OUTLINE OF A CODE OF CONDUCT FOR TRANSFER OF NUCLEAR POWER PLANT TECHNOLOGY TO CONSUMER COUNTRIES

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Abstract

This report contributes to ongoing debate about the future role of nuclear fission power, by outlining a code of conduct for transfer of nuclear power plant (NPP) technology to consumer countries. The term "consumer" is used here to refer to a country that is a party to the Nuclear Non-Proliferation Treaty (NPT) and has not developed an indigenous capability to design or manufacture the major components of an NPP. The code outlined here would apply to the transfer of Generation III NPP technology during the next few decades. Relevant items of technology would pertain to light-water reactors (LWRs) or CANDU reactors. Before outlining the content of a potential code, this report provides background regarding codes of conduct, sustainability, and trends in the use of nuclear power. It then discusses ten issue areas for a code of conduct, and outlines a process for constructing a code that accounts for each issue area. The World Nuclear Association Charter of Ethics, reproduced here, might be one point of departure for such a process.

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.

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I. Introduction

Nuclear fission provides about 15 percent of world electricity production.[1] The future of the nuclear power industry is unclear. Some observers expect or call for the industry to fade away over the coming decades, while others expect or call for a nuclear "renaissance" involving the construction of a large number of nuclear power plants (NPPs).[2] The prospects of a renaissance were diminished when a March 2011 earthquake and tsunami initiated simultaneous accidents at four NNPs on the Fukushima Dai-ichi (Number 1) site in Japan.[3]

As a contribution to ongoing discussion of the industry's future, this report outlines a potential code of conduct for transfer of NPP technology, with a focus on transfer to consumer countries. The report was drafted prior to the occurrence of the Fukushima NPP accidents, but has not required significant alteration in light of these events.

Although there are differing opinions about the nuclear industry's prospects, there is broad agreement that the use of nuclear fission for commercial purposes involves complex socio-technical issues that are significant from a public-policy perspective. These issues are manifested at scales ranging from local to international. To address such issues, governments have established or employed an array of institutions. At the international level, the lead institution is the International Atomic Energy Agency (IAEA). Other institutions function at regional, national, provincial, and local levels. These institutions regulate or influence the commercial nuclear industry in a variety of ways. Formal, legal control is typically concentrated at the national level, through bodies such as the US Nuclear Regulatory Commission (NRC).

The various institutions exercise their influence via agreements, rules, and advisory documents of many different kinds. For example, the IAEA is the technical overseer of the Nuclear Non-Proliferation Treaty (NPT) but has no power to enforce compliance. To a limited extent, that power resides in the UN Security Council. At the national level, regulatory agencies are empowered by legislation, and use that power to promulgate and enforce a set of rules. In the USA, for example, the Atomic Energy Act (AEA), the National Environmental Policy Act (NEPA), and other federal Acts specify the powers and responsibilities of NRC. In turn, NRC promulgates a large body of rules and enforces compliance with these rules by the US commercial nuclear industry.

[1] Nuclear fission's share of world electricity production was about 15 percent in 2008, down from a peak of about 17 percent in the early 1990s. See: World Nuclear Association website, http://www.world-nuclear.org/info/inf01.html, accessed on 18 April 2010.
[2] Throughout this report, the term "nuclear power plant" means a fission reactor and its associated equipment, including equipment to produce electricity. Future types of nuclear power plant (Generation IV or later, if any are built) might also produce hydrogen, potable water, and/or process heat.
[3] JAIF, 2011.

Regime limitations

This diverse array of institutions, and the rules and other instruments through which they exercise influence, constitute a multi-faceted, polycentric, government-created regime that seeks to address policy-relevant issues related to the commercial nuclear industry. The regime has been taking shape since the early 1950s, and continues to grow. As might have been expected, the regime has grown unevenly across the spectrum of significant issues. Moreover, some issues have become salient only during recent decades. For example, the concept of sustainable development entered mainstream policy discourse only during the latter part of the 1980s, as did the threat of anthropogenic climate change. The regime does not address sustainability or climate change to any significant extent.

When the regime does address an issue, it often does so in a way that avoids confrontation with powerful interests. This phenomenon reflects the jealous prerogatives of nation states and the political influence of industrial lobbies. More broadly, the regime does not currently provide a comprehensive, objective framework for policy debate and decision making about commercial nuclear activities. A recent Canadian study confirms this conclusion in regard to three sub-regimes – for nuclear safety, security, and nonproliferation – of the nuclear-power regime. The study considers the potential for a nuclear-power renaissance over the next few decades, finds that outcome unlikely, and states:[4]

> "A lesser nuclear revival than widely expected might appear to imply that there should be no concerns about global governance of nuclear energy. Nothing could be further from the truth. The existing regimes for nuclear safety, security and nonproliferation, despite improvements in recent years, are still inadequate to meet current challenges, much less new ones."

Role of a code of conduct

In a situation where governments have failed to create a comprehensive framework for policy debate and decision making, it is natural for major stakeholders to think about alternative arrangements. Their thinking may turn to the creation of a code of conduct. Such codes are typically voluntary, and can therefore be put in place much faster than can treaties, laws, and regulations. Also, a code of conduct can provide roles for stakeholders other than governments, including corporations, foundations, academic centers, international non-governmental organizations (NGOs), and local NGOs. Within the quasi-formal context of a code of conduct, groups of stakeholders can come together, potentially with some governments, to express a consensus view about how to act on issues related to the subject of interest. In the present instance, that subject is an aspect of the commercial use of nuclear fission.

[4] Frechette and Findlay, 2010, page 6.

Scope of this report

This report outlines a potential code of conduct for the transfer of NPP technology, with a focus on transfer to consumer countries. The term "consumer" is used here to refer to a country that is a party to the NPT and has not developed an indigenous capability to design or manufacture the major components of a nuclear power plant. Most countries in that category also currently lack an indigenous capability to design or manufacture the major components of other facilities in a commercial nuclear fuel cycle, especially facilities for uranium enrichment or nuclear fuel reprocessing.[5] Moreover, countries that do have capabilities in enrichment or reprocessing technology are now generally reluctant to transfer that technology to other countries, in contrast to their position a few decades ago. Their current, restrictive policy can be attributed to concern about the proliferation of nuclear weapons and, perhaps, to a desire to protect their oligopoly in the nuclear-technology market.[6]

Thus, it is assumed in this report that a consumer country would typically not possess or seek the acquisition of a uranium enrichment facility or a nuclear fuel reprocessing facility during the time period covered by the code of conduct discussed here. It follows that the consumer country would import fresh nuclear fuel for its NPPs, with the possible exception of cases where CANDU reactors are fueled by natural uranium.[7] It further follows that the consumer country would either export the spent (i.e., used) nuclear fuel from its NPPs or would store that fuel for an extended period. The country might engage in uranium mining, would probably use radioactive isotopes for various purposes, and might operate a research reactor. Those activities are not addressed by the code of conduct discussed here.

During the next few decades, any NPP that is acquired by a consumer country will be in the "Generation III" category. Types of NPP in that category employ pressurized-water reactors (PWRs), boiling-water reactors (BWRs), or CANDU reactors. PWRs and BWRs are cooled and moderated by light water, and are therefore types of light-water reactor (LWR). CANDU reactors are of Canadian design and are moderated by heavy water.

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[5] Iran is one exception to this tendency. Russia is supplying technology for the Bushehr nuclear power plant in Iran. In that context, Iran is a consumer country. At the same time, however, Iran is constructing and operating uranium-enrichment facilities using indigenous technology that is based on design information obtained illicitly through the A. Q. Khan network. Thus, Iran is a special case in regard to this report. Brazil is another special case, because it operates uranium-enrichment facilities to provide fuel for its commercial reactors and planned submarine-propulsion reactors. South Africa has a well-developed indigenous capability in uranium enrichment, and Argentina has some capability, but both countries currently purchase enrichment services on world markets.

[6] Former IAEA Director General Mohamed ElBaradei repeatedly drew attention, when in office, to the nuclear-weapon-proliferation implications of uranium enrichment and spent-fuel reprocessing. See, for example: ElBaradei, 2009.

[7] In this report it is assumed that LWRs or CANDU reactors in consumer countries would typically not use mixed-oxide (MOX) fuel containing recycled plutonium. Also, it is assumed that CANDU reactors in consumer countries would typically not use DUPIC fuel containing recycled spent fuel from LWRs.

Currently-operating CANDU reactors are cooled by heavy water, but a version under development would be cooled by light water.

The preceding paragraphs set boundaries for a potential code of conduct. The code discussed here would address the transfer of a particular category of nuclear technology (i.e., NPPs employing LWRs or CANDU reactors) to a particular set of countries. Other activities related to nuclear fission would not be addressed. Also, the code would apply only during the next few decades. These limitations are consistent with the ad hoc, temporary nature of most codes of conduct. Moreover, in the present instance, designing a code with long-term applicability is not feasible, given the many uncertainties about the development of the nuclear industry over the coming decades. For example, if a worldwide nuclear-power renaissance does occur, many consumer countries will acquire indigenous capabilities in relevant technologies, and the concept of a consumer country will have declining utility.

Although limited in its scope, the code of conduct discussed here would be a complex instrument. This code would have to complement the government-created regime that is outlined above, which is very complex. Also, the code would be obliged to reflect the perspectives of the entities that subscribe to it. This report argues that the subscribing entities would ideally include or represent all major stakeholder groups in a consumer country, similar groups in neighboring countries that could be affected by an NPP in the consumer country, vendors of NPP technology and services, and the governments of countries where major vendors are based. Within such a broad range of subscribing entities, there may be wide divergence of interests and perspectives. A code of conduct would have to be correspondingly complex in order to account for the diversity. Otherwise, the code would inevitably be watered down to a lowest common denominator, and would not be useful.

This report should be seen as a point of departure for dialogue and further analysis about a code of conduct. Here, issue areas for a code of conduct are identified, and a process is outlined whereby an overall code that accounts for each issue area could be constructed.

Structure of this report

This report begins with a narrative in six sections, including this introduction (Section I). Background information is provided in Section II, including information regarding codes of conduct, sustainability, and trends in nuclear power. Then, Section III identifies ten issue areas for a code of conduct, and Section IV outlines a process for constructing a code that accounts for each issue area. Conclusions are presented in Section V, and a bibliography is provided in Section VI. Tables and figures follow, numbered according to the section of the narrative to which they refer. The report ends with two appendices. Documents cited in footnotes and elsewhere are listed in the bibliography unless fully identified at the point of citation.

II. Background

II.1 Codes of Conduct: Purposes and Participants

Codes of conduct related to industrial activities are often created by, and apply to, a group of entities that have business or professional interests in the relevant industry. Such an industry-based code of conduct can be viewed as a form of business self-regulation. Three major purposes of such a code have been identified.[8] First, the code could have an aspirational purpose, perhaps functioning as a charter of ethics. Second, the code could have an educational or advisory purpose, providing specific but non-binding guidance. Third, the code could have a restrictive purpose, providing enforceable direction.

The World Nuclear Association (WNA) represents many businesses that are active in the nuclear industry. WNA has articulated a Charter of Ethics that is reproduced in full as Appendix A of this report. That Charter serves the aspirational purpose described above. By contrast, the World Association of Nuclear Operators (WANO) serves a nominally advisory purpose and, as a practical matter, a restrictive purpose. WANO describes its role as follows:[9]

> "As every organisation in the world that operates a nuclear electricity generating plant is a member of WANO, it is a truly international organisation, cutting across political barriers and interests. WANO is an association set up purely to help its members achieve the highest practicable levels of operational safety, by giving them access to the wealth of operating experience from the world-wide nuclear community. WANO is non profit making and has no commercial ties. It is not a regulatory body and has no direct association with governments. WANO has no interests other than nuclear safety."

The World Institute for Nuclear Security (WINS) has been established on a model similar to that of WANO, except that WINS focuses on improving the security of fissile and radioactive materials. Also, individuals can be members of WINS. The WINS mission is:[10] "To provide an international forum for those accountable for nuclear security to share and promote the implementation of best security practices". Members of WINS are obliged to follow a code of conduct that places special emphasis on confidentiality.

An interesting example of a code of conduct for nuclear technology is the IAEA Code of Conduct on the Safety of Research Reactors, which was formally adopted by the IAEA General Conference in September 2004. Prior to its adoption, concern was expressed in IAEA circles about both the safety and security of research reactors. A factor underlying

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[8] Letts and Cunningham, 2009.

[9] WANO website, http://www.wano.org.uk/WANO_Documents/What_is_Wano.asp, accessed on 29 April 2010.

[10] WINS website, http://www.wins.org/content.aspx?id=1, accessed on 29 April 2010.

the concern about security is that just under half of the world's 272 research reactors (using 2004 data) are fueled by highly enriched uranium, which can be used directly in a nuclear weapon. Curiously, however, the code of conduct that was adopted does not address the physical protection of research reactors. Nor does it apply to military research reactors.[11] IAEA has described the adopted code as follows:[12]

> "The Code is a non-binding international legal agreement, where States determine their own level of commitment to its guidance. The Code was derived from more detailed international standards that have been promulgated for the safe day-to-day operation, construction, shutdown and decommissioning of research reactors, [IAEA official] Mr. Brockman said. "It will pave the way for the continued evolution of these standards," he said."

In each example mentioned above, a code of conduct applies to a select group of participants: the members of WNA, WANO, or WINS; or the member States of IAEA. Limiting the types of participant in this manner will inevitably exclude stakeholders whose perspectives and interests differ from those of the select group. Excluding such stakeholders creates the potential for a code of conduct to be self-serving. That outcome could occur, for example, if participants adopted a code worded in broad generalities but not including any observable and enforceable metrics. A study of voluntary, industry-based codes of conduct in the Australian mineral and petroleum industries has described the potential for self-serving codes as follows:[13]

> "The most commonly stated purpose of voluntary codes of conduct is the improvement of environmental and social performance. For example, both the voluntary frameworks compared below include improving performance in their statements of purpose. However, research has indicated that the underlying purpose of adopting voluntary codes of conduct is centered on the improvement of corporate image rather than performance."

Broadening participation

If a code of conduct is to be fully effective, and not serve narrow interests, one of its essential features should be the participation of a broad range of stakeholders. For the code under discussion here, the participating stakeholders for each country of application would ideally include:

- The consumer-country government at the national, provincial, and local levels, including legislative and executive branches of government;
- Civil society of the consumer country, represented by a range of NGOs and associations, especially those working for sustainability;

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[11] IAEA, 2004.
[12] IAEA, "The Code of Conduct on the Safety of Research Reactors", accessed from the IAEA website, http://www.iaea.org/NewsCenter/Features/ResearchReactors/conduct.html, on 8 April 2010.
[13] Sarker and Gotzman, 2009, page 6.

- Academia and professional societies of the consumer country;
- Small and large businesses in the consumer country, represented by associations;
- Similar stakeholders in neighboring countries that could be affected by an NPP in the consumer country;
- Potential vendors of NPP technology and services to the consumer country; and
- Governments of countries where major vendors are based.

Making a code of conduct operational

If a code of conduct is to go beyond mere rhetoric, and become operational, four major conditions should be satisfied. First, the code should apply to specific, observable actions, and not be phrased in generalities. Second, the provisions of the code for each specified action should be accompanied by metrics to predict or determine the extent of compliance with the code. Third, there should be a credible process of observation using those metrics. Fourth, the code should be enforceable in the sense that non-compliance results in significant consequences for the offending party.

This report does not provide text for a code of conduct. As a step toward that outcome, the report discusses ten issue areas for a code of conduct, and outlines a process for constructing a code that accounts for each issue area. The purpose of the resulting code would be to determine, to the satisfaction of participating stakeholders, if transfer of NPP technology to a consumer country is appropriate under some set of achievable conditions. As a practical matter, the code would apply to the construction of one or more Generation III NPPs, employing LWRs or CANDU reactors, in a particular consumer country. The conditions under which that construction might be appropriate include the characteristics of plant sites, the choice of plant type and vendor, regulatory arrangements, host-country policy for management of radioactive waste, and other factors. In determining the appropriateness of constructing NPPs, the participating stakeholders would necessarily consider alternative options for supplying electricity or the services that electricity can enable.

In order to make the determination outlined in the preceding paragraph, participating stakeholders would have to be provided with a body of well-structured information. Some of that information would be of the type that may now be provided in an environmental impact statement (EIS). In the United States, NEPA requires NRC to prepare an EIS as part of the licensing process for an NPP, and many other countries have similar requirements. Any EIS prepared under NEPA must consider a proposed project and a set of alternative options. In practice, the quality of NPP-related EISs – measured by indicators such as scope, completeness, objectivity, and openness – varies considerably within the United States and, to an even greater extent, around the world.

As mentioned above, this report discusses ten issue areas for a code of conduct. In each issue area, the discussion concludes by addressing two questions. First, what are the major concerns in this issue area? Second, by what mechanisms could participating stakeholders obtain detailed information about these concerns, and about the implications of alternative pathways of action? In some instances, a well-conducted EIS could provide the needed information. In other instances, additional analyses would be required.

II.2 Sustainability, the Precautionary Principle, and Nuclear Power

NPPs are large units of capital investment with long life cycles. Planning and construction of an NPP could occupy a decade, the plant could operate for six or more decades, its decommissioning would occupy additional decades, and the radioactive wastes it creates would need to be sequestered for hundreds of millennia. Also, operation of an NPP causes a range of significant impacts on the environment and society. Thus, transfer of NPP technology to a consumer country should be considered within a broad, long-term context. The concept of sustainability can make a major contribution to framing that context. Note from Appendix A that WNA makes sustainability a central principle in its Charter of Ethics.

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.[14] 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”.[15] 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.[16]

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.[17] 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.

[14] IPCC, 2007.
[15] MEA, 2005, page 1.
[16] GAO, 2007.
[17] Campbell et al, 2007.

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).[18] 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 (WCED) in 1987.[19] 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.[20]

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”. NEA 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.

According to 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

[18] Raskin et al, 2002.
[19] WCED, 1987.
[20] NEA, 2000.

emissions of CO_2 to the atmosphere cannot be eliminated instantly, but must be reduced over time. With the best of intentions, we cannot pass on to coming generations an atmosphere containing CO_2 at its "natural" 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 CO_2 and other greenhouse gases. The 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.

Unplanned releases, and diversion of material

One topic addressed in the NEA report was the potential for a nuclear power plant 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. Note that an unplanned release could be caused by an accident or by deliberate, malevolent action.

Another type of unplanned incident at a nuclear power plant would be the diversion of fissile or radioactive material from the plant, for use in nuclear or radiological weapons. Given that the incident is assumed to be unplanned, it would not be the result of deliberate action by the host government. Thus, the diversion would be performed by a sub-national group. If the diverted material were used in a nuclear or radiological weapon, the outcomes could include significant, adverse effects on sustainability.

A different but related type of incident would be a planned diversion of fissile or radioactive material by the host government. In considering planned diversion, this report focuses on diversion of fissile material that could be used in nuclear weapons. Such a diversion would be a breach of the government's obligations under the NPT, or would occur after the host country had withdrawn from the NPT. The potential for such a diversion is an issue of nuclear-weapon proliferation.

The potential for an unplanned release of radioactive material, or for an unplanned diversion of fissile or radioactive material, is discussed in more detail in Section III.2 of this report. The potential for a planned diversion of fissile material is discussed further in Section III.3.

The precautionary principle

The preceding discussion addresses two potential adverse outcomes of operating a nuclear power plant – an unplanned release of radioactive material, or 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 sustainability. In a policy or planning context, policy makers and other stakeholders must grapple with such conjunctions of uncertainty and significance. The precautionary principle offers guidance in these situations. This principle has been much discussed, and is incorporated in laws and regulations in a number of countries.

Consider, for example, the Canadian Environmental Assessment Act of 1992. In that Act, the concept of precaution appears twice in the Purposes section.[21] 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 simultaneously promote principles of sustainability and of precaution. That general commitment has been applied to specific cases by panels convened under the Act.[22]

In 2007, the Canadian government issued a Cabinet Directive on Streamlining Regulation.[23] 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 construction and operation of a nuclear power plant, if the design or mode of operation 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 construction, even though the potential for harm could not be characterized with full scientific certainty as to consequences and probability.

[21] Justice Department, 2007.
[22] Gibson, 2000.
[23] Government of Canada, 2007.

Efforts to address sustainability issues in NPP design

During the past four decades, there have been sporadic efforts to address sustainability issues while developing designs for new nuclear power plants. Persons involved in those efforts did not, until recently, employ the language of sustainability. A conceptual progression over time is evident, but that progression has not arrived at designs that reflect a comprehensive framework of sustainability principles. The primary focus of attention has been on designs that are intended reduce the risk of an unplanned release of radioactive material. Some designs of this type are discussed in Appendix B to this report. Note that those designs have typically been developed only to a conceptual level, and none has been constructed. Also, the world's present fleet of nuclear power plants, and the Generation III plants that are currently being offered, do not employ those design concepts to any significant extent.

During the past decade, proponents of a nuclear power renaissance have begun to use the language of sustainability, especially in connection with proposed Generation IV reactors and fuel cycles. Those proponents argue that use of fast-spectrum reactors and closed fuel cycles could extend the life of uranium reserves, allow the use of thorium as a fuel, and reduce the amount of radioactive waste that would be sent for disposal. The reactors could have passive-safety features and be refueled at long intervals by removing and replacing a "cassette" of fuel, thus avoiding onsite access to fuel. Fission heat could be used to produce electricity, hydrogen, process heat, and/or potable water.[24]

As discussed in Section II.3, below, the proposed Generation IV reactors would push against engineering limits in a variety of respects. Linking those reactors to a closed fuel cycle would add another level of technical difficulty. Costs are almost impossible to predict. The overall strategy assumes major technological advance across several fronts, an implementation plan that unfolds over a century or longer, strong centralized control by national governments and supra-national entities, and public acceptability of those actions. The feasibility of that strategy, and its contribution to sustainability, are questionable. Nevertheless, the European Commission's Directorate-General for Research offers that strategy as a long-term, sustainable future for nuclear power. In the Directorate-General's vision, Generation IV systems would be developed over the next several decades. During that period, Generation III reactors would be constructed as an interim source of electricity. The Directorate-General concedes that the Generation III reactors would not meet sustainability criteria.[25]

A broader view of sustainability

Since WCED introduced the concept of sustainable development in 1987, research and practical experience have led to a deeper understanding of the imperatives and principles

[24] See, for example: Wade, 2000.
[25] European Commission, 2007.

of sustainability. It is now recognized that sustainability involves a range of considerations, including the flexibility and resilience of engineered, natural, and social systems.[26] The precautionary principle has become part of the sustainability paradigm.

Engineers who seek to implement the sustainability paradigm in practical situations typically view the pursuit of sustainability as a multi-objective optimization problem.[27] To address such a problem, analysts must identify system boundaries, seek an understanding of the dynamic behaviors and interactions of the relevant systems, articulate a framework of indicators and criteria, and apply a process of optimization. Nuclear power has not yet been subjected to such an analysis. A group at the University of Manchester has begun that task. According to their funding agency, “it is far from clear how sustainable the nuclear option is overall, compared to other generating options”.[28]

Various authors have articulated indicators and criteria whereby engineered systems can be designed in a more sustainable manner. For example, Anastas and Zimmerman have set forth twelve principles of "green" engineering.[29] Those principles are summarized in Table II-1. Another group of authors has set forth twelve principles of “green” industrial chemistry.[30] Those two sets of principles provide some guidance for assessing the sustainability of nuclear power.

II.3 Trends in Nuclear Power

Construction of new nuclear power plants in consumer countries should be viewed in the context of worldwide trends in the use of nuclear power. Worldwide trends will largely determine the types of plant that are available, the economics of the nuclear fuel cycle, standards for safety and security of nuclear facilities, public acceptability of nuclear power, and other factors. At present, trends related to nuclear power are unclear, and there are widely varying views about the merits and prospects of this energy source.

From a global perspective, nuclear power is in a transitional phase. Annual, worldwide capacity additions peaked in 1985 and have been modest since 1990.[31] If construction of NPPs does not resume, total capacity will decline as plants are retired. Observers view this situation in widely differing ways. Some call for a 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.

[26] Homer-Dixon, 2007.
[27] Sahely et al, 2005.
[28] EPSRC, 2007.
[29] Anastas and Zimmerman, 2003.
[30] Poliakoff et al, 2002.
[31] IAEA, 2006.

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.[32] 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.[33] 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.[34] Some argue that nuclear power can and should be phased out, even during an effort to dramatically reduce greenhouse gas emissions from electricity generation.[35] Others argue that scenarios for expansion of nuclear capacity are implausible, and that the role of nuclear power will continue to decline.[36]

III. Issue Areas for a Code of Conduct

III.1 Planned Impacts on Humans, the Environment, and Natural Resources

Section II.2, above, discusses the potential for a nuclear power plant to experience a significant, unplanned incident. Two types of incident in that category are discussed – an unplanned release of radioactive material, and a diversion of fissile or radioactive material. In addition, an NPP, like many types of industrial facility, has "planned" impacts on humans, the surrounding environment, and natural resources. These impacts are planned in the sense that they are expected, routine by-products of facility operation.

As mentioned above, an EIS must be prepared as part of the licensing process for a new NPP in the United States, and many other countries have similar requirements. A well-conducted EIS provides an opportunity to systematically examine a plant's planned and unplanned impacts. Unplanned impacts can be examined using the concept of "risk", as discussed in Section III.2, below. Within the framework of an EIS, it is possible to

[32] NERAC/GIF, 2002.
[33] Ansolabehere et al, 2003.
[34] Romm, 2008.
[35] Makhijani, 2007; Greenpeace International, 2007.
[36] Schneider and Froggatt, 2007; Schneider et al, 2009; Findlay, 2010.

compare the benefits of operating an NPP with the costs (which include adverse impacts, planned and unplanned).

Comparing nuclear and coal plants

In considering planned and unplanned impacts, it is useful to compare an NPP with a conventional, coal-fired power plant. These facilities are similar in some ways and significantly different in others. Consider some similarities. First, both the NPP and the coal plant are inefficient in converting thermal energy to electricity. Thus, they must dissipate large amounts of waste heat to the environment while operating. The waste heat is conveyed directly to a lake, a river, or the ocean, or to the atmosphere via wet or dry cooling towers. Also, a plant of either type represents a large stock of embodied energy and materials, in forms such as concrete and steel. Finally, both plants are part of a fuel cycle that begins by mining raw material (uranium or coal) and requires the disposal of streams of waste.

One major difference is that the nuclear plant creates in its reactor core a large amount of radioactive material. As a result, the nuclear plant could have unplanned impacts of great severity, and its waste remains hazardous for many millennia. A second difference is that the nuclear plant creates fissile material (plutonium) that could be used in nuclear weapons. A third difference is that greenhouse gas emissions, summed across the fuel cycle, are significantly greater for the coal plant (per kWh of electricity generation).

Long-term management of radioactive waste

The spent fuel discharged from an NPP contains radioactive material that remains hazardous for hundreds of millennia. If the spent fuel is reprocessed, its radioactive inventory does not disappear, but simply changes form. Nuclear power programs around the world proceed on the explicit or implicit assumption that the radioactive waste they produce will eventually be placed in repositories. Yet, no repository exists, other than for comparatively minor streams of low-level waste. In the United States, for example, the federal government has been attempting for half a century to open a repository. This effort has failed for an array of social and technical reasons.[37] The Yucca Mountain repository project has been cancelled.

In the absence of a repository, stocks of spent nuclear fuel and high-level waste from reprocessing are accumulating around the world. This accumulation is, from one perspective, a planned activity. It is planned in the sense that it is a predictable accompaniment to operating NPPs. From that viewpoint, the general impacts of long-term management of radioactive waste might be regarded as planned impacts. (Accidents or attacks affecting this waste would yield unplanned impacts.) From another perspective, however, the continuing accumulation of radioactive waste is an unplanned

[37] Thompson, 2008b.

activity, because there is no proven method for long-term management of the waste. The contrast between these perspectives reflects an unresolved issue in societal ethics.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the planned impacts from an NPP include:

- Impacts similar to those of a coal plant, including the dissipation of waste heat;
- Net energy and materials balance of the NPP over its lifetime, accounting for the complete nuclear fuel cycle;
- Net emissions of greenhouse gases associated with the NPP over its lifetime, accounting for the complete nuclear fuel cycle;
- Special impacts related to long-term management of radioactive waste from the NPP; and
- Releases of radioactive material, radiation exposures, and resulting adverse health effects associated with the NPP over its lifetime, accounting for the complete nuclear fuel cycle.

A well-conducted EIS could provide considerable information to stakeholders regarding the above-stated concerns. This information could be provided for several possible configurations and sites of a potential NPP, and analogous information could be provided for alternatives to an NPP. To date, EISs have typically not examined net energy and materials balances and net greenhouse gas emissions, although these are important indicators of sustainability. That omission represents a regrettable delay – which should be promptly rectified – in the response of regulatory agencies to the imperatives of sustainability. There is a technical literature on these matters, although that literature is weak in regard to net materials balances.[38] There has been controversy over estimation of net energy balances and greenhouse gas emissions. Such controversy could be largely resolved through studies conducted according to the principles of science.

Planned releases of radioactive material, radiation exposures, and resulting adverse health effects are subjects that are examined in many EISs. In many instances, however, EISs fail to examine these subjects across the complete nuclear fuel cycle. Such a full examination would, for example, analyze long-term leakage from radioactive waste repositories.[39] Another important point about radiological questions is that, after decades of study, there remains substantial scientific uncertainty about the magnitudes and causes of radiation-induced health effects. Consider, for example, a recent German study (the KiKK study) that shows increased incidence of childhood leukemia with proximity to NPPs.[40]

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[38] For example, see: World Nuclear Association, "Energy Balances and CO2 Implications", accessed from the WNA website, http://www.world-nuclear.org/info/inf100.html, on 29 April 2010.
[39] National Research Council, 1983.
[40] Nussbaum, 2009; Fairlie, 2009.

The impacts related to long-term management of radioactive waste pose a special challenge to authors of a code of conduct. Continued accumulation of this waste, in the absence of a repository, poses an unresolved question of societal ethics.

III.2 Risk of Unplanned Impacts on Humans, the Environment, and Natural Resources

As explained above, operation of an NPP creates the potential for an unplanned release of radioactive material, or for an unplanned diversion of fissile or radioactive material by a sub-national group. Incidents in those categories could result in significant, adverse impacts on humans, the environment, and natural resources. The risk of such unplanned impacts is addressed here. The potential for a planned diversion of fissile material by the host government is addressed in Section III.3, below.

A large, unplanned release or a substantial diversion would be a high-impact, low-probability incident. Analysts in the nuclear industry and its regulatory bodies address such incidents by defining an indicator called "risk". They typically define that indicator as the arithmetic product of a numerical indicator of impacts and a numerical indicator of probability. Given that definition, they frequently argue that equal levels of risk should be equally acceptable to citizens. That argument is not, however, a scientific statement. It is, instead, a statement representing a particular set of values and interests. In this report, a broader definition of risk is used.[41]

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 impacts of potential releases. The first PRA for a nuclear power plant was known as the Reactor Safety Study, and was published by NRC in 1975.[42] A PRA for a nuclear power plant 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. For example, NRC adapted PRA techniques in developing its 1994 rule requiring protection of a nuclear power plant against attack using a vehicle bomb.[43]

[41] In this report, the term "risk" is used to encompass a range of qualitative and quantitative information about the potential for an adverse outcome.
[42] NRC, 1975.
[43] NRC, 1994.

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.[44] By contrast, during an intentional attack on a nuclear power plant, 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.

It should be noted that a substantial release of radioactive material could originate not only in the reactor core of an NPP, but in parts of the plant where spent fuel is stored. This possibility is of particular concern at LWR plants where a large amount of spent fuel is stored under water in a pool adjacent to the reactor but outside the reactor containment. That mode of storage applies at all LWR plants in the United States and most LWR plants worldwide. The pools typically 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 determined 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.[45] The resulting fire could spread to adjacent fuel assemblies and propagate across the pool. Extinguishing the fire, once it had been initiated, could be difficult or impossible. Spraying water on the fire could feed an exothermic reaction between steam and zirconium. The fire could release a large amount of radioactive material to the atmosphere, including tens of percent of the pool's inventory of Cesium-137. In that event, 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.[46]

[44] In some core-damage accidents, a common cause – such as a powerful earthquake – would simultaneously overcome a number of safety features. An earthquake and the following tsunami had this effect at the Fukushima Dai-ichi NPP site in Japan in March 2011.

[45] It is evident that spontaneous ignition of fuel cladding occurred in the spent-fuel pool of the Unit 4 NPP at the Fukushima Dai-ichi site following the March 2011 earthquake and tsunami. Ignition is evident because a damaging hydrogen explosion occurred in the Unit 4 reactor building, and the amount of hydrogen required to cause this damage could only have come from the burning of fuel cladding, in a steam atmosphere, within the pool. See, for example: JAIF, 2011. Details about spent-fuel damage at this site are not available at the time of writing. A factor that may have reduced the propensity for spent-fuel damage at NPPs at this site, in comparison to the propensity at similar NPPs in the United States, is that each reactor-adjacent pool at Units 1-6 at Fukushima Dai-ichi contained, on average, less than one-third of the amount of spent fuel that is now stored in similar pools at NPPs in the United States. See: Thompson, 2006; Kumano, 2010.

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

Vulnerability of NPPs to malevolent acts

To date, there has been no significant release of radioactive material at a nuclear power plant as a result of a malevolent act. Nevertheless, there is a history of malevolent and violent acts related to nuclear reactors around the world.[47] Consider some examples. NPPs under construction in Iran were repeatedly bombed from the air by Iraq in the period 1984 to 1987. Yugoslav Air Force fighters made a threatening overpass of the Krsko NPP in Slovenia – which was operating at the time – a few days after Slovenia declared independence in 1991. Reactors in Iraq – whose nominal purpose was research – were destroyed by aerial bombing by Israel in 1981 and by the United States in 1991. In 1987, Iranian radio threatened an attack by unspecified means on US nuclear power plants if the United States attacked launch sites for Iran's Silkworm anti-ship missiles. Bombs damaged nuclear power plants under construction in Spain in 1977 and in South Africa in 1982. Anti-tank missiles struck a plant under construction in France in 1982. North Korean commandos were killed while attempting to come ashore near a South Korean plant in 1985. In 2007, Israel destroyed by aerial bombing a reactor that was being clandestinely constructed in Syria – presumably for production of plutonium for nuclear weapons. These and other events illustrate the external-actor threat to nuclear power plants. Numerous crimes and acts of sabotage by plant personnel illustrate the "insider" threat. Finally, the aerial attacks on buildings in New York and Washington on 11 September 2001 demonstrated that an attack on a civilian facility by a skilled, highly motivated, and well-resourced sub-national group is a credible incident.

Table III-1 describes some potential modes and instruments of attack on a nuclear power plant, and also describes the defenses that are now provided at US plants. There is no defense against a range of credible attacks. Defenses at NPPs around the world are typically no more robust than at US plants. Among the instruments of attack mentioned in Table III-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 III-2 provides some general information about shaped charges and their capabilities. That table does not provide any technical information that would assist an attacker. Unfortunately, however, withholding technical information does not remove the threat. Expertise in the design and use of shaped charges is widely available around the world. Arms manufacturers are actively developing tandem warheads that employ shaped charges. For example, in January 2008 Raytheon successfully tested the shaped-

[47] Thompson, 1996.

charge penetrating stage for its Tandem Warhead System.[48] The shaped charge penetrated 19 feet (5.8 m) into steel-reinforced concrete with a compressive strength of 12,600 psi.

There is considerable evidence that each of the existing (Generation II) NPPs and the proposed Generation III plants could experience a substantial release of radioactive material as a result of a credible malevolent act.[49] This vulnerability does not reflect a lack of design options. Nuclear engineers have always been able to design plants that are much more robust than the present and proposed plants. In illustration, nuclear reactors used for naval propulsion are designed to ride out battle shock. Appendix B shows that designs for attack-resistant NPPs have been considered within the commercial nuclear industry. Yet, the industry has not adopted such designs, and regulators such as NRC have accepted that decision.

Estimating the probabilities and impacts of unplanned releases

PRAs for nuclear power plants 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 impacts, and the uncertainty and variability of those indicators. Typically, PRAs focus on atmospheric releases originating in the reactor core. The adverse impacts of such releases at downwind locations 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 damage to the reactor core 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 core-damage probability.

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 core-damage sequences. The findings would be expressed in terms of a group of release

[48] Raytheon, 2008.
[49] Thompson, 2007; Thompson, 2008a.

categories characterized by magnitude, probability, timing, isotopic composition, and other characteristics.

Third, a Level 3 PRA analysis would be performed, to yield the 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 impacts of the released material would be estimated, accounting for the material's distribution in the biosphere. As mentioned above, the impacts would include adverse health effects and socio-economic impacts.

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.[50] PRA findings rely on numerous assumptions and judgments. There is no certainty that all of the relevant factors are captured. Findings of very low probability cannot be validated by direct experience.[51] Moreover, a PRA cannot estimate the probabilities of malevolent acts, because there is no statistical basis for doing so. A PRA that considered malevolent acts would have to postulate the occurrence of a set of such acts and then estimate their impacts, accounting for variable factors such as wind speed and direction.

NUREG-1150

The high point of PRA practice worldwide was reached in 1990 with publication by NRC of its NUREG-1150 study, which examined five different US nuclear power plants using a common methodology.[52] 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.

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[50] Hirsch et al, 1989.

[51] Prior to March 2011 there had 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). At the Fukushima Dai-ichi site, an earthquake and tsunami in March 2011 caused accidents leading to core damage at three NPPs (Units 1-3) and spent-fuel damage at the Unit 4 NPP and, potentially, at Units 1-3 as well. See: JAIF, 2011. The magnitude of the radioactive release at Fukushima is unclear at the time of writing, but may have been a substantial fraction of the magnitude of the Chernobyl release.

[52] NRC, 1990.

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, recent PRA findings have limited credibility.

Figures III-1 through III-3 show some findings from the NUREG-1150 study that are relevant to this report. The findings are for a PWR plant at the Surry site, and a BWR plant at the Peach Bottom site. Those plants typify many of the Generation II plants in the present worldwide fleet of nuclear power plants.

In viewing Figures III-1 and III-2, it should be noted that NUREG-1150 itself warns that estimated core-damage probabilities lower than 1 per 100,000 reactor-year (RY) should be viewed with caution because of limitations in PRA. There is much evidence to support that warning.[53] Indeed, a core-damage probability estimate of 1 per 100,000 RY is already an order of magnitude lower than can be directly validated by operating experience.[54]

[53] Hirsch et al, 1989.
[54] NPPs worldwide accumulated about 14,000 RY of operating experience through April 2010. See: WNA website, http://www.world-nuclear.org/, accessed on 29 April 2010.

The potential for a diversion of material

Most of the radioactive material at an NPP is contained within the reactor core and within spent fuel stored at the plant. The remainder is contained within systems used to maintain the purity of the plant's cooling water, or to filter gaseous or liquid effluents. All of the fissile material at the plant is contained within reactor fuel – fresh, spent, or in the reactor core. The greatest concern about diversion is that spent fuel will be diverted, because spent fuel contains plutonium and a large quantity of radioactive material. These constituents could be chemically separated from spent fuel and used in nuclear weapons or radiological weapons (dirty bombs). Alternatively, an intact spent fuel assembly or fuel rod could be combined with explosives to make a radiological weapon.

As discussed in Section III.3, below, types of NPP vary in their vulnerability to diversion of spent fuel. NPPs employing CANDU reactors are significantly more vulnerable in this respect than are plants employing LWRs. Note, however, that diversion of spent fuel from a CANDU plant would be a difficult task for a sub-national group unless plant security had become degraded.

The radioactive inventory available for release or diversion

At an NPP, the reactor core and stored spent fuel assemblies contain a variety of radioactive isotopes.[55] One isotope, namely Cesium-137, is especially useful as an indicator of the potential for radiological harm. Cesium-137 is a radioactive isotope with a half-life of 30 years. This isotope accounts for most of the offsite radiation exposure that is attributable to the 1986 Chernobyl reactor accident, and for about half of the radiation exposure that is attributable to fallout from the testing of nuclear weapons in the atmosphere.[56] Cesium is a volatile element that would be liberally released during accidents or attack scenarios that involve overheating of nuclear fuel.

Table III-3 shows estimated inventories of Cesium-137 in the reactor cores of three types of Generation III nuclear power plants. The ACR-1000 plant is a CANDU, while the US-EPR and AP1000 plants are LWRs. Cesium-137 would, in the event of a large unplanned release from a reactor core to the atmosphere, dominate the lifetime radiation dose that exposed persons would receive due to contamination of land, buildings, vegetation and water. Also shown in Table III-3 are estimated core inventories of Iodine-131 for the same three plants. Iodine-131 represents a category of comparatively short-

[55] In an operating reactor, an active fuel assembly contains radioactive isotopes with half-lives ranging from seconds to millennia. After the reactor is shut down or a fuel assembly becomes spent (i.e., it is discharged from the reactor), the assembly's inventory of each isotope declines at a rate determined by the isotope's half-life. Thus, an atmospheric release from an operating reactor would contain short- and longer-lived isotopes, while a release from a spent-fuel-storage facility would contain only longer-lived isotopes. That difference has implications for the environmental impacts of a release, and for the emergency response that would be appropriate.
[56] DOE, 1987.

lived radio-isotopes that would dominate the decay heat produced in a reactor core during the first several days after reactor shut-down, and that would dominate the radiation dose that persons exposed offsite would receive during that period if an unplanned release to the atmosphere were to occur.

As an indication of the radioactive inventory of stored spent fuel, consider the two NPPs now operating at the Indian Point site near New York City. Each plant has an adjacent spent-fuel pool that is nearly full. A facility for dry storage of spent fuel is being established on the site to accommodate additional spent fuel. Each spent-fuel pool contains about 2,500 PBq of Cesium-137, and one dry-storage module will contain about 48 PBq of Cesium-137.[57]

For comparison with these quantities, note that the 1986 Chernobyl reactor accident released to the atmosphere about 90 PBq of Cesium-137. Also, atmospheric testing of nuclear weapons, mostly in the 1950s and 1960s, released about 740 PBq of Cesium-137.[58] Detonation of a 10-kilotonne-yield fission weapon would release about 0.07 PBq of Cesium-137.[59]

The amount of radioactive material available for release or diversion from an NPP far exceeds the amount that is of concern in the context of a radiological weapon. Consider, for example, a study sponsored by Defence Research and Development Canada that estimated the economic impact of an open-air explosion of a radiological dispersal device (dirty bomb) at the CN Tower in Toronto.[60] The assumed release consisted of 37 TBq (0.037 PBq) 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 500 mrem (5 mSv) per year, the estimated economic impact would be $28 billion, whereas for a cleanup standard of 15 mrem (0.15 mSv) per year the impact would be $250 billion. The magnitudes of those impacts are interesting, considering that the assumed release (0.037 PBq of Cesium-137) is a tiny fraction of the release that could occur from a nuclear power plant (hundreds of PBq of Cesium-137).

Concerns in this issue area, and mechanisms for obtaining information

The preceding discussion of unplanned impacts has identified various types and causes of unplanned incidents that could result in significant, adverse impacts. Table III-4 provides an overall classification of such incidents. Across that spectrum of potential incidents, major concerns regarding unplanned impacts from an NPP include:

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[57] Thompson, 2007, Table 2-1.
[58] The fallout from atmospheric testing of nuclear weapons was widely distributed across the planet, mostly in the Northern hemisphere. By contrast, an atmospheric release from a nuclear power plant would typically create a concentrated plume that would travel downwind at a comparatively low altitude.
[59] Thompson, 2007, Table 2-2.
[60] Cousins and Reichmuth, 2007.

- Potential adverse impacts from accidental releases from the NPP, and the probabilities of those impacts;
- Potential adverse impacts from malevolence-induced releases from the NPP, and factors affecting the probabilities of those impacts; and
- Potential adverse impacts from malevolent diversion of fissile or radioactive material from the NPP (with special attention to spent fuel), and factors affecting the probabilities of those impacts.

An expanded-scope EIS could provide useful information to stakeholders regarding the above-stated concerns. This information could be provided for several possible configurations and sites of a potential NPP. A Level 3 PRA could provide the necessary information related to accidental releases, as has been done in a number of EISs. For malevolence-induced releases, a modified PRA analysis could be employed, involving the postulation of a set of malevolent acts. There is some experience in using such an analysis. A similar approach could be taken in examining the potential impacts of diversion.

III.3 Implications for Proliferation of Nuclear Weapons

This report assumes that a consumer country would be a party to the NPT. Thus, the country would have formally agreed to refrain from using its capability in nuclear technology to construct nuclear weapons. Nevertheless, it is widely acknowledged that a country might breach its obligations under the NPT, or might withdraw from the NPT, in order to construct nuclear weapons. For example, there is fear that Iran might accumulate a stock of highly-enriched uranium (HEU) while remaining a party to the NPT, and then withdraw from the NPT and use the HEU in nuclear weapons.

Any nuclear activity in a country could, to some degree, contribute to the country's ultimate achievement of a capability to construct nuclear weapons. The crucial ingredient, however, is fissile material – HEU, or plutonium. Thus, concern about proliferation of nuclear weapons focuses especially on two technologies. Uranium enrichment technology can be used to make HEU. Reprocessing technology can separate plutonium from the spent fuel discharged from a reactor. The availability of these technologies has been a prominent subject on diplomatic agendas for decades. In illustration, the IAEA Director General stated to the UN Security Council in September 2009:[61]

> "A second issue [of nuclear non-proliferation] is the growing number of states that have mastered uranium enrichment or plutonium reprocessing. Any one of these states could develop nuclear weapons in a short span of time, if, for example, it decided to withdraw from the NPT. To address this, I believe that we need to move from national to multinational control of the nuclear fuel cycle. As a first step, I have proposed the establishment of a low enriched uranium bank to

[61] ElBaradei, 2009.

> assure states a guaranteed supply of nuclear fuel for their reactors so that they might not need their own enrichment or reprocessing capability. A number of complementary proposals have also been made."

This report assumes that a consumer country would typically not possess or seek the acquisition of a uranium enrichment facility or a reprocessing facility during the time period covered by a code of conduct for transfer of NPP technology. That assumption would apply to any version of the code that is worth the trouble of negotiating. Also, any worthwhile code of conduct would specify that the consumer country would subscribe to Additional Protocols to its safeguards agreements with the IAEA, as a precondition for receiving NPP technology. IAEA describes an Additional Protocol as follows:[62]

> "The Additional Protocol is a legal document granting the IAEA complementary inspection authority to that provided in underlying safeguards agreements. A principal aim is to enable the IAEA inspectorate to provide assurance about both declared and possible undeclared activities. Under the Protocol, the IAEA is granted expanded rights of access to information and sites."

A consumer country might accept these provisions but decide, at a later time, to breach its agreements and acquire fissile material for actual or potential use in nuclear weapons. A logical route for a country adopting that course of action would be to separate plutonium from spent fuel discharged from NPPs within the country. A spent-fuel reprocessing facility designed for that purpose could be considerably smaller, simpler, and cheaper than a commercial reprocessing facility.

A code of conduct for transfer of NPP technology should address the potential for this outcome. The potential derives, in part, from NPP design features. Spent fuel could be diverted to weapons use from some types of NPP with comparative ease. Heavy-water reactors (HWRs) such as the CANDU design are in this category, because they employ on-line refueling and natural-uranium fuel.

At a reactor employing on-line refueling, prevention of diversion of spent fuel must rely heavily on administrative measures. By contrast, LWRs undergo batch refueling at intervals of one or more years. Thus, diversion of spent fuel from an LWR plant is comparatively difficult. Also, a reactor employing on-line refueling is well suited to making plutonium with an isotopic composition (rich in Plutonium-239) that allows the plutonium to be used in a nuclear weapon of comparatively crude design.

Reactors that employ enriched-uranium fuel, such as LWRs, depend upon access to uranium enrichment services. By contrast, reactors using natural-uranium fuel, such as

[62] IAEA, "IAEA Safeguards Overview: Comprehensive Safeguards Agreements and Additional Protocols", accessed from the IAEA website, http://www.iaea.org/Publications/Factsheets/English/sg_overview.html, on 28 April 2010.

CANDU reactors, are not dependent in that manner.[63] For a country possessing indigenous uranium deposits, CANDU reactors offer the prospect of an entirely indigenous nuclear fuel cycle without enrichment. If indigenous uranium is not available, it can be obtained from many sources.

Historically, CANDU reactors and other HWRs have contributed significantly to actual and threatened proliferation of nuclear weapons. A concise summary of that contribution was provided by David Fischer and Paul Szasz, both former IAEA officials, writing in 1985:[64]

> "The proliferation record of the CANDU power reactor and of the large Canadian research reactor (also an HWR but somewhat differently designed) is much worse than that of the much more numerous and widespread LWR. An unsafeguarded Canadian research HWR reactor produced the plutonium for India's 1974 nuclear explosion; a safeguarded CANDU power reactor might be the source of spent fuel for Pakistan's pilot reprocessing plant. A safeguarded CANDU power reactor and a Canadian research HWR would probably have served the same purpose in the Republic of Korea and Taiwan respectively, had the United States not forcefully intervened and persuaded both countries to abandon their reprocessing plans. Both countries (parties to the NPT) still operate these reactors. A safeguarded CANDU or a West German-supplied natural uranium/heavy water power reactor will probably serve as the source of spent fuel for the Argentine reprocessing plant. In the case of Israel an unsafeguarded French natural uranium-fuelled and heavy water moderated reactor also served as the source of unsafeguarded plutonium.
>
> In short, four of the five NNWS operating unsafeguarded 'sensitive' plants (Argentina, India, Israel and Pakistan) – including, in each case, one or more reprocessing plants – have incorporated HWRs, which can easily produce weapon-usable plutonium, in their nuclear structures. Two NPT NNWS (the Republic of Korea and Taiwan), in another region of political tension, have also done so."

Inventories of plutonium produced by NPPs

Nuclear power plants produce large amounts of plutonium, contained within their spent fuel. As shown in Table III-5, it has been estimated that NPPs worldwide would produce about 2.1 million kg of plutonium through 2010.

For comparison with the quantities shown in Table III-5, note that the critical mass of a bare sphere of plutonium (pure Plutonium-239, alpha-phase) is about 10 kg. The radius of that sphere would be about 5 cm. With addition of a natural uranium reflector about

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[63] A proposed CANDU reactor – the ACR-1000 – differs from its predecessors because, although it would employ on-line refueling, it would be fueled by low-enriched uranium instead of natural uranium.

[64] Fischer and Szasz, 1985, page 49.

10 cm thick, the critical mass would be reduced to about 4.4 kg, comprising a sphere with a radius of about 3.6 cm, the size of an orange. The critical mass could be further reduced using implosion techniques. An implosion device built to a modern design could achieve a nuclear explosion using 2 to 3 kg of plutonium.[65]

Nuclear warheads deployed by the nuclear-weapon states each contain, on average, about 3 to 4 kg of plutonium.[66] The world's inventory of military plutonium, at the end of 1994, was about 249,000 kg, mostly held by the former USSR and the USA. About 70,000 kg of that plutonium was in operational warheads.[67]

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the nuclear-weapon-proliferation implications of an NPP include:

- The potential for the NPP to contribute to proliferation of nuclear weapons, especially via separation of plutonium from spent fuel discharged from the NPP; and
- The effects of NPP design characteristics on that potential.

An appropriate mechanism for informing stakeholders about the above-stated concerns would be a proliferation-impact assessment for each NPP project. Such an assessment could be an adjunct to an EIS for the project.

III.4 Requirements and Implications for Governance

The breadth and complexity of the issues outlined in this report demonstrate the need for sophisticated governance in a country receiving NPP technology. If a country were to be a candidate to receive NPP technology under a code of conduct, the governance of the country would have to satisfy a range of requirements. Less obviously, however, the introduction of nuclear power into a country would, over time, alter the characteristics of governance in that country. Thus, national governance and a nuclear-power program would co-evolve, each influencing the other.

The NPT has minimal requirements directly related to governance within its State Parties. Article IV (1) states:

> "Nothing in this Treaty shall be interpreted as affecting the inalienable right of all the Parties to the Treaty to develop research, production and use of nuclear energy for peaceful purposes without discrimination and in conformity with articles I and II of this Treaty."

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[65] Barnaby, 1992.
[66] Albright et al, 1997, page 34.
[67] Albright et al, 1997, Table 14.2.

Other parts of the NPT modify the "inalienable right" of each party to receive commercial nuclear technology. For example, Article III obliges each party to accept IAEA safeguards. However, the NPT ignores many aspects of governance that could affect a country's fitness to receive nuclear technology. For example, the NPT is silent about a country's obligations to protect people and the environment against radiological harm. Other international agreements do address such matters to some extent. Nevertheless, as mentioned in Section I of this report, the international regime that applies to nuclear power has substantial deficiencies.

A country that is fit to receive NPP technology would have a stable government at political and administrative levels. It would have a stable body of law and an effective judicial system. It would possess sophisticated human resources across a range of disciplines. Using these and other assets, the country's government would meet a diverse set of responsibilities at two levels. Internationally, its responsibilities would address matters such as nuclear-weapon proliferation and trans-boundary pollution. Domestically, it would be responsible for serving its citizens, protecting them against a range of threats, preserving natural resources, etc. The country's governance structure would have to be durable enough to continue performing these functions for many decades.[68]

There is no generally agreed scorecard to determine a country's fitness in this respect. If such a scorecard were drawn up by an international group of experts, it might turn out that many countries now possessing NPP technology would not satisfy the criteria of the scorecard. Thus, as a practical matter, the determination of "fitness" is affected by history and entrenched power.

As mentioned above, a country's governance would co-evolve with its nuclear-power sector. Section III.8, below, describes a potential for this co-evolution to proceed in an adverse direction. Fear of attacks on commercial nuclear facilities could feed authoritarian tendencies in government, manifested by measures such as secrecy and surveillance of the population.

The preceding discussion is somewhat abstract. A fuller discussion of governance issues would be informed by relevant experience. Some of that experience is sordid. For example, a US vendor received a contract in the 1970s to build an NPP in the Philippines. The US Export-Import Bank (Eximbank) provided much of the financing. Later, it was reported that the vendor had bribed the Marcos dictatorship in order to receive the contract. The safety of the NPP design was not reviewed according to regulatory requirements that applied in the USA. The Philippine government did not require the preparation of an EIS. Eximbank showed little concern for the interests of the Philippine

[68] There is a limited discussion of NPP-related governance issues in: IAEA, 2007.

people.[69] Construction was completed, but the reactor never operated and the plant remains mothballed.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the requirements and implications for governance that relate to a country's acquisition of NPP technology include:

- Deficiencies in the international regime that applies to nuclear power, regarding governance issues; and
- The lack of a governance scorecard to assess a country's fitness to receive NPP technology.

One mechanism for providing stakeholders with information about these concerns would be studies that review relevant literature and experience. Another mechanism would be a consensus-seeking exercise among representatives of stakeholder groups, to test the feasibility of agreeing on: (i) a governance scorecard; and (ii) a credible process to complete that scorecard for each relevant country. If such consensus could be achieved, it would be appropriate to complete scorecards for all countries that possess or seek to acquire NPP technology. The findings could contain some surprises.

III.5 Implications for Land Use

Many people now recognize that land use is an important aspect of policy and planning in the energy sector. Fertile land is a finite natural resource that has been much abused, and there are competing demands for its use. Rising populations and expectations create increasing demands for the growth of plants as sources of food, fiber, or fuel. At the same time, concerns about planetary carbon management, biodiversity, and the protection of watersheds drive policies to protect forests and undeveloped land. Meanwhile, expansion of cities, roads, and other items of infrastructure creates further pressure on land use.

Given the importance of land use in sustainability, there is a surprisingly incomplete technical literature about land use in the context of energy systems. This literature is most highly developed in the context of biofuel crops and their implications for food crops, forest protection, etc.[70] In the context of nuclear power and competing sources of electricity, the literature is poorly developed. Consider, for example, a 2007 paper by Jesse Ausubel that compares land requirements for nuclear power and renewable sources of electricity.[71] In discussing the land required for wind farms, Ausubel fails to note that the footprint of each wind turbine is small, while the land between turbines can be used for other purposes. He also ignores the large potential for offshore wind farms.

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[69] Bello et al, 1979.
[70] See, for example: Melillo et al, 2009.
[71] Ausubel, 2007.

Similarly, in discussing the area needed for photovoltaic cells, he fails to note that rooftops are prime locations for these devices.

One function of a code of conduct for transfer of NPP technology could be to codify a systematic, consensus-based protocol for assessing land use by nuclear power, alternative sources of electricity, and alternative options for supplying the services enabled by electricity. In the case of nuclear power, factors to be considered would include:

- Direct land use for each NPP and associated parts of the nuclear fuel cycle;
- Land use for electricity transmission corridors;
- Implications of exclusion zones and emergency-response zones around NPPs;
- Implications for land use of the dissipation of waste heat from an NPP (e.g., down-river implications of dissipating waste heat to a river); and
- Potential effects on land use of an unplanned radioactive release from an NPP.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the land-use implications of an NPP include:

- An unmet need for a consensus-based protocol to assess land use by nuclear power, by alternative sources of electricity, and by alternative options for supplying the services enabled by electricity; and
- A lack of technical literature upon which to base that protocol.

One mechanism for providing stakeholders with information about these concerns would be a set of studies that review relevant literature, identify gaps in understanding, and conduct analyses to fill in those gaps. Subsequently, stakeholders could seek consensus on a protocol for assessing land use by energy systems.

III.6 Compatibility with the Country's Development Trajectory

Introduction of nuclear power into a country is a significant step in the country's economic and industrial development, especially if the country has a comparatively small population or is at an early stage of development. A large expansion of nuclear generating capacity in a country that already has some capacity would also be significant, but in a qualitatively different manner. Here, attention is focused on consumer countries that do not already have nuclear power.

If the acquisition of NPPs by such a country is contemplated, stakeholders need to understand if nuclear power is compatible with the optimal development trajectory of the country. IAEA has recognized this need, stating:[72]

> "If a State is considering the introduction of nuclear power, then it is essential that it develops a comprehensive strategy to assess energy needs, and understand the potential role, appropriateness, viability and commitments associated with nuclear energy in the context of plans for national and socioeconomic development."

IAEA frames this issue as a responsibility of the consumer country government (the State). Other observers argue that the responsibility should be more widely shared, because the consumer country government may lack the capability or inclination to fully recognize the implications of acquiring NPPs. The latter view underlies the concept of a code of conduct as discussed in this report. A London-based institute has framed the shared-responsibility viewpoint as follows:[73]

> "Leaving aside the proliferation and security questions for the moment, countries contemplating investing in nuclear energy generation for peaceful purposes need to ensure that they are fully informed of the facts concerning the complexity of nuclear energy's infrastructural requirements and the wider economic, domestic and development implications of the energy choices before them. Exporters of nuclear facilities for civilian electricity generation should be obliged by law to provide potential buyers – especially in developing states – with a full analysis of the electricity grid architecture, fuel supply arrangements, geological and waste implications, and other infrastructural requirements and changes relevant to that decision before any production contracts are signed."

The effects of NPP acquisition on a country's development trajectory would be direct and indirect. Direct effects would include the need to develop a capability to manage radioactive waste. Indirect effects might be more significant. Notably, nuclear power can be seen as representing a 20th century paradigm of electricity service, involving large generating plants and passive consumers. A new paradigm is emerging, involving dispersed, smaller generating units, greater emphasis on the efficiency with which electricity services are performed, and active load management through a smart grid. The two paradigms are in some respects antithetical. Thus, introduction of nuclear power might help to lock in an old electricity paradigm, depriving the country of the benefits of a new paradigm. Benefits of the new paradigm could include greater flexibility and resilience, steadily improving efficiency in delivery of electricity services, encouragement of innovation and entrepreneurship, and lower costs. Developing countries might embrace this new electricity paradigm in the way they have embraced mobile phones, avoiding the step of building out a landline network.

[72] IAEA, 2007, page 3.
[73] AIDD, 2010.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the compatibility of NPP acquisition with a country's optimal development trajectory include:

- The potential for NPP acquisition to adversely affect the country's development trajectory, especially by helping to lock in an obsolete electricity paradigm;
- The capability and inclination of the host-country government to recognize the implications of NPP acquisition; and
- The responsibilities of NPP vendors and other actors involved in the transfer of NPP technology.

One mechanism to inform stakeholders about these concerns would be a policy-setting exercise by the host government, articulating an explicit paradigm for development of the country's electricity sector. That exercise should involve facilitated consensus-seeking among relevant stakeholders. A second, subsequent mechanism to inform stakeholders would be an assessment of the compatibility of a proposed NPP acquisition with the country's electricity paradigm. NPP vendors should share the responsibility for conducting a thorough assessment. To be credible, both mechanisms would have to be implemented transparently and in consultation with a full range of stakeholders.

III.7 Flexibility and Resilience

Since WCED introduced the concept of sustainability in 1987, researchers and practitioners have gained a deeper understanding of its principles. They now recognize that sustainability involves a range of considerations, including the flexibility and resilience of engineered, natural, and social systems.[74]

The flexibility of a system is its ability to adjust to changing circumstances. After an adjustment, the system might return to performing its original functions. Alternatively, the system might perform additional or different functions. The resilience of a system is its ability to experience shocks and then return to its original configuration or be re-constituted in a different configuration. Clearly, there is overlap between the concepts of flexibility and resilience. Perhaps the major difference between them is that flexibility can be exhibited continuously or repeatedly over time, potentially leading to gradual but substantial change in the configuration and functions of the system, whereas resilience is exhibited in particular instances of sudden shock.

A variety of events or trends could test the flexibility and resilience of an energy system such as an NPP and its supporting infrastructure. These include:

- Civil disturbance or social breakdown;

[74] Homer-Dixon, 2007.

- Attack by a sub-national group;
- War or threat of war;
- Natural disaster (flood, earthquake, hurricane, etc.);
- Disease pandemic;
- Economic crisis or economic decline;
- Major political change;
- Effects of climate change (rising sea level, rising surface temperature, altered precipitation, etc.); or
- Cultural transition to new values and expectations.

Each of these events and trends is familiar from history, including the history of recent decades. There is ample reason to expect comparable events and trends over the six or more decades during which a new NPP might operate. Curiously, however, planning processes for NPPs typically ignore many of these potential stresses. For example, a typical EIS for a new NPP in the United States considers natural disasters to some extent, might consider the effects of climate change if the EIS has been prepared recently, but ignores the other potential events and trends listed above.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the flexibility and resilience of an NPP include:

- The events and trends that could stress an NPP and its supporting infrastructure during the plant's life cycle; and
- The flexibility and resilience that the NPP would exhibit if it experienced such stress.

During the planning process for a new NPP, it would be important to consider the flexibility and resilience of a proposed NPP design and alternative options. Those options would include alternative NPP sites and designs, together with other options to supply electricity or the services enabled by electricity. An expanded-scope EIS could identify a range of stresses and then assess the flexibility and resilience of a proposed NPP, and a set of alternative options, across that range. Such an EIS would provide useful information to stakeholders regarding the above-stated concerns.

III.8 Social Impacts

In an industrial society, a large item of infrastructure is both an expression of the society and an influence upon it. More generally, a society and its technology are woven together in socio-technical systems. When a new technology is introduced, one might expect that there would be a systematic process to assess the technology's impacts on society, and to track the ways in which the technology and society become interwoven. In practice, processes of this type are rare, despite ample experience showing that the social impacts of a new technology can be significant, and may be adverse.

Nuclear power has the potential to create significant social impacts that reflect its special hazards. Because an NPP contains a large inventory of radioactive and fissile material, it must be heavily regulated and protected by a security force. These requirements give the host-country government and its security agencies a substantial role in a nominally commercial activity, and can feed authoritarian tendencies. The NPP owner also becomes engaged with security issues to a much greater extent than does the owner of a typical industrial facility.

The social impacts that derive from an NPP's hazard potential are especially evident in the context of secrecy. When commercial nuclear power was introduced in the 1960s, the level of secrecy associated with the industry was comparatively low, at least in the USA and other Western countries. Over time, the level of secrecy has increased, especially since the September 2001 attacks on New York and Washington. The adverse social impacts of this enhanced secrecy do not receive the attention they deserve. One of these impacts is a distorted understanding of NPP risk.

Secrecy and the understanding of risk

As discussed elsewhere in this report, nuclear power plants can experience incidents that lead to severe impacts on the environment. Assessing the risk of such impacts requires thorough technical analysis, supported by detailed information about plant design. Some people argue that analysis of this type should be performed in secure settings by experts who subsequently announce their findings to citizens and policy makers. That approach is preferred by many experts. Experience shows, however, that the approach leads to an entrenched culture of secrecy. Such a culture is not compatible with a clear-headed, science-based understanding of risk. 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.[75]

The wider context of secrecy

A declared motive for the secrecy that now surrounds the nuclear industry is fear that a nuclear facility could be attacked by a sub-national group. Yet, secrecy has substantial, adverse effects on a society. Secrecy is typically accompanied by other measures that strengthen authoritarian tendencies in government, such as surveillance of the domestic population.

Decision makers do not always understand that a rush to measures such as secrecy and surveillance can hand a victory to hostile, sub-national groups. A more mature, multi-faceted response may be appropriate. Table III-6 illustrates the potential for such a response. It shows alternative approaches to protecting NPPs and other elements of critical infrastructure, and the strengths and weaknesses of these approaches. One of the approaches shown in Table III-6 is to adopt robust, inherently-safe designs for infrastructure facilities. Appendix B describes efforts to develop such designs for NPPs.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the social impacts of an NPP include:

- The adverse social impacts arising from the special hazard potential of an NPP, mediated by measures such as enhanced secrecy; and
- The potential to reduce those adverse impacts by adopting a more robust NPP design.

An expanded-scope EIS could provide stakeholders with useful information related to these concerns. Such an EIS could assess social impacts for a proposed NPP design, for

[75] Thompson, 1998.

alternative NPP sites and designs, and for other options to supply electricity or the services enabled by electricity.

III.9 Economic Feasibility and Impacts

The economic feasibility of an NPP project is a basic test of the project's merits. If the project is economically infeasible, one could argue, none of the other issue areas discussed in this report comes into play. In practice, however, economic feasibility is intertwined with other issue areas. For example, Section III.10, below, discusses the allocation of financial risk across the parties involved in an NPP acquisition. It is not unusual for proponents to reduce the publicly-stated costs associated with an NPP by allocating a major part of the financial risk to stakeholders (e.g., taxpayers, or electricity customers) who may be unaware that they bear the risk. This phenomenon is part of a larger process whereby nuclear power is widely subsidized, as noted in a report on the status of this industry:[76]

> "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."

Thus, in the context of a code of conduct for NPP transfer, stakeholders need full information about the costs associated with nuclear power. That information should extend across the nuclear fuel cycle, and across the lifetimes of the facilities and activities that constitute the cycle. Subsidies, and assumptions about future costs, should be explicitly identified. There is, at present, no broadly agreed protocol for providing the needed information. As a result, stakeholders are faced with widely varying claims about costs.

Available data, although incomplete, show a rising trend in costs as the proposed nuclear renaissance unfolds. Consider, for example, recent trends in the estimated "overnight" costs of constructing an NPP in the United States.[77] In the period 2001-2005, analysts estimated overnight costs of around $2,000 per kW (2008$). By 2009, utilities were estimating overnight costs of $3,000 to $5,000 per kW (2008$), and independent analysts were estimating overnight costs of $6,000 to $10,000 per kW (2008$). This escalation occurred before any construction began. Historical experience strongly suggests that cost escalation would continue during construction.[78]

[76] Schneider et al, 2009, page 7.
[77] Overnight costs neglect financing costs and other costs that depend on duration of the construction phase.
[78] Cooper, 2009b, Figure III-1.

The economic issues associated with NPP acquisition are not limited to the economic feasibility of the acquisition. NPP acquisition could create economic impacts in the consumer country. One category of economic impacts would be the opportunity costs that can arise when some of a country's financial resources, human resources, political attention, and land are allocated to one investment rather than another. In the case of NPP acquisition, alternative investments would include renewable sources of energy, and projects to improve the efficiency with which electricity services (e.g., lighting, cooling) are delivered. If alternative investments could provide electricity services at a lower overall cost than would be incurred by acquiring the NPP, the difference would be the opportunity cost of the NPP acquisition.

Another category of potential economic impacts would be costs arising from an unplanned release of radioactive material. Those costs could be substantial. For example, Entergy, the licensee of two NPPs at the Indian Point site near New York City, has estimated the offsite costs of an "early high" release from the reactor at one of these NPPs at $60-70 billion.[79] Other release scenarios, or the consideration of factors neglected by Entergy, would yield much higher cost estimates.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the economic feasibility and impacts of NPP acquisition include:

- The lack of a broadly agreed protocol to provide full information about the costs associated with NPP acquisition;
- Widespread subsidizing of nuclear power;
- Rising costs of NPP construction;
- Opportunity costs of NPP acquisition; and
- Potential economic impacts of unplanned releases.

One mechanism for informing stakeholders about these concerns would be a process to seek consensus on a protocol for a full description of nuclear-power costs, including subsidies. If a consensus-based protocol emerged, the protocol could be used for a proposed NPP acquisition, assisting stakeholders to determine the economic feasibility of the acquisition. Accompanying analyses could assess opportunity costs and the potential economic impacts of unplanned incidents.

III.10 Allocation of Technical and Financial Risk

Assessing the economic feasibility of an NPP project involves estimation of trends in the costs associated with NPP construction and operation, together with estimation of trends in the electricity market that would be served by the project. Both types of estimate are accompanied by various uncertainties. Each party with a financial interest in a proposed

[79] Thompson, 2007, Table 6-1.

project (the plant owner, the reactor vendor, etc.) would attempt to account for those uncertainties, and would attempt to structure its involvement so as to limit its financial risk in the event that trends move in unexpected directions.

The efforts of the various parties to limit their financial risk would be formalized in a web of contracts and agreements that have the effect of allocating financial risk across the parties. Given the financial magnitude of an NPP project, some parties could bear substantial risk. Yet, the allocation of financial risk is rarely done in a transparent and systematic manner. Thus, members of a stakeholder group (e.g., electricity consumers) might bear a substantial financial risk of which they are not aware.[80]

Overall financial risk is compounded by the potential for unexpected technical problems that lead to increased costs. Experience in the USA during the 1970s and 1980s demonstrates that this potential can be significant. During that period there was growing awareness of NPP safety issues, leading to plant modifications and other actions that involved increased costs. The growth of safety awareness was significantly, but not exclusively, attributable to the occurrence of the Three Mile Island NPP accident in 1979.

Charles Komanoff, in a book published in 1981, examined the escalation of costs associated with nuclear generation in the USA.[81] He showed that efforts to reduce the risk of a reactor accident were major drivers of that escalation, and he predicted that this effect would continue during the 1980s. A subsequent compilation of data showed that his prediction was correct.[82] 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.[83] Efforts to reduce accident risk were major drivers of both trends.

Analysts examining the potential for a nuclear power renaissance are well aware of the history of cost escalation.[84] NPP vendors and other advocates of the renaissance recognize that substantial cost escalation would 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.[85] Such an event, whether caused by an accident or a malevolent act,

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[80] Mark Cooper has examined (see: Cooper, 2009a) the allocation of financial risk to US stakeholders that is implied by the use of federal loan guarantees and "construction work in progress" payments to launch a nuclear-power renaissance in the USA. He finds that taxpayers and electricity customers would bear a substantial part of the financial risk.
[81] Komanoff, 1981.
[82] Komanoff and Roelofs, 1992.
[83] Komanoff and Roelofs, 1992, pp 17-20.
[84] Hultman et al, 2007.
[85] 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

would increase public pressure for adoption of risk-reducing measures at NPPs worldwide. That pressure could become especially powerful if the public became aware that the nuclear industry had rejected innovative NPP designs – such as the PIUS design described in Appendix B – in favor of Generation III designs that pose a higher risk.

Concerns in this issue area, and mechanisms for obtaining information

Major concerns regarding the allocation of technical and financial risk include:

- The potential overall financial risk associated with an NPP project, accounting for the possibility of unexpected technical problems; and
- The lack of a transparent, systematic process for allocating financial risk across the project parties and affected stakeholders.

Participating stakeholders could be informed about these concerns through two mechanisms. One mechanism would be an assessment, using probabilistic techniques, of the overall financial risk associated with an NPP project. The assessment would identify a range of potential problems that could increase costs, and would estimate the contribution of such problems to the overall financial risk. The second mechanism would be a transparent analysis of practices and options for allocation of the overall financial risk.

IV. Constructing a Code of Conduct that Accounts for Each Issue Area

Section II.1, above, states that the purpose of a code of conduct would be to determine, to the satisfaction of participating stakeholders, if transfer of Generation III NPP technology to a consumer country is appropriate under achievable conditions. Relevant conditions would include the characteristics of plant sites, the choice of plant type and vendor, regulatory arrangements, host-country policy for management of radioactive waste, and other factors. In determining if construction of NPPs in a consumer country is appropriate, the participating stakeholders would consider alternative options for supplying electricity or the services that electricity can enable.

Also, Section II.1 sets forth requirements for an effective code of conduct:

- The code should involve a broad range of stakeholders;
- The code should apply to specific, observable actions;
- There should be metrics to predict or determine the extent of compliance with the code;
- There should be a credible process of observation using those metrics; and
- The code should be enforceable.

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society. Second, annual NPP capacity additions worldwide were already beginning to decline in 1986. The effect of the 2011 Fukushima accidents on cost trends will become apparent over future years.

A group of stakeholder delegates could be convened to develop a code of conduct that meets these requirements. The delegates would represent the stakeholder groups that would participate in the eventual application of the code. These delegates would engage in a process of facilitated dialogue, seeking consensus on the text of a code of conduct.

WNA's Charter of Ethics, reproduced in Appendix A, might be one point of departure for this dialogue process. The Charter sets forth some general principles with which many stakeholders could agree. The Premises of the Charter would, however, have to be open for debate. Many stakeholders would argue that some of the Premises are factually incorrect. The pursuit of consensus at the level of an aspirational charter, addressing general principles and broadly accepted facts, would be a test of the feasibility of developing a widely supported code of conduct.

If the dialogue process survived this early test, it could move on to develop text that meets the requirements set forth above. The text would need to address a number of issue areas. This report provides guidance for that stage of the process by outlining ten issue areas, and by summarizing the major concerns in each issue area.

In developing text that accounts for all issue areas, the delegates would need detailed information about a variety of relevant subjects. This report outlines mechanisms by which that information could be provided. Many of the mechanisms involve an expansion or refinement of EIS practice.[86] Principles for such expansion or refinement could be agreed as part of the process of consensus-seeking. Information mechanisms based on those principles could then be developed and tested. The resulting information mechanisms would be available to support the practical application of a code of conduct, if such a code eventually emerges. These mechanisms would also be valuable in the absence of a broadly supported code of conduct. A rich supply of information is a key prerequisite for a transition to a sustainable civilization.

V. Conclusions

C1. Governments have, over half a century, created a regime that seeks to address policy-relevant issues regarding the commercial nuclear power industry; that regime has substantial deficiencies.

C2. A code of conduct for transfer of NPP technology to consumer countries could potentially correct for some of the regime deficiencies during the next few decades; the code should involve participation by a broad range of stakeholders, should specify observable actions, should provide metrics to determine compliance, and should be enforceable in the sense that non-compliance results in significant consequences for the offending party.

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[86] Some people view the preparation of an EIS as a formality to be observed after the design of a project is completed. That view fails to appreciate the enabling role that a well-conducted EIS can perform. An EIS can be a key part of a planning process to ensure that investments in infrastructure serve broad interests of present and future generations.

C3. The code should address a range of issues; ten issue areas are outlined in this report.

C4. A group of stakeholder delegates could be convened to develop a code of conduct; these delegates would seek consensus through a process of facilitated dialogue.

C5. Achievement of consensus on principles and procedures would be a test of the feasibility of developing a widely supported code of conduct.

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Table II-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 III-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 NPPs around the world are typically no more robust than at US plants.

Table III-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 USA for $0.4-1.0 million

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

Table III-3
Estimated Core Inventories of Iodine-131 and Cesium-137 at Three Types of NPP in the Generation III Category

Plant Type	Core Inventory (PBq)		Normalized Core Inventory (PBq per GWe)	
	Iodine-131	Cesium-137	Iodine-131	Cesium-137
ACR-1000	3,640	172	3,640	172
US-EPR	5,140	914	3,210	571
AP1000	3,560	418	3,560	418

Notes:
(a) The estimated inventories are from: Bruce Power, 2008, Volume 3, Appendix E.
(b) According to Bruce Power, the nominal capacities of the three plant types are: ACR-1000 (1,000 MWe); US-EPR (1,600 MWe); AP1000 (1,000 MWe).
(c) Bruce Power shows the core inventory of Iodine-131 in the AP1000 plant as 3.56E+04 PBq. Here, that value is adjusted downward by one order of magnitude, assuming an error of that amount by Bruce Power.
(d) The half-lives of Iodine-131 and Cesium-137 are 8 days and 30 years, respectively.
(e) Presumably, the core inventories were estimated for full-power, steady-state operation.
(f) 1 PBq = 1.0E+15 Bq. 1 Bq = 1 decay per second.

Table III-4
Types and Causes of Potential Unplanned Incidents at a Nuclear Power Plant

Type of Incident	Cause of Incident		
	Accident Initiated by Internal Events	Accident Initiated by External Events	Intentional, Malevolent Acts
Unplanned release of radioactive material from the reactor core	X	X	X
Unplanned release of radioactive material from stored spent fuel	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

Note:
The symbol X indicates that a combination of incident type and incident cause is possible.

Table III-5
Estimated Discharge of Plutonium from Nuclear Power Reactors, 1961-2010: Selected Countries and World Total

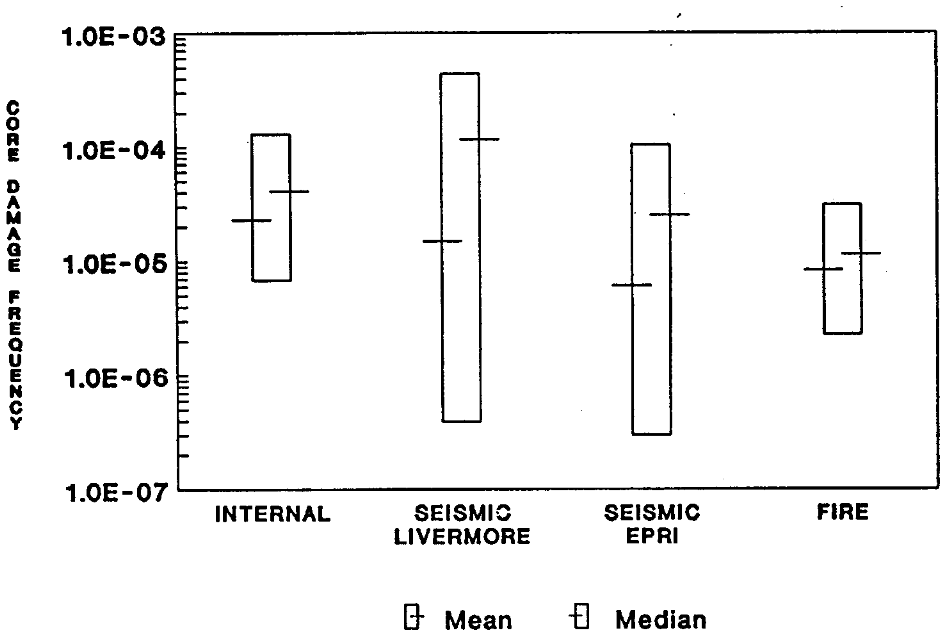
Country	Cumulative Discharge of Plutonium (kg)		
	1961-1993	**1994-2010**	**1961-2010**
Argentina	5,970	12,200	18,170
Brazil	520	4,400	4,920
Canada	67,230	99,270	166,500
India	4,500	21,120	25,620
Korea (South)	14,670	49,870	64,540
Pakistan	410	780	1,190
South Africa	2,340	5,600	7,940
WORLD TOTAL	846,200	1,278,760	2,124,960

Source:
Albright et al, 1997, Tables 5.3 and 5.4.

Table III-6
Selected Approaches to Protecting a Country's Critical Infrastructure From Attack by Sub-National Groups, and Some Strengths and Weaknesses of these Approaches

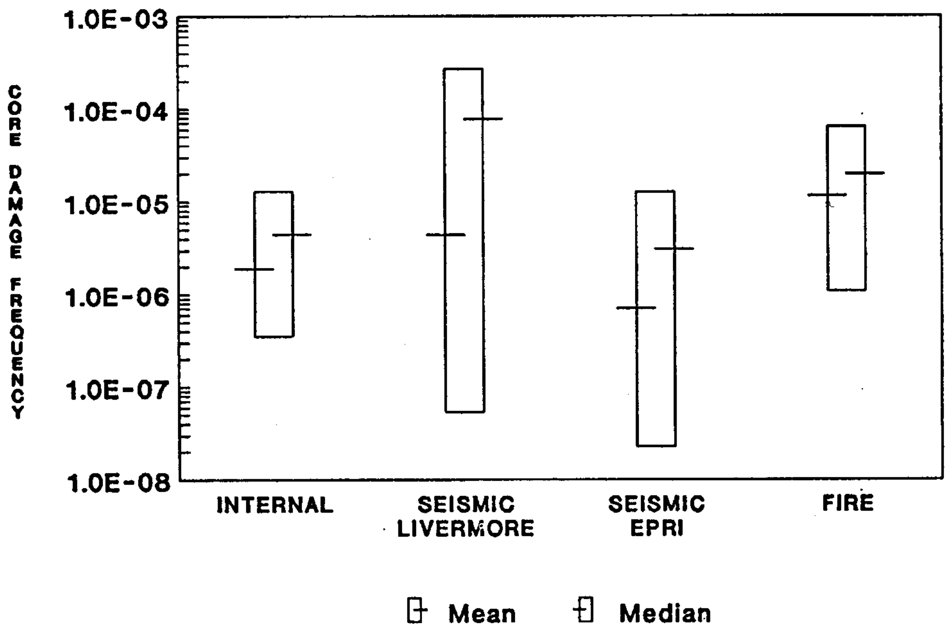
Approach	Strengths	Weaknesses
Offensive military operations internationally	• Could deter or prevent governments from supporting sub-national groups hostile to the Country	• Could promote growth of sub-national groups hostile to the Country, and build sympathy for these groups in foreign populations • 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 III-1
Core Damage Frequency for Accidents at a Surry PWR Nuclear Power Plant, as Estimated in the NRC Study NUREG-1150



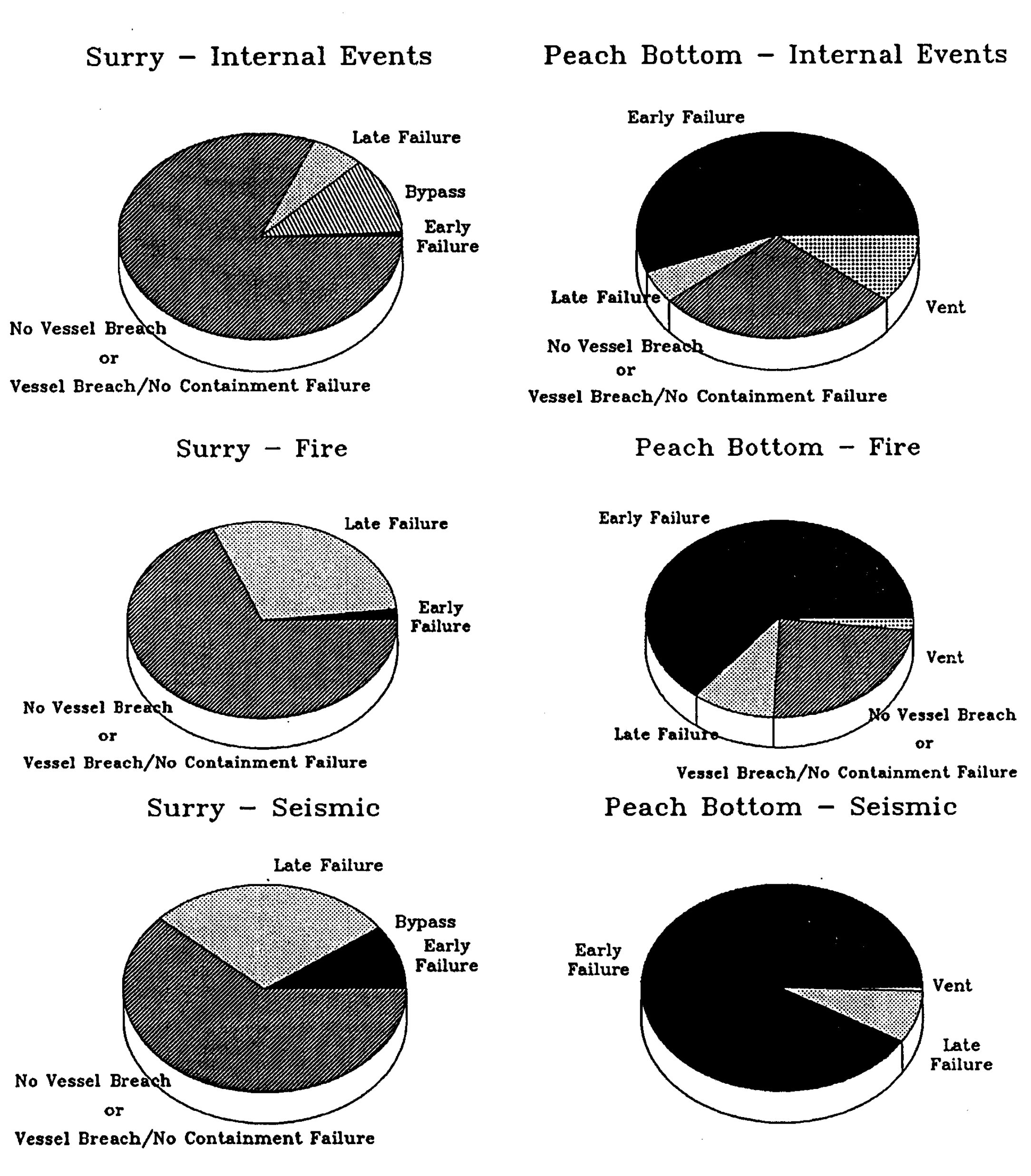
Notes:
(a) This figure is adapted from Figure 8.7 of: NRC, 1990.
(b) The bars range from the 5^{th} percentile (lower bound) to the 95^{th} percentile (upper bound) of the estimated core damage frequency (CDF). CDF values shown are per reactor-year (RY).
(c) Two estimates are shown for the CDF from earthquakes (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 III-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 III-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



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

Appendix A:

The World Nuclear Association (WNA) Charter of Ethics

Note: The Charter is reproduced here in its entirety. The text is from Annex 1 of: WNA, 2010.

****

“The World Nuclear Association established its Charter of Ethics to serve as a common credo amongst Member organizations. This affirmation of values and principles summarizes the responsibilities of the nuclear industry and the surrounding legal and institutional framework that has been constructed through international cooperation to fulfil President Eisenhower's seminal vision of 'Atoms for Peace'. The text follows:

We, the Members of the World Nuclear Association, affirm:

Premises

* Our belief that sustainability must be the guiding principle of global development - requiring worldwide policies that meet the needs and aspirations of the present generation without compromising the opportunity of future generations to fulfil their needs and aspirations;
* Our confidence that nuclear power is a 'sustainable development' technology because its fuel will be available for multiple centuries, its safety record is superior among major energy sources, its consumption causes virtually no pollution, its use preserves valuable fossil resources for future generations, its costs are competitive and still declining, and its waste can be securely managed over the long-term;
* Our conviction that nuclear technology is a unique and indispensable tool of sustainable global development -
    • Unparalleled in its capacity to generate electricity cleanly, safely and on a large scale for a rapidly expanding world population whose future depends on the availability of environmentally sound energy resources; and
    • Highly beneficial and cost-effective in worldwide efforts to promote agricultural productivity, eradicate virulent pests, protect livestock health, preserve food, develop water resources, enhance human nutrition, improve medical diagnosis and treatment, and advance environmental science;
* Our recognition that nuclear science is proving equally valuable in supporting industrial societies and in helping the world's poorest countries to advance;
* Our keen awareness of the need to strengthen and sustain public confidence, both in the reliability of nuclear technology and in the people and institutions responsible for its use;

Principles

* Our commitment to ensuring that nuclear technology is used safely and peacefully;
* Our resolve to prevent and expose unsafe or illicit practices regarding nuclear material and to use all necessary precautions to protect individuals, society and the environment from any harmful radiological effects arising from nuclear material during use, storage, transport and waste disposal;
* Our adherence to the principle and practice of transparency regarding all types of civil nuclear activity, insofar as there exists a demonstrable public interest in the availability of such information and consistent with the public interest in protecting:

    • Commercially valuable knowledge; and

    • The confidentiality integral to full and candid participation in voluntary systems of review and exchange designed to enhance and maintain nuclear safety;

* Our strong support for the work performed -

    • By governments, through the International Atomic Energy Agency (IAEA), to promulgate nuclear safety standards for the worldwide nuclear industry and to ensure that there has been no spread of nuclear weapons arising from the civil nuclear fuel cycle; and

    • In industry, through the World Association of Nuclear Operators (WANO), to develop and maintain, using a comprehensive system of technical exchange and operational peer review, a rigorous safety culture at nuclear facilities worldwide;

International Legal Obligations

* Our individual and common responsibility to uphold respective international legal commitments embodied in -

    • The IAEA statute; safeguards agreements concluded pursuant to the Treaty on the Non-Proliferation of Nuclear Weapons; and regional and bilateral accords providing for IAEA verification;

    • The Convention on Nuclear Safety; the Convention on the Physical Protection of Nuclear Material; the Convention on Early Notification of a Nuclear Accident; the Convention on Assistance in the Case of Nuclear Accident or Radiological Emergency; the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter; and the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management; and

    • Other international treaties and conventions that contribute to ensuring the safe and peaceful use of nuclear technology throughout the world;

Public Policy

* Our intention to cooperate, in a spirit of partnership, with those engaged in the research, development and operation of other technologies that yield energy without adverse effect on the biosphere; and
* Our determination to promote, as a matter of ethical principle and urgent public need, an ongoing debate on energy resources that focuses citizens and governments alike on the real choices facing humankind and on the severe dangers - for the prospects of global development and for the biosphere - if decision-making on this fundamental policy is

shaped by ideology and myth rather than by science and facts."

Appendix B:

Designing a Nuclear Power Plant to Pose a Comparatively Low Level of Risk of an Unplanned Release of Radioactive Material[87]

The most reliable option for reducing the risk of an unplanned release of radioactive material from 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).[88] 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 power 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:[89]

[87] A lengthier version of this discussion is provided in: Thompson, 2008a.
[88] Watson et al, 1972.
[89] Watson et al, 1972, Appendix I.

> "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".[90]

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:[91]

> "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 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;

<u>and</u> against:

[90] Overbye et al, 2002.
[91] Hannerz, 1983, pp 1-2.

• 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".[92]

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.[93] To date, no PIUS plant has been ordered.

PRIME reactors

In 1991, a study conducted at Oak Ridge National Laboratory examined various types of commercial nuclear reactor that were under development at the time.[94] Some types of reactor represented a comparatively small evolutionary step from existing reactors. Their safety systems tended to be simpler, and to rely more on passive mechanisms, than the safety systems of existing reactors. Other types of reactor were said to have PRIME characteristics. That acronym applied to designs with the features:

• Passive safety systems;
• Resilient safety systems;
• Inherent safety characteristics (no need for safety systems);
• Malevolence resistance; and
• Extended safety (remaining in a safe state for an extended period after an accident or attack).

[92] Hannerz, 1983, page 3.
[93] Hannerz, 1983, pp 73-76.
[94] Forsberg and Reich, 1991.

The Oak Ridge study identified several types of reactor as being in the PRIME category. Those reactors, which were in various stages of development, were: the PIUS reactor; the ISER reactor being developed in Japan; the Advanced CANDU Project; modular, high-temperature, gas-cooled reactors being developed in the USA and Germany; and a molten-salt reactor being developed jointly by the USSR and the USA. The Oak Ridge study did not set forth a framework of indicators and criteria that could be used to assess the comparative merits of those reactors, or to determine if a reactor belonged in the PRIME category.

Design criteria for substantial reduction of risk

Table App B-1 sets forth criteria for designing and siting a nuclear power plant that would pose a risk of unplanned release that is substantially lower than the risk posed by the Generation II plants that are now in use worldwide, and by the Generation III plants that vendors are currently offering. 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 B-1 are achievable. If ASEA-Atom’s cost projections were accurate, there would be no overall cost premium for complying with such criteria.

Table App B-1
Criteria for Design and Siting of an NPP that Would Pose an Unplanned-Release Risk Substantially Lower than is Posed by Generation II or III NPPs

Application of Criteria	Criteria
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 the reactor core and to spent fuel stored adjacent to the 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, Section 4.3.