as the PIUS design. Instead, the industry chose to pursue "Generation III" designs that represent a comparatively small evolutionary step from the Generation II designs now in use. That decision has yielded a level of risk, for new NPPs, that is not substantially lower than the risk posed by existing plants.[89] Regulators, including CNSC, could have sought to steer the industry toward innovative, lower-risk designs, by adopting highly stringent criteria for safety and security. Instead, regulators have accommodated the nuclear industry, by adopting criteria that are achievable by Generation III designs. The process of accommodation is clearly evident in CNSC's relaxation of its safety goals for new NPPs, as discussed in Section 5, above.

RISK REDUCTION AT EXISTING NUCLEAR POWER PLANTS

At an existing NPP, efforts to reduce risk could be made in areas including: (i) physical modification of the plant (capital additions); (ii) new procedures for operation and maintenance; (iii) personnel enhancement (training, etc.); (iv) enhanced site security (guards, gates, etc.); (v) enhanced capability for onsite damage control (firefighting, etc.); and (vi) enhanced capability for offsite emergency response.

Table 6-1 illustrates the potential for reducing risk at an existing plant. The table shows options for reducing the risk of a fire in a spent-fuel pool equipped with high-density racks. As explained in Section 5, above, such a fire could occur if water were lost from the pool. High-density pool storage of spent fuel is standard practice at existing NPPs in the USA, and would be a likely practice at new PWR or BWR plants in Canada, if any are built.

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[86] IAEA, 2006.
[87] Keystone Center, 2007, pp 25-26.
[88] Okrent, 1981.
[89] Thompson, 2008a.

7. Risk Posed by Nuclear Power Plants in Canada

7.1 Scope of this Discussion

Sections 7.2 through 7.4, below, outline the risk posed by operation of existing or new NPPs in Canada. A comprehensive assessment of that risk would be a major undertaking. Although some relevant studies have been done, there are major gaps in knowledge. For the purpose of estimating risk costs, this report draws from available sources to present a broad-brush picture of risk. Where possible, risk estimates developed by the nuclear industry are used here.

7.2 Types of Nuclear Power Plant that Could Operate in Canada

All of the existing NPPs in Canada are CANDU plants. At present, 18 of these plants are operational. All are in the Generation II category. All but two are in Ontario. The Ontario plants are unusual because they share safety and support systems (e.g., a vacuum building) in 4-unit or 8-unit blocks. Most NPPs in the world do not share systems to this extent.

NEW PLANTS

The Ontario government is contemplating the construction of new NPPs at the Darlington site. Three types of NPP are candidates, as follows:

(i) the US EPR, a PWR plant offered by AREVA;

(ii) the AP1000, a PWR plant offered by Westinghouse; and

(iii) the ACR-1000, a CANDU plant offered by Atomic Energy of Canada Limited (AECL).

Each of these plant types is in the Generation III category, as mentioned above.[90]

There is no operational experience for any of them, and limited construction experience. Two EPR plants are being built, in Finland and France. In April 2009, concrete pouring began for the first of four AP1000 plants ordered for a site in China. No order has been placed for an ACR-1000 plant.

As a Canadian product, the ACR-1000 is a likely candidate for construction in Ontario. However, the technical competence of AECL – the vendor of the ACR-1000 plant – is under question because of AECL's experience with the MAPLE reactors. AECL built these two reactors at the Chalk River laboratories to produce medical isotopes. In May 2008 the MAPLE reactors were scrapped without ever becoming operational. AECL had concluded that the reactors were unfit to operate, and that their deficiencies could not be rectified within any reasonable budget and timeframe.[91]

7.3 Potential Radioactive Releases and their Offsite Impacts

PRAs, despite their limitations, are important sources of information about the potential for, and consequences of, releases of radioactive material from NPPs. For the new plants being considered for use in Ontario, PRAs are not available. For the existing plants in Canada, there is a body of PRA-related literature, with limitations as discussed below.

Unfortunately, Canada lacks a fully developed PRA culture. PRAs performed in Canada for CANDU reactors find very low probabilities for large releases. Based on those findings, the PRAs do not estimate the radiological impacts of large releases. Yet, the low probabilities are not credible.[92] The practice of ignoring large releases deprives citizens and policy makers of needed information. For example, in a recent analysis of the risk of continued operation of the Pickering B station, the largest release considered included 71 TBq of Cesium-137.[93] That is a comparatively small release, and is categorized as such in Table 5-3.

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[90] Some plant designs are said to be in a Generation III+ category. That designation has no technical meaning, because it presumes a generally-accepted classification scheme that does not exist.

[91] Thompson, 2008a, Section 5.

[92] Thompson, 2000; IRSS, 1992.

[93] SENES, 2007, Table B.5.3-1.

The high point of PRA practice in Canada was reached by Ontario Hydro in its preparation of the Darlington Probabilistic Safety Evaluation (DPSE).[94] DPSE was conducted for internal initiating events only. It was conducted to Level 3, except that the impacts of the largest releases – in Ex-Plant Release Category 0 (EPRC 0) – were not evaluated. It was not subjected to an official, independent review. Thus, DPSE did not rise to the quality of NRC's NUREG-1150 study, which is discussed in Section 5, above.

A focused review of DPSE was conducted by a team led by this author.[95] Several deficiencies were revealed. For example, DPSE had failed to identify an event sequence – involving failure of service water supply – that would be familiar to analysts conducting PRAs for PWR plants. In light of that and other deficiencies in DPSE, our team concluded that a reasonable estimate of the probability of a large, accidental radioactive release to the atmosphere from the Darlington plant would be 1 per 10,000 RY. Our value is comparable to the probability derived from occurrence of the TMI and Chernobyl accidents. (As mentioned above, those events suggest a core-damage probability of 1.5 per 10,000 RY, and a large-release probability of 0.7 per 10,000 RY.) Interestingly, our value is also comparable to the 95th percentile (high-confidence) value of DPSE's estimate of the probability of release category EPRC 0, adjusted to account for external initiating events. The adjusted, 95th percentile probability of EPRC 0 is 1.2 per 10,000 RY.[96]

PRAs are not available for the new NPPs that might be built at the Darlington site in Ontario. Lacking a PRA, one can take two approaches to estimating the probability of a large, accidental atmospheric release from a new plant. First, one can assume a 10-fold reduction in release probability for a new (Generation III) plant, by comparison with an existing (Generation II) plant. That assumption yields a release probability, for a new plant, of 1 per 100,000 RY. Second, one can rely on the CNSC safety goals, which are discussed in Table 5-3. Those goals now state that the probability (assumed here to be the mean probability) of a large release from a new NPP is below 1 per 1 million RY. As discussed in Section 5, above, one can reasonably assume that CNSC's position is that the 95th percentile (high-confidence) probability of a large release is 1 per 100,000 RY.

Table 7-1 assembles a set of selected data about radioactive releases and their offsite impacts. Those data support this report's estimation, in Section 9, below, of the risk costs of offsite impacts. The metric used in Table 7-1 for offsite impacts is lifetime population dose. In this report, population dose is assumed to scale linearly with the amount of Cesium-137 released to the atmosphere. That assumption is supported by the finding that most of the offsite population dose from the 1986 Chernobyl accident was from Cesium-137.[97]

Table 7-2 shows estimates of population dose and frequency for potential accidental atmospheric releases of radioactive material from three nuclear generating stations in Ontario. These estimates are by the licensees (i.e., operators). Each station has four CANDU units. Each release shown is from a single unit (i.e., NPP).

7.4 Potential Onsite Impacts of Fuel-Damage Events

A range of fuel-damage events could occur at an NPP, and the fraction of the material released from the fuel that reached the environment would vary according to the characteristics of each event. Ontario Hydro, in its DPSE study, estimated the risk of onsite economic impacts from fuel-damage events at the existing CANDU nuclear power plants at the Darlington site. That estimate considered only accidents initiated by internal events. Table 7-3 shows Ontario Hydro's findings, adjusted to 2009 Can $.

An interesting observation from Table 7-3 is that almost 90 percent of the risk of onsite economic impacts arises from fuel damage categories FDC 6 through FDC 9. The lowest mean probability for one of these categories is 1 per 500 RY. Thus, the overall risk is dominated by events with a comparatively high probability.

To illustrate the risk of onsite impacts, consider fuel damage category FDC 7. Table 7-3 shows that this event has an estimated probability of 3 per 1,000 RY (i.e., 48 percent over 40 years, at the 4-unit Darlington station) and would cause damage between $790 million and $2,500 million to the operator.

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[94] Ontario Hydro, 1987.

[95] IRSS, 1992.

[96] DPSE (Ontario Hydro, 1987) states in its Table 5-6 that the probability of EPRC 0 is 4.4 per 1 million RY. Applying an uncertainty factor of 14 (see Table 5-5 of DPSE), and a multiplier of 2 to account for external initiating events, one finds a 95th percentile value for EPRC 0 of 1.2 per 10,000 RY.

[97] DOE, 1987.

8. The Canadian Government's Consideration of Risk-Related Costs

The proposed NLCA limits the operator's third-party liability to $650 million. The Canadian government's choice of a $650 million limit reflects a balance of considerations, which have been set forth by an advisor to Natural Resources Canada.[98] (See a relevant quote in Section 2, above.) Part of the government's rationale is that the $650 million limit "addresses foreseeable, rather than catastrophic Chernobyl-type accidents".[99]

This statement alleges that a Chernobyl-scale release of radioactive material is not "foreseeable". Yet, that very event occurred in 1986. Also, the 1979 Three Mile Island accident could, with comparatively minor variation, have yielded an atmospheric release comparable to that at Chernobyl. Moreover, government and industry studies performed in the USA (see Section 5, above) and Canada (see Section 7, above) show that large, accidental releases of radioactive material are entirely foreseeable. The potential for such releases is further exacerbated by the well-recognized possibility of malevolent acts at NPPs.

One could reasonably expect that the Canadian government's choice of a $650 million limit would be based upon detailed analysis, informed by practical experience, PRAs, and assessments of the risk of malevolent acts. No such analysis is evident. A related report was prepared for CNSC, but it considered only design-basis accidents.[100] The releases considered in that report included only noble gases and iodine isotopes. The largest Iodine-131 release considered was 24 TBq.[101] Yet, CNSC's safety goals for new NPPs categorize a "small release" as a release that exceeds 1,000 TBq of Iodine-131. (See Table 5-3.)

ECONOMIC IMPACT OF CESIUM-137 DEPOSITION IN TORONTO

A study sponsored by Defence Research and Development Canada provides useful information about the economic impact of an unplanned release of radioactive material. The study estimated the economic impact of an open-air explosion of a radiological dispersal device (i.e., a dirty bomb) at the CN Tower in Toronto.[102] The assumed release consisted of 37 TBq of Cesium-137. The estimated economic impact varied considerably, according to the cleanup standard that was assumed in the analysis. That standard was expressed in terms of the radiation dose rate that would remain after completion of the cleanup. For a cleanup standard of 5 mSv per year, the estimated economic impact would be $28 billion, whereas for a cleanup standard of 0.15 mSv per year the impact would be $250 billion. The magnitudes of those impacts are interesting, considering that the assumed release (37 TBq of Cesium-137) is a tiny fraction of the release that could occur from an NPP. CNSC's safety goals for new NPPs categorize a "large release" as a release that exceeds 100 TBq of Cesium. (See Table 5-3.) Each NPP at the Darlington site in Ontario – where there are four CANDU plants – contains about 65,000 TBq of Cesium-137 in its reactor core.[103]

IMPLICIT SUBSIDY VIA THE NLA

The Canadian government gave financial support to a study, by two UK analysts, of the implicit subsidy that arises from the provisions of the *Nuclear Liability Act*.[104] The study sought to take an "empirical" approach to estimating the implicit subsidy. It generated a range of findings for that indicator, expressed as cent per kWh of nuclear generation. The approach taken was interesting. Unfortunately, however, the study had severe flaws as follows:

(i) the study assumed a formula, for the probability density function of monetized offsite damages, that lacked a credible rationale;

(ii) the assumed formula can, depending on the parameters chosen, yield a probability density function with a very long right-hand tail that is inconsistent with the phenomena that can cause offsite damages;

(iii) the study did not disclose the parameters used for its formula;

(iv) the analysts misunderstood expert findings regarding worst-case damages, believing (incorrectly) that these findings referred to the probability that damages would be "equal to or greater than" a particular $ value; and

(v) equation (3) of the study shows a lower bound of integration that is too high by six orders of magnitude.

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[98] Henault, 2009.
[99] Henault, 2009.
[100] ISR, 2003.
[101] ISR, 2003, Tables 7 and 35.
[102] Cousins and Reichmuth, 2007.
[103] ISR, 2003, Table 36. Also see Table 7-1 of this report, which shows a Darlington NPP reactor core inventory of 67,000 TBq of Cesium-137.
[104] Heyes and Heyes, 2000.

SEVERE ACCIDENT STUDY

An engineer who apparently has long experience in the Canadian nuclear industry, John W. Beare, has commented on the Canadian practice of not examining the consequences of the largest potential releases from NPPs, stating:[105]

> *"If the Commission [CNSC] is concerned about the cost-benefit aspects of its safety requirements it could start by completing the Severe Accident Study research project started about 1988 but never completed. The conclusion of the preliminary study is that, in the event of a catastrophic accident, a release of radioactive material proportionately as large as that from Chornobyl could not be ruled out. In the case of a water-cooled reactor like CANDU such a release could be in the form of a relatively cool aerosol and not be dispersed as much as at Chornobyl. The radiation doses close to the reactor could be higher than at Chornobyl."*

It appears that Beare is referring to a Severe Accident Study conducted under the aegis of the Atomic Energy Control Board, whose functions were taken over by CNSC in 2000. Beare says that the study was initiated in 1988, while NRC was working on its NUREG-1150 study. The NUREG-1150 study was completed in 1990, establishing the high point of PRA practice for NPPs.[106] Canada's analogous study was, apparently, abandoned.

9. This Report's Estimation of Risk-Related Costs

9.1 Scope of this Discussion

Drawing upon analysis in preceding sections of this report, Sections 9.2 through 9.5 address the cost implications of the risk of operating NPPs in Canada. Section 9.2 discusses the costs of measures intended to reduce risk. Section 9.3 provides quantitative estimates of the risk costs of offsite impacts of unplanned radioactive releases. The releases could arise from accidents or malevolent acts. Section 9.4 provides quantitative estimates of the risk costs of onsite impacts of fuel-damage events. An overview of risk costs is provided in Section 9.5. The estimates presented here reflect assumptions and sources that are identified in the narrative of the report, and in the notes to tables and figures. A reader could repeat the analysis with different assumptions.

Here, the term "risk costs" refers to monetized impacts of potential radioactive releases, on a per annum basis. The monetization of impacts involves assumptions, as discussed below.

9.2 Costs of Measures Intended to Reduce Risk

As discussed in Section 6, above, options are available to reduce the risk of operating NPPs. Each option has a cost, which can be compared to its benefit. The NLCA would be a mechanism for risk mitigation, by providing compensation for damage. Risk reduction and risk mitigation are closely related, and should be considered within the same framework. Sustainability, the precautionary principle, and full accounting of costs are the three pillars of that framework, as discussed in Section 3, above.

The NLCA would impose direct costs, in the form of premiums. If the premiums are insufficient to cover the risk costs, the NLCA would also impose indirect costs, in the form of an implicit public subsidy for nuclear power. That subsidy could crowd out investment in risk-reduction options. Some of those options, and their costs, are sketched here.

Experience in the USA during the 1970s and 1980s provides important information about the cost implications of efforts to reduce the risk from operating NPPs. During that period there was growing awareness of safety issues, leading to actions that involved cost increments. The growth of awareness was significantly, but not exclusively, attributable to the occurrence of the TMI accident in 1979.

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[105] Beare, 2005, paragraph 192.
[106] NRC, 1990.

Charles Komanoff, in a book published in 1981, examined the escalating trends of costs associated with nuclear generation in the USA.[107] He showed that efforts to reduce risk were a major driver of cost escalation, and he predicted that this effect would continue during the 1980s. A subsequent compilation of data showed that his prediction was correct.[108] Construction/capital costs in the 1970s averaged 1.95 cent per kWh (1990 $), but rose to an average of 3.51 cent per kWh (1990 $) in the 1980s. Annual capital additions grew from an average of 0.35 cent per kWh (1990 $) in the 1970s to 0.89 cent per kWh (1990 $) in the 1980s.[109] Efforts to reduce risk were a major driver of those trends.

Analysts examining the potential for a nuclear power "renaissance" are well aware of the history of cost escalation.[110] Plant vendors and other advocates of the renaissance recognize that substantial cost escalation will prevent their ambitions from being realized. They hope to curb this escalation through measures such as standardizing of designs and "streamlining" of regulation. It is not clear, however, that they fully appreciate the potential for an unplanned release, at any NPP in the world, to override those measures.[111] Such an event, whether caused by an accident or a malevolent act, would increase public pressure for adoption of risk-reducing measures at plants in Canada and elsewhere. That pressure could become especially powerful if the public became aware that the nuclear industry had rejected innovative plant designs – such as the PIUS design – in favor of Generation III designs that pose a higher risk.

EXAMPLES OF THE COST OF RISK REDUCTION

Table 9-1 provides an example of a capital-addition cost that would lead to risk reduction at a new or existing PWR. This example would be relevant to Canada if a PWR plant were built at the Darlington site or elsewhere. The cost would arise from the re-equipping of the plant's spent-fuel pool with low-density racks, an option shown in the first row of Table 6-1.[112] That measure would require the transfer of spent fuel to dry storage after 5 years of storage in the pool.

Another example of a cost of risk reduction is the additional expenditures in Canada since 2001 to enhance security measures at nuclear installations. Capital costs for these measures have totaled about $300 million, and ongoing costs are about $60 million per year.[113] Licensees are bearing the majority of these costs. It can be presumed that most of the expenditure has been at NPPs.

9.3 Risk Costs of Offsite Impacts of Radioactive Releases

The potential for unplanned radioactive releases from NPPs in Canada is discussed in Section 7.3, above, with a focus on atmospheric releases. That discussion also addresses the offsite radiological impacts of releases, with a focus on lifetime population dose (collective dose commitment). Table 7-1 summarizes information that is relevant to an assessment of the risk costs of offsite impacts. Note that Table 7-1 considers the potential for releases from reactor cores and spent-fuel pools.

MONETIZING RADIOLOGICAL IMPACTS

One of the steps in assessing the risk costs of radiological impacts is to assign a monetary value to radiation dose. Here, the relevant dose is the lifetime population dose arising from a release. That dose is statistically linked to the incidence of radiation-caused morbidity and mortality in the exposed population.

The potential for a population dose, as a result of an unplanned release from an NPP, would be a foreseeable outcome of a decision to operate the plant with a particular level of risk. As discussed in Section 6, above, options are available to reduce the risk. Implementation of those options would involve expenditures. Thus, the monetary value to be assigned to population dose should reflect the tradeoff between the cost of receiving a dose and the cost of avoiding that dose. That tradeoff is made routinely in the operation of NPPs, in the context of small, routine releases of radioactive material. The tradeoff is formalized through the concept of keeping radiation exposure "as low as reasonably achievable" (ALARA).

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[107] Komanoff, 1981.
[108] Komanoff and Roelofs, 1992.
[109] Komanoff and Roelofs, 1992, pp 17-20.
[110] Hultman et al, 2007.
[111] The 1986 Chernobyl accident had a less visible effect on cost trends than did the 1979 TMI accident. Two factors may explain that outcome. First, the Chernobyl accident occurred in a closed, non-Western society. Second, annual capacity additions were already beginning to decline in 1986.
[112] The cost estimate in Table 9-1 assumes that the pool would be re-equipped with low-density racks prior to the 11th year of plant operation.
[113] Frappier, 2007.

CNSC has provided regulatory guidance for implementing the ALARA concept.[114] The CNSC guidance document notes that implementation of ALARA requires the assigning of a monetary value to population dose, and refers the reader to an IAEA report that discusses specific monetary values.[115] The IAEA report is titled, *Optimization of Radiation Protection in the Control of Occupational Exposure*.[116] Table III-2 of the IAEA report shows that owners of US nuclear power plants were, in the early 1990s, assigning an average value of US $1 million to each person-Sv of occupational exposure. The same value (in Can $) was used at the Gentilly plant in Canada.

Analysis published in 1992, by a team led by this author, noted that NRC was then recommending a value of $1,000 per person-rem ($100,000 per person-Sv) for population dose in the ALARA context. NRC also used a dose value of $1,000 per person-rem at that time to determine if a risk-reducing plant modification was economically justified. A value of $1,000 per person-rem, if updated to a 1992 value to account for inflation and new scientific information about the health effects of radiation, would amount to $1 million per person-Sv.[117]

In this report, a potential population dose is assigned a value of $1 million per person-Sv in 1992 Can $. That value is adjusted upward to 2009 Can $ by a factor of 1.36, a CPI inflator provided by Bank of Canada.

ESTIMATING RISK COSTS

As discussed in Section 7, above, Table 7-2 shows licensee estimates of frequency and population dose for potential accidental atmospheric releases from some CANDU stations. The population dose can be monetized as described above. Table 9-2 shows the results of that monetization for the Bruce A station. Similar tables could be prepared for the Bruce B and Pickering B stations, using data from Table 7-2.

Table 9-2 shows, for example, that release EPRC 2 from the Bruce A station would cause offsite health damage of $49.1 billion. The licensee estimates the probability of an EPRC 2 release at 3.6 per 10 million RY. Release EPRC 7 has a higher estimated probability – 2.6 per 100,000 RY – and would cause offsite health damage of $1.05 billion. Note that these probability estimates are mean values, and the 95th percentile value could be an order of magnitude higher. Also, these probability estimates do not account for external initiating events and malevolent acts.

As shown in Table 5-3, CNSC specifies a large-release probability of no more than 1 per 1 million RY as a safety goal for new NPPs. That probability value is often said by regulators and the nuclear industry to be a threshold, above which potential accidents are "credible". Using that criterion, release EPRC 7 at Bruce A is clearly credible, and release EPRC 2 would be credible if external initiating events, uncertainty, and malevolent acts were considered.[118]

Table 7-1 assembles a set of selected data about radioactive releases and their offsite impacts. Those data are used to develop the release cases shown in Table 9-3. Application of a population-dose value of $1.36 million per person-Sv to those cases yields the risk costs shown in Table 9-3. In that table, the CANDU plants at the Darlington site represent the existing CANDU plants across Canada.

Table 9-4 extends Table 9-3 by showing the risk costs for specific values of: (i) the plant's capacity factor; and (ii) the probability of a release caused by malevolent action. In addition, Table 9-4 combines the risk costs for accidental and malevolent releases. The capacity factors shown in Table 9-4 and elsewhere in this report are illustrative, and do not imply that NPPs in Canada will achieve any particular capacity factor. The malevolent release probabilities (MRPs) shown in Table 9-4 are not the product of statistical analysis. Instead, they provide a range of quantitative probabilities that serves as a proxy for a qualitative assessment of the potential for malevolent action.

Table 9-4 shows some very large risk costs for releases from spent-fuel pools at new plants. In the worst instance, the risk costs for pool releases would be 99 cent per kWh.[119] That is a remarkable finding, but is a true reflection of the risk posed by storage of a large amount of spent nuclear fuel in a high-density pool.

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[114] CNSC, 2004.

[115] CNSC, 2004, page 3.

[116] IAEA, 2002.

[117] IRSS, 1992, Volume 2, page 22.

[118] As another example, consider release EPRC 5A at the Pickering B station. Table 7-2 shows an estimated probability of 7.1 per 10 million RY for this release. Monetization of the health impact of this release at $1.36 million per person-Sv yields damage of $1.2 billion.

[119] In this instance, pool release cases 1B-H (high accidental-release probability) and 2B (high malevolent-release probability) are combined, and the plant's capacity factor is 0.8.

As discussed in Section 6, above, options are available for dramatically reducing the risk of a release from a spent-fuel pool, especially by reverting to the use of low-density racks and transferring fuel to dry storage. The cost of implementing that option would be comparatively modest, as shown in Table 9-1. This report assumes implementation of that option.

Table 9-5 simplifies the findings in Table 9-4, by excluding releases from spent-fuel pools and by assuming that the capacity factor of each plant would be 0.9. Further simplification is provided in Table 9-6, which sets forth policy-applicable risk costs of offsite impacts of radioactive releases. The term "policy-applicable" means that these estimates are appropriate for policy purposes, such as assessing the NLCA. Table 9-6 considers releases caused by accidents and by malevolent acts, and shows risk costs for existing plants and new plants.

9.4 Risk Costs of Onsite Impacts of Fuel-Damage Events

The potential for onsite impacts of fuel-damage events at existing CANDU plants in Canada is discussed in Section 7.4, above. Table 7-3 shows an estimate by Ontario Hydro of the risk of such onsite impacts. The risk is expressed in 2009 Can $ per RY of plant operation.

Table 9-7 converts Ontario Hydro's findings to risk costs of onsite impacts of fuel-damage events. Ontario Hydro considered only accidents initiated by internal events. It is reasonable to double Ontario Hydro's estimate of risk to account for external initiating events and malevolent acts. It is also reasonable to use the Darlington estimate for all existing CANDU plants in Canada, because all but two of these plants are in multi-unit blocks.

Note that the dominant component of the risk costs shown in Table 9-7 is the cost of replacement power due to forced outage of NPPs. (See the notes to Table 7-3.) Analysts considering the economics of nuclear generation in Canada should be wary of double counting the costs of forced outages.

9.5 An Overview of Risk Costs

The estimated risk costs in Tables 9-6 and 9-7 are combined in Table 9-8, which summarizes this report's overall findings regarding the risk costs of nuclear generation in Canada. Also shown in Table 9-8 are the estimated insurance premiums that would be paid under the NLCA to provide coverage of the risk costs.

Table 9-8 shows that operation of an existing NPP in Canada creates offsite risk costs of 2.7 to 5.4 cent per kWh of electricity produced, plus additional onsite risk costs of 2.7 to 5.6 cent per kWh. Under the NLCA, the only evident accounting for these risk costs as costs of production would be through payment of insurance premiums amounting to 0.02 cent per kWh, to cover offsite damage to third parties up to a $650 million limit. Thus, the public now provides, and would provide under the NLCA, an implicit subsidy to NPP operators of 5.4 to 11.0 cent per kWh. In 2007, Canadian nuclear generation was 88.2 billion kWh.[120] Thus, the total, implicit subsidy across all Canadian NPPs during 2007 was $4.8 billion to 9.7 billion.

CONSISTENCY OF THESE FINDINGS WITH NUCLEAR INSURERS' ASSUMPTIONS

The analysis underlying Table 9-8 involves various uncertainties and assumptions. Other analysts might make different assumptions, yielding different findings. However, the assumptions made here are reasonable, and are consistent with assumptions made by nuclear insurers. Limited information is publicly available regarding the premiums set by nuclear insurers. Nevertheless, enough information has been disclosed to show how nuclear insurers view the risk posed by operating NPPs.

Underlying Table 9-8 are assumptions including: (i) the probability of an accidental release from an existing NPP in Canada is 1 per 10,000 RY; and (ii) the probability of a malevolent release is between 1 per 1 million RY and 1 per 10,000 RY. (See Table 9-6.) These probability values can be compared with the event probabilities that are implicit in nuclear premiums. To make this comparison, the indicator used here is "implied probability of event" (IPOE), defined as the insurance premium (in $ per RY) divided by the covered amount (in $). IPOE is a simplified event probability (per RY) that assumes perfect forecasting and no profit or administrative costs.

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[120] Statistics Canada, 2009.

In Canada, a premium of $125,000 per RY was paid in 1995 for $75 million of coverage. (See Section 2, above.) That is equivalent to an IPOE of 1.7 per 1,000 RY. In the USA, a premium of $400,000 per RY is paid for $300 million of coverage. (See Section 4, above.) That is equivalent to an IPOE of 1.3 per 1,000 RY. In France, a premium of 110,000 Euro per RY was paid in 2008 for 31 million Euro of coverage. (See Section 4, above.) That is equivalent to an IPOE of 3.5 per 1,000 RY.

Clearly, commercial nuclear insurers do not accept nuclear industry claims that the probability of a radioactive release is very small. Instead, the insurers take a conservative position that is consistent with the empirical record, including the Chernobyl and Three Mile Island events. The probability assumptions underlying Table 9-8 are less conservative than the insurers' assumptions. It should also be noted that commercial insurers refuse to provide full coverage of $650 million of operator liability in Canada (see Section 2, above) and 700 million Euro of liability in Europe (see Section 4, above).

10. Regulatory Issues and Secrecy

In all industrial sectors except the nuclear sector, the public is protected against adverse, unplanned impacts by two major mechanisms. First, corporations are fully liable for economic damage arising from adverse impacts, which creates a powerful incentive to adopt measures that enhance safety and security. Insurance companies reinforce the incentive by setting premiums, deductibles, and other conditions that account for risk. Second, government regulators impose requirements related to safety and security.

The NLCA would, by limiting an NPP operator's liability, hinder the functioning of the first mechanism. The primary mechanism for protecting the public would be government regulation, in the form of CNSC requirements related to safety and security. Thus, an assessment of the NLCA must account for the quality of CNSC regulation. That subject is addressed here, with attention to the role of secrecy.

At least four major questions arise regarding the quality of CNSC regulation. First, are CNSC's criteria for the design and siting of new NPPs adequate? Second, given CNSC's present reliance on a probabilistic paradigm of safety, is the PRA culture in Canada adequate to support that paradigm? Third, does CNSC have the necessary independence and authority to perform its functions? Fourth, what is the role of secrecy?

DESIGN AND SITING CRITERIA

CNSC's design and siting criteria for new NPPs reflect a paradigm in which potential accidents and malfunctions at an NPP are categorized as "design-basis" events that would not lead to a substantial radioactive release if the plant functioned as designed, and "beyond-design-basis" events that could lead to such a release.[121] Events in the latter category are addressed probabilistically, using the concept of risk.[122] Although purportedly scientific, the risk concept as currently applied is actually a form of dogma. The probabilistic paradigm reflects fundamental weaknesses in design. Generation II nuclear power plants, and the proposed Generation III plants, are unable to ride out a variety of credible events outside their design basis. An alternative paradigm is available, as illustrated by the proposed design and siting criteria set forth in the Appendix to this report.

Within the traditional paradigm, CNSC has progressively weakened the plant design criteria that are set forth in CNSC document RD-337. Two instances of weakening have been documented by this author.[123] First, during preparation of the Draft version of RD-337, CNSC withdrew a requirement to prioritize inherent safety. That action was taken to allow the continued operation of existing CANDU plants, and to promote the sale of new CANDU 6 plants by AECL. Second, during the transition from Draft to Final versions of RD-337, CNSC weakened its quantitative safety goals. That action made it easier for plant vendors to claim that their designs comply with the safety goals.

CANADA'S PRA CULTURE

As discussed in Sections 5 and 7, above, Canada never achieved a fully developed PRA culture.[124] Moreover, Canada's PRA culture has degenerated during the past two decades. Now, PRAs are performed in secret and find extremely low probabilities for large releases. Based on those probability findings, the PRAs do not estimate the environmental impacts of large releases. Yet, the low probabilities are not credible. The practice of ignoring large releases deprives citizens and policy makers of needed information.

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[121] For additional information, see: Thompson, 2008a.

[122] In CNSC's risk paradigm, the probabilities of beyond-design-basis threats (events involving malevolent acts) are addressed qualitatively, but not always explicitly. Often, a threat is ignored, which implicitly assigns a probability of zero to that threat.

[123] Thompson, 2008a, Section 4.2.

[124] For additional information, see: Thompson, 2008a.

Canada's isolation from best practice in the PRA field leaves CNSC unprepared to implement its probabilistic safety paradigm. For example, CNSC currently lacks the ability to credibly determine if a new plant complies with the quantitative safety goals set forth in Table 5-3.

CNSC'S INDEPENDENCE AND AUTHORITY

A credible regulator must be able to demonstrate, on a sustained basis, its independence from political pressure, and its ability to exert authority.[125] In the case of CNSC, a related challenge is to discard CNSC's traditional regulatory approach, which has ad hoc and incestuous qualities, and to adopt a more modern and professional approach.

One piece of evidence that illustrates the deficiencies in the traditional CNSC approach is the progressive weakening of the document RD-337 as it moved from pre-Draft to Draft to Final versions. Supporting evidence includes the vagueness of the life extension requirements in CNSC document RD-360.[126] Contrasting evidence, indicating the existence of professionalism within the CNSC, includes the CNSC Staff's insistence that Ontario Power Generation conducts detailed studies of safety issues related to life extension of the Pickering B units.[127]

Tension between the CNSC's traditional regulatory approach and a more professional, politically-independent approach is illustrated by events in late 2007 and early 2008 related to AECL's operation of the NRU reactor at Chalk River.[128] That reactor had been producing a substantial fraction of the radioisotopes used for medical tests and procedures worldwide. Its continued operation was particularly important in light of AECL's failure to make the MAPLE reactors operational. In November 2007, CNSC ordered AECL to cease operation of the NRU reactor, pending the upgrading of safety systems. CNSC had been dissatisfied with AECL's progress in making the upgrade. In December 2007, the Canadian parliament voted to override CNSC's order, and the NRU reactor was re-started. Continuing conflict between the CNSC President and the Canadian government led to the President's dismissal in January 2008. An independent evaluation of these events yielded findings including the following:[129]

> *"Based on a review of these events, and related internal and external communications of both organizations, a fundamental observation of the Talisman Team is that the CNSC regulatory program and the AECL regulatory compliance program are 'expert based' and not 'process based'. The regulatory effectiveness of both organizations can be significantly improved by developing and implementing formal processes, to be used for establishing and complying with regulatory requirements."*

The Canadian government's dismissal of the CNSC president, Linda Keen, created concern among nuclear regulators in other countries. At the 2008 Nuclear Safety Convention review meeting, Keen's dismissal was discussed as follows:[130]

> *"Her case was cited as illustrating insufficient regulatory independence, and the final statement from the 2008 meeting underlined the need to maintain strong and independent regulators."*

Keen has alleged that the NRU situation was an excuse to fire her. She cited as a larger reason her earlier refusal to grandfather safety standards for AECL's CANDU 6, a type of NPP designed in the 1970s, insisting instead that the CANDU 6 be reviewed against 2007 standards. [131] That refusal reduced AECL's prospects for marketing the CANDU 6 in Canada and elsewhere. AECL is a politically influential Crown corporation.

SECRECY AND NPP RISK

The nuclear power industry and its regulators, in Canada and elsewhere, are prone to secretive behavior. For some purposes, such as protection of trade secrets or the privacy of personnel, secrecy is widely accepted and is comparatively harmless. In the context of safety and security, however, secrecy has significant, negative impacts. Experience shows that an entrenched culture of secrecy is not compatible with a clear-headed, science-based understanding of the risk of NPP operation. Entrenched secrecy perpetuates dogma, stifles dissent, creates opportunities for corruption, and can create a false sense of security. In illustration, the culture of secrecy in the former USSR was a major factor contributing to the occurrence of the 1986 Chernobyl reactor accident.[132]

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[125] CNSC, 2007b.
[126] CNSC, 2008c.
[127] Schaubel, 2008.
[128] CBC News, 2008.
[129] Talisman, 2008, page i.
[130] MacKenzie and MacLachlan, 2009, page 9.
[131] MacKenzie and MacLachlan, 2009, page 10.
[132] Thompson, 1998.

Some countries have a tradition of governmental secrecy. The USSR was a prominent example, and suffered accordingly. Other countries, including Canada and the USA, have recognized the benefits of an open society. In the latter group of countries, a considerable amount of information about NPPs and their risks has been publicly available until recent years. Much of this information has been accessible through the regulatory agencies. Since the attacks on New York and Washington in September 2001 that situation has changed, as discussed below.

Prior to September 2001, there were differences between the USA and Canada regarding the availability of information about accidents and malfunctions at NPPs. One difference related to the creation of information, rather than its dissemination. In the USA, numerous PRAs were conducted at Level 3, and there was considerable scientific and public debate about the risks of large releases of radioactive material. In Canada, by contrast, the environmental impacts of large releases were not assessed. Also, the Canadian nuclear industry and its regulator were comparatively reluctant to disclose information that they created.[133] As a result of these factors, Canada has seen less scientific and public debate about the risks of large releases than has occurred in the USA.

Since September 2001, NRC has become notably more secretive. NRC has justified that position by pointing to the risk of attack on NPPs and other nuclear facilities. Yet, NRC has not required its licensees to significantly strengthen the existing plants. Nor has NRC required that robustness against attack be a major design objective for new plants. One could reasonably suspect that a major motive for NRC's secrecy is protection of the status quo. NRC opposes requests by state and local governments and citizen groups that malevolent acts be considered in EISs.[134]

AN OPPORTUNITY TO REDUCE SECRECY IN CANADA

CNSC has departed from current US practice by including resistance to malevolent acts in its proposed design criteria for new NPPs. Similarly, CEAA guidelines depart from US practice by requiring consideration of malevolent acts in an EIS for a new NPP. CNSC, CEAA, and the other relevant agencies deserve commendation for this new approach. It remains to be seen, however, if CNSC will accommodate the consideration of malevolent acts without resorting to excessive secrecy.

CNSC could greatly reduce the need for secrecy by requiring that new NPPs be highly robust against attack. If a plant is robust against credible attacks, secrecy about its design and operation serves no purpose. For example, the proposed design and siting criteria set forth in the Appendix would provide a high degree of robustness. If new NPPs in Canada were designed to meet such criteria, secrecy about their design and operation would not be necessary.

THE WIDER CONTEXT OF SECRECY

A declared motive for the secrecy that now surrounds the nuclear industry is fear that a nuclear installation could be attacked by a sub-national group. Yet, secrecy has substantial adverse effects on a society. Thus, a rush to secrecy hands a victory to hostile, sub-national groups. A more mature, multi-faceted response is needed. Table 10-1 illustrates the factors that should be considered in developing an integrated strategy to protect NPPs and other elements of critical infrastructure.

One of the protective approaches described in Table 10-1 is to build infrastructure facilities that are highly robust and inherently safe. The incremental costs of that approach are not necessarily onerous. In illustration, Table 9-1 shows the estimated incremental cost of transferring spent fuel from a PWR spent-fuel pool to dry storage after 5 years of storage in the pool. That action would allow the pool to be re-equipped with low-density storage racks. If the pool were re-equipped in that manner, attackers could no longer achieve combustion of the spent fuel simply by removing water from the pool. The incremental cost, beginning in the 11th year of plant operation, would be 0.04 cent per kWh.

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[133] For example, the performance of an independent, focused review of the Darlington Probabilistic Safety Evaluation was initially hindered by Ontario Hydro, which delayed its provision of a full set of DPSE documents for more than 6 months. When those documents were eventually provided, they revealed significant deficiencies in DPSE. See: IRSS, 1992, Volume 2, Annex I, pp a-c.

[134] Since 2002, NRC has been in litigation with a group of intervenors, led by San Luis Obispo Mothers for Peace, who have requested that an EIS be prepared for a new spent-fuel-storage installation at the Diablo Canyon site, to address the environmental impacts of malevolent acts. The intervenors are supported by a ruling from the 9th Circuit of the US Court of Appeals. NRC refuses to implement that ruling at sites beyond the reach of the 9th Circuit, and the intervenors allege that NRC has not properly implemented the ruling in the Diablo Canyon instance. The interests of the intervenors extend beyond the Diablo Canyon spent-fuel-storage installation. They seek a legal precedent with wider application.

11. Deficiencies in the NLCA, and Options for Improvement

Five criteria for assessing the NLCA are set forth in Section 3.4, above. Information and analysis provided in this report allow the NLCA to be assessed against those criteria. Deficiencies in the NLCA are evident, as discussed in the following paragraphs.

NLCA DEFICIENCIES RELATED TO FULL ACCOUNTING

In regard to Criterion #1 (Full accounting – information disclosure), the NLCA would not require Canada's nuclear industry and government to publish a full spectrum of information relevant to nuclear risk and nuclear insurance. Thus, the present situation would continue, as described in various sections of this report. Information published in Canada about the risk posed by operation of NPPs is often incomplete or misleading, and there is a dearth of information about the operation of the nuclear insurance sector. This situation is incompatible with democracy, given the public-policy significance of nuclear risk and nuclear insurance.

In regard to Criterion #2 (Full accounting – damage coverage), the NLCA would not ensure that commercial insurance covers the full range of potential damage arising from incidents at NPPs. The liability of commercial insurers would be limited to $650 million, and a substantial portion of that exposure would be reinsured by the Canadian government. Monetized damage to third parties could far exceed $650 million. Studies by the Canadian nuclear industry show that offsite health costs from some potential accidents at existing NPPs could exceed $50 billion. Table 9-2 shows estimated offsite health costs from potential accidental releases at the Bruce A station, derived from an industry study. The EPRC 2 release would impose health costs of $49.1 billion. Application of the same methodology to the Pickering B station shows that an EPRC 1 release at that station would impose health costs of $52.0 billion.[135]

The nuclear industry says that accidents with such large consequences have low probability. Yet, offsite health costs could exceed $1 billion for accidents that the industry concedes are "credible" because their probability is comparatively high. For example, Table 9-2 shows that an EPRC 7 release from the Bruce A station would impose health costs of $1.05 billion, and the probability of the release is 2.6 per 100,000 RY.[136] That probability is well above the credibility threshold of 1 per 1 million RY that is often cited by industry and regulators.

Moreover, there are reasons to doubt that accident probabilities are as low as the nuclear industry claims. Nuclear insurers assume much higher probabilities. (See Section 9.5, above.) Also, the potential for malevolent acts must be considered. Overall, the probability of an event causing offsite damage exceeding $50 billion is substantially higher than is shown by industry studies. (See Sections 5 and 7, above.)

In the USA, a two-tier system of nuclear insurance provides about $11 billion of coverage for damage to third parties. In Germany, there is no limit on an NPP operator's liability for damage to third parties. Each NPP operator in Germany must provide security of 2.5 billion Euro toward its liability. (See Section 4, above.)

An unplanned release of radioactive material could cause economic damage to the operator of an NPP even if most of the released material is contained within the plant buildings. Studies by the nuclear industry show that accidents with a comparatively high probability could cause damage to the operator in excess of $650 million. Table 7-3 shows findings from a study by Ontario Hydro regarding the onsite costs of potential accidents at the Darlington nuclear station. For example, an accident in the FDC 7 category has an estimated probability of 3 per 1,000 RY (i.e., 48 percent over 40 years, at this 4-unit station) and would cause damage between $790 million and $2,500 million to the operator. It appears that no insurance coverage of such an accident exists now in Canada or would exist under the NLCA. Although the damage would directly affect the operator, its costs would ultimately be borne by society at large. Insurance coverage of damage to the operator is provided in the USA. (See Section 4, above.)

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[135] Table 7-2 shows that an EPRC 1 release at Pickering B would cause a population dose of 38,200 person-Sv. Monetization of that dose at $1.36 million per person-Sv yields health costs of $52.0 billion.

[136] If an accident's probability is 2.6 per 100,000 RY, then its cumulative probability over 40 years for a population of 18 NPPs (Canada's operational population of NPPs at present) is 2 percent.

In regard to Criterion #3 (Full accounting – accounting for risk costs as costs of production), the NLCA would not ensure that the risk costs of operating each NPP are accounted for as costs of production. This report contains quantitative analysis to address that issue, and the summary findings are presented in Table 9-8. That table shows that risk costs would far exceed insurance premiums. There is no other mechanism to incorporate risk costs as production costs. Thus, most of the risk costs would be borne by the public at large, representing a large, implicit subsidy of nuclear power. For example, Table 9-8 shows that operation of an existing NPP in Canada creates offsite risk costs of 2.7 to 5.4 cent per kWh of electricity produced, plus additional onsite risk costs of 2.7 to 5.6 cent per kWh. Under the NLCA, the only evident accounting for these risk costs as costs of production would be through payment of insurance premiums amounting to 0.02 cent per kWh, to cover offsite damage to third parties up to a $650 million limit. Thus, the public now provides, and would provide under the NLCA, an implicit subsidy to NPP operators of 5.4 to 11.0 cent per kWh. In 2007, the total, implicit subsidy across all Canadian NPPs was $4.8 billion to 9.7 billion for the year. (See Section 9.5, above.) Such a large subsidy is a significant violation of the polluter-pays principle. (See Section 3, above.)

The analysis underlying Table 9-8 involves various uncertainties and assumptions. Other analysts might make different assumptions, yielding different findings. However, the assumptions made here are reasonable, and the findings are robust. Risk costs exceed insurance premiums by a factor of 270 to 550. Although limited information is publicly available regarding the premiums set by nuclear insurers, accessible data show that nuclear insurers make assumptions about nuclear risk that are consistent with the assumptions made here. (See Section 9.5, above.)

NLCA DEFICIENCIES RELATED TO THE PRECAUTIONARY PRINCIPLE

In regard to Criterion #4 (The precautionary principle), the NLCA would not be compatible with coherent and consistent application of the precautionary principle in Canada. Underlying the NLCA is an assumption that consideration of the risk of unplanned radioactive releases from NPPs should, in the practical context of liability and insurance, be confined to comparatively small releases. That assumption is implicit in the choice of $650 million as a liability limit, and is confirmed by official sources. (See Sections 2 and 8, above.) Yet, that assumption is contradicted by studies conducted by the Canadian nuclear industry, analogous studies conducted in other countries by industry and government, experience with the 1986 Chernobyl accident and the 1979 Three Mile Island accident, and a well-recognized potential for malevolent acts at NPPs. Those sources of information show that damage far in excess of $650 million is a realistic possibility. (See Sections 5 and 7, above.) The NLCA ignores that possibility, and would, therefore, be incompatible with the precautionary principle. (See Section 3, above.) Moreover, the NLCA's liability limit has no basis in either systematic technical analysis or public debate, both of which are central to application of the precautionary principle. A relevant technical analysis – the Severe Accident Study – was initiated by the Canadian government in the late 1980s but never completed. (See Section 8, above.)

NLCA DEFICIENCIES RELATED TO SUSTAINABILITY

In regard to Criterion #5 (Sustainability), the NLCA would not be compatible with a transition of Canada's economy toward sustainability. There are at least three major aspects of this incompatibility. First, the NLCA would violate the precautionary principle, thereby tending to suppress policies and actions flowing from that principle. As a result, opportunities to reduce the risk of NPP operation would be lost, and Canada would bear an unnecessarily high risk of a radioactive release with devastating impacts on the environment, economy, and society. (See Section 6, above, for a discussion of options for risk reduction.) Second, the NLCA would create a large, implicit public subsidy for nuclear power, thereby distorting decisions about public and private investment in systems for production and use of energy. (See the discussion above regarding Criterion #3.) In that way, the NLCA would suppress innovation in sustainable energy systems, and would inhibit market processes for cost-effective deployment of such systems. Third, the NLCA would continue the present climate of incomplete and often misleading information about nuclear risks and nuclear insurance. (See Sections 2, 5, 7, 8 and 10, above.) That climate is antithetical to the open, science-based, and participatory exchange of information that is necessary for Canada's transition to sustainability.

INCOMPATIBILITY OF THE NLCA WITH EXISTING CANADIAN LAW

The polluter-pays principle was upheld unanimously by the Supreme Court of Canada in a 2003 decision. The precautionary principle has important roles in the *Canadian Environmental Assessment Act* of 1992 and the *Federal Sustainable Development Act* of 2008. (See Section 3, above.) Yet, the NLCA would violate both the polluter-pays principle and the precautionary principle. Thus, the NLCA would be incompatible with existing Canadian law, and may be incompatible with Canada's international commitments. Also, the NLCA would create subsidies for nuclear generation of electricity. One subsidy is implicit in the $650 million liability limit. Another subsidy would be the Canadian government's reinsurance of risk that the nuclear insurers refuse to cover. (See Section 2, above.) Both subsidies may be incompatible with Canada's existing laws and international commitments.

OPTIONS FOR IMPROVING THE NLCA

The preceding paragraphs identify significant deficiencies in the proposed NCLA. Options that could address those deficiencies, to varying extents, include:

Option #1: Disclosure of nuclear insurance data

The NLCA would require the timely publication of data on nuclear insurance coverage, premiums, reinsurance, and compensation. This option would have negligible direct cost. It would help to provide the open, science-based, and participatory exchange of information that is necessary for Canada's transition to sustainability.

Option #2: Full assessment of NNP risk

Voting by Parliament on the NLCA would be preceded by publication of a comprehensive assessment of the risk posed by NPP operation in Canada. The Canadian government could prepare that assessment, building upon the Severe Accident Study that the government initiated in the late 1980s but never completed. (See Section 8, above.) As part of Option #2, the NLCA could provide for its own review at specified intervals, preceded each time by an updated NPP risk assessment.

Option #3: Full commercial insurance

The NLCA would prohibit nuclear reinsurance by the Canadian government. This option would help to ensure that nuclear insurance premiums reflect the full risk of NPP operation.

Option #4: Increased liability limit

The NLCA would have a third-party liability limit much higher than $650 million, or no limit. Other countries have demonstrated this option. (See Section 4, above.) In the USA, a two-tier system of nuclear insurance provides about $11 billion of coverage for damage to third parties. In Germany, there is no limit on an NPP operator's liability for damage to third parties, and each NPP operator must provide security of 2.5 billion Euro toward its liability.

Option #5: Coverage of onsite damage

The NLCA would require NPP operators to have commercial insurance coverage for onsite damage, including loss of electricity production. In the USA, the NRC requires insurance coverage for onsite damage other than loss of electricity production, and additional insurance is available to cover loss of electricity production. (See Section 4, above.)

Option #6: Economic channeling

The NLCA would require economic channeling of liability, as under the Price-Anderson Act in the USA. Economic channeling would not set ordinary tort law aside, which the NLCA's currently-proposed legal channeling would do. Under economic channeling, suppliers of nuclear technology, services, and materials would have stronger incentives to promote high levels of safety and security at NPPs. (See Section 4, above.)

Option #7: Operator-pooled, second-tier coverage

The NLCA would require all Canadian NPP operators to participate in pooled, second-tier coverage via retroactive premiums, as under the Price-Anderson Act. In the USA, this approach provides about $11 billion of total coverage for damage to third parties. (See Section 4, above.) A variant of Option #7 would involve all US NPP licensees and all Canadian NPP operators participating in a common pool that provides second-tier coverage. Implementing that variant would require a treaty between Canada and the USA.

12. Conclusions and Recommendations

Major **conclusions** of this report include:

C1. Future operation of NPPs in Canada should be consistent with a policy framework that is appropriate for the 21st century.

C2. The NLCA should be assessed against a framework as described in conclusion C1. Five criteria are developed in this report to support such an assessment.

C3. The NLCA would not meet any of the five criteria described in conclusion C2. The NLCA's failure to meet these criteria would arise from a variety of significant deficiencies.

C4. The NLCA would be incompatible with existing Canadian law, and may be incompatible with Canada's international commitments.

C5. Options are available to improve the NLCA. Some options are outlined in this report.

Based on the preceding conclusions and the body of this report, the following actions regarding the NLCA **are recommended**:

R1. The NLCA should not be enacted in its present form.

R2. The Canadian government should prepare a comprehensive assessment of the risk posed by NPP operation in Canada, the opportunities for reducing that risk, and the accompanying risk costs and risk-reduction costs.

R3. The Canadian government should prepare a legal analysis of the compatibility of the NLCA with Canada's existing laws and international commitments.

R4. The Canadian government should prepare a systematic study of options for improving the NLCA, to include the options outlined in this report.

R5. Parliament should sponsor a public event at which representatives of a wide range of stakeholders would discusses the analyses called for in recommendations R2 through R4, and would present their own analyses.

R6. A revised NLCA should be prepared, informed by the public event called for in recommendation R5.

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Table 1-1

Classification of Potential Accidents and Malfunctions at a Nuclear Power Plant

MODE OF IMPACT OF ACCIDENT OR MALFUNCTION	TYPE OF ACCIDENT OR MALFUNCTION		
	Accidents Initiated by Internal Events	**Accidents Initiated by External Events**	**Releases and Diversions Initiated by Intentional, Malevolent Acts**
Unplanned release of radioactive material from the reactor core	X	X	X
Unplanned release of radioactive material from spent fuel, during storage or transfer to/from storage	X	X	X
Unplanned release of radioactive or hazardous chemical material from another part of the plant	X	X	X
Diversion of fissile or radioactive material for illicit use	Not applicable	Not applicable	X

NOTES:

(a) The symbol X indicates that there is a potential for accidents and malfunctions in the designated category.

(b) For further background, see: Thompson, 2008a.

Table 3-1

The Twelve Principles of Green Engineering, According to Anastas and Zimmerman

Principle 1	Designers need to strive to ensure that all material and energy inputs and outputs are as inherently non-hazardous as possible.
Principle 2	It is better to prevent waste than to treat or clean up waste after it is formed.
Principle 3	Separation and purification operations should be designed to minimize energy consumption and materials use.
Principle 4	Products, processes, and systems should be designed to maximize mass, energy, space, and time efficiency.
Principle 5	Products, processes, and systems should be “output pulled” rather than “input pushed” through the use of energy and materials.
Principle 6	Embedded entropy and complexity must be viewed as an investment when making design choices on recycle, reuse, or beneficial disposition.
Principle 7	Targeted durability, not immortality, should be a design goal.
Principle 8	Design for unnecessary capacity or capability (e.g., “one size fits all” solutions) should be considered a design flaw.
Principle 9	Material diversity in multi-component products should be minimized to promote disassembly and value retention.
Principle 10	Design of products, processes, and systems must include integration and interconnectivity with available energy and materials flows.
Principle 11	Products, processes, and systems should be designed for performance in a commercial “afterlife”.
Principle 12	Material and energy inputs should be renewable rather than depleting.

SOURCE: Anastas and Zimmerman, 2003.

Table 5-1

Some Potential Modes and Instruments of Attack on a Nuclear Power Plant

ATTACK MODE/INSTRUMENT	Characteristics	Present Defenses at US Plants
Commando-style attack	→ Could involve heavy weapons and sophisticated tactics → Successful attack would require substantial planning and resources	Alarms, fences and lightly-armed guards, with offsite backup
Land-vehicle bomb	→ Readily obtainable → Highly destructive if detonated at target	Vehicle barriers at entry points to Protected Area
Small guided missile (anti-tank, etc.)	→ Readily obtainable → Highly destructive at point of impact	None if missile launched from offsite
Commercial aircraft	→ More difficult to obtain than pre-9/11 → Can destroy larger, softer targets	None
Explosive-laden smaller aircraft	→ Readily obtainable → Can destroy smaller, harder targets	None
10-kilotonne nuclear weapon	→ Difficult to obtain → Assured destruction if detonated at target	None

NOTES:

(a) This table is adapted from: Thompson, 2007, Table 7-4. Further citations are provided in that table and its supporting narrative.

(b) Defenses at Canadian plants are no more robust than at US plants. See: Frappier, 2007.

Table 5-2

The Shaped Charge as a Potential Instrument of Attack

CATEGORY OF INFORMATION	Selected Information in Category
General information	→ Shaped charges have many civilian and military applications, and have been used for decades → Applications include human-carried demolition charges or warheads for anti-tank missiles → Construction and use does not require assistance from a government or access to classified information
Use in World War II	→ The German MISTEL, designed to be carried in the nose of an un-manned bomber aircraft, is the largest known shaped charge → Japan used a smaller version of this device, the SAKURA bomb, for kamikaze attacks against US warships
A large, contemporary device	→ Developed by a US government laboratory for mounting in the nose of a cruise missile → Described in detail in an unclassified, published report (citation is voluntarily withheld here) → Purpose is to penetrate large thicknesses of rock or concrete as the first stage of a "tandem" warhead → Configuration is a cylinder with a diameter of 71 cm and a length of 72 cm → When tested in November 2002, created a hole of 25 cm diameter in tuff rock to a depth of 5.9 m → Device has a mass of 410 kg; would be within the payload capacity of many general-aviation aircraft
A potential delivery vehicle	→ A Beechcraft King Air 90 general-aviation aircraft will carry a payload of up to 990 kg at a speed of up to 460 km/hr → A used King Air 90 can be purchased in the US for $0.4-1.0 million

SOURCE: Thompson, 2007, Table 7-6. Further citations are provided in that table and its supporting narrative.

Table 5-3

Safety Goals for a New Nuclear Power Plant, as Specified in CNSC Regulatory Document RD-337

(ATTENTION: The table shows the safety goals in the Draft version of RD-337; the notes show how the goals were weakened in the Final version.)

TYPE OF OUTCOME	SAFETY GOALS	
	Sum of frequencies of all event sequences that can lead to this outcome	
	Should be less than	**Shall not exceed**
Small Release to the Environment (more than 1 PBq of Iodine-131)	1 per 1 million plant-years	1 per 100,000 plant-years
Large Release to the Environment (more than 0.1 PBq of Cesium-137)	1 per 10 million plant-years	1 per 1 million plant-years
Core Damage (significant core degradation)	1 per 1 million plant-years	1 per 100,000 plant-years

NOTES:

(a) The table as shown describes the safety goals set forth by the CNSC in October 2007 in the document: *Design of New Nuclear Power Plants, RD-337, Draft*. See: CNSC, 2007a, page 5.

(b) In November 2008, the CNSC Staff published a Final version of RD-337. See: CNSC, 2008a. Section 4.2.2 of the Final version sets forth safety goals that exhibit the following changes from the table above. First, the numerical goals in the "should be less than" category are abandoned. Second, the numerical goals in the "shall not exceed" category are retained, but with different language. RD-337 now states that the sum of frequencies of all event sequences that can lead to a specified outcome "is less than" a numerical value. Both changes represent a significant weakening of the safety goals.

Table 6-1

Selected Options to Reduce the Risk of a Spent-Fuel-Pool Fire at a Nuclear Power Plant that Employs High-Density Pool Storage

OPTION	Passive or Active?	Does Option Address Fire Scenarios Arising From: Malevolent Acts?	Does Option Address Fire Scenarios Arising From: Other Events?	COMMENTS
Re-equip pool with low-density, open-frame racks	Passive	Yes	Yes	→ Would substantially reduce pool inventory of radioactive material → Would prevent auto-ignition of fuel in almost all cases
Install emergency water sprays above pool	Active	Yes	Yes	→ Spray system must be highly robust → Spraying water on overheated fuel could feed Zr-steam reaction
Mix hotter (younger) and colder (older) fuel in pool	Passive	Yes	Yes	→ Could delay or prevent auto-ignition in some cases → Would be ineffective if debris or residual water block air flow → Could promote fire propagation to older fuel
Minimize movement of spent-fuel cask over pool	Active	No (Most cases)	Yes	→ Could conflict with adoption of low-density, open-frame racks
Deploy air-defense system (e.g., Sentinel and Phalanx) at plant	Active	Yes	No	→ Implementation would require presence of military personnel at plant
Develop enhanced onsite capability for damage control	Active	Yes	Yes	→ Would require new equipment, staff and training → Personnel must function in extreme environments

SOURCE: Thompson, 2007, Table 9-1. Further citations are provided in that table's supporting narrative.

Table 7-1

Radioactive Releases and Offsite Impacts for the 1986 Chernobyl Accident and Some Potential Accidents at Nuclear Power Plants: Selected Data

ACCIDENT CASE	Inventory of Cesium-137 Available for Release	Probability of Release to Atmosphere	Fraction of Cesium-137 Inventory Released to Atmosphere	Lifetime Population Dose (million person-Sv)
Chernobyl Unit 4 in 1986 (capacity = 1.0 GWe)	→ Reactor core: 223 PBq → Spent-fuel pool: ?	→ Reactor core: 1.0 (known) → Spent-fuel pool: 0 (known)	→ Reactor core: 40% (estimated from known release) → Spent fuel: 0% (known)	→ 1.2 (estimated from known release)
Generation II plant (generic)	→ Varies by plant type & mode of spent-fuel storage	→ Reactor core: 1/13,400 = 7.5E-05 per RY → Spent fuel: ?	→ Varies by plant type and scenario	→ Varies by plant type, scenario and site
Darlington CANDU plant (capacity = 0.88 GWe)	→ Reactor core: 67 PBq → Spent-fuel pool: ?	→ Reactor core: 1.0E-04 per RY (estimated) → Spent-fuel pool: 0 (assumed)	→ Reactor core: 50% (est.) from each of two reactors → Spent fuel: 0% (assumed)	→ 2.7 (estimated)
Indian Point Unit 2 PWR plant (capacity = 1.08 GWe)	→ Reactor core: 420 PBq → Spent-fuel pool: 2,500 PBq	→ Reactor core: 7.4E-05 per RY (estimated) → Spent-fuel pool: 2.0E-06 per RY (est.)	→ Reactor core: 23% (est.) → Spent fuel: 50% (est.)	?
Generation III plant at Darlington site (amounts in this row are normalized to a plant capacity of 1.0 GWe)	→ Reactor core: 390 PBq → Spent-fuel pool: 2,300 PBq	→ Reactor core: 1.0E-06 per RY (CNSC goal) → Spent fuel: 1.0E-06 per RY (CNSC goal)	→ Reactor core: 50% (est.) → Spent fuel: 50% (est.)	→ Reactor core: 7.9 → Spent fuel: 46 (both amounts are extrapolated from the Darlington CANDU case)

NOTES:

(a) Actual releases would include isotopes in addition to Cesium-137.

(b) RY = reactor-year

(c) "Population dose" is also known as "collective dose commitment". Lifetime dose is typically calculated for a 50-year period.

(d) Data in the first row are from: DOE, 1987; NRC, 1987; IRSS, 1992, Volume 2, Annex III. Lifetime population dose is from: DOE, 1987, Table 5.16.

(e) In the second row, the probability of a substantial reactor-core release is determined by the occurrence of one such event (at Chernobyl Unit 4) during the 13,400 RY of worldwide commercial reactor operation accrued through 2008.

(f) Data in the third row are from: IRSS, 1992, Volume 2. The probability of a reactor-core release is an IRSS estimate for internal + external initiating events, excluding malevolent acts. The estimated lifetime population dose is a weighted average over the set of the most frequent weather conditions at Darlington, where that set accounts for 20% of the frequency of all weather conditions at the site. Dose was calculated by the MACCS code up to a distance of 1,000 km, assuming no relocation of populations. The estimated release of Cesium-137 is 67 PBq for two reactors, which is equivalent to a release of 67/(2 x 0.88) = 38 PBq per GWe.

(g) Data in the fourth row are from Entergy and the author, in: Thompson, 2007. Entergy estimates a core-damage probability, accounting for internal + external initiating events + uncertainty, excluding malevolent acts, of 1.4E-04 per RY. Entergy's estimate of the conditional probability of an Early High release is adjusted here to account for containment bypass during High/Dry core-damage sequences (see: Thompson, 2007, Table 5-3). The estimated probability of a release from the spent-fuel pool is taken from the NRC study NUREG-1353 (see: Thompson, 2007, Table 6-2).

(h) In the fifth row, inventories of Cesium-137 are adjusted from the Indian Point Unit 2 inventories in proportion to plant capacity. Release probabilities are set to the CNSC safety goal for a Large Release (see Table 5-3). The estimated release of Cesium-137 is 0.5 x 390 = 195 PBq for the reactor core and 0.5 x 2,300 = 1,150 PBq for the spent-fuel pool. Lifetime population dose is extrapolated from the Darlington CANDU case by assuming that dose is proportional to the release of Cesium-137, yielding an estimated dose of (195/67) x 2.7 = 7.9 million person-Sv for the reactor release and (1,150/67) x 2.7 = 46 million person-Sv for the spent-fuel release.

Table 7-2

Licensee Estimates of Frequency and Population Dose for Potential Accidental Atmospheric Releases of Radioactive Material from Some CANDU Stations in Ontario

EX-PLANT RELEASE CATEGORY	Bruce A		Bruce B		Pickering B	
	Freq. (per RY)	**Pop. Dose (p-Sv)**	**Freq. (per RY)**	**Pop. Dose (p-Sv)**	**Freq. (per RY)**	**Pop. Dose (p-Sv)**
EPRC 1	1.5E-07	32,700	2.8E-09	32,900	1.1E-10	38,200
EPRC 2	3.6E-07	36,100	9.1E-08	35,400	1.0E-11	16,000
EPRC 3	6.4E-08	10,500	2.7E-08	10,400	1.0E-11	19,800
EPRC 4	8.6E-08	8,700	6.9E-08	8,730	2.4E-10	7,920
EPRC 5A	2.2E-09 (EPRC 5)	22,700 (EPRC 5)	2.0E-10 (EPRC 5)	22,700 (EPRC 5)	7.1E-07	900
EPRC 5B					2.1E-08	230
EPRC 6	9.1E-07	2,750	1.8E-07	2,800	1.0E-11	3,600
EPRC 7	2.6E-05	770	3.5E-06	760	1.0E-11	22,000
EPRC 8	7.0E-10	40	4.7E-10	40	1.3E-06	11
EPRC 9	2.8E-05	240	5.9E-06	240	1.0E-06	40
EPRC 10	3.0E-05	7	5.8E-05	7	?	?

NOTES:

(a) Bruce A estimates are from: Bruce Power, 2005, Table 3.5.11-5. Quantities shown are mean estimates. Population dose is to 200 km radius. It appears that frequency estimates cover internal initiating events.

(b) Bruce B estimates are from: OPG, 1999, Tables 2-11 and 2-12. Quantities shown are mean estimates. Population dose is to 200 km radius. Frequency estimates cover internal initiating events and loss of offsite power.

(c) Pickering B estimates are from: OPG, 2008, Table 5; and SENES, 2007, Table 5.3-3. Quantities shown are mean estimates. Population dose is to 100 km radius. Radiation risk coefficient is 0.05 delayed fatalities per person-Sv. Frequency estimates cover internal initiating events, loss of offsite power, and some screenhouse failures.

(d) EPRC definitions differ across the studies cited.

(e) RY = reactor-year.

Table 7-3

Ontario Hydro Estimate of the Risk of Onsite Economic Impacts from Fuel-Damage Events at the Darlington Nuclear Power Plants (Existing CANDU Plants)

FUEL DAMAGE CATEGORY	Est. Mean Probability (Uncertainty Factor)	Est. Onsite Economic Impacts (million 2009 Can $)	Risk of Onsite Economic Impacts (million 2009 Can $ per RY)	
			Using Mean Estimate of FDC Probability	Using 95th Percentile Estimate of FDC Probability
FDC 0	3.8E-06 per RY (UF = 6)	?	?	?
FDC 1	2.0E-06 per RY (UF = 6)	6,400 to 11,500	0.013 to 0.023	0.077 to 0.14
FDC 2	8.0E-05 per RY (UF = 6)	5,800 to 10,200	0.46 to 0.82	2.80 to 4.90
FDC 3	4.7E-04 per RY (UF = 4)	3,400 to 5,900	1.60 to 2.80	6.40 to 11.10
FDC 4	3.0E-05 per RY (UF = 10)	3,400 to 6,200	0.10 to 0.19	1.02 to 1.90
FDC 5	1.0E-04 per RY (UF = 10)	2,700 to 5,200	0.27 to 0.52	2.70 to 5.20
FDC 6	2.0E-03 per RY (UF = 10)	1,900 to 3,700	3.80 to 7.40	38.0 to 74.0
FDC 7	3.0E-03 per RY (UF = 5)	790 to 2,500	2.40 to 7.50	11.90 to 37.5
FDC 8	2.0E-03 per RY (UF = 10)	120 to 600	0.24 to 1.20	2.40 to 12.0
FDC 9	2.3E-02 per RY (UF = 3)	390 to 700	8.97 to 16.10	26.9 to 48.3
TOTAL RISK			**17.9 to 36.6**	**92.2 to 195.0**

NOTES:

(a) Estimates are from the Darlington Probabilistic Safety Evaluation (DPSE). See: Ontario Hydro, 1987, Tables 5-2, 5-8 and 5-9. For additional data from the full version of DPSE, see: IRSS, 1992, Volume 2, Annex IV.

(b) DPSE provided cost estimates in 1985 Can $. These are adjusted here to 1991 Can $ by a multiplier of 1.25 (see: IRSS, 1992, Volume 2, Annex IV), and from 1991 Can $ to 2009 Can $ by a multiplier of 1.36 (CPI inflator from Bank of Canada). The combined multiplier is 1.70.

(c) DPSE did not estimate the risk of onsite economic impacts for FDC 0.

(d) These estimates are limited to fuel damage in a reactor core or a fueling machine, caused by accidents initiated by internal events.

(e) Replacement power is the dominant component of the estimated onsite economic impacts. The other component considered by DPSE is the cost of decontamination and repair.

(f) The range of estimated onsite economic impacts is from a “best estimate” (lower bound) to a “probable maximum” (upper bound).

(g) The Darlington station has four CANDU units (plants) that share many safety and support systems (e.g., fueling duct and vacuum building), which means that a fuel-damage event at one unit could readily lead to adverse impacts on the other units. DPSE determined that accidents in categories FDC 1 through FDC 9 would lead to forced outage of all four units. For example, given the occurrence of an FDC 1 accident, the estimated duration of the forced outage would be 45-72 months for all four units, and an additional 65-126 months for the unit that suffered fuel damage.

(h) The uncertainty factor (UF) in the second column is DPSE’s estimate of the ratio of the 95th percentile value to the mean value.

Table 9-1

Estimation of Cost to Transfer Spent Fuel from a PWR Spent-Fuel Pool to Dry Storage After 5 Years of Storage in the Pool

ESTIMATION STEP	ESTIMATE
Average period of use of a fuel assembly in the reactor core	5 years
Period of storage of a spent-fuel assembly in the spent-fuel pool, prior to transfer to dry storage	5 years
Point in plant history when transfer of spent fuel to dry storage begins	11th year of plant operation
Average annual transfer of spent fuel from pool to dry storage	36 fuel assemblies
Capital cost of transferring spent fuel from pool to dry storage (given a dry-storage cost of $200 per kgU, and a mass of 450 kgU per fuel assembly)	$3.2 million per year
Capital cost of transferring spent fuel from pool to dry storage (given a plant capacity of 1.08 GWe, and a capacity factor of 0.9)	0.04 cent per kWh of nuclear generation

NOTES:

(a) This calculation employs data that apply to the Indian Point 2 nuclear power plant in New York state. Comparable data would apply to a new PWR plant in Canada.

(b) Data in this table are from Tables 2-1 and 9-2 of: Thompson, 2007.

(c) The capital cost begins in the 11th year of plant operation, and continues while the plant operates.

(d) The cost can be regarded as being in 2009 Can $.

Table 9-2

Risk Indicators for Potential Accidental Atmospheric Releases of Radioactive Material from the Bruce A Station

EX-PLANT RELEASE CATEGORY	Frequency (per RY)	Population Dose (person-Sv)	Monetized Health Impact ($ million in 2009 Can $)
EPRC 1	1.5E-07	32,700	44,500
EPRC 2	3.6E-07	36,100	49,100
EPRC 3	6.4E-08	10,500	14,300
EPRC 4	8.6E-08	8,700	11,800
EPRC 5A	2.2E-09 (EPRC 5)	22,700 (EPRC 5)	30,900 (EPRC 5)
EPRC 5B			
EPRC 6	9.1E-07	2,750	3,740
EPRC 7	2.6E-05	770	1,050
EPRC 8	7.0E-10	40	54
EPRC 9	2.8E-05	240	330
EPRC 10	3.0E-05	7	10

NOTES:

(a) Frequencies are mean estimates by the licensee, as shown in Table 7-2.

(b) Population doses are mean estimates by the licensee, as shown in Table 7-2.

(c) Population dose is converted here to monetized health impact using a coefficient of $1.36 million per person-Sv (2009 Can $).

Table 9-3

Risk Costs of Offsite Impacts of Accidental or Malevolent Releases of Radioactive Material from Nuclear Power Plants in Canada: Selected Cases

RELEASE CASE	Lifetime Population Dose (million person-Sv)	Probability of Release	Risk Costs of Release (million 2009 Can $ per RY)	Risk Costs of Release (2009 Can cent per kWh)
CASE 1A: Accidental release at existing CANDU reactor	→ Reactor release: 1.5	→ 1.0E-04 per RY	→ Reactor release: 210	→ Reactor release: 2.4/C
CASE 1B-L: Accidental release at new Gen III reactor or spent-fuel pool (lower probability)	→ Reactor release: 7.9 → Spent-fuel release: 46	→ Reactor core: 1.0E-06 per RY (CNSC goal) → Spent fuel: 1.0E-06 per RY (CNSC goal)	→ Reactor release: 11 → Spent-fuel release: 63	→ Reactor release: 0.13/C → Spent-fuel release: 0.72/C
CASE 1B-H: Accidental release at new Gen III reactor or spent-fuel pool (higher probability)	→ Reactor release: 7.9 → Spent-fuel release: 46	→ Reactor core: 1.0E-05 per RY (10 x CNSC goal) → Spent fuel: 1.0E-05 per RY (10 x CNSC goal)	→ Reactor release: 110 → Spent-fuel release: 630	→ Reactor release: 1.3/C → Spent-fuel release: 7.2/C
CASE 2A: Malevolent release at existing CANDU reactor	→ Reactor release: 1.5	→ MRP per RY	→ Reactor release: MRP x 2.1E+06	→ Reactor release: (MRP x 2.4E+04)/C
CASE 2B: Malevolent release at new Gen III reactor or spent-fuel pool	→ Reactor release: 7.9 → Spent-fuel release: 46	→ Reactor core: MRP per RY → Spent fuel: MRP per RY	→ Reactor release: MRP x 1.1E+07 → Spent-fuel release: 6.3E+07	→ Reactor release: (MRP x 1.3E+05)/C → Spent-fuel release: (MRP x 7.2E+05)/C

NOTES:

(a) This table is developed from the data shown in Table 7-1.

(b) Population dose (in person-Sv) and risk costs (in $ per RY) are shown here for a 1 GWe-capacity plant, and can be scaled linearly to other capacities.

(c) C = average annual capacity factor of a plant.

(d) Malevolent release probability (MRP) = probability (per RY) that a malevolent act will yield a large atmospheric release.

(e) In this table, lifetime population dose is assigned a monetary value of 1992 Can $1 million per person-SV. That value is converted to 2009 Can $ using a CPI inflator of 1.36, from Bank of Canada.

(f) In the first and fourth rows, the release contains 38 PBq of Cesium-137. Population dose is scaled linearly from the Darlington CANDU case.

(g) In the second, third and fifth rows, the reactor release contains 195 PBq of Cesium-137, and the spent-fuel release contains 1,150 PBq of Cesium-137. Population dose is scaled linearly from the Darlington CANDU case.

Table 9-4

Range of Risk Costs of Offsite Impacts of Accidental and Malevolent Releases of Radioactive Material from Nuclear Power Plants in Canada: Existing or New Plants

CASES	RISK COSTS OF RELEASES (2009 CAN CENT PER KWH)			
	Av. Capacity Factor (C) = 0.8		**Av. Capacity Factor (C) = 0.9**	
	Malevolent Release Prob. (MRP) = 1.0E-04 per RY	**Malevolent Release Prob. (MRP) = 1.0E-06 per RY**	**Malevolent Release Prob. (MRP) = 1.0E-04 per RY**	**Malevolent Release Prob. (MRP) = 1.0E-06 per RY**
CASES 1A & 2A: Release at existing CANDU plant	→ Case 1A: 3.0 → Case 2A: 3.0 **TOTAL: 6.0**	→ Case 1A: 3.0 → Case 2A: 0.03 **TOTAL: 3.0**	→ Case 1A: 2.7 → Case 2A: 2.7 **TOTAL: 5.4**	→ Case 1A: 2.7 → Case 2A: 0.03 **TOTAL: 2.7**
CASES 1B-L & 2B: Release at new Gen III plant (lower accident prob.)	→ Case 1B-L (reactor): 0.16 → Case 1B-L (pool): 0.9 → Case 2B (reactor): 16.0 → Case 2B (pool): 90.0 **TOTAL: 107.0**	→ Case 1B-L (reactor): 0.16 → Case 1B-L (pool): 0.9 → Case 2B (reactor): 0.16 → Case 2B (pool): 0.9 **TOTAL: 2.1**	→ Case 1B-L (reactor): 0.14 → Case 1B-L (pool): 0.8 → Case 2B (reactor): 14.0 → Case 2B (pool): 80.0 **TOTAL: 95.0**	→ Case 1B-L (reactor): 0.14 → Case 1B-L (pool): 0.8 → Case 2B (reactor): 0.14 → Case 2B (pool): 0.8 **TOTAL: 1.9**
CASES 1B-H & 2B: Release at new Gen III plant (higher accident prob.)	→ Case 1B-H (reactor): 1.6 → Case 1B-H (pool): 9.0 → Case 2B (reactor): 16.0 → Case 2B (pool): 90.0 **TOTAL: 117.0**	→ Case 1B-H (reactor): 1.6 → Case 1B-H (pool): 9.0 → Case 2B (reactor): 0.16 → Case 2B (pool): 0.9 **TOTAL: 11.7**	→ Case 1B-H (reactor): 1.4 → Case 1B-H (pool): 8.0 → Case 2B (reactor): 14.0 → Case 2B (pool): 80.0 **TOTAL: 103.0**	→ Case 1B-H (reactor): 1.4 → Case 1B-H (pool): 8.0 → Case 2B (reactor): 0.14 → Case 2B (pool): 0.8 **TOTAL: 10.3**

NOTE:

Amounts in this table are calculated from the formulae shown in Table 9-3.

Table 9-5

Selected Range of Risk Costs of Offsite Impacts of Accidental and Malevolent Releases of Radioactive Material from Nuclear Power Plants in Canada: Existing or New Plants, Excluding Releases from Spent-Fuel Pools

CASES (Excluding Releases from Spent-Fuel Pools)	Risk Costs for Accidental and Malevolent Releases, Assuming Av. Capacity Factor of 0.9 (2009 Can cent per kWh)	
	Malevolent Release Prob. (MRP) = 1.0E-04 per RY	Malevolent Release Prob. (MRP) = 1.0E-06 per RY
Cases 1A & 2A: Release at existing CANDU plant	5.4	2.7
Cases 1B-L & 2B: Release at new Gen III plant (lower accident prob.)	14.1	0.28
Cases 1B-H & 2B: Release at new Gen III plant (higher accident prob.)	15.4	1.5

NOTES:

(a) Amounts in this table are from Table 9-4.

(b) There are two rationales for excluding releases from spent-fuel pools when assessing risk costs. First, the potential for such releases could be greatly reduced by adopting alternative modes of storage of spent fuel. Second, the inventory of Cesium-137 in a pool would grow over time, reaching its maximum value after several decades of reactor operation.

Table 9-6

Policy-Applicable Risk Costs of Offsite Impacts of Accidental or Malevolent Releases of Radioactive Material from Nuclear Power Plants in Canada

CASE	Risk Costs for Accidental or Malevolent Releases (2009 Can cent per kWh)	
	High Probability of Malevolent Release	**Low Probability of Malevolent Release**
Existing CANDU plant	5.4	2.7
New Generation III plant	15.4	1.5

NOTES:

(a) Amounts in this table are from Table 9-5.

(b) Releases from spent-fuel pools are excluded here.

(c) The average capacity factor of the plant is assumed to be 0.9.

(d) High probability of malevolent release = 1 per 10,000 RY; low probability = 1 per 1 million RY.

(e) Here, the probability of an accidental release from an existing CANDU reactor is 1 per 10,000 RY, and the probability of an accidental release from a new Generation III reactor is 1 per 100,000 RY.

Table 9-7

Risk Costs of Onsite Impacts of Fuel-Damage Events at Existing CANDU Plants, Using an Ontario Hydro Estimate of the Risk of Economic Impacts at the Darlington Plants

INDICATOR	Value of Indicator	
	Using Mean Estimate of Probabilities of Fuel Damage Categories	Using 95th Percentile Estimate of Probabilities of Fuel Damage Categories
Risk of onsite economic impacts	17.9 to 36.6 (million 2009 Can $ per RY)	92.2 to 195.0 (million 2009 Can $ per RY)
Risk costs of onsite economic impacts (OH estimate for internal initiating events only)	0.26 to 0.53 (2009 Can cent per kWh)	1.33 to 2.81 (2009 Can cent per kWh)
Risk costs of onsite economic impacts (internal initiating events + external events + malevolent acts)	0.5 to 1.1 (2009 Can cent per kWh)	2.7 to 5.6 (2009 Can cent per kWh)

NOTES:

(a) This table is developed from data shown in Table 7-3.

(b) Ontario Hydro considered the occurrence of accidents involving Fuel Damage Categories FDC 1 through FDC 9, but not the most severe Category (FDC 0).

(c) Ontario Hydro considered fuel damage in a reactor core or a fueling machine, caused by accidents initiated by internal events.

(d) Values in the first row are from Table 7-3. Values in the second row are calculated from the first row.

(e) Values in the third row are adjusted upward from values in the second row by a factor of 2, to account for accidents initiated by external events, and for malevolent acts.

(f) Each Darlington plant has a capacity of 0.88 GWe. A capacity factor of 0.9 is assumed here.

Table 9-8

Risk Costs of Nuclear Generation in Canada: Summary of this Report's Findings

CATEGORY OF IMPACTS FROM UNPLANNED RELEASES OF RADIOACTIVE MATERIAL	Category of Risk Costs and the Insurance Premiums that are Paid to Provide Coverage of these Costs	Magnitude of Risk Costs and Insurance Premiums	
		For an Existing CANDU Plant	For a New Generation III Plant
Offsite Impacts	Risk Costs (2009 Can cent per kWh)	2.7 to 5.4	1.5 to 15.4
	Insurance Premiums Under the NLCA (2009 Can cent per kWh)	0.02	As for existing CANDU plant?
Onsite Impacts	Risk Costs (2009 Can cent per kWh)	2.7 to 5.6	Smaller amount than for existing CANDU plant
	Insurance Premiums Under the NLCA (2009 Can cent per kWh)	No explicit premium is evident	No explicit premium is evident

NOTES:

(a) Risk costs in the first row are from Table 9-6.

(b) Risk costs in the third row are from Table 9-7, using the 95th percentile probability estimate, and considering internal events + external events + malevolent acts.

(c) Insurance premiums are as discussed in Section 2 of this report.

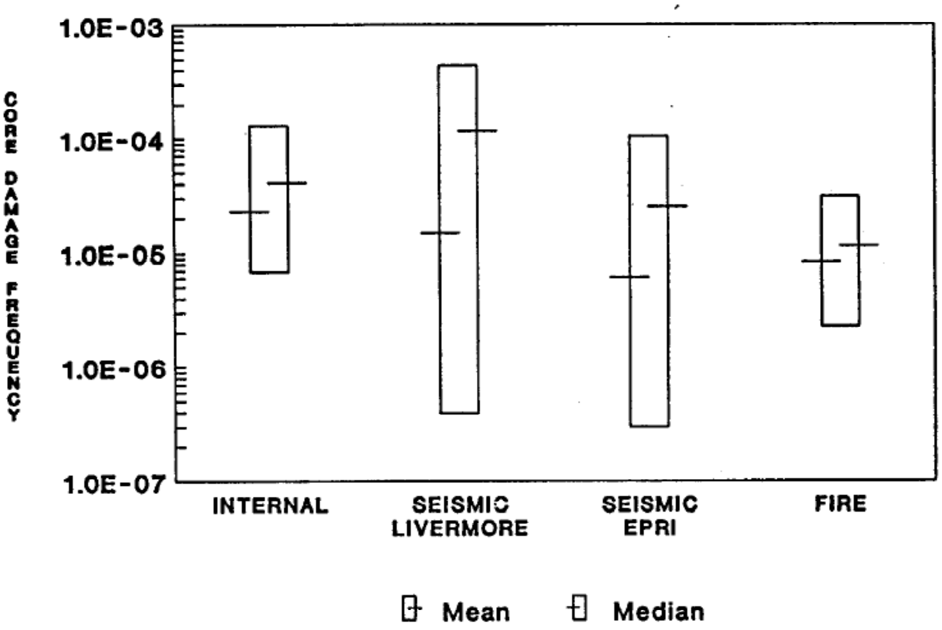
Table 10-1

Selected Approaches to Protecting Canadian Critical Infrastructure From Attack by Sub-National Groups, and Some Strengths and Weaknesses of these Approaches

APPROACH	STRENGTHS	WEAKNESSES
Offensive military operations internationally	→ Could deter or prevent governments from supporting sub-national groups hostile to Canada	→ Could promote growth of sub-national groups hostile to Canada, and build sympathy for these groups in foreign populations → Could be costly in terms of lives, money, etc.
International police cooperation within a legal framework	→ Could identify and intercept potential attackers	→ Implementation could be slow and/or incomplete → Requires ongoing international cooperation
Surveillance and control of the domestic population	→ Could identify and intercept potential attackers	→ Could destroy civil liberties, leading to political, social and economic decline
Secrecy about design and operation of infrastructure facilities	→ Could prevent attackers from identifying points of vulnerability	→ Could suppress a true understanding of risk → Could contribute to political, social and economic decline
Active defense of infrastructure facilities (by use of guards, guns, gates, etc.)	→ Could stop attackers before they reach the target	→ Requires ongoing expenditure & vigilance → May require military involvement
Robust and inherently-safe design of infrastructure facilities	→ Could allow target to survive attack without damage, thereby enhancing protective deterrence → Could substitute for other protective approaches, avoiding their costs and adverse impacts → Could reduce risks from accidents & natural hazards	→ Could involve higher capital costs

Figure 5-1

Core Damage Frequency for Accidents at a Surry PWR Nuclear Power Plant, as Estimated in the NRC Study NUREG-1150



NOTES:

(a) This figure is adapted from Figure 8.7 of: NRC, 1990.

(b) The bars range from the 5th percentile (lower bound) to the 95th percentile (upper bound) of the estimated core damage frequency (CDF). CDF values shown are per reactor-year (RY).

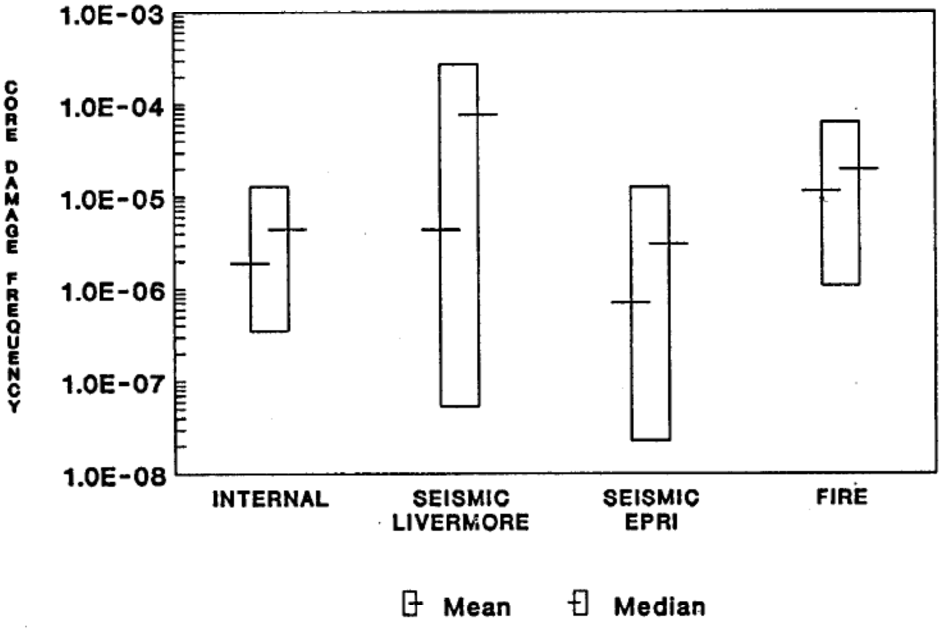
(c) Two estimates are shown for the CDF from earthquakes (seismic effects). One estimate derives from seismic predictions done at Lawrence Livermore National Laboratory (Livermore), the other from predictions done at the Electric Power Research Institute (EPRI).

(d) CDFs are not estimated for external initiating events other than earthquakes and fires.

(e) Malevolent acts are not considered.

Figure 5-2

Core Damage Frequency for Accidents at a Peach Bottom BWR Nuclear Power Plant, as Estimated in the NRC Study NUREG-1150



NOTES:

(a) This figure is adapted from Figure 8.8 of: NRC, 1990.

(b) The bars range from the 5th percentile (lower bound) to the 95th percentile (upper bound) of the estimated core damage frequency (CDF). CDF values shown are per reactor-year (RY).

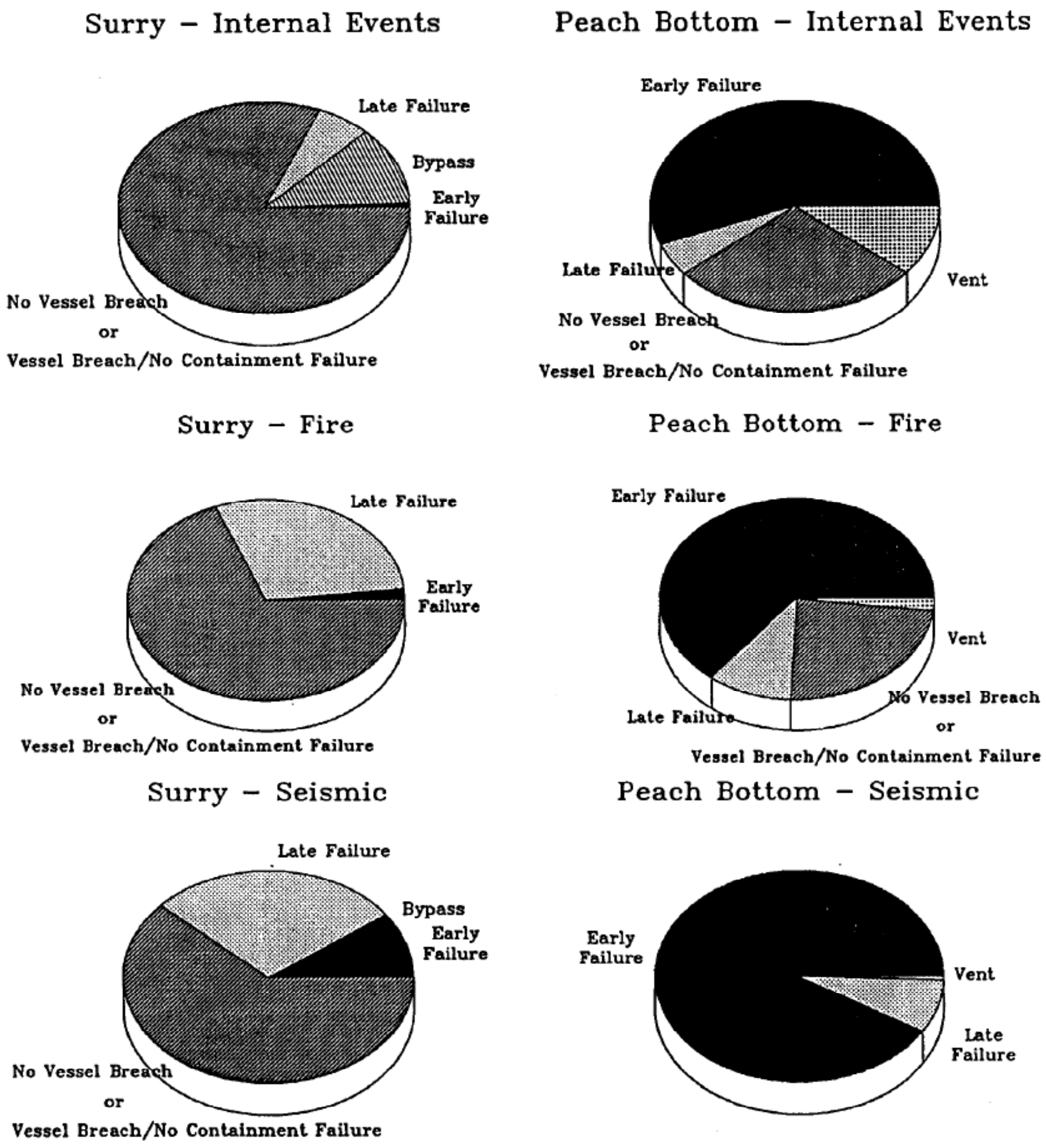
(c) Two estimates are shown for the CDF from earthquakes (seismic effects). One estimate derives from seismic predictions done at Lawrence Livermore National Laboratory (Livermore), the other from predictions done at the Electric Power Research Institute (EPRI).

(d) CDFs are not estimated for external initiating events other than earthquakes and fires.

(e) Malevolent acts are not considered.

Figure 5-3

Conditional Probability of Containment Failure Following a Core-Damage Accident at a Surry PWR or Peach Bottom BWR Nuclear Power Plant, as Estimated in the NRC Study NUREG-1150


Surry – Internal Events

Peach Bottom – Internal Events

Surry – Fire

Peach Bottom – Fire

Surry – Seismic

Peach Bottom – Seismic

NOTE:

This figure is adapted from Figure 9.5 of: NRC, 1990.

APPENDIX

Designing Nuclear Power Plants to Pose a Comparatively Low Level of Risk[137]

The most reliable option for reducing the risk posed by a nuclear power plant would be to design the plant according to highly stringent criteria of safety and security. During the 1970s and 1980s, some plant vendors and other stakeholders sought to develop designs that could meet such criteria. One design approach was to provide a highly robust containment – which might be an underground cavity – to separate nuclear fuel from the environment. Another approach was to incorporate principles of "inherent" or "intrinsic" safety into the design. The two approaches could be complementary.

UNDERGROUND SITING

In the 1970s, there were several studies on constructing NPPs underground. Those studies are exemplified by a report published in 1972 under the auspices of the California Institute of Technology (Caltech).[138] The report identified a number of advantages of underground siting. Those advantages included highly-effective confinement of radioactive material in the event of a core-damage accident, isolation from falling objects such as aircraft, and protection against malevolent acts. Based on experience with underground testing of nuclear weapons, the report concluded that an appropriately designed plant would provide essentially complete containment of the radioactive material liberated from a reactor core during a core-damage event.

The Caltech report described a preliminary design study for underground construction of an LWR plant with a capacity of 1,000 MWe. The minimum depth of the underground cavities containing the plant components would be 150 to 200 feet. The estimated cost penalty for underground siting would be less than 10 percent of the total plant cost.

In an appendix, the Caltech report described four underground nuclear reactors that had been constructed and operated in Europe. Three of those reactors supplied steam to turbo-generators, above or below ground. The largest of those reactors and its above-ground turbo-generator made up the Chooz plant in France, which had a capacity of 270 MWe. In describing the European reactors, the report noted:[139]

> *"The motivation for undergrounding the plant appears to be insurance of containment of accidentally released radioactivity and also physical protection from damage due to hostile military action."*

Since the 1970s, underground siting of NPPs has been considered by various groups. For example, in 2002 a workshop was held under the auspices of the University of Illinois to discuss a proposed US-wide "supergrid". That grid would transmit electricity – via superconducting DC cables – and liquid hydrogen, which would provide cooling to the DC cables and be distributed as fuel. Much of the energy fed to the grid would be supplied by nuclear power plants, which could be constructed underground. Motives for placing those plants underground would include "reduced vulnerability to attack by nature, man or weather" and "real and perceived reduced public exposure to real or hypothetical accidents".[140]

THE PIUS REACTOR

In the 1980s the reactor vendor ASEA-Atom developed a preliminary design for an "intrinsically safe" commercial reactor known as the Process Inherent Ultimate Safety (PIUS) reactor. An ASEA-Atom official described the company's motives for developing the reactor as follows:[141]

> "The basic designs of today's light water reactors evolved during the 1950s when there was much less emphasis on safety. Those basic designs held certain risks, and the control of those risks led to an increasing proliferation of add-on systems and equipment ending up in the present complex plant designs, the safety of which is nevertheless being questioned. Rather than to continue into this 'blind alley', it is now time to design a truly 'forgiving' light water reactor

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[137] A lengthier version of this discussion is provided in: Thompson, 2008a.

[138] Watson et al, 1972.

[139] Watson et al, 1972, Appendix I.

[140] Overbye et al, 2002.

[141] Hannerz, 1983, pp 1-2.

> in which ultimate safety is embodied in the primary heat extraction process itself rather than achieved by add-on systems that have to be activated in emergencies. With such a design, system safety would be completely independent of operator actions and immune to malicious human intervention."

The central goal of the PIUS design was to preserve fuel integrity "under all conceivable conditions". That goal translated to a design specification of "complete protection against core melting or overheating in case of:

- any credible equipment failures;
- natural events, such as earthquakes and tornadoes;
- reasonably credible operator mistakes; and
- combinations of the above;

and against:

- inside sabotage by plant personnel, completely knowledgeable of reactor design (this can be considered an envelope covering all possible mistakes);
- terrorist attacks in collaboration with insiders;
- military attack (e.g., by aircraft with 'off-the-shelf' non-nuclear weapons); and
- abandonment of the plant by the operating personnel".[142]

To meet those requirements, ASEA-Atom designed a light-water reactor – the PIUS reactor – with novel features. The reactor pressure vessel would contain sufficient water to cool the core for at least one week after reactor shut-down. Most of that water would contain dissolved boron, so that its entry into the core would inherently shut down the reactor. The borated water would not enter the core during normal operation, but would enter through inherent mechanisms during off-normal conditions. The reactor pressure vessel would be made of pre-stressed concrete with a thickness of 25 feet. That vessel could withstand an attack using 1,000-pound bombs. About two-thirds of the vessel would be below ground.

ASEA-Atom estimated that the construction cost of a four-unit PIUS station with a total capacity of 2,000 MWe would be about the same as the cost of a station equipped with two 1,000 MWe "conventional" light-water reactors. The PIUS station could be constructed more rapidly, which would offset its slightly lower thermal efficiency. Thus, the total generating cost would be about the same for the two stations. ASEA-Atom estimated (in 1983) that the first commercial PIUS plant could enter service in the early 1990s, if a market existed.[143] To date, no PIUS plant has been ordered.

DESIGN CRITERIA FOR REDUCING RISK

Table App-1 sets forth criteria for designing and siting a nuclear power plant that would pose a risk substantially lower than is posed by the Generation II plants that are now in use worldwide, and by the Generation III plants whose construction in Ontario is being considered. These criteria are similar to ASEA-Atom's design specification for the PIUS plant. Thus, there is evidence that the criteria set forth in Table App-1 are achievable. If ASEA-Atom's cost projections were accurate, there would be no overall cost premium for complying with such criteria.

An initial review of the three types of Generation III plants whose construction in Ontario is being considered shows that none of the three designs could meet the criteria in Table App-1.[144]

Table App-1

Criteria for Design and Siting of a New Nuclear Power Plant that Poses a Residual Risk Substantially Lower than is Posed by Generation II or III Plants

APPLICATION OF CRITERIA	Criteria

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[142] Hannerz, 1983, page 3.

[143] Hannerz, 1983, pp 73-76.

[144] Thompson, 2008a, Section 5.

Safety performance of the plant during reactor operation (design-basis criteria)	No significant damage of the reactor core or adjacent stored spent fuel in the event of: → Loss of all electrical power (AC & DC), compressed air, other power sources, and normal heat sinks for an extended period (e.g., 1 week); → Abandonment of the plant by operating personnel for an extended period (e.g., 1 week); → Takeover of the plant by hostile, knowledgeable persons who are equipped with specified explosive devices, for a specified period (e.g., 8 hours); → Military attack by specified means (e.g., 1,000-pound air-dropped bombs); → An extreme, specified earthquake; → Conceivable erroneous operator actions that could be accomplished in a specified period (e.g., 8 hours); or → Any combination of the above.
Safety performance of the plant during reactor refueling (design-basis criteria)	A specified maximum release of radioactive material to the accessible environment in the event of: → Loss of reactor coolant at a specified time after reactor shut-down, with replacement of the coolant by fluid (e.g., air, steam, or unborated water) creating the chemical and nuclear reactivity that would maximize the release of radioactive material, at a time when the plant's containment is most compromised; and → Any combination of the events specified above, in the context of reactor operation.
Site specification (radiological-impact criteria)	In the event of the maximum release of radioactive material specified above, in the context of reactor refueling, radiological impacts would not exceed specified values regarding: → Individual dose; → Population dose; and → Land areas in various usage categories that would be contaminated above specified levels.

NOTES:

(a) The criteria in the first two rows of this table would apply to spent fuel stored adjacent to the reactor core. Separate criteria would apply to an independent facility for storing spent fuel, whether onsite or offsite.

(b) For a more detailed discussion, see: Thompson, 2008a.

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