COMMENTS OF RIVERKEEPER ON NYSDOS PUBLIC NOTICE F-2012-1028 – APPLICATION OF ENTERGY FOR COASTAL CONSISTENCY CERTIFICATION FOR THE PROPOSED RELICENSING OF INDIAN POINT
(October 30, 2013)

Attachment 14

Thompson
Attachment 2

INSTITUTE FOR RESOURCE AND SECURITY STUDIES
27 Ellsworth Avenue, Cambridge, Massachusetts 02139, USA
Phone: 617-491-5177 Fax: 617-491-6904
Email: info@irss-usa.org

Risk-Related Impacts from Continued Operation of the Indian Point Nuclear Power Plants

by
Gordon R. Thompson

28 November 2007

Prepared under the sponsorship of
Riverkeeper, Tarrytown, New York

Abstract

Entergy has submitted an application to the US Nuclear Regulatory Commission (NRC) for 20-year extensions of the operating licenses of the Indian Point 2 (IP2) and Indian Point 3 (IP3) nuclear power plants. This report discusses potential adverse impacts on the environment from continued operation of the IP2 and IP3 plants. Relevant impacts relate in various ways to the risk of radiological harm from unplanned releases of radioactive material to the environment. Unplanned releases of radioactive material from the IP2 or IP3 reactors or their spent fuel could arise as a result of conventional accidents – incidents caused by human error, equipment failure or natural events – or deliberate, malicious actions. Entergy and the NRC have identified some of the risk-related impacts of continued operation of the IP2 and IP3 plants. This report shows that neither party has provided a complete and accurate assessment of those impacts. Deficiencies in the risk analyses provided by Entergy and the NRC are illustrated here by examining four issues: (i) containment bypass during a core-damage accident due to induced failure of steam generator tubes; (ii) a fire in a spent-fuel pool; (iii) attack on a reactor and/or its spent fuel; and (iv) adverse impacts of the NRC's regulatory approach.

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 this mission, IRSS conducts technical and policy analysis, public education, and field programs. IRSS projects always reflect a concern for practical solutions to resource and security problems.

About the Author

Gordon R. Thompson is the executive director of IRSS and a research professor at Clark University, Worcester, Massachusetts. He studied and practiced engineering in Australia, and received a doctorate in applied mathematics from Oxford University in 1973, for analyses of plasma undergoing thermonuclear fusion. Dr. Thompson has been based in the USA since 1979. His professional interests encompass a range of technical and policy issues related to international security and protection of natural resources. He has conducted numerous studies on the environmental and security impacts of nuclear facilities and options for reducing these impacts.

Acknowledgements

This report was prepared by IRSS under the sponsorship of Riverkeeper, an independent, member-supported environmental organization based in Tarrytown, New York. Diane Curran and Phillip Musegaas assisted the author by obtaining information that was used during preparation of the report. The author, Gordon R. Thompson, is solely responsible for the content of the report.

Contents

List of Tables
(Tables are located at the end of the report.)

1. Introduction, Terminology and Scope

Entergy, a corporate group, has submitted an application to the US Nuclear Regulatory Commission (NRC) for 20-year extensions of the operating licenses of the Indian Point 2 (IP2) and Indian Point 3 (IP3) nuclear power plants. The current operating licenses expire in 2013 (IP2) and 2015 (IP3). Each plant features a Westinghouse pressurized-water reactor (PWR) with a dry containment. Three nuclear power plants were built at the Indian Point site, which is on the bank of the Hudson River. The Indian Point 1 plant has been shut down and is in SAFSTOR mode.

This report discusses potential adverse impacts on the environment arising from continued operation of the IP2 and IP3 plants through the periods of their current or extended operating licenses. Here, the term "environment" includes humans, human society and property, as well as other features and attributes of the biosphere. The adverse impacts that are considered here can be reasonably foreseen but will not necessarily occur.[1]

This report focuses on adverse impacts that are related to the risk of radiological harm from unplanned releases of radioactive material to the atmosphere, surface water or ground water. The radioactive material would be released from the IP2 or IP3 reactor or from the spent (i.e., no longer usable) fuel discharged from these reactors. Unplanned releases are distinct from the comparatively small, planned releases that occur during operation of a nuclear power plant. Here, the term "risk" encompasses the type and scale of potential adverse outcomes together with the probabilities of occurrence of those outcomes.[2] Two categories of risk-related impacts are addressed here. The first category consists of direct radiological harm (radiation-induced human illnesses, etc.) and the indirect social and economic impacts arising from that direct harm. The second category consists of regulatory impacts that arise from the NRC's general approach to the licensing of nuclear power plants. Both categories of impact are discussed further in Section 3, below.

Unplanned releases of radioactive material

Unplanned releases of radioactive material from the IP2 or IP3 reactors or their spent fuel could arise as a result of two types of accident. The term "conventional accidents" is

---

[1] An event can be reasonably foreseen even if there is no statistical basis to support a quantitative estimate of the event's probability. The NRC accepted that point when it promulgated a rule requiring protection of nuclear power plants against vehicle bombs. See: NRC, 1994.

[2] Some analysts define "risk" as the arithmetic product of two quantitative indicators: a consequence indicator; and a probability indicator. That definition is simplistic and can be misleading, and is not used in this report. That definition is especially inappropriate for risks associated with malicious actions, because there is usually no statistical basis to support quantitative estimates of the probabilities of such actions. In this report, the risk of an activity is defined as a set of quantitative and qualitative information that describes the potential adverse outcomes from the activity and the probabilities of occurrence of those outcomes.

used here to refer to incidents caused by human error, equipment failure or natural events.[3] By contrast, "malice-induced accidents" are incidents caused by deliberate, malicious actions. The parties taking those malicious actions could be national governments or sub-national groups.[4] In considering malicious actions, this report focuses on actions by sub-national groups.

Risk analyses by NRC, Entergy and IRSS

The NRC has discussed some of the risk-related impacts of operating a nuclear power plant for an extended period, in the *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (NUREG-1437).[5] The NRC has discussed some of the risk-related impacts associated with storage of spent fuel, in documents including the *Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel* (NUREG-0575).[6] Entergy has discussed some of the risk-related impacts of continued operation of the IP2 and IP3 plants, in the Environmental Report that is provided as Appendix E of Entergy's License Renewal Application.[7] Neither the NRC nor Entergy has provided a complete and accurate assessment of the risk-related impacts of continued operation of the IP2 and IP3 plants.

This report demonstrates the deficiencies in NRC's and Entergy's analyses by examining four neglected risk issues, as discussed below. IRSS's examination does not purport to provide a comprehensive assessment of risk-related impacts for operation of the IP2 and IP3 plants. Such an assessment would require financial support at a much higher level than was available for our examination. Preparation of such an assessment is a duty of Entergy and the NRC, a duty that neither party has performed. Section 10, below, describes the assessments that Entergy and the NRC should perform. In the absence of a comprehensive assessment, this report provides illustrative analyses of selected issues. Assumptions of IRSS's analyses are stated, and the author would be pleased to engage in open technical debate regarding these analyses.

Protection of sensitive information

One of the neglected risk issues examined in this report is the potential for deliberate attack on one or more of the IP2 and IP3 reactors and the adjacent pools for storage of spent fuel. Any responsible analyst who discusses the potential for an attack on a nuclear power plant is careful about making statements in public settings. The author of this report exercises such care. The author has no access to classified information, and this

---

[3] The NRC's Glossary, accessed at the NRC web site (www.nrc.gov) on 25 June 2007, contains no definition of "accident". The terms "conventional accident" and "malice-induced accident" are used in this report. Both types of accident can be foreseen, and a licensee should be able to maintain control of a facility if either type of accident occurs.
[4] Relevant sub-national groups could be based in the USA or in other countries.
[5] NRC, 1996.
[6] NRC, 1979.
[7] Entergy, 2007a, Appendix E.

report contains no such information. However, a higher standard of discretion is necessary. An analyst should not publish sensitive information, defined here as detailed information that could substantially assist an attacking group to attain its objectives, even if this information is publicly available from other sources. On the other hand, if a plant's design and operation leave the plant vulnerable to attack, and the vulnerability is not being addressed appropriately, then a responsible analyst is obliged to publicly describe the vulnerability in general terms.

This report exemplifies the balance of responsibility described in the preceding paragraph. Vulnerabilities of the IP2 and IP3 plants are described here in general terms. Detailed information relating to those vulnerabilities is withheld here, although that information has been published elsewhere or could be re-created by many persons with technical education and/or military experience. For example, this report does not provide cross-section drawings of the IP2 and IP3 plants, although such drawings have been published for many years and are archived around the world.

NRC license proceedings provide potential forums at which sensitive information could be discussed without concern about disclosure to potential attackers. Rules and practices are available so that the parties to a license proceeding could discuss sensitive information in a protected setting.

Structure of this report

The remainder of this report has eleven sections. Section 2 describes selected characteristics of the IP2 and IP3 plants and their spent fuel. Section 3 outlines the categories of risk-related impacts that are relevant to continued operation of the IP2 and IP3 plants. Then, Section 4 discusses the risk assessments proffered by the NRC in NUREG-1437 and by Entergy in its License Renewal Application.

Sections 5 through 8 examine four selected risk issues that have been neglected by the NRC and Entergy. These issues are: reactor containment bypass via induced failure of steam generator tubes (Section 5); fire in a spent-fuel pool (Section 6); attack on a reactor and/or its spent fuel (Section 7); and the wider context of nuclear-facility risk (Section 8). Section 9 summarizes IRSS's findings regarding these issues, and discusses options for reducing risk. The discussion in Sections 5 through 9 identifies major deficiencies in the risk assessments proffered by the NRC and Entergy. Section 10 describes the analyses required from Entergy and the NRC to correct these deficiencies in the context of a license extension application for the IP2 and IP3 plants.

Conclusions are set forth in Section 11, and a bibliography is provided in Section 12. All documents cited in the text of this report are listed in the bibliography. Tables are provided at the end of the report.

2. Selected Characteristics of the Indian Point Nuclear Power Plants and their Spent Fuel

During operation, each of the IP2 and IP3 reactors accumulates a large inventory of radioactive material inside the fuel assemblies that make up the reactor core. Periodically, some of the fuel assemblies are discharged from the reactor because they are "spent" in the sense that they are no longer suitable for power generation. Each spent fuel assembly contains a substantial amount of radioactive material, and is stored for a period of years in a rack that sits on the floor of a water-filled pool. A pool of this type is located immediately outside the containment of each reactor. After each of these pools has received spent fuel to near its full capacity, batches of previously-discharged fuel assemblies will be periodically removed from the pool and transferred to an independent spent fuel storage installation (ISFSI) located on the Indian Point site, in order to clear space in the pool for fuel assemblies newly discharged from the adjacent reactor.[8] At the ISFSI, the spent fuel will stored dry, within air-cooled modules. The IP2 and IP3 spent-fuel pools contribute significantly to the potential for unplanned releases of radioactive material at the Indian Point site, as discussed later in this report.

The radiological risk posed by a nuclear facility is determined by two factors: the facility's inventory of radioactive material; and the potential for release of that material to the environment. At the Indian Point site, all but a small fraction of the site's inventory of radioactive material is contained within fuel assemblies at six facilities: the IP2 and IP3 reactors; the IP1, IP2 and IP3 spent-fuel pools; and the ISFSI when that facility is operational. The IP1 pool is not discussed in this report.

Active or spent fuel assemblies contain a variety of radioactive isotopes.[9] 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.[10] Cesium is a volatile element that would be liberally released during conventional accidents or attack scenarios that involve overheating of nuclear fuel.

Table 2-1 shows estimated amounts of cesium-137 in nuclear fuel in the IP2 and IP3 reactors and spent-fuel pools, and in one of the spent-fuel storage modules of the Indian

---

[8] The Indian Point ISFSI has been established, but has not yet received spent fuel. Loading of spent fuel into storage modules at the ISFSI could commence in Spring 2008 or subsequently.

[9] 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 emergency response that would be appropriate for each release.

[10] DOE, 1987.

Point ISFSI when that facility is operational.[11] Table 2-2 compares these amounts with atmospheric releases of cesium-137 from detonation of a 10-kilotonne fission weapon, the Chernobyl reactor accident of 1986, and atmospheric testing of nuclear weapons. These data show that release of a substantial fraction of the cesium-137 in an Indian Point nuclear facility would create comparatively large radiological consequences.

In the IP2 and IP3 spent-fuel pools, as at nuclear power plants across the USA, spent fuel is stored in high-density racks. This configuration has significant implications for risk because loss of water from such a pool would, over a wide range of scenarios, lead to spontaneous ignition of the hottest spent fuel and a fire that would spread across the pool. That fire would release to the atmosphere a substantial fraction of the pool's inventory of cesium-137, together with other radioactive isotopes. The potential for this event at Indian Point is discussed further in Section 6, below.

3. Categories of Risk-Related Impacts from Continued Operation of the IP2 and IP3 Plants

As explained in Section 1, above, two categories of risk-related impacts are addressed here. The first category consists of direct radiological harm (radiation-induced human illnesses, etc.) and the indirect social and economic impacts arising from that direct harm. The second category consists of regulatory impacts that arise from the NRC's general approach to licensing of nuclear power plants.

Direct and indirect radiological impacts

This report addresses the direct radiological harm, and the associated indirect impacts, that would result from an unplanned release of radioactive material to the environment. More specifically, the report focuses on the potential for an unplanned atmospheric release. Such a release could cause radiological consequences at the Indian Point site and at downwind, offsite locations. The released material would travel in a plume of gases and small particles. The particles would settle on the ground and other surfaces at downwind locations, and would then be re-distributed by rain, wind, etc. Humans could be irradiated through various pathways including inhalation, external exposure, and ingestion of contaminated food and water. Types of radiological consequences could 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

[11] The estimates shown in Table 2-1 employ the best information available to the author. Entergy could supply information that could be used to improve the accuracy of these estimates.

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

An unplanned atmospheric release of radioactive material from the IP2 or IP3 reactors or their spent fuel could arise as a result of a conventional accident or a malice-induced accident. In this report, a conventional accident is a sequence of events initiated by human error, equipment failure, or natural forces. The potential for a conventional accident at a nuclear facility can be examined using the techniques of probabilistic risk assessment (PRA). In the PRA field, accident-initiating events are typically categorized as "internal" events (human error, equipment failure, etc.) or "external" events (earthquakes, fires, strong winds, etc.). A malice-induced accident would involve a deliberate attack at the Indian Point site. Such an attack could be mounted by a variety of actors, in a variety of ways, for various motives. The potential for an attack is discussed further in Section 7, below. That discussion shows how PRA techniques can be adapted to examine the risks of malice-induced accidents.

Regulatory impacts

The NRC's general approach to licensing of nuclear power plants creates regulatory impacts that adversely affect the environment. Granting of license extensions for the IP2 and IP3 plants would increase this burden of adverse impacts.

The potential for regulatory impacts is recognized in Executive Order 12866. That Order requires Federal agencies to "assess all costs and benefits of available regulatory alternatives". It further requires that "in choosing among alternative regulatory approaches, agencies should select those approaches that maximize net benefits".[12] The NRC argues that it is not required to comply with Executive Order 12866, but states that its regulatory analysis guidelines reflect the intent of that Order.[13] Moreover, the NRC sets forth Principles of Good Regulation in five categories: (i) independence, (ii) openness; (iii) efficiency; (iv) clarity; and (v) reliability.[14]

This report addresses two respects in which the NRC's regulatory approach does not reflect the intent of Executive Order 12866 and does not uphold the NRC's Principles of Good Regulation. First, the NRC's approach to the licensing of nuclear power plants contributes to an inappropriate, counterproductive approach by the Federal government to protection of the nation's critical infrastructure. Second, the NRC has adopted a policy of excessive secrecy that yields various adverse impacts, including suppression of clear-headed discussion of the risk posed by nuclear plants. These issues are discussed further in Section 8, below.

---

[12] Clinton, 1993, Section 1.
[13] NRC, 2004, page 1.
[14] Principles of Good Regulation, accessed at the NRC web site (www.nrc.gov) on 20 November 2007.

4. Consideration of Risk by the NRC and Entergy

From the earliest years of the nuclear-technology era, analysis and experience have shown that a nuclear reactor can undergo an accident in which the reactor's fuel is damaged. This damage can lead to a release of radioactive material within the reactor and, potentially, from the reactor to the external environment. An early illustration of this accident potential occurred in the UK in 1957, when an air-cooled reactor at Windscale caught fire and released radioactive material to the atmosphere. At that time, spent fuel was not perceived as a significant hazard.

When the IP2 and IP3 plants received their construction permits in 1966 and 1969, respectively, there was limited technical understanding of the potential for severe accidents at commercial reactors. In this context, "severe" means that the reactor core is severely damaged, which typically involves melting of some fraction of the core materials. Analysts in the PRA field typically refer to such an event as a "core-damage" accident. That term is used here. Knowledge about the potential for core-damage accidents was substantially improved by completion of the Reactor Safety Study (WASH-1400) in 1975.[15] That study, although deficient in various respects, established the basic principles for a reactor PRA. More knowledge has accumulated from analysis and experience since 1975.[16]

The NRC has discussed some of the risk-related impacts of continued operation of a nuclear power plant, in its *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (NUREG-1437).[17] Entergy has discussed some of the risk-related impacts of continued operation of the IP2 and IP3 plants, in the Environmental Report that is provided as Appendix E of the License Renewal Application.[18]

Chapter 5 of NUREG-1437 discusses the radiological risk of conventional accidents at various commercial reactors in the USA. In that discussion, the NRC claims that the risk attributable to earthquakes and other external initiating events is "adequately addressed by a generic consideration of internally initiated severe accidents".[19] NUREG-1437 also provides a brief discussion of the potential for a deliberate attack on a reactor, concluding:[20]

> "Although the threat of sabotage events cannot be accurately quantified, the commission believes that acts of sabotage are not reasonably expected. Nonetheless, if such events were to occur, the commission would expect that

---

[15] NRC, 1975.
[16] Relevant experience includes the Three Mile Island reactor accident of 1979 and the Chernobyl reactor accident of 1986.
[17] NRC, 1996.
[18] Entergy, 2007a, Appendix E.
[19] NRC, 1996, page 5-18.
[20] NRC, 1996, page 5-18.

> resultant core damage and radiological releases would be no worse than those expected from internally initiated events."

The merit of that statement is discussed in Section 7, below. NUREG-1437 also provides a brief discussion of the potential for a fire in a spent-fuel pool, concluding:[21]

> "NRC has also found that, even under the worst probable cause of a loss of spent-fuel pool coolant (a severe seismic-generated accident causing a catastrophic failure of the pool), the likelihood of a fuel-cladding fire is highly remote (55 FR 38474)."

The merit of that statement is discussed in Section 6, below.

Entergy's Environmental Report assesses the risks of core-damage events at the IP2 and IP3 reactors. Only conventional accidents are considered. Spent-fuel-pool fires are not considered. For each reactor, risk is framed in terms of the monetized offsite and onsite costs of a set of potential atmospheric releases of radioactive material, multiplied for each release by its estimated annual probability, summed (with discounting) over the 20-year period of license extension. The resulting indicator is a "present value of cost risks" for the reactor. A variety of assumptions and approximations are used during the estimation of this indicator.

The Environmental Report examines a variety of Severe Accident Mitigation Alternatives (SAMAs) that could reduce risks. For each SAMA, a "benefit" is determined by estimating the amount by which this SAMA would, if adopted, reduce the present value of cost risks of reactor operation. The cost of implementing the SAMA is also estimated. If the benefit exceeds the cost, the SAMA is determined to be "cost effective". The Environmental Report does not reach a final verdict on the cost-effectiveness of the SAMAs that it considers. Instead, it selects, from an initial set of postulated SAMAs, a subset of SAMAs that are potentially cost-effective. Entergy states that SAMAs in that subset "have been submitted for detailed engineering cost-benefit analysis".[22]

In the 1990s, each of the IP2 and IP3 plants was subjected to an Individual Plant Examination (IPE).[23] Those studies examined the potential for a reactor core damage event initiated by internal initiating events. Each plant was subsequently subjected to an Individual Plant Examination of External Events (IPEEE), which considered external initiating events.[24] The IPEs, IPEEEs and supporting information, including independent reviews commissioned by the NRC, are publicly available through the NRC. Entergy's current knowledge of risk derives, according to the Environmental Report, from probabilistic safety assessments (PSAs) that update the IPEs and IPEEEs. The PSAs are cited in the Environmental Report but are not regarded by the NRC staff as part of the

---

[21] NRC, 1996, pp 6-72 to 6-75.
[22] Entergy, 2007a, Appendix E, page 4-73.
[23] Consolidated Edison, 1992; NYPA, 1994.
[24] Consolidated Edison, 1995; NYPA, 1997.

License Renewal Application, and are not available to the public.[25] Thus, the PSAs cannot be independently reviewed in a public forum. The same is true of Entergy's SAMA analyses, which are only partially published and which rest upon the PSAs. Yet, the NRC has tasked a contractor with reviewing Entergy's SAMA analyses for the IP2 and IP3 plants.[26] It is not clear how this contractor can provide a credible review.

Sections 5 through 8, below, examine four selected risk issues that have been neglected by the NRC and Entergy. In part, that examination adopts the methodology that Entergy uses to discuss SAMAs. IRSS's use of that methodology is not a general endorsement of Entergy's SAMA analyses, their methodology or their assumptions. IRSS uses the methodology to illustrate the significance of the neglected risk issues.

5. Neglected Risk Issue #1: Reactor Containment Bypass via Induced Failure of Steam Generator Tubes

During a core-damage accident at a reactor, radioactive material would be released from the damaged fuel to the reactor coolant system (RCS). A portion of that material would then travel from the RCS to the interior of the reactor containment building. Some of that portion may then travel from the interior of the containment to the external environment, through pathways that existed prior to the accident or were created during the accident. Alternatively, radioactive material may travel directly from the RCS to the external environment through pathways that bypass the containment. Core-damage scenarios involving containment bypass deserve careful consideration in a reactor risk assessment, because the release of radioactive material to the environment could be comparatively large during such a scenario. Entergy's Environmental Report does not provide an adequate examination of this issue for the IP2 and IP3 reactors. As discussed below, the Environmental Report does not properly address the potential for containment bypass via induced failure of steam generator tubes.

The IP2 and IP3 reactors have large, dry containment structures. Containments of this type have some capability to withstand destructive phenomena that accompany core-damage accidents, such as hydrogen explosions or steam explosions.[27] Thus, if containment bypass does not occur, the fraction of the radioactive material released from damaged fuel that reaches the environment might be comparatively small. Many studies have been done in the PRA field to estimate this fraction across a range of core-damage scenarios. Entergy's Environmental Report finds that the fraction is comparatively small for a majority of core-damage sequences. IRSS does not examine that finding directly. Instead, this report shows that Entergy has substantially under-estimated the potential for containment bypass. If bypass occurs, the strength of the containment is irrelevant.

---

[25] Communications between Diane Curran and staff of the NRC Public Document Room, August 2007.
[26] Letter (and attachments) from Joyce Fields, NRC Contracting Officer, to James Meyer, Information Systems Laboratories, Rockville, Maryland, 22 June 2007.
[27] No US commercial reactor has a containment that was specifically designed to withstand all of the destructive phenomena that could accompany a core-damage accident.

The IP2 and IP3 reactors are PWRs. This type of reactor has a potential containment-bypass pathway that requires especially careful consideration. The pathway involves failure of one or more of the tubes in one or more of the reactor's four steam generators. There are 3,200 tubes in each steam generator at the IP2 and IP3 reactors. Each tube has a diameter of 0.9 inches and a wall thickness of 0.05 inches.[28] They are, therefore, comparatively fragile. Yet, the thin walls of these tubes form part of the containment boundary. The tube walls separate the RCS from the secondary side of the steam generators, where water is boiled to generate steam that is fed to the plant's turbogenerator.[29]

A 28-inch-diameter steam pipe leaves each steam generator and passes through the containment wall. Outside the containment, each pipe is equipped with an isolation valve that can block the flow of steam. Upstream of the isolation valve, but outside the containment, each pipe is connected to five safety valves that exhaust to the atmosphere. These valves are set to open at pressures ranging from 1,065 to 1,120 psig, consistent with the steam system's design pressure of 1,085 psig. That pressure is substantially lower than the RCS design pressure of 2,485 psig.[30] Thus, if steam generator tubes fail while the RCS is at or near its design pressure, fluid from the RCS would enter the secondary side via the failed tubes, water in that fluid would flash to steam, and a pulse of pressure would occur in the steam pipes, causing one or more of the safety valves to open. Then, if a safety valve sticks open, a pathway would be created that connects the RCS to the external atmosphere. That pathway would bypass the containment, could not be blocked, and would remain open for the duration of the accident.[31] The release of radioactive material through this pathway could be substantial. In this manner, the steam generator tubes would function as an "Achilles' heel" in the containment boundary.

Tube failure during a High/Dry accident sequence

Failure of steam generator tubes could be an initiating event for a core-damage accident, or could be induced by phenomena that accompany such an accident. The scenario of greatest risk significance is one in which failure is induced by heating of the steam generator tubes while there is a high differential pressure between the RCS and the secondary side. Those conditions would be most severe during "High/Dry" core-damage scenarios (accident sequences) in which the secondary side dries out due to unavailability of feedwater and the RCS pressure remains high while primary coolant (i.e., water) is lost and the core is uncovered. During such a scenario, there would be a period when the upper portions of the RCS are occupied by steam and by hydrogen generated from steam-zirconium reaction in the core, while the lower portions of the RCS are occupied by residual water. Convective circulation of the steam-hydrogen mixture would transfer

---

[28] Entergy, 2007b, Table 4.1-4. This source describes the IP2 plant; the IP3 plant has a similar design.
[29] The RCS is the "primary side" of the steam generators.
[30] Entergy, 2007b, Table 4.1-4, Section 10.2.1. This source describes the IP2 plant; the IP3 plant has a similar design.
[31] At the IP2 and IP3 plants, there is no valve that can close the pathway from the core to the secondary side safety valves if steam generator tubes are ruptured.

heat to the steam generator tubes and other portions of the RCS boundary, increasing their temperature. The ability of the affected areas to withstand the high pressure inside the RCS would decrease correspondingly. The temperature of the steam generator tubes would rise comparatively quickly because the tubes have thin walls. That effect would offset the fact that convective circulation into the interior of the tubes would be comparatively weak unless a reactor coolant pump were restarted or the "loop seal" of residual water in the cold legs of the RCS were lost in other ways.

The potential for containment bypass due to induced failure of steam generator tubes has been known for two decades. During the first half of that period, NRC and licensee analysts asserted that the likelihood of this event is low.[32] The NRC adopted that position in its NUREG-1150 study.[33] However, a subsequent study at Idaho National Engineering Laboratory (INEL) determined that the NUREG-1150 position "was based on expert opinion with little supporting analysis".[34] The INEL study was followed by an NRC Staff study of the risk of induced failure of steam generator tubes.[35] The latter two studies showed the complexity of this issue and the need for further research.

The NRC has continued to support analysis on the issue. Findings from a computer modeling exercise sponsored by the NRC, using the SCAD/RELAP5 model, were released in August 2006.[36] The exercise simulated a "station blackout" event at a Westinghouse 4-loop PWR. The IP2 and IP3 reactors are in this category. A station blackout event represents many of the potential High/Dry sequences of interest here.

In the modeled event, the core is uncovered when the accident has proceeded for about 10,000 seconds (2.8 hours). Then, steam and hydrogen circulate convectively through the upper portions of the RCS, transferring heat to structures in the RCS boundary. Failure of those structures is predicted to occur during the period 13,500 to 14,600 seconds. The structures fail because they are weakened by rising temperature to the point where they can no longer sustain the high pressure inside the RCS. Modeling shows that the hottest steam generator tube fails 155 seconds prior to the next most vulnerable portion of the RCS boundary (the hot leg), even if the tube is pristine. Similar results were found in four of six sensitivity cases.[37] The hottest tube would fail earlier if that tube is degraded, and some degree of tube degradation will always be present in practice. Also, a number of tubes, typically in proximity to each other, would be in the "hottest" category, and would therefore fail at about the same time. Moreover, hot gas released from the first rupture would impinge on surrounding tubes, promoting their failure. Thus, it can reasonably be assumed that the breach in the RCS boundary would involve a number of tubes.

---

[32] Thompson, 2000, Section 4.2.
[33] NRC, 1990b, Volume 2, page C-66.
[34] Ellison et al, 1996, page 7-6.
[35] NRC, 1998.
[36] Fletcher and Beaton, 2006a; Fletcher and Beaton, 2006b.
[37] Fletcher and Beaton, 2006b, Table 13.

The above-described modeling exercise assumed, based on PRA analysis, that leakage through secondary side safety valves would depressurize the secondary side of each steam generator.[38] Thus, a pathway to the atmosphere from the secondary side would be open prior to and after tube failure. Sticking open of one or more of the 20 safety valves (5 for each of the 4 steam pipes) is likely because valves could lift 50 or more times as the secondary side boils dry.[39] These valves could lift again as a result of RCS pressure pulses during the accumulator-discharge phase of the accident sequence.[40] The potential for valves to stick open at that time would be enhanced by the presence of small particles of fuel in the fluid passing through the valves.[41]

These modeling results do not provide the final word regarding the potential for induced failure of steam generator tubes. They are, however, a key source of guidance for a risk assessment conducted in 2007. In light of these results, it is currently prudent to assume that: (i) any High/Dry sequence would involve induced failure of steam generator tubes; and (ii) one or more of the secondary side safety valves downstream of the affected steam generator(s) would remain open after tube failure. In other words, any High/Dry sequence would involve a bypass of the containment and a substantial release of radioactive material to the atmosphere. Such a release would be comparable to the "Early High" release category discussed in Entergy's Environmental Report.[42] Entergy's estimates of the magnitude of an Early High release are used here, without any implication that IRSS accepts those estimates as definitive.[43]

Risk implications of induced tube failure

The next step in addressing this issue is to estimate, for the IP2 and IP3 reactors, the probability of a core-damage accident featuring induced failure of steam generator tubes. Table 4-1 shows Entergy's estimates of the core damage frequency (CDF) for these reactors. Those estimates are used here, without any implication that IRSS accepts them as definitive. Tables 5-1 and 5-2 show various estimates of the share of CDF that is attributable to accident sequences in the High/Dry category. In two instances (the first two rows of Table 5-2), that share is taken directly from a table in the cited document, by summing relevant entries in the table. In other instances, the share is inferred from the cited document in the manner described in Tables 5-1 and 5-2. All of the cited documents were prepared by Entergy or preceding licensees. From the overall picture provided by Tables 5-1 and 5-2, it is reasonable to assume that High/Dry sequences account for 50 percent of CDF for the IP2 and IP3 reactors.

---

[38] Fletcher and Beaton, 2006a, Section 2.2.
[39] NRC, 1998, Section 2.3.3.
[40] NRC, 1998, Section 2.1.2.
[41] Thompson, 2000, Section 4.2.
[42] Entergy, 2007a, Appendix E, Tables E.1-10 and E.3-10.
[43] Consideration of the effects of high burnup of fuel could lead to a higher estimate for the release of radioactive material. See: Thompson, 2000, Section 4.2.

That assumption should be considered in combination with the above-stated assumption that all High/Dry sequences would lead to an atmospheric release equivalent to the Early High release described by Entergy. The combined assumptions are used here to correct Entergy's estimates of the conditional probabilities of atmospheric release categories, given the occurrence of core damage. Tables 5-3 and 5-4 show those corrections. It can be seen that the conditional probability of an Early High release rises from 3.6 percent to 51.8 percent for the IP2 reactor, and from 8.2 percent to 54.1 percent for the IP3 reactor. In Tables 5-5 and 5-6, IRSS applies the same correction to Entergy's estimates of population dose risk (PDR) and offsite economic cost risk (OECR). Table 5-7 carries the correction through to the estimation of the present value of cost risks associated with atmospheric releases from the IP2 or IP3 reactor. It can be seen that the estimated present value of cost risks rises, in comparison with Entergy's estimate, by a factor of 5.42 for the IP2 reactor and 3.18 for the IP3 reactor. Note that the estimated values shown in Table 5-7 consider only those core-damage sequences that arise from internal initiating events. Also, uncertainty is not considered in Table 5-7. Entergy's practice is to use multipliers, as shown in Table 4-1, to account for external initiating events and uncertainty.

To summarize, IRSS has shown that Entergy has substantially under-estimated (by factors of 5.42 and 3.18, respectively) the present value of cost risks for 20 years of extended operation of the IP2 and IP3 reactors. The under-estimation derives from Entergy's lack of proper consideration of the potential for containment bypass via induced failure of steam generator tubes. Deliberate, malicious acts could be relevant to that issue, but IRSS has not considered such acts in the analysis described above. A major consequence of Entergy's under-estimation of the present value of cost risks is that Entergy's SAMA analyses are incorrect and must be redone. Revised analyses would require consideration of a range of SAMAs, including SAMAs that Entergy has previously determined to be not cost effective. That matter is discussed further in Section 9, below.

6. Neglected Risk Issue #2: Fire in a Spent-Fuel Pool

6.1 Recognition of the Spent-Fuel Hazard

Until 1979 it was widely assumed that stored spent fuel did not pose risks comparable to those associated with reactors. This assumption arose because a spent fuel assembly does not contain short-lived radioactivity, and therefore produces less radioactive decay heat than does a similar fuel assembly in an operating reactor. However, that factor was counteracted by the introduction of high-density, closed-form storage racks into spent-fuel pools, beginning in the 1970s. The pools at the present generation of US nuclear plants were originally designed so that each held only a small inventory of spent fuel, with the expectation that spent fuel would be stored briefly and then taken away for reprocessing. Low-density, open-frame storage racks were used. Cooling fluid can circulate freely through such a rack. When reprocessing was abandoned in the United States, spent fuel began to accumulate in the pools. Excess spent fuel could have been offloaded to other storage facilities, allowing continued use of low-density racks. Instead, as a cost-saving measure, high-density racks were introduced, allowing much larger amounts of spent fuel to be stored in the pools.

The potential for a pool fire

Unfortunately, the closed-form configuration of the high-density racks would create a major problem if water were lost from a spent-fuel pool. The flow of air through the racks would be highly constrained, and would be almost completely cut off if residual water or debris were present in the base of the pool. As a result, removal of radioactive decay heat would be ineffective. Over a broad range of water-loss scenarios, the temperature of the zirconium fuel cladding would rise to the point (approximately 1,000 degrees C) where a self-sustaining, exothermic reaction of zirconium with air or steam would begin. Fuel discharged from the reactor for 1 month could ignite in less than 2 hours, and fuel discharged for 3 months could ignite in about 3 hours.[44] Once initiated, the fire would spread to adjacent fuel assemblies, and could ultimately involve all fuel in the pool. A large, atmospheric release of radioactive material would occur. For simplicity, this potential disaster can be described as a "pool fire".

Water could be lost from a spent-fuel pool through leakage, boiling, siphoning, pumping, displacement by objects falling into the pool, or overturning of the pool. These modes of water loss could arise from events, alone or in combination, that include: (i) acts of malice by persons within or outside the plant boundary; (ii) an accidental aircraft impact; (iii) an earthquake; (iv) dropping of a fuel cask; (v) accidental fires or explosions; and (vi) a severe accident at an adjacent reactor that, through the spread of radioactive material and other influences, precludes the ongoing provision of cooling and/or water makeup to the pool.

These events have differing probabilities of occurrence. None of them is an everyday event. Nevertheless, they are similar to events that are now routinely considered in planning and policy decisions related to commercial nuclear reactors. To date, however, such events have not been given the same attention in the context of spent-fuel pools.

Some people have found it counter-intuitive that spent fuel, given its comparatively low decay heat and its storage under water, could pose a fire hazard. This perception has slowed recognition of the hazard. In this context, a simple analogy may be helpful. We all understand that a wooden house can stand safely for many years but be turned into an inferno by a match applied in an appropriate location. A spent-fuel pool equipped with high-density racks is roughly analogous, but in this case ignition would be accomplished by draining water from the pool. In both cases, a triggering event would unleash a large amount of latent chemical energy.

---

[44] This sentence assumes adiabatic conditions.

The sequence of studies related to pool fires

Two studies completed in March 1979 independently identified the potential for a fire in a drained spent-fuel pool equipped with high-density racks. One study was by members of a scientific panel assembled by the German state government of Lower Saxony to review a proposal for a nuclear fuel cycle center at Gorleben.[45] After a public hearing, the Lower Saxony government ruled in May 1979, as part of a broader decision, that high-density pool storage of spent fuel would not be acceptable at Gorleben. The second study was done by Sandia Laboratories for the NRC.[46] In light of knowledge that has accumulated since 1979, the Sandia report generally stands up well, provided that one reads the report in its entirety. However, the report's introduction contains an erroneous statement that complete drainage of the pool is the most severe situation. The body of the report clearly shows that partial drainage can be a more severe case, as was recognized in the Gorleben context. Unfortunately, the NRC continued, until October 2000, to employ the erroneous assumption that complete drainage is the most severe case.

The NRC has published various documents that discuss aspects of the potential for a spent-fuel-pool fire. Several of these documents are discussed below. Only three of the various documents are products of processes that provided an opportunity for formally structured public comment and, potentially, for in-depth analysis of risks and alternatives. One such document is the August 1979 generic environmental impact statement (GEIS) on handling and storage of spent fuel (NUREG-0575).[47] The second document is the May 1996 GEIS on license renewal (NUREG-1437).[48] These two documents purported to provide systematic analysis of the risks and relative costs and benefits of alternative options. The third document is the NRC's September 1990 review (55 FR 38474) of its Waste Confidence Decision.[49] That document did not purport to provide an analysis of risks and alternatives.

NUREG-0575 addresses the potential for a spent-fuel-pool fire in a single sentence that cites the 1979 Sandia report. The sentence reads:[50]

> "Assuming that the spent fuel stored at an independent spent fuel storage installation is at least one year old, calculations have been performed to show that loss of water should not result in fuel failure due to high temperatures if proper rack design is employed."

Although this sentence refers to pool storage of spent fuel at an independent spent fuel storage installation, NUREG-0575 regards at-reactor pool storage as having the same

[45] Thompson et al, 1979.
[46] Benjamin et al, 1979.
[47] NRC, 1979.
[48] NRC, 1996.
[49] NRC, 1990a.
[50] NRC, 1979, page 4-21.

properties. This sentence misrepresents the findings of the Sandia report. The sentence does not define "proper rack design". It does not disclose Sandia's findings that high-density racks promote overheating of exposed fuel, and that overheating can cause fuel to self-ignite and burn. The NRC has never corrected this deficiency in NUREG-0575.

NUREG-1437 also addresses the potential for a spent-fuel-pool fire in a single sentence, which in this instance states:[51]

> "NRC has also found that, even, under the worst probable cause of a loss of spent-fuel pool coolant (a severe seismic-generated accident causing a catastrophic failure of the pool), the likelihood of a fuel-cladding fire is highly remote (55 FR 38474)."

The parenthetic citation is to the NRC's September 1990 review of its Waste Confidence Decision. Thus, NUREG-1437's examination of pool fires is totally dependent on the September 1990 review. In turn, that review bases its opinion about pool fires on the following four NRC documents:[52] (i) NUREG/CR-4982;[53] (ii) NUREG/CR-5176;[54] (iii) NUREG-1353;[55] and (iv) NUREG/CR-5281.[56] These documents are discussed in Section 6.2, below. That discussion reveals substantial deficiencies in the documents' analysis of the potential for a pool fire.

Thus, neither of the two GEISs (NUREG-0575 and NUREG-1437), nor the September 1990 review of the Waste Confidence Decision, provides a technically defensible examination of spent-fuel-pool fires and the associated risks and alternatives. The statements in each document regarding pool fires are inconsistent with the findings of subsequent, more credible studies discussed below.

The most recent published NRC technical study on the potential for a pool fire is an NRC Staff study, originally released in October 2000 but formally published in February 2001, that addresses the risk of a pool fire at a nuclear power plant undergoing decommissioning.[57] This author submitted comments on the study to the NRC Commissioners in February 2001.[58] The study was in several respects an improvement on previous NRC documents that addressed pool fires. It reversed the NRC's longstanding, erroneous position that total, instantaneous drainage of a pool is the most severe case of drainage. However, it did not consider acts of malice. Nor did it add significantly to the weak base of technical knowledge regarding the propagation of a fire from one fuel assembly to another. Its focus was on a plant undergoing

---

[51] NRC, 1996, pp 6-72 to 6-75.
[52] NRC, 1990a, page 38481.
[53] Sailor et al, 1987.
[54] Prassinos et al, 1989.
[55] Throm, 1989.
[56] Jo et al, 1989.
[57] Collins and Hubbard, 2001
[58] Thompson, 2001a.

decommissioning. Therefore, it did not address potential interactions between pools and operating reactors, such as the interactions discussed in Section 6.3, below.

In 2003, eight authors, including the present author, published a paper on the risks of spent-fuel-pool fires and the options for reducing these risks.[59] That paper aroused vigorous comment, and its findings were disputed by NRC officials and others. Critical comment was also directed to a related report by this author.[60] In an effort to resolve this controversy, the US Congress requested the National Academy of Sciences (NAS) to conduct a study on the safety and security of spent-fuel storage. The NAS submitted a classified report to Congress in July 2004, and released an unclassified version in April 2005.[61] Press reports described considerable tension between the NAS and the NRC regarding the inclusion of material in the unclassified NAS report.[62]

Since September 2001, the NRC has not published any document that contains technical analysis related to the potential for a pool fire. The NRC has claimed that it is conducting further analysis in a classified setting. The scope of information treated as secret by the NRC is highly questionable. Much of the relevant analysis would address issues such as heat transfer and fire propagation. Calculations and experiments on such subjects should be performed and reviewed in the public domain. Classification is appropriate for other information, such as specific points of vulnerability of a spent-fuel pool to attack.

6.2 Technical Understanding of Pool Fires

Section 6.1, above, introduces the concept of a pool fire and describes the history of analysis of pool-fire risks. There is a body of technical literature on these risks, containing documents of varying degrees of completeness and accuracy. Current opinions about the risks vary widely, but the differences of opinion are more about the probabilities of pool-fire scenarios than about the physical characteristics of these scenarios. In turn, differing opinions about probabilities lead to differing support for risk-reducing options. This situation is captured in a comment by Allan Benjamin on a paper (Alvarez et al, 2003) by this author and seven colleagues.[63] Benjamin's comment is quoted in the unclassified NAS report as follows:[64]

> "In a nutshell, [Alvarez et al] correctly identify a problem that needs to be addressed, but they do not adequately demonstrate that the proposed solution is cost-effective or that it is optimal."

The "proposed solution" to which Benjamin refers is the re-equipment of spent-fuel pools with low-density, open-frame racks, transferring excess spent fuel to onsite dry storage.

---

[59] Alvarez et al, 2003.
[60] Thompson, 2003.
[61] NAS, 2006.
[62] Wald, 2005.
[63] Allan Benjamin was one of the authors of: Benjamin et al, 1979.
[64] NAS, 2006, page 45.

In fact, however, the [Alvarez et al] authors had not claimed to complete the level of analysis, especially site-specific analysis, that risk-reducing options should receive in an Environmental Report or environmental impact statement (EIS). These authors stated:[65]

> "Finally, all of our proposals require further detailed analysis and some would involve risk tradeoffs that also would have to be further analyzed. Ideally, these analyses could be embedded in an open process in which both analysts and policy makers can be held accountable."

The paper by Alvarez et al is consistent with current knowledge of pool-fire phenomena, including the findings set forth in the unclassified NAS report. The same cannot be said for all of the NRC documents that were cited in the NRC's September 1990 review of its Waste Confidence Decision. As discussed in Section 6.1, above, four NRC documents were cited to support that review's finding regarding the risks of pool fires.[66] In turn, the May 1996 GEIS on license renewal (NUREG-1437) relied on the September 1990 review for its position on the risks of pool fires. The four NRC documents are discussed in the following paragraphs.

NUREG/CR-4982 was prepared at Brookhaven National Laboratory to provide "an assessment of the likelihood and consequences of a severe accident in a spent fuel storage pool".[67] The postulated accident involved complete, instantaneous loss of water from the pool, thereby excluding important phenomena from consideration. The Brookhaven authors employed a simplistic model to examine propagation of a fire from one fuel assembly to another. That model neglected important phenomena including slumping and burn-through of racks, slumping of fuel assemblies, and the accumulation of a debris bed at the base of the pool. Each of these neglected phenomena would promote fire propagation. The study ignored the potential for interactions between a pool fire and a reactor accident. It did not consider acts of malice. Overall, this study did not approach the completeness and quality needed to support consideration of a pool fire in an EIS.

NUREG/CR-5176 was prepared at Lawrence Livermore National Laboratory.[68] It examined the potential for earthquake-induced failure of the spent-fuel pool and the pool's support systems at the Vermont Yankee and Robinson Unit 2 plants. It also considered the effect of dropping a spent-fuel shipping cask on a pool wall. Overall, this study appears to have been a competent exercise within its stated assumptions. With appropriate updating, NUREG/CR-5176 could contribute to the larger body of analysis that would be needed to support consideration of a pool fire in an EIS.

NUREG-1353 was prepared by a member of the NRC Staff to support resolution of NRC Generic Issue 82.[69] It postulated a pool accident involving complete, instantaneous loss

[65] Alvarez et al, 2003, page 35.
[66] NRC, 1990a, page 38481.
[67] Sailor et al, 1987.
[68] Prassinos et al, 1989.
[69] Throm, 1989.

of water from the pool, thereby excluding important phenomena from consideration. It relied on the fire-propagation analysis of NUREG/CR-4982. As discussed above, that analysis is inadequate. In considering heat transfer from boiling water reactor (BWR) fuel after water loss, NUREG-1353 assumed that a high-density rack configuration would involve a 5-inch open space between each row of fuel assemblies. That assumption is inappropriate and non-conservative. Modern, high-density BWR racks have a center-to-center distance of about 6 inches in both directions. Thus, NUREG-1353 under-estimated the potential for ignition of BWR fuel. Overall, NUREG-1353 did not approach the completeness and quality needed to support consideration of a pool fire in an EIS.

NUREG/CR-5281 was prepared at Brookhaven National Laboratory to evaluate options for reducing the risks of pool fires.[70] It took NUREG/CR-4982 as its starting point, and therefore shared the deficiencies of that study.

Clearly, these four NRC documents do not provide an adequate technical basis for an EIS that addresses the risks of pool fires. The knowledge that they do provide could be supplemented from other documents, including the unclassified NAS report, the paper by Alvarez et al, and the NRC Staff study (NUREG-1738) on pool-fire risk at a plant undergoing decommissioning.[71] However, this combined body of information would be inadequate to support the preparation of an EIS. For that purpose, a comprehensive, integrated study would be required, involving analysis and experiment. The depth of investigation would be similar to that involved in preparing the NRC's December 1990 study on the risks of reactor accidents (NUREG-1150).[72]

A pool-fire "source term"

The incompleteness of the present knowledge base is evident when one needs a "source term" to estimate the radiological consequences of a pool fire. The concept of a source term encompasses the magnitude, timing and other characteristics of an atmospheric release of radioactive material. Present knowledge does not allow an accurate theoretical or empirically-based prediction of the source term for a postulated pool-fire scenario. Available information indicates that, for a broad range of scenarios, the atmospheric release fraction of cesium-137 would be between 10 and 100 percent. This report assumes a cesium-137 release fraction of about 50 percent. Table 2-1 shows that the inventory of cesium-137 in the IP2 or IP3 pool during the period of license extension would be about 70 MCi. Thus, a release of 35 MCi of cesium-137 is used here to examine the consequences of a pool fire at the IP2 or IP3 plant.

---

[70] Jo et al, 1989.
[71] Collins and Hubbard, 2001.
[72] NRC, 1990b.

6.3 Initiation of a Pool Fire

The initiation of a pool fire would require the loss of water from a pool, and the absence of water makeup or spray cooling of the exposed fuel during the period while it heats up to the ignition temperature. As stated above, that period would be just a few hours if fuel has been recently discharged from the reactor. After ignition, water spray would be counterproductive, because it would feed a steam-zirconium reaction.

Water could be lost from a spent-fuel pool through leakage, boiling, siphoning, pumping, displacement by objects falling into the pool, or overturning of the pool. These modes of water loss could arise from events, alone or in combination, that include: (i) acts of malice by persons within or outside the plant boundary; (ii) an accidental aircraft impact; (iii) an earthquake; (iv) dropping of a fuel cask; (v) accidental fires or explosions; and (vi) a severe accident at an adjacent reactor that, through the spread of radioactive material and other influences, precludes the ongoing provision of cooling and/or water makeup to the pool.

Given the major consequences of a pool fire, analyses should have been performed to examine pool-fire scenarios across a full range of initiating events. The NRC has devoted substantial attention and resources to the examination of reactor-core-damage scenarios, through studies such as NUREG-1150.[73] Neither the NRC nor the nuclear industry has conducted a comparable, comprehensive study of pool fires. In the absence of such a study, this report provides illustrative analysis of selected issues.

The NUREG-1353 estimate of pool-fire probability

As discussed above, the NRC document NUREG-1353 was deficient in various respects. It did, however, provide an estimate for the probability of a pool fire at a PWR plant. That estimate is 2 per million reactor-years.[74] The NRC has not issued a revised estimate for that probability. Thus, it is appropriate to examine the implications of the NUREG-1353 estimate for pool-fire risk at the IP2 or IP3 plant. IRSS performs such an examination, as described below. It does not follow that IRSS accepts the NUREG-1353 probability estimate as definitive.

A pool fire accompanied by a reactor accident

At the IP2 and IP3 plant, the pool is outside but immediately adjacent to the reactor containment, and shares some essential support systems with the reactor. Thus, it is important to consider potential interactions between the pool and the reactor in the context of accidents. There could be at least three types of interaction. First, a pool fire and a core-damage accident could occur together, with a common cause. For example, a

[73] NRC, 1990b.
[74] Throm, 1989, Table 4.7.1.

severe earthquake could cause leakage of water from the pool, while also damaging the reactor and its supporting systems to such an extent that a core-damage accident occurs. Second, the high radiation field produced by a pool fire could initiate or exacerbate an accident at the reactor by precluding the presence and functioning of operating personnel. Third, the high radiation field produced by a core-damage accident could initiate or exacerbate a pool fire, again by precluding the presence and functioning of operating personnel. Many core-damage sequences would involve the interruption of cooling to the pool, which would call for the presence of personnel to provide makeup water or spray cooling of exposed fuel.

The third type of interaction was considered in a license-amendment proceeding in regard to expansion of spent-fuel-pool capacity at the Harris nuclear power plant. There were three parties to the proceeding – the NRC Staff, Carolina Power and Light (CP&L), and Orange County. The Harris plant has one reactor and four pools. The reactor – a PWR – is in a cylindrical, domed containment building. The four pools are in a separate, adjacent building that was originally intended to serve four reactors. Only one reactor was built. Two pools were in use at high density prior to the proceeding, and the proceeding addressed the activation of the two remaining pools, also at high density.

During the proceeding, the Atomic Safety and Licensing Board (ASLB) determined that the potential for a pool fire should be considered, and ordered the three parties to analyze a single scenario for such a fire.[75] In the postulated scenario, a severe accident at the Harris reactor would contaminate the Harris site with radioactive material to an extent that would preclude actions needed to supply cooling and makeup to the Harris pools. Thereafter, the pools would boil and dry out, and fuel within the pools would burn. Following the ALSB's order, Orange County submitted a report by this author.[76] The NRC Staff submitted an affidavit by members of the Staff.[77] CP&L – the licensee – submitted a document prepared by ERIN Engineering.[78]

Orange County's analysis found that the minimum value for the best estimate of a pool fire, for the ASLB's postulated scenario, is 1.6 per 100 thousand reactor-years. That estimate did not account for acts of malice, degraded standards of plant operation, or gross errors in design, construction or operation. The NRC Staff estimated, for the same scenario, that the probability of a pool fire is on the order of 2 per 10 million reactor-years. The ASLB accepted the Staff's estimate, thereby concluding that, for the particular configuration of the Harris plant, the postulated scenario is "remote and speculative"; the ASLB then terminated the proceeding without conducting an evidentiary hearing.[79] Elsewhere, the author has described deficiencies in the ASLB's ruling.[80]

[75] ASLB, 2000.
[76] Thompson, 2000.
[77] Parry et al, 2000.
[78] ERIN, 2000.
[79] ASLB, 2001.
[80] Thompson, 2001b.

One reason for the difference in the probability estimates proffered by Orange County and the NRC Staff was their differing assessments of the spread of radioactive material from the reactor containment building to the separate, adjacent pool building. The Staff agreed with Orange County on some other matters. For example, the Staff reversed its previous, erroneous position that comparatively long-discharged fuel will not ignite in the event of water loss from a high-density pool. NRC Staff members stated that loss of water from pools containing fuel aged less than 5 years "would almost certainly result in an exothermic reaction", and also stated: "Precisely how old the fuel has to be to prevent a fire is still not resolved."[81] Moreover, the Staff assumed that a fire would be inevitable if the water level fell to the top of the racks.

Most importantly for present purposes, the technical submissions of all three parties agreed that the onset of a pool fire in two of the pools in the Harris pool building would preclude the provision of cooling and water makeup to the other two pools. This effect would arise from the spread of hot gases and radioactive material throughout the pool building, which would preclude access by operating personnel. Thus, the pools not involved in the initial fire would boil and dry out, and their fuel would burn. The parties' agreement on this point established that the radiation field created by an accident at one part of a nuclear plant could, by precluding access by personnel, cause an accident at another part of the plant. Whether or not this effect would occur in a particular scenario would depend on the specific configuration of the plant and the characteristics of the scenario.

IRSS does not, at present, offer an analysis of the potential for a conventional accident at the IP2 or IP3 reactor to initiate a fire in the adjacent pool, or vice versa. That analysis would be part of any comprehensive assessment of the risks posed by continued operation of the IP2 and IP3 plants. The analysis would need to be done specifically for the Indian Point site, and could not rely on findings for the Harris plant.

Interactions between a core-damage accident and a pool fire could be especially important in the context of an attack on the Indian Point site. Attackers could, either deliberately or inadvertently, release radioactive material from one facility (e.g., a reactor) that precludes personnel access to other facilities (e.g., a pool), thereby initiating accidents at those facilities. This matter is discussed in Section 7, below.

IRSS is aware of one instance in which the NRC published an analysis of the impacts of deliberate, malicious actions at a spent-fuel pool. Such an analysis was provided in NUREG-0575, the August 1979 GEIS on handling and storage of spent fuel. That analysis is discussed further in Section 7, below.

[81] Parry et al, 2000, paragraph 29.

6.4 Consideration of Pool Fires in SAMA Analyses

Entergy has not considered pool fires in its SAMA analyses for the IP2 and IP3 plants. IRSS provides an illustrative analysis to show the significance of Entergy's neglect of pool fires. The results are shown in Tables 6-1 through 6-3.

Table 6-1 shows estimated offsite costs from potential atmospheric releases of radioactive material. Two categories of release are addressed. The first category consists of Early High releases from the IP2 and IP3 reactors. Entergy estimates the offsite costs of such releases to be $66 billion for the IP2 reactor and $56 billion for the IP3 reactor. The second category consists of a fire in a spent-fuel pool at the IP2 or IP3 plant. IRSS assumes that the release from such a fire would include 35 MCi of cesium-137, as discussed above. A study by Beyea et al estimates the offsite costs of a 35 MCi release of cesium-137 from the Indian Point site to be $461 billion.[82] In that study, the authors identify a number of factors that, if considered, could increase their estimate. A further increase would occur if indirect impacts of the release were considered. Indirect economic impacts would include: (i) loss of market share for products from the region and across the US, due to stigma effects; (ii) loss of tourist revenue in the region and across the US, due to stigma effects; (iii) prolonged, costly litigation that retards recovery from the event; and (iv) loss of confidence in regional and national stability and governance, causing outflow of capital and skilled labor.

Table 6-2 shows estimated offsite cost risks for the two categories of atmospheric release discussed in the preceding paragraph. For Early High releases from the IP2 and IP3 reactors, the estimates are from Entergy. For the release from a pool fire, the NUREG-1353 estimate of probability is combined with the Beyea et al estimate of offsite costs. The table shows that the offsite cost risk of a pool fire is substantially higher than the offsite cost risk of an Early High release from a core-damage accident.

Table 6-3 carries this analysis forward to provide estimates of the present value of cost risk for: (i) the full spectrum of releases from core-damage accidents at the IP2 and IP3 reactors; and (ii) a pool fire at the IP2 or IP3 plant. The table shows that the present value of cost risk is greatest for the pool fire, even without considering the onsite component of that indicator for a pool fire. The analysis is further developed in Table 7-7, which is discussed below.

Tables 6-2 and 6-3 are developed within the risk-assessment paradigm employed by Entergy and the NRC. They employ an estimate of pool-fire probability that the NRC set forth in NUREG-1353 and has not repudiated. That estimate is comparable to Entergy's estimate of the probability of an Early High release from the IP2 or IP3 reactor. The two tables show that the risk of a pool fire exceeds the risk of a core-damage accident. Yet,

---

[82] Beyea et al, 2004.

Entergy examines the risk of a core-damage accident but ignores the risk of a pool fire. There is no logical basis for ignoring pool-fire risk.

7. Neglected Risk Issue #3: Attack on a Reactor and/or its Spent Fuel

7.1 The General Threat Environment

The potential for a deliberate attack on a commercial nuclear facility arises within a larger context, namely the general threat environment for the US homeland. That environment reflects, in turn, a complex set of factors operating internationally.

If the IP2 and IP3 plants receive 20-year license extensions, they will operate until 2033 (IP2) and 2035 (IP3), discharging spent fuel throughout that period. The proposed Yucca Mountain repository could not accommodate more than a fraction of these reactors' cumulative discharge of spent fuel, and it is increasingly unlikely that this repository will open. No other option is currently available for removing spent fuel from the Indian Point site. At that site, as at nuclear power plant sites across the US, the most likely outcome is that spent fuel will be stored at the site for the foreseeable future, potentially for longer than a century.[83] Thus, in assessing the risks of malicious actions at the Indian Point site, one should consider the general threat environment over the next century.

The threat from sub-national groups

The US homeland has not been attacked by another nation since World War II. One factor behind this outcome has been the US deployment of military forces with a high capability for counter-attack. There have, however, been significant attacks on the US homeland and other US assets by sub-national groups since World War II. Such attacks are typically not deterred by US capability for counter-attack, because the attacking group has no identifiable territory. Indeed, sub-national groups may attack US assets with the specific purpose of prompting US counter-attacks that harm innocent persons, thereby undermining the global political position of the US.

Attacks on the homeland by sub-national groups in recent decades include vehicle bombings of the World Trade Center in New York in February 1993 and the Murrah Federal building in Oklahoma City in April 1995, and aircraft attacks on the World Trade Center and the Pentagon in September 2001. Outside the homeland, attacks on US assets by sub-national groups have included vehicle-bomb attacks on a Marine barracks in Beirut in October 1983 and embassies in Tanzania and Kenya in August 1998, and a boat-bomb attack on the USS Cole in October 2000. At present, sub-national groups routinely attack US forces in Iraq.

In many of these incidents, the attacking group has been based outside the US. An exception was the Oklahoma City bombing, where the attacking group was domestic in

[83] Thompson, 2005.

both its composition and its motives. There is concern that future attacks within the US may be made by groups that are domestically based but have linkages to, or sympathy with, interests outside the US. This phenomenon was exhibited in London in July 2005, when young men born in the UK conducted suicide bombings in underground trains and a bus.

Reducing the risks of attack by sub-national groups requires a sophisticated, multi-faceted and sustained policy. An unbalanced policy can be ineffective or counterproductive. Since September 2001, the US government has implemented a policy that is heavily weighted toward offensive military action. Evidence is accumulating that this policy has been significantly counterproductive. Table 7-1 provides a sample of the evidence. The table shows recent public-opinion data from four Muslim-majority countries (Morocco, Egypt, Pakistan, Indonesia). In each country, a majority (ranging from 53 percent of respondents in Indonesia to 86 percent in Egypt) believes that the primary goal of the US "war on terrorism" is to weaken Islam or control Middle East resources (oil and natural gas). One expression of this belief is that substantial numbers of people (ranging from 19 percent of respondents in Indonesia to 91 percent in Egypt) approve of attacks on US troops in Iraq. Smaller numbers of people (ranging from 4 to 7 percent of respondents) approve of attacks on civilians in the US.[84]

The great majority of people, in these four countries and elsewhere, will not participate in attacks on US assets. However, there are consequences when millions of people believe that the US seeks to undermine their religion and culture and control their resources. Among other consequences, this belief creates a social climate that can help sub-national groups to form and to acquire the skills, funds and equipment they need in order to mount attacks. From a US perspective, such groups are "terrorists". Within their own cultures, they may be seen as soldiers engaged in "asymmetric warfare" with a powerful enemy.

Many experts who study these issues see a substantial probability that the US homeland will, over the coming years, be subjected to an attack comparable in severity to the attack of September 2001. Table 7-2 summarizes the judgment of a selected group of experts on this matter.

The threat environment over the coming decades

As mentioned above, an assessment of the risks of malicious actions at the Indian Point site should consider the general threat environment over the next century. Forecasting trends in the threat environment over such a period is a daunting exercise, with inevitably uncertain findings. Nevertheless, a decision about extended operation of the IP2 and IP3 reactors must reflect either an implicit or an explicit forecast of trends in the general threat environment. It is preferable that the forecast be explicit, and global in scope, because the US cannot be insulated from broad trends in violent conflict and social disorder.

---

[84] Kull et al, 2007.

Numerous analysts – in academia, government and business – are involved in efforts to forecast possible worldwide trends that pertain to violence. These efforts rarely attempt to look forward more than one or two decades. Two examples are illustrative. First, a group based at the University of Maryland tracks a variety of indicators for most of the countries in the world, in a data base that extends back to 1950 and earlier. Using these data, the group periodically provides country-level assessments of the potential for outbreaks of violent conflict.[85] Second, the RAND corporation has conducted a literature review and assessment of potential worldwide trends that would be adverse for US national security.[86]

Several decades ago, some analysts of potential futures began taking an integrated world view, in which social and economic trends are considered in the context of a finite planet. In this view, trends in population, resource consumption and environmental degradation can be significant, or even dominant, determinants of the options available to human societies. A well-known, early example of this genre is the *Limits to Growth* study, sponsored by the Club of Rome, which modeled world trends by using systems dynamics.[87] A more recent example is the work of the Global Scenario group, convened by the Stockholm Environment Institute (SEI).[88] This work was informed by systems-dynamics thinking, but focused on identifying the qualitative characteristics of possible future worldwide scenarios for human civilization. SEI identified three types of scenario, with two variants of each type, as shown in Table 7-3. The Conventional Worlds scenario has Market Forces and Policy Reform variants, the Barbarization scenario has Breakdown and Fortress World variants, while the Great Transitions scenario has Eco-Communalism and New Sustainability Paradigm variants.

The SEI scenarios provide a useful framework for considering the paths that human civilization could follow during the next century and beyond. Not all paths are possible. Notably, continued trends of resource depletion and irreversible degradation of ecosystems would limit the range of options available to succeeding generations. Similarly, destruction of human and industrial capital through large-scale warfare could inhibit economic and social recovery for many generations.

At present, the dominant world paradigm corresponds to the Market Forces scenario. Policy Reform is pursued at the rhetorical level, but is weakly implemented in practice. In parts of the world, notably in Africa, the Breakdown scenario is already operative. Aspects of the Fortress World scenario are also evident, and are likely to become more prominent if trends of resource depletion and ecosystem degradation continue, especially if major powers reject the dictates of sustainability and use armed force to secure resources. One sign of resource depletion is a growing body of analysis that predicts a

---

[85] Marshall and Gurr, 2005.
[86] Kugler, 1995.
[87] Meadows et al, 1972.
[88] Raskin et al, 2002.

peak in world oil production within the next few decades.[89] This prediction is sobering in view of the prominent role played by oil in the origins and conduct of war in the 20th century.[90] A now-familiar sign of ecosystem degradation is anthropogenic, global climate change. Analysts are considering the potential for climate change to promote, through its adverse impacts, social disorder and violence.[91] Other manifestations of ecosystem degradation are also significant. The recent 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".[92] According to analysts at the United Nations University in Bonn, continuation of such trends could create up to 50 million environmental refugees by the end of the decade.[93]

At present, human population and material consumption per capita are growing to a degree that visibly stresses the biosphere. Moreover, ecosystem degradation and resource depletion coexist with economic inequality, increasing availability of sophisticated weapons technology, and an immature system of global governance. Major powers are doing little to address these problems. It seems unlikely that these imbalances and sources of instability will persist at such a scale during the remainder of the 21st century without major change occurring. That change could take various forms, but two broad-brush scenarios can illustrate the range of possible outcomes. In one scenario, there would be a transition to a civilization similar to the New Sustainability Paradigm articulated by SEI. That civilization would be comparatively peaceful and technologically sophisticated. Alternatively, the world could descend into a form of barbarism such as the Fortress World scenario articulated by SEI. That society might be locally prosperous, within enclaves, but would be violent and unstable.

In assessing the likelihood of malicious actions at the Indian Point site, it would be prudent to adopt a pessimistic assumption of the potential for violent conflict in the future. Using SEI terminology, one could assume a Fortress World scenario with a high incidence of violent conflict of a type that involves sophisticated weapons and tactics. Violence might be perpetrated by national governments or by sub-national groups. A RAND corporation analyst has contemplated such a future in the following terms:[94]

> "A dangerous world may offer an insidious combination of nineteenth-century politics, twentieth-century passions, and twenty-first century technology: an explosive mixture of multipolarity, nationalism, and advanced technology."

---

[89] Hirsch et al, 2005; GAO, 2007.
[90] Yergin, 1991.
[91] Gilman et al, 2007; Campbell et al, 2007; Smith and Vivekananda, 2007.
[92] MEA, 2005, page 1.
[93] Adam, 2005.
[94] Kugler, 1995, page 279.

7.2 National Policy and Practice on Homeland Security

To mount an effective response to the general threat environment for the US homeland, the nation needs a coherent homeland-security strategy that links responses to an array of specific threats, such as the potential for a deliberate attack on a commercial nuclear facility. As discussed below, there are deficiencies in the strategy that has actually been implemented. The nominal strategy was articulated by the White House in the *National Strategy for Homeland Security*, first published in July 2002 and updated in October 2007. That document sets forth four major goals:[95]

"• Prevent and disrupt terrorist attacks;
• Protect the American people, our critical infrastructure, and key resources;
• Respond to and recover from incidents that do occur; and
• Continue to strengthen the foundation to ensure our long-term success."

The document defines critical infrastructure as including "the assets, systems, and networks, whether physical or virtual, so vital to the United States that their incapacitation or destruction would have a debilitating effect on security, national economic security, public health or safety, or any combination thereof".[96] Commercial nuclear reactors and their spent fuel are identified in the document as elements of the nation's critical infrastructure and key resources.

Protecting critical infrastructure

The US Department of Homeland Security has issued the *National Infrastructure Protection Plan* (NIPP), whose purpose is to provide "the unifying structure for the integration of critical infrastructure and key resources (CI/KR) protection into a single national program".[97] Other Federal agencies, including the NRC, have confirmed their acceptance of the NIPP.

The NIPP identifies three purposes of measures to protect critical infrastructure and key resources: (i) deter the threat; (ii) mitigate vulnerabilities; and (iii) minimize consequences associated with an attack or other incident. The NIPP identifies a range of protective measures as follows:[98]

> "Protection can include a wide range of activities such as improving business protocols, hardening facilities, building resiliency and redundancy, incorporating hazard resistance into initial facility design, initiating active or passive countermeasures, installing security systems, leveraging "self-healing"

---

[95] White House, 2007, page 1.
[96] White House, 2007, page 25.
[97] DHS, 2006, page iii.
[98] DHS, 2006, page 7.

> technologies, promoting workforce surety programs, or implementing cyber security measures, among various others".

Protective measures of these types could significantly reduce the probability that an attack would be successful. Such measures could, therefore, "deter" attacks by altering attackers' cost-benefit calculations. That form of deterrence is different from deterrence attributable to an attacked party's capability to counter-attack. For convenience, the two forms of deterrence are described hereafter as "protective deterrence" and "counter-attack deterrence". It should be noted that the effective functioning of both forms of deterrence requires that: (i) potential attackers are aware of the deterrence strategy; and (ii) the deterrence strategy is technically credible. That requirement means that the existence and capabilities of protective measures, such as those identified in the NIPP, should be widely advertised. The technical details of a protective measure should, however, remain confidential if disclosure of those details would allow the measure to be defeated.

From the statement quoted above, it is clear that the authors of the NIPP recognize the potential benefits of designing protective measures into a facility before it is constructed. At the design stage, attributes such as resiliency, redundancy, hardening and passive operation can often be incorporated into a facility at a comparatively low incremental cost. Capturing opportunities for low-cost enhancement of protective measures would allow decision makers to design against a more pessimistic (i.e., more prudent) threat assumption, thereby strengthening protective deterrence, reducing the costs of other security functions (e.g., guard forces), and enhancing civil liberties (e.g., by reducing the perceived need for measures such as wiretapping). Moreover, incorporation of enhanced protective measures would often reduce risks associated with conventional accidents (e.g., fires), extreme natural events (e.g., earthquakes), or other challenges not directly attributable to human malice.

Protective deterrence as part of a balanced policy for homeland security

As mentioned above, reducing the risks of attack by sub-national groups requires a sophisticated, multi-faceted and sustained policy. The policy must balance multiple factors operating within and beyond the homeland. An unbalanced policy can be ineffective or counterproductive.

A high-level task force convened by the Council on Foreign Relations (CFR) in 2002 understood the need for a balanced policy for homeland security.[99] One of the task force's major conclusions recognized the value of protective deterrence, while also recognizing that offensive military operations by the US could increase the risk of attack on the US. The conclusion was as follows:[100]

[99] Members of the task force included two former Secretaries of State, two former chairs of the Joint Chiefs of Staff, a former Director of the CIA and the FBI, two former US Senators, and other eminent persons.
[100] Hart et al, 2002, pp 14-15.

> "*Homeland security measures have deterrence value*: US counterterrorism initiatives abroad can be reinforced by making the US homeland a less tempting target. We can transform the calculations of would-be terrorists by elevating the risk that (1) an attack on the United States will fail, and (2) the disruptive consequences of a successful attack will be minimal. It is especially critical that we bolster this deterrent now since an inevitable consequence of the US government's stepped-up military and diplomatic exertions will be to elevate the incentive to strike back before these efforts have their desired effect."

The NIPP could support a vigorous national program of protective deterrence, as recommended by the CFR task force in 2002. However, current priorities of the US government are not consistent with such a program. Resources and attention devoted to offensive military operations are much larger than those devoted to the protection of critical infrastructure.[101] The White House states, in the *National Strategy for Combating Terrorism*, issued in September 2006:[102] "We have broken old orthodoxies that once confined our counterterrorism efforts primarily to the criminal justice domain." In practice, that statement means that the US government relies overwhelmingly on military means to reduce the risks of attacks on US assets by sub-national groups. That policy continues despite mounting evidence, as illustrated by Tables 7-1 and 7-2, that it is unbalanced and counterproductive.

A well-informed analyst of homeland security summarizes current national priorities in the following statement:[103]

> "Since the White House has chosen to combat terrorism as essentially a military and intelligence activity, it treats homeland security as a decidedly second-rate priority. The job of everyday citizens is to just go about their lives, shopping and traveling, while the Pentagon, Central Intelligence Agency, and National Security Agency wage the war."

During a future Presidential administration, national priorities may shift, leading to greater emphasis on protective deterrence. Unfortunately, critical-infrastructure facilities approved or constructed prior to that policy shift may lack the protective design features that are envisioned in the NIPP. Persons responsible for the design or licensing of currently-proposed activities, such as extended operation of the IP2 and IP3 reactors, could anticipate a national policy shift and take decisions accordingly.

Section 8, below, discusses the options and issues that should be considered in developing a balanced policy for protecting US critical infrastructure from attack by sub-national groups. That discussion shows the potential benefits that could be gained by assigning a higher priority to protective deterrence.

---

[101] Flynn, 2007.
[102] White House, 2006, page 1.
[103] Flynn, 2007, page 11.

7.3 Commercial Nuclear Facilities as Potential Targets of Attack

A sub-national group contemplating an attack within the US homeland would have a wide choice of targets. Also, groups in that category could vary widely in terms of their capabilities and motivations. In the context of potential attacks on nuclear facilities, the groups of concern are those that are comparatively sophisticated in their approach and comparatively well provided with funds and skills. The group that attacked New York and Washington in September 2001 met this description. A group of this type could choose to attack a US nuclear facility for one or both of two broad reasons. First, the attack could be highly symbolic. Second, the impacts of the attack could be severe.

Nuclear facilities as symbolic targets

From the symbolic perspective, commercial nuclear facilities are inevitably associated with nuclear weapons. The association further extends to the United States' large and technically sophisticated capability for offensive military operations. Application of that capability has aroused resentment in many parts of the world. Although nuclear weapons have not been used by the United States since 1945, US political leaders have repeatedly threatened, implicitly or explicitly, to use nuclear weapons again. Those threats coexist with efforts to deny nuclear weapons to other countries. The US government justified its March 2003 invasion of Iraq in large part by the possibility that the Iraqi government might eventually deploy nuclear weapons. There is speculation that the United States will attack nominally commercial nuclear facilities in Iran to forestall Iran's deployment of nuclear weapons.[104] Yet, the US government rejects the constraint of its own nuclear weapons by international agreements such as the Non-Proliferation Treaty.[105] As an approach to international security, this policy has been criticized by the director general of the International Atomic Energy Agency as "unsustainable and counterproductive".[106] It would be prudent to assume that this policy will motivate sub-national groups to respond asymmetrically to US nuclear superiority, possibly through an attack on a US commercial nuclear facility.

Radiological impacts of an attack on a nuclear facility

The impacts of an attack on a commercial nuclear facility could be severe because these facilities typically contain large amounts of radioactive material. Release of this material to the environment could create a variety of severe impacts. Also, as explained in Section 7.4, below, US nuclear facilities are provided with a defense that is "light" in a military sense. Moreover, imprudent design choices have made a number of these facilities highly vulnerable to attack. That combination of factors means that many US nuclear facilities can be regarded as potent radiological weapons that await activation by an enemy.

[104] Hersh, 2006; Brzezinski, 2007.
[105] Deller, 2002; Scarry, 2002; Franceschini and Schaper, 2006.
[106] ElBaradei, 2004, page 9.

As explained in Section 2, above, a facility's inventory of the radioactive isotope cesium-137 provides an indicator of the facility's potency as a radiological weapon. Table 2-1 shows estimated amounts of cesium-137 in nuclear fuel in the IP2 and IP3 reactors and spent-fuel pools, and in one of the spent-fuel storage modules of the Indian Point ISFSI when that facility is operational. Table 2-2 compares these amounts with atmospheric releases of cesium-137 from detonation of a 10-kilotonne fission weapon, the Chernobyl reactor accident of 1986, and atmospheric testing of nuclear weapons. These data show that release of a substantial fraction of the cesium-137 in an Indian Point nuclear facility would create comparatively large radiological consequences.

Section 7.6, below, discusses the impacts of attack-induced atmospheric releases of radioactive material from facilities at Indian Point, in the context of SAMA analyses.

7.4 The NRC's Approach to Nuclear-Facility Security

A policy on protecting nuclear facilities from attack is laid down in NRC regulation 10 CFR 50.13. That regulation was promulgated in September 1967 by the US Atomic Energy Commission (AEC) – which preceded the NRC – and was upheld by the US Court of Appeals in August 1968. It states:[107]

> "An applicant for a license to construct and operate a production or utilization facility, or for an amendment to such license, is not required to provide for design features or other measures for the specific purpose of protection against the effects of (a) attacks and destructive acts, including sabotage, directed against the facility by an enemy of the United States, whether a foreign government or other person, or (b) use or deployment of weapons incident to US defense activities."

Some readers might interpret 10 CFR 50.13 to mean that licensees are not required to design or operate nuclear facilities to resist potential attacks by sub-national groups. The NRC has rejected that interpretation in the context of vehicle-bomb attacks, stating:[108]

> "It is simply not the case that a vehicle bomb attack on a nuclear power plant would almost certainly represent an attack by an enemy of the United States, within the meaning of that phrase in 10 CFR 50.13."

Events have obliged the NRC to progressively require greater protection against attacks by sub-national groups. A series of events, including the 1993 vehicle-bomb attack on the World Trade Center in New York, persuaded the NRC to introduce, in 1994, regulatory amendments requiring licensees to defend nuclear power plants against vehicle bombs.[109] The attacks on New York and Washington in September 2001 led the NRC to require additional protective measures.

[107] Federal Register, Vol. 32, 26 September 1967, page 13445.
[108] NRC, 1994, page 38893.
[109] NRC, 1994.

With rare exceptions, the NRC has refused to consider potential malicious actions in the context of license proceedings or environmental impact statements. The NRC's policy on this matter is illustrated by a September 1982 ruling by the Atomic Safety and Licensing Board in the operating-license proceeding for the Harris nuclear power plant. An intervenor, Wells Eddleman, had proffered a contention alleging, in part, that the plant's safety analysis was deficient because it did not consider the "consequences of terrorists commandeering a very large airplane.....and diving it into the containment." In refusing to consider this contention, the ASLB stated:[110]

> "This part of the contention is barred by 10 CFR 50.13. This rule must be read *in pari materia* with 10 CFR 73.1(a)(1), which describes the "design basis threat" against which commercial power reactors *are* required to be protected. Under that provision, a plant's security plan must be designed to cope with a violent external assault by "several persons," equipped with light, portable weapons, such as hand-held automatic weapons, explosives, incapacitating agents, and the like. Read in the light of section 73.1, the principal thrust of section 50.13 is that military style attacks with heavier weapons are not a part of the design basis threat for commercial reactors. Reactors could not be effectively protected against such attacks without turning them into virtually impregnable fortresses at much higher cost. Thus Applicants are not required to design against such things as artillery bombardments, missiles with nuclear warheads, or kamikaze dives by large airplanes, despite the fact that such attacks would damage and may well destroy a commercial reactor."

The design basis threat

The NRC requires its licensees to defend against a design basis threat (DBT), a postulated attack that has become more severe over time. The present DBT for nuclear power plants was promulgated in January 2007. Details are not publicly available. (The NRC publishes a summary description, which is provided below.) The present DBT is similar to one ordered by the NRC in April 2003.[111] At that time, the NRC described its order as follows:[112]

> "The Order that imposes revisions to the Design Basis Threat requires power plants to implement additional protective actions to protect against sabotage by terrorists and other adversaries. The details of the design basis threat are safeguards information pursuant to Section 147 of the Atomic Energy Act and will not be released to the public. This Order builds on the changes made by the Commission's February 25, 2002 Order. The Commission believes that this DBT represents the largest reasonable threat against which a regulated private security force should be expected to defend under existing law."

---

[110] ASLB, 1982.
[111] NRC Press Release No. 07-012, 29 January 2007.
[112] NRC Press Release No. 03-053, 29 April 2003.

From that statement, and from other published information, it is evident that the NRC requires a comparatively "light" defense for nuclear power plants and their spent fuel. The scope of the defense does not reflect a full spectrum of threats. Instead, it reflects a consensus about the level of threat that licensees can "reasonably" be expected to resist.[113] In illustration of this approach, when the NRC adopted the currently-applicable DBT rule in January 2007, it stated that the rule "does not require protection against a deliberate hit by a large aircraft", and that "active protection [of nuclear power plants] against airborne threats is addressed by other federal organizations, including the military".[114]

The present DBT for "radiological sabotage" at a nuclear power plant has the following published attributes:[115]

> "(i) A determined violent external assault, attack by stealth, or deceptive actions, including diversionary actions, by an adversary force capable of operating in each of the following modes: A single group attacking through one entry point, multiple groups attacking through multiple entry points, a combination of one or more groups and one or more individuals attacking through multiple entry points, or individuals attacking through separate entry points, with the following attributes, assistance and equipment:
>
> > (A) Well-trained (including military training and skills) and dedicated individuals, willing to kill or be killed, with sufficient knowledge to identify specific equipment or locations necessary for a successful attack;
> > (B) Active (e.g., facilitate entrance and exit, disable alarms and communications, participate in violent attack) or passive (e.g., provide information), or both, knowledgeable inside assistance;
> > (C) Suitable weapons, including handheld automatic weapons, equipped with silencers and having effective long range accuracy;
> > (D) Hand-carried equipment, including incapacitating agents and explosives for use as tools of entry or for otherwise destroying reactor, facility, transporter, or container integrity or features of the safeguards system; and
> > (E) Land and water vehicles, which could be used for transporting personnel and their hand-carried equipment to the proximity of vital areas; and
>
> (ii) An internal threat; and
> (iii) A land vehicle bomb assault, which may be coordinated with an external assault; and

[113] Fertel, 2006; Wells, 2006; Brian, 2006.
[114] NRC Press Release No. 07-012, 29 January 2007.
[115] 10 CFR 73.1 Purpose and scope, accessed from the NRC web site (www.nrc.gov) on 14 June 2007.

(iv) A waterborne vehicle bomb assault, which may be coordinated with an external assault; and
(v) A cyber attack."

That DBT seems impressive, and is more demanding than previously-published DBTs. However, the DBT cannot be highly demanding in practice, given the equipment that the NRC requires for a security force. Major items of required equipment are semiautomatic rifles, shotguns, semiautomatic pistols, bullet-resistant vests, gas masks, and flares for night vision.[116] Plausible attacks could overwhelm a security force equipped in this manner. Also, press reports state that the assumed attacking force contains no more than six persons.[117] The average US nuclear-plant site employs about 77 security personnel, covering multiple shifts.[118] Thus, comparatively few guards are on duty at any given time.[119]

Table 7-4 sets forth some potential modes and instruments of attack on a nuclear power plant, and summarizes the present defenses against these modes and instruments. That table shows that a variety of potential attack scenarios could not be effectively resisted by present defenses. Potential attacks at Indian Point are discussed in Section 7.5, below.

Protective deterrence and the NRC

A rationale for the present level of protection of nuclear facilities was articulated by the NRC chair, Richard Meserve, in 2002:[120]

> "If we allow terrorist threats to determine what we build and what we operate, we will retreat into the past – back to an era without suspension bridges, harbor tunnels, stadiums, or hydroelectric dams, let alone skyscrapers, liquid-natural-gas terminals, chemical factories, or nuclear power plants. We cannot eliminate the terrorists' targets, but instead we must eliminate the terrorists themselves. A strategy of risk avoidance – the elimination of the threat by the elimination of potential targets – does not reflect a sound response."

That statement shows no understanding of the need for a balanced policy to protect critical infrastructure, employing the principles of protective deterrence. There is considerable potential to embody those principles in the design of nuclear facilities, especially new facilities. It has been known for decades that nuclear power plants could

---

[116] 10 CFR 73 Appendix B – General Criteria for Security Personnel, Section V, accessed from the NRC web site (www.nrc.gov) on 14 June 2007.
[117] Hebert, 2007.
[118] Holt and Andrews, 2006.
[119] If each member of a 77-person security force were on duty 40 hours/week for 42 weeks/year (allowing 10 weeks/year for vacation, illness, training, etc.), the average number of persons on duty at any time would be 15.
[120] Meserve, 2002, page 22.

be designed to be more robust against attack. For example, in the early 1980s the reactor vendor ASEA-Atom developed a preliminary design for an "intrinsically safe" commercial reactor known as the PIUS reactor. Passive-safety design principles were used. The design basis for the PIUS reactor included events such as equipment failures, operator errors and earthquakes, but also included: (i) takeover of the plant for one operating shift by knowledgeable saboteurs equipped with large amounts of explosives; (ii) aerial bombardment with 1,000-pound bombs; and (iii) abandonment of the plant by the operators for one week.[121]

Consideration of malicious actions in environmental impact statements

As stated above, the NRC has generally refused to consider potential malicious actions in environmental impact statements. An exception is the NRC's August 1979 GEIS on handling and storage of spent fuel (NUREG-0575), which considered potential sabotage events at a spent-fuel pool.[122] Table 7-5 describes the postulated events, which encompassed the detonation of explosive charges in the pool, breaching of the walls of the pool building and the pool floor by explosive charges or other means, and takeover of the central control room for one half-hour. Involvement of up to about 80 adversaries was implied.

NUREG-0575 did not recognize the potential for an attack with these attributes to cause a fire in the pool.[123] Technically-informed attackers operating within this envelope of attributes could cause a fire in a spent-fuel pool at the IP2 or IP3 plant or any other operating nuclear power plant in the US.[124] Informed attackers could use explosives, and their command of the control room for one half-hour, to drain water from the pool and release radioactive material from the adjacent reactor. The radiation field from the reactor release and the drained pool could preclude personnel access, thus precluding recovery actions if command of the plant were returned to the operators after one half-hour. Exposure of spent fuel to air would initiate a fire that would release to the atmosphere a large fraction of the pool's inventory of cesium-137.[125]

Pursuant to a ruling by the 9th Circuit of the US Court of Appeals, in 2007 the NRC Staff issued a Supplement to its October 2003 Environmental Assessment (EA) for a proposed ISFSI at the Diablo Canyon site. The Supplement purported to address the risks of potential malicious actions at the ISFSI. A draft version of the Supplement was issued in May 2007 and a final version was issued in August 2007.[126] IRSS prepared a detailed

---

[121] Hannerz, 1983.
[122] NRC, 1979, Section 5 and Appendix J.
[123] The sabotage events postulated in NUREG-0575 yielded comparatively small estimated radioactive releases.
[124] Spent-fuel pools at the IP2 and IP3 plants and other US nuclear power plants are currently equipped with high-density racks for holding spent fuel. Loss of water from a pool equipped with high-density racks would, over a wide range of water-loss scenarios, lead to ignition and burning of spent fuel assemblies.
[125] Alvarez et al, 2003; Thompson, 2006; NAS, 2006.
[126] NRC, 2007a; NRC, 2007b.

review of the draft version and a short review of the final version.[127] There was little change from the draft to the final version. Both versions exhibited grave deficiencies. Neither version provided a credible assessment of the risks of potential malicious actions.

The NRC Staff has refused to implement the 9th Circuit ruling in regions of the US, such as New York State, that do not fall under the jurisdiction of the 9th Circuit. Nevertheless, the US Environmental Protection Agency (EPA) has requested the NRC Staff to provide, in the EIS for license extension of the IP2 and IP3 plants, "an analysis of the impacts of intentional destructive acts (e.g., terrorism)".[128] The EPA cites the 9th Circuit ruling as requiring such an analysis.

7.5 Vulnerability of the IP2 and IP3 Reactors and Pools to Attack

The IP2 and IP3 plants were not designed to withstand an attack. Nor were they designed to withstand a conventional accident involving core damage. However, they are comparatively massive structures. Thus, they have some ability to survive an attack or a conventional core-damage accident without necessarily suffering a large release of radioactive material. More precisely, a range of attack scenarios and conventional core-damage scenarios can be articulated, and an atmospheric source term can be estimated for each scenario. PRA techniques have been developed to examine conventional accident scenarios. Those techniques could be adapted to examine attack scenarios, by postulating for each scenario an initiating event (the attack) and assessing the conditional probabilities and other characteristics of the various possible outcomes of that event. The NRC employed that approach in developing its vehicle-bomb rule.[129]

PRA studies have been done for the IP2 and IP3 reactors, in the form of IPEs, IPEEEs and, more recently, PSAs. That work could be built upon to develop a broad picture of the vulnerability of these reactors to attack. The analysis could be further extended to assess the risks of pool fires arising from conventional accidents or attacks, with consideration of pool-reactor interactions. A comprehensive assessment of the risks of continued operation of the IP2 and IP3 plants would include all of these elements. Such an assessment could be performed without access to classified information, by using existing engineering knowledge and models, and by developing new models. Published professional literature provides illustrations of analytic techniques that could be used.[130]

A comprehensive assessment of the risks posed by operation of the IP2 and IP3 plants does not exist. If such an assessment did exist, parts of it would not be appropriate for publication. In the absence of that assessment, IRSS provides here some illustrative analysis of the vulnerability of the IP2 and IP3 reactors and pools to attack. The analysis is general and brief, to avoid disclosing sensitive information. IRSS could expand upon this analysis if given the opportunity to do so in a protected setting. It should be noted

[127] Thompson, 2007a; Thompson, 2007b.
[128] EPA, 2007.
[129] NRC, 1994.
[130] See, for example: Morris et al, 2006; Honnellio and Rydell, 2007; Sdouz, 2007.

that skilled attackers could readily obtain or infer a much greater depth of knowledge about the plants' vulnerability than is provided here.

Table 7-4 and the discussion in Section 7.4, above, show that US commercial nuclear plants are provided with a comparatively light defense. Thus, a sub-national group with personnel, resources and preparation time comparable to those involved in the September 2001 attacks on New York and Washington could mount an attack at the Indian Point site with a substantial probability of success.

Modes of attack

An attack might begin with actions that put the IP2 and/or IP3 plant in a compromised state and create stress for plant personnel. For example, attackers could sever the site's electricity grid connection and disable the service water system without needing to penetrate the site boundary. Due to a design deficiency at this site, lack of service water would disable the emergency diesel generators. Thus, the site would lose its primary supplies of electricity and cooling water. Additional actions, which could be accomplished by an insider, could then initiate a core-damage sequence.[131] The attackers might be satisfied to achieve core damage, recognizing that core damage would not necessarily lead to a large release of radioactive material. Alternatively, the attack plan might include actions that compromise the integrity of the reactor containment, in order to ensure a large atmospheric release.

The containment structure is a reinforced concrete vertical cylinder topped by a hemispherical dome made of the same material. The side walls are 4.5 feet thick with a 0.4 inch thick steel liner, and the dome is 3.5 feet thick with a 0.5 inch thick steel liner.[132] By some standards, this is a robust structure. It could, however, be readily breached using instruments of attack that are available to sub-national groups. For example, Table 7-6 shows the capability of shaped charges.[133] A shaped charge could be delivered by a general-aviation aircraft used as a cruise missile in remote-control or kamikaze mode. Alternatively, shaped charges could be placed by attackers who reach the target locations by parachute, ultralight aircraft, helicopter, or site penetration from land or the Hudson River. The attack might involve a standoff component in which shaped-charge warheads are delivered from an offsite location by an instrument such as the TOW (tube-launched, optically-tracked, wire-guided) missile. A shaped charge could be the first stage of a tandem device. In that configuration, the first stage penetrates a structure and is followed by a second stage that damages equipment inside the penetrated structure via fragmentation, blast, incendiary or "thermobaric" effects. An appropriately designed tandem device of this kind could be used to attack the IP2 or IP3 reactor without any other actions being taken, with a high probability of causing a large atmospheric release of radioactive material.

---

[131] The additional actions, which could be taken in advance of the attack, would disable equipment that is needed to maintain core cooling if the primary supplies of electricity and cooling water are unavailable.
[132] Entergy, 2007b, Section 5.1.2. This source describes the IP2 plant; the IP3 plant has a similar design.
[133] Also see: Walters, 2003.

The spent-fuel pools at the IP2 and IP3 plants are immediately outside the respective reactor containments. The floor of each pool is below the local grade level. However, the site slopes downward toward the Hudson River, so the pool floor is above river level. The pool walls are made of concrete, 3 to 6 feet thick.[134] As discussed above, a sub-national group could obtain the instruments needed to breach such a wall. Attackers might choose to breach the wall at the local grade level. That action would cause the water level in the pool to fall to near the top of the spent-fuel storage racks. Thereafter, the remaining water would boil and, if makeup water were not supplied, the pool could boil dry in about a day. As fuel assemblies became exposed, their temperature would rise. An assembly exposed for the majority of its length could heat up to ignition temperature in a few hours.[135]

In favorable circumstances, plant operators and other personnel could potentially prevent the initiation of a pool fire by the attack postulated above. To prevent a fire, the operators would have to improvise a water makeup system, or a system to spray water on exposed fuel assemblies. The operators' tasks would be greatly complicated by the radiation field from exposed fuel.[136] To prevent operators from providing makeup or spray water, the attackers could combine an attack on the pool with an attack on the adjacent reactor. The release of radioactive material from the reactor would generate a local radiation field that would, over a wide range of attack scenarios, preclude operator access for a period of days.

Aircraft as instruments of attack

Many people have suggested that an aircraft could be used as an instrument of attack on a nuclear facility. The NRC Staff considered this possibility in its Supplement to the EA for the proposed Diablo Canyon ISFSI, as discussed above.[137] The Staff made the mistaken assumption that a large, fuel-laden commercial aircraft would pose the greatest threat using this attack mode. Large, commercial aircraft caused major damage to the World Trade Center and the Pentagon in September 2001, but they would not be optimal as instruments of attack on a nuclear power plant. They 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. Note that the US General Accounting Office (GAO) expressed concern, in September 2003 testimony to Congress, about the potential for malicious use of general-aviation aircraft. The testimony stated:[138]

---

[134] Entergy, 2007b, Table 9.5-1. This source describes the IP2 plant; the IP3 plant has a similar design.
[135] Thompson, 2000.
[136] Alvarez et al, 2003.
[137] NRC, 2007a; NRC, 2007b.
[138] Dillingham, 2003, page 14.

> "Since September 2001, TSA [the Transportation Security Administration] has taken limited action to improve general aviation security, leaving it far more open and potentially vulnerable than commercial aviation. General aviation is vulnerable because general aviation pilots are not screened before takeoff and the contents of general aviation planes are not screened at any point. General aviation includes more than 200,000 privately owned airplanes, which are located in every state at more than 19,000 airports. Over 550 of these airports also provide commercial service. In the last 5 years, about 70 aircraft have been stolen from general aviation airports, indicating a potential weakness that could be exploited by terrorists."

7.6 Consideration of Potential Attacks in SAMA Analyses

In order to consider potential attacks on the IP2 and IP3 plants in SAMA analyses, it is necessary to assign a probability to each potential attack scenario. At present, there is no statistical basis to support quantitative estimates of these probabilities. However, reasonable assumptions of probability can be postulated and used in SAMA analyses to: (i) compare the risks of conventional accidents with the risks of postulated attacks; and (ii) identify and examine SAMAs that reduce these risks.

Here, IRSS provides some illustrative analyses of potential attacks that yield a large atmospheric release from a reactor and/or a pool fire. The probability of such an attack is postulated here to be 1 per 10,000 reactor-years. That number corresponds to a probability of about 1 per century across the US fleet of 104 commercial reactors, assuming that all the reactors are equally attractive as targets. In the SAMA analyses described here, the probability of 1 per 10,000 reactor-years includes a factor of uncertainty. Given the anticipated threat environment over the coming decades, and the vulnerability of the IP2 and IP3 plants, a postulated probability of 1 per 10,000 reactor-years is at the lower end of the range of assumptions that would be prudent in the context of homeland-security planning.

Table 7-7 shows the estimated present value of cost risks of an atmospheric release from the IP2 and IP3 plants. Attack-induced releases are considered, for a postulated probability of 1 per 10,000 reactor-years. Releases caused by conventional accidents are also considered, carrying forward the analyses summarized in Tables 5-7 and 6-3 to include internal and external initiating events and uncertainty. Thus, Table 7-7 provides an overall summary of the present value of cost risks as estimated by Entergy and IRSS. These estimates are discussed further in Section 9, below.

The illogic of NUREG-1437

The illustrative analysis that IRSS provides here does not purport to be comprehensive. Nevertheless, it shows that PRA techniques can be adapted to assess risks and risk-reducing options related to malice-induced accidents. IRSS's analysis also shows the illogic of the NRC's position in its GEIS on license renewal (NUREG-1437), regarding malice-induced accidents. As cited in Section 4, above, that position has two major elements.[139] First, the NRC asserts that malice-induced accidents "are not reasonably expected". That statement is contradicted by numerous events before and after the GEIS was published in May 1996. Second, the NRC asserts that, in the event of a malice-induced accident, "radiological releases would be no worse than those expected from internally initiated events". That statement ignores the opportunities available to skilled attackers to cause a very large release. One such opportunity is to cause a combined release from a reactor and the adjacent spent-fuel pool. Another opportunity is to cause core damage and a breach of containment, in order to maximize the release from a reactor.

8. Neglected Risk Issue #4: The Wider Context of Nuclear-Facility Risk

This report addresses two categories of risk-related impacts: (i) direct radiological harm and the indirect social and economic impacts arising from that direct harm; and (ii) regulatory impacts arising from the NRC's general approach to the licensing of nuclear power plants. Impacts in the second category adversely affect the environment across the United States and globally. Granting of license extensions for the IP2 and IP3 plants would add to that burden of adverse regulatory impacts. Understanding the additional burden requires one to view the risks posed by Indian Point facilities in a wider context.

Here, IRSS provides illustrative analyses of two respects in which the NRC's approach to the licensing of nuclear power plants creates adverse regulatory impacts. First, the NRC's licensing approach does not support a policy of protective deterrence. Instead, it contributes to a counterproductive approach by the Federal government to protection of the nation's critical infrastructure. Second, the NRC has adopted a policy of excessive secrecy that yields various adverse impacts, including suppression of clear-headed discussion of the risk posed by nuclear plants.

The NRC's failure to support protective deterrence

Section 7, above, describes the need for protective deterrence as part of a balanced policy for homeland security. The role of protective deterrence is illustrated by Table 8-1, which shows the strengths and weaknesses of approaches to protecting US critical infrastructure from attack by sub-national groups. That table shows the benefits that could flow from adoption of resilient design, passive defense, and other protective measures for infrastructure facilities such as the IP2 and IP3 plants. The NIPP envisions the use of such measures. Yet, the NRC does not require these measures. Instead, the NRC prefers an approach that relies on offensive military operations, surveillance of the domestic population, and related measures as the primary means of protecting nuclear facilities. That preference is evident in the NRC Staff's Supplement to the EA for the Diablo Canyon ISFSI, which states that "the broad actions taken by the Federal

[139] NRC, 1996, page 5-18.

government and the specific actions taken by the NRC since September 11, 2001, have helped to reduce the potential for terrorist attacks against NRC-regulated facilities".[140] The Staff does not recognize that many actions taken by the Federal government have been counterproductive.

The NRC's preference for secrecy instead of robust design

As an illustrative exercise, consider a proposed nuclear facility (e.g., a reactor, a spent-fuel pool, or an ISFSI) that would contain a large amount of radioactive material. There are two design options. Option A would employ a design that was developed several decades ago. It would have a comparatively low ability to resist an attack. In an effort to compensate for its vulnerability, it would be protected by a force of armed guards. Detailed information about the option's design, and about the guard force, would be secret. The public would be excluded from any effective role in the licensing of this option. The licensing and operation of this option would occur in a climate of fear. By contrast, Option B would employ a modern design using hardening, resiliency and passive protection as envisioned in the NIPP. It would have a comparatively high ability to resist an attack. As a result, a less capable guard force would be required, there would be no need for secrecy, and the public would have full access to license proceedings.

To further simplify this exercise, assume that the estimated life-cycle costs and radiological risks of Options A and B would be identical. In that case, Option A would be clearly inferior because it would increase the use of secret information and decrease the public's role in decision-making, tendencies that are antithetical to US traditions and inconsistent with long-term national prosperity. Put differently, Option A would have higher levels of social and economic impacts. Moreover, if a malicious action were to cause a release of radioactive material, the social and economic impacts would be higher if Option A had been chosen, because the public would tend to blame the government that had excluded them from the decision-making arena.

This exercise, although highly simplified, is far from theoretical. Design options have been employed that are highly vulnerable to attack, and the NRC has become much more secretive in recent years. Consider the case of spent-fuel pools equipped with high-density racks. All the spent-fuel pools at US nuclear power plants are so equipped. The NRC asserts that these pools are adequately safe and secure. Yet, since September 2001 the NRC has not published any technical analysis on the safety and security of spent-fuel pools, and has repeatedly denied requests by intervenors that spent-fuel-pool risks be addressed in evidentiary hearings. As a result, the NRC has never published any analysis on the risks of a spent-fuel-pool fire initiated by malicious action, and has never allowed an examination of these risks in a license proceeding. In this real-world case, spent-fuel pools equipped with high-density racks are Option A. An Option B is available, namely

[140] NRC, 2007a, page 4. Also see: Meserve, 2002.

re-equipping the pools with low-density, open-frame racks, as was intended when the present generation of US nuclear power plants was designed.[141]

The costs of secrecy

As stated above, secrecy is antithetical to US traditions and inconsistent with long-term national prosperity. Thus, an EIS for a nuclear facility should consider the social and economic impacts of secrecy. That consideration would tend to favor design options involving features such as hardening, resiliency and passive protection. In some instances, secrecy-related impacts could be so high that they outweigh any benefits from operating the facility. It should be remembered that nuclear facilities exist to serve society, rather than vice versa.[142]

It should also be noted that the safety and security of nuclear facilities will be significantly and adversely affected by an entrenched culture of secrecy. Such a culture is not compatible with a clear-headed, science-based approach to the understanding of risks. Entrenched secrecy perpetuates dogma, stifles dissent, 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.[143]

The limited effectiveness of knowledge suppression

Within the NRC and elsewhere, factions will argue that suppression of knowledge can reduce the risks of malicious actions at nuclear facilities. Knowledge suppression is, however, a strategy with limited effectiveness. Nuclear fission power is a mature technology based on science from the mid-20th century. Detailed information about nuclear technology and individual nuclear facilities is archived at many locations around the world, and large numbers of people have worked in nuclear facilities. Similarly, information about weapons and other devices that could be used to attack nuclear facilities is widely available. Large numbers of people have been trained to use such devices in a military context. Thus, it would be prudent to assume that sophisticated sub-national groups can identify and exploit vulnerabilities in US nuclear facilities.

A balanced approach to managing sensitive information

From the preceding discussion, it is clear that managing sensitive information should be done carefully, balancing several considerations. The NRC has not achieved this balance since September 2001. Instead, the NRC has taken a crude, counterproductive approach in which it is excessively secretive while also making assertions about safety and security

---

[141] In this case, Option B would have a much lower radiological risk than Option A, but a higher capital cost.

[142] The NRC's Principles of Good Regulation state, in the context of openness: "Nuclear regulation is the public's business, and it must be transacted publicly and candidly". See: Principles of Good Regulation, accessed at the NRC web site (www.nrc.gov) on 20 November 2007.

[143] Thompson, 2002, Section X.

that do not withstand critical examination. To help correct this situation, the NRC should engage public stakeholders (citizen groups, academics, state and local governments, etc.) and licensees in a dialogue that seeks consensus on an effective, balanced policy for management of sensitive information. Implementation of that policy would not necessarily require changes in NRC rules.

9. An Integrated View of Risk-Related Impacts and Options for Reducing these Impacts

Sections 5 through 8, above, discuss risk issues that have been neglected by the NRC and Entergy. In Sections 5 through 7, that discussion yields quantitative findings that are expressed as variations on SAMA analyses conducted by Entergy. Those findings are summarized in Table 7-7, which shows the estimated present value of cost risks (PVCR) of an atmospheric release from the IP2 and IP3 plants for five cases. In the following discussion, PVCR is used as an indicator of risk, which does not imply that PVCR is the only or best indicator of risk.

The first case addressed in Table 7-7 encompasses conventional accidents leading to core damage. In that case, Entergy estimates the PVCR at $10.7 million for the IP2 plant and the same amount for the IP3 plant. Correction of those estimates by IRSS, to account for containment bypass during High/Dry sequences, yields a PVCR of $58.0 million for the IP2 plant and $34.1 million for the IP3 plant.

The second case encompasses conventional accidents leading to a pool fire. Assuming a probability for this event as determined in NUREG-1353, IRSS finds the PVCR to be $27.7 million. Note that IRSS does not regard the NUREG-1353 probability estimate as definitive.

The third case encompasses malice-induced accidents leading to core damage. In that case, IRSS postulates an accident probability of 1 per 10,000 reactor-years. That postulate, linked to the SAMA analyses and assumptions articulated by Entergy, yields a PVCR of $73.2 million for the IP2 plant and $62.4 million for the IP3 plant.

The fourth case encompasses malice-induced accidents leading to a pool fire, with a postulated accident probability of 1 per 10,000 reactor-years. In that case, IRSS finds the PVCR to be $498 million.

The fifth case encompasses malice-induced accidents leading to core damage at a reactor and a fire in the adjacent pool, with a postulated accident probability of 1 per 10,000 reactor-years. In that case, IRSS finds the PVCR to be $569 million for the IP2 plant and $559 million for the IP3 plant. Note that plausible attacks could lead to core damage and pool fires at both plants, yielding a higher value of PVCR than is estimated here.

SAMAs relevant to conventional accidents leading to core damage

Entergy has identified SAMAs that could reduce the PVCR of conventional accidents leading to core damage. Several of these SAMAs address, to varying extents, the potential for containment bypass due to induced failure of steam generator tubes. Entergy's neglect of that potential has resulted in under-estimation of PVCR by $47.3 (58.0 minus 10.7) million for the IP2 plant and $23.4 (34.1 minus 10.7) million for the IP3 plant. Thus, according to Entergy's methodology, any SAMA that could eliminate this type of containment bypass would be cost-effective if its cost were less than $47.3 million for the IP2 plant and $23.4 million for the IP3 plant.[144]

The potential for containment bypass due to failure of steam generator tubes, whether induced or spontaneous, is a major design weakness in the present generation of PWRs. These plants were designed decades ago. In examining SAMAs that address this bypass problem, analysts should draw lessons from recent design studies. For example, engineers working on the design of Westinghouse's IRIS reactor (a PWR undergoing pre-application licensing) were very conscious of the potential for induced failure of steam generator tubes during High/Dry core-damage sequences. Accordingly, they developed a design that seeks to eliminate this potential.[145] In the IRIS design, the steam generators are of a once-through type employing Inconel 690 tubes in a helical coil. These tubes are expected to have a high resistance to creep rupture. The primary coolant is on the exterior of the tubes, so that the tube walls are in compression rather than tension. The secondary-side piping is designed for full primary pressure, which has eliminated the need for secondary-side safety valves. These design features, taken together, are expected to dramatically reduce the potential for containment bypass via failed steam generator tubes.

The IP2 and IP3 plants cannot be modified to meet the level of safety that is expected of a new plant. Nevertheless, Entergy should redo its SAMA analyses, to properly examine options that reduce the risk arising from containment bypass due to failure of steam generator tubes. The preferred options should be those that rely on passive safety and robust design, as employed in the IRIS design. Options that employ active systems and operator actions are less reliable and more prone to degradation over a period of years. Entergy has identified an option that may have some of the needed attributes. That option is designated as Phase II SAMA Candidate Number 019 for the IP2 plant and Number 017 for the IP3 plant. It involves increasing the pressure capacity of the secondary side such that steam generator tube failure would not cause the secondary side safety valves to open. Entergy estimates the cost of this SAMA to be $13 million for the IP2 plant and the same amount for the IP3 plant.[146] That cost is substantially below the

---

[144] The break-even costs would actually be somewhat higher than these amounts, because Entergy's SAMA analyses already involve a contribution to PVCR from core-damage sequences involving failure of steam generator tubes.
[145] Maioli et al, 2004.
[146] Entergy, 2007a, Appendix E, Tables E.2-2 and E.4-2.

break-even costs discussed above ($47.3 million for the IP2 plant and $23.4 million for the IP3 plant) for options that eliminate the bypass potential, providing a strong indication that this SAMA would be cost-effective.[147]

SAMAs relevant to pool fires

Entergy has not identified any SAMA that could reduce the PVCR of conventional or malice-induced accidents that lead to a pool fire. Options that could achieve this outcome are described in Table 9-1. By far the most effective and reliable option would be to re-equip the pools with low-density, open-frame racks, as was intended when the IP2 and IP3 plants were designed. Table 9-2 provides a cost estimate for implementing this option by transferring spent fuel from the pool to an onsite ISFSI. The estimated cost of the option would be $43 to 86 million for the IP2 plant and $41 to 83 million for the IP3 plant.

It should be noted that an identical operation (transferring the same amount of spent fuel from the pool to an onsite ISFSI) would otherwise occur during decommissioning of the plant, if there were no offsite location (such as a repository at Yucca Mountain) to which spent fuel could be taken at that time. As stated in Section 7.1, above, it is likely that spent fuel will be stored at the Indian Point site for the foreseeable future, potentially for longer than a century. Assuming that outcome, the net present cost of the option of re-equipping each pool with low-density, open-frame racks would be, in the context of a 20-year license extension, the difference between the cost of implementing the option now and the present value of the same cost incurred 20 years in the future.[148] Assuming a discount rate of 7 percent per year, the present value would be 25 percent of the cost 20 years in the future. Thus, the net present cost of transferring spent fuel to an onsite ISFSI would be $32 to 65 million for the IP2 plant and $31 to 62 million for the IP3 plant.[149]

Table 7-7 shows two estimates for the PVCR of a pool fire at the IP2 or IP3 plant. One estimate, for a conventional accident with a probability as in NUREG-1353, is $27.7 million. That estimate of PVCR would not be sufficient to justify the estimated net present cost ($31 to 65 million) of re-equipping each pool with low-density, open-frame racks. However, a comprehensive, site-specific assessment of the risk of a pool fire caused by a conventional accident would probably yield a higher estimate of PVCR.[150]

A discount rate of 7 percent per year is generally used in this report, following Entergy's practice. That rate is not necessarily appropriate for SAMA analysis. If a rate of 3 per cent per year is used for the cost-benefit comparison described in the preceding paragraph, one finds that the PVCR of a pool fire rises from $27.7 million to $38.7

---

[147] The cost of this SAMA is substantially below the break-even cost. Thus, the SAMA does not need to entirely eliminate the bypass potential in order to be cost-effective.
[148] The comparatively small cost of rack replacement is neglected here.
[149] 1.0 – 0.25 = 0.75; 0.75 x 43 to 86 = 32 to 65; 0.75 x 41 to 83 = 31 to 62.
[150] The estimated frequency and offsite costs of the event would probably be significantly higher than the values shown in Table 6-2.

million, while the net present cost of re-equipping each pool with low-density, open-frame racks falls from a range of $31 to 65 million to a range of $18 to 39 million. In that case, re-equipping each pool with low-density racks would be clearly justified. Note that Entergy uses a discount rate of 3 percent per year to test the sensitivity of its SAMA analyses. There is a strong ethical argument for using a discount rate of zero to assess the risk of radiological harm. With that rate, the PVCR of a pool fire would rise from $27.7 million to $51.5 million.

The second estimate of PVCR for a pool fire that is shown in Table 7-7, postulating a successful attack with a probability of 1 per 10,000 reactor-years, is $498 million. That value would amply justify the estimated $31 to 65 million net present cost of re-equipping each pool with low-density, open-frame racks.

SAMAs relevant to malice-induced accidents leading to core damage

Entergy has not identified any SAMA whose specific purpose would include reducing the PVCR of malice-induced accidents that lead to reactor core damage. A broad set of SAMAs should be developed for this purpose, and their respective contributions to risk reduction should be assessed by adapting PRA techniques. Some SAMAs in the set would be identical to, or closely related to, SAMAs that could reduce the PVCR of conventional accidents that lead to core damage. Other SAMAs would be useful primarily, or entirely, for decreasing the risk of attack. Identifying and assessing appropriate SAMAs is a task that should be viewed in the context of homeland-security planning. That task should be implemented as described in Section 10, below.

Section 7.5, above, provides a brief discussion of one respect in which a design deficiency at the IP2 and IP3 plants makes these plants vulnerable to attack. The particular design deficiency is the dependence of the emergency diesel generators on a supply of service water for cooling. At the Indian Point site, attackers could sever the site's electricity grid connection and disable the service water system without needing to penetrate the site boundary. Indirectly, this attack would disable the emergency diesel generators. Thus, the site would lose its primary supplies of electricity and cooling water. Additional actions, which in some attack scenarios would not require penetration of the site boundary, could then initiate a core-damage sequence and a breach of the containment, leading to a large atmospheric release. Entergy has identified two SAMAs that could potentially prevent this attack from succeeding, although Entergy does not discuss the use of these SAMAs for that purpose. The SAMAs are designated as Phase II SAMA Candidates Numbers 031 and 032 for the IP2 plant and Numbers 028 and 029 for the IP3 plant. They would provide backup sources of cooling water for the emergency diesel generators at a cost of $1.7 million (IP2 SAMA #031 or IP3 SAMA #028) or $0.5 million (IP2 SAMA #032 or IP3 SAMA #029).[151] This example shows how a SAMA could reduce risks from both conventional accidents and malice-induced accidents.

[151] Entergy, 2007a, Appendix E, Tables E.2-2 and E.4-2.

SAMAs that would be useful primarily for decreasing the risk of attack can be illustrated by options intended to prevent the impact of an aircraft on vulnerable portions of the IP2 or IP3 plant. Such an impact could occur in the context of a conventional accident (loss of power, etc.) affecting an aircraft. The probability of such an impact can be quantitatively estimated from the historical record of aircraft crashes, and is comparatively low. Alternatively, the impact could be part of a deliberate attack. In planning such an attack, a well-informed group of attackers would probably choose to employ a general-aviation aircraft laden with explosive material, as discussed in Section 7.5, above. There are at least two options at the Indian Point site for preventing deliberate impact by an aircraft. First, an active defense could be mounted using systems such as Sentinel and Phalanx.[152] Implementation of that defense would require the presence of US military personnel at the site, and would raise complex questions of command authority. Second, vulnerable portions of the site could be surrounded by one or more steel cages (made of beams, cables and nets) designed to shred an approaching aircraft and cause its explosive payload, if any, to detonate at a safe distance. A campaigning organization, Committee to Bridge the Gap, has termed this concept "Beamhenge".[153]

Options for reducing regulatory impacts

Section 8, above, discusses two respects in which the NRC's licensing approach creates adverse regulatory impacts. First, the NRC's licensing approach contributes to a counterproductive approach by the Federal government to protection of the nation's critical infrastructure. Second, the NRC has adopted a policy of excessive secrecy that yields various adverse impacts.

Options for reducing these regulatory impacts would necessarily be consistent with a policy of protective deterrence. In the context of the IP2 and IP3 plants, these impacts could be reduced by developing SAMAs that emphasize resilient design, passive defense, and related protective measures as envisioned in the NIPP. The set of SAMAs developed for the IP2 and IP3 plants should cover a full spectrum of threats, addressing conventional and malice-induced accidents, core-damage sequences, pool fires, and reactor-pool interactions.

Special attention must be given to the processes through which SAMAs related to malice-induced accidents are developed and considered in license proceedings. Stakeholder involvement in these processes should be maximized, consistent with protection of sensitive information. That subject is addressed further in Section 10, below.

---

[152] Sentinel is a portable radar system that can detect and track approaching aircraft. Phalanx is an automated machine gun that is mounted on naval vessels for use against approaching aircraft, missiles, or small boats. See: Thompson, 2004.

[153] <http://www.committeetobridgethegap.org/beamhenge.html>, accessed on 18 November 2007.

10. Analyses Required From Entergy and the NRC

The NRC has determined that the risk of reactor core damage due to a conventional accident must be considered in environmental-impact analyses related to an application to extend the operating license of a nuclear power plant. Thus, the NRC has determined that core damage due to a conventional accident is a reasonably foreseeable event, and that the risk of this event is neither remote nor speculative. By contrast, the NRC does not require consideration of the risk of core damage due to a malice-induced accident, or the risk of a pool fire caused by a conventional accident or a malice-induced accident. Entergy takes the same position.

This report shows that the position taken by Entergy and the NRC lacks a logical foundation. Illustrative risk analyses by IRSS, whose findings are summarized in Table 7-7, demonstrate the illogic of Entergy and NRC's position in two respects. First, the risk of a pool fire at the IP2 or IP3 plant due to a conventional accident is greater than the risk of reactor core damage due to a conventional accident, as estimated by Entergy. Thus, a pool fire due to a conventional accident is a reasonably foreseeable event, and should be considered. Second, given a prudent assumption about the probability of attack, the risk of core damage or a pool fire at the IP2 or IP3 plant due to a malice-induced accident is greater than the risk of core damage due to a conventional accident, as estimated by Entergy. Thus, a malice-induced accident affecting the IP2 or IP3 reactor or their spent fuel is a reasonably foreseeable event, and should be considered.

In addition, IRSS shows that Entergy has substantially under-estimated the risk of reactor core damage due to a conventional accident, by failing to properly consider the potential for containment bypass.

Thus, IRSS's illustrative analyses have revealed major deficiencies in risk analyses performed by Entergy and the NRC. IRSS's analyses do not purport, however, to provide a comprehensive assessment of: (i) risk-related impacts for operation of the IP2 and IP3 plants; or (ii) deficiencies in analyses by Entergy and the NRC. Such assessments would require financial support at a much higher level than was available for our work.

Specific tasks for Entergy and the NRC

Entergy and the NRC should revise and supplement their analyses of risk-related impacts. In performing that work, Entergy and the NRC should rectify the deficiencies identified by IRSS, and should seek out and rectify other deficiencies. One source of guidance regarding other deficiencies is a November 2007 report prepared for Riverkeeper by Edwin Lyman.[154] In revising and supplementing their analyses, Entergy and the NRC should undertake at least three tasks, described in the following paragraphs.

---

[154] Lyman, 2007.

First, Entergy should revise the Environmental Report in its License Renewal Application. The revised Environmental Report should address the risks of core-damage events and pool fires at the IP2 and IP3 plants due to conventional accidents and malice-induced accidents, examining each of these categories of risk in similar detail. Reactor-pool interactions should be comprehensively examined. Options for reducing the full range of risks should be considered using at least the depth of analysis that is employed for SAMAs in the present Environmental Report.

Second, the NRC should prepare a supplement that updates and corrects its August 1979 GEIS on handling and storage of spent fuel (NUREG-0575). That supplement should address the risk of pool fires to at least the depth of analysis and experiment that was conducted to prepare the NRC's December 1990 study on the risks of reactor accidents (NUREG-1150). The supplement should consider initiation of pool fires by conventional accidents and malice-induced accidents. A full range of options for reducing risk should be assessed, with explicit reference to the NIPP and the principles of protective deterrence.

Third, the NRC should prepare a supplement that updates and corrects its May 1996 GEIS on license renewal (NUREG-1437). That supplement should address the risk of reactor core damage due to malice-induced accidents, to at least the depth of analysis and experiment that was conducted to prepare NUREG-1150. The supplement should also incorporate the findings of the above-specified supplement to NUREG-0575. While incorporating those findings, the supplement to NUREG-1437 should ensure that pool-reactor interactions during conventional accidents or malice-induced accidents are thoroughly considered. A full range of options for reducing risk should be assessed, with explicit reference to the NIPP and the principles of protective deterrence.

Processes for considering risks and risk-reducing options related to malice-induced accidents

The NRC should give special attention to designing processes for considering risks and risk-reducing options related to malice-induced accidents, both generically and in the context of site-specific license proceedings. Involvement of a full range of stakeholders in these processes should be maximized, consistent with protection of sensitive information.

An important step by the NRC would be to engage public stakeholders (citizen groups, academics, state and local governments, etc.) and licensees in a dialogue that seeks consensus on an effective, balanced policy for management of sensitive information. Implementation of that policy would not necessarily require changes in NRC rules.

The generic supplements to NUREG-0575 and NUREG-1437 that are specified above should place sensitive information in classified appendices. Arrangements should be made that allow all stakeholders to contribute sensitive information to the supplements, with assurance that the information would remain protected. In site-specific licensing contexts, sensitive information should be discussed in protected settings. A balanced, consensus-based policy for management of sensitive information would facilitate productive involvement by stakeholders in generic and site-specific regulatory arenas.

11. Conclusions

11.1 Deficiencies in Risk Analyses by the NRC and Entergy, and IRSS's Examination of Selected Risk Issues

The NRC has discussed some of the risk-related impacts of continued operation of a nuclear power plant, in the GEIS for license renewal (NUREG-1437). Entergy has discussed some of the risk-related impacts of continued operation of the IP2 and IP3 plants, in the Environmental Report that is provided as Appendix E of Entergy's License Renewal Application. Neither the NRC nor Entergy has provided a complete and accurate assessment of the risk-related impacts of continued operation of the IP2 and IP3 plants. This report identifies substantial deficiencies in NRC's and Entergy's risk analyses, by examining selected risk issues. Some of the findings of our examination are expressed in terms of the methodology that Entergy uses to discuss SAMAs. IRSS's use of that methodology is not a general endorsement of Entergy's SAMA analyses, their methodology or their assumptions. Major findings of IRSS's examination of risk issues (see, especially, Table 7-7) include:

(i) Studies conducted by the NRC show that Entergy has under-estimated the extent to which the reactor containment would be bypassed during core-damage sequences arising from conventional accidents at the IP2 or IP3 reactors. IRSS's correction of that deficiency within the SAMA framework increases the present value of cost risks by a factor of 5.42 for the IP2 reactor and 3.18 for the IP3 reactor. Incorporation of this correction into Entergy's SAMA analyses would require consideration of a range of SAMAs, including SAMAs that Entergy has previously determined to be not cost effective.

(ii) Studies conducted by the NRC, the National Academy of Sciences and other entities show that loss of water from an IP2 or IP3 spent-fuel pool would, over a wide range of scenarios, lead to spontaneous ignition of the hottest spent fuel and a fire that would spread across the pool. That fire would release to the atmosphere a substantial fraction of the pool's inventory of cesium-137, together with other radioactive isotopes. Entergy has not addressed this threat in the License Renewal Application. The NRC has, in various documents, discussed the potential for a conventional accident to initiate a spent-fuel-pool fire, but none of those documents is an environmental impact statement that meets the standards of the National Environmental Policy Act.

(iii) PRA techniques could be used to assess the risk of a pool fire at the IP2 or IP3 plant, initiated by a conventional accident. In the absence of a thorough assessment of this type, IRSS has conducted illustrative analysis within the

SAMA framework. This analysis shows, given the pool-fire probability estimated in the NRC document NUREG-1353, that the present value of cost risk for a pool fire would be $27.7 million, compared to the $10.7 million estimated by Entergy for a core-damage event at the IP2 or IP3 reactor. Consideration of other factors would, with reasonable assumptions, substantially increase the present value of cost risk for a pool fire. The expected offsite costs of a pool fire at Indian Point would be at least $461 billion, and would be substantially greater if indirect costs were considered. Entergy's SAMA analyses employ a discount rate of 7 percent per year. There is a strong ethical argument for using a substantially lower discount rate to assess the risk of radiological harm. With a discount rate of 3 percent per year, the PVCR of a pool fire would rise from $27.7 million to $38.7 million, and with a rate of zero it would rise to $51.5 million.

(iv) Options are available to reduce the risk of a pool fire at the IP2 and IP3 plants. SAMA analyses should be conducted to assess the benefits and costs of these options. Notably, each pool could be re-equipped with low-density, open-frame storage racks, as was intended when the Indian Point plants were constructed. That option would dramatically reduce the risk of a pool fire. The cost-benefit findings set forth in (iii), above, and (viii), below, justify the implementation of that option at the IP2 and IP3 plants.

(v) The IP2 and IP3 reactors and their spent fuel are vulnerable to attack by sub-national groups. A successful attack could be accomplished by a group with assets similar to those of the group that attacked New York and Washington on 11 September 2001. Such a group could obtain or construct the necessary instruments of attack and employ these instruments without assistance from a government and without access to classified information. The probability of an attack at Indian Point by a well-equipped group cannot be determined by statistical analysis. Given the present threat environment and potential trends in that environment, it would be imprudent to assume a probability lower than 1 per 10,000 reactor-years during the next several decades.

(vi) PRA methodology can be adapted to assess the risk of attack on a nuclear facility. This is done by postulating a set of attacks with given characteristics, and then using PRA techniques to assess the outcomes of the postulated attacks and the conditional probabilities of those outcomes. Given the current level of defense provided at US nuclear power plants, a sophisticated and determined attack by a sub-national group would have a high conditional probability of causing a large atmospheric release of radioactive material from the IP2 or IP3 reactor or spent-fuel pool. Attackers could choose to attack a reactor and the adjacent pool, using the radioactive release from the reactor to preclude the personnel access that would be needed to perform damage control at the pool.

(vii) Neither the NRC nor Entergy has published any credible assessment of the risk of attack on a facility at Indian Point. There is no evidence that either party has conducted a thorough, credible assessment in secret. Indeed, published statements by the NRC and Entergy indicate that neither party has an accurate understanding of the risk of attack on the IP2 or IP3 reactor or their spent fuel.

(viii) In the absence of an assessment by the NRC or Entergy of the risk of attack, IRSS has conducted illustrative analysis within the SAMA framework. Assuming a probability of a successful attack of 1 per 10,000 reactor-years, this analysis finds that the present value of cost risk for an attack on a reactor would be $73.2 million for IP2 and $62.4 million for IP3, compared to the $10.7 million estimated by Entergy for a core-damage event caused by a conventional accident at the IP2 or IP3 reactor. These numbers indicate that a variety of SAMAs could be implemented to reduce the risk of attack on the IP2 or IP3 reactor. IRSS's analysis also shows that the present value of cost risk for an attack on an IP2 or IP3 spent-fuel pool would be $498 million. As a result, there would be a high benefit-cost ratio for SAMAs that substantially reduce pool risk. Notably, IRSS estimates that re-equipment of the IP2 or IP3 pool with open-frame racks, which would dramatically reduce the risk of a pool fire, could be done for a cost of $41 to 86 million. The same cost would otherwise be incurred during decommissioning of the plant, when spent fuel would be offloaded from the pool to dry storage. Thus, the net present cost of this option would be $31 to 65 million given the discount rate of 7 per cent per year that is used by Entergy, and $18 to 39 million given a discount rate of 3 percent per year.

(ix) The environment is adversely affected by regulatory impacts arising from the NRC's general approach to the licensing of nuclear power plants. Granting of license extensions for the IP2 and IP3 plants would add to the burden of adverse regulatory impacts. Two types of impact are illustrative. First, the NRC's licensing approach does not support a policy of protective deterrence. Instead, it contributes to a counterproductive approach by the Federal government to protection of the nation's critical infrastructure. Second, the NRC has adopted a policy of excessive secrecy that yields various adverse impacts.

(x) Increasing the inherent robustness of nuclear facilities against attack would reduce adverse regulatory impacts in two respects. First, enhanced robustness of these facilities would contribute to the adoption of a more effective approach to protection of the nation's critical infrastructure, through a national strategy of protective deterrence. Second, enhanced robustness of nuclear facilities would reduce the perceived need for secrecy, thereby reducing the adverse impacts that flow from excessive secrecy.

(xi) The National Infrastructure Protection Plan articulates principles for increasing the inherent robustness of infrastructure facilities against attack. There are opportunities at Indian Point to implement those principles, especially in the context of storing spent fuel. Enhanced robustness of facilities at Indian Point could significantly reduce the radiological and regulatory risk-related impacts of continued operation of the IP2 and IP3 plants. Neither Entergy nor the NRC has proffered any analysis or plan regarding implementation of the NIPP principles at Indian Point.

11.2 Analyses Required from Entergy and the NRC

The NRC has determined that the risk of reactor core damage due to a conventional accident must be considered in environmental-impact analyses related to extension of the operating license of a nuclear power plant. Thus, the NRC has determined that core damage due to a conventional accident is a reasonably foreseeable event, and that the risk of this event is neither remote nor speculative. IRSS shows that the risk of a pool fire at the IP2 or IP3 plant due to a conventional accident is greater than the risk of reactor core damage due to a conventional accident, as estimated by Entergy. Thus, a pool fire due to a conventional accident is a reasonably foreseeable event, and should be considered. Also, IRSS shows that the risk of core damage or a pool fire at the IP2 or IP3 plant due to a malice-induced accident is greater than the risk of core damage due to a conventional accident, as estimated by Entergy. Thus, a malice-induced accident affecting the IP2 or IP3 reactor or their spent fuel is a reasonably foreseeable event, and should be considered. In addition, IRSS shows that Entergy has under-estimated the risk of reactor core damage due to a conventional accident. Therefore, revision and supplementation of NRC's and Entergy's risk analyses is needed in at least the following respects:

(i) Entergy should revise the Environmental Report in its Indian Point License Renewal Application, as specified in Section 10, above.

(ii) The NRC should prepare a supplement that updates and corrects its August 1979 GEIS on handling and storage of spent fuel (NUREG-0575). The supplement should meet the specifications set forth in Section 10, above. It should explicitly address the principles of the NIPP.

(iii) The NRC should prepare a supplement that updates and corrects its May 1996 GEIS on license renewal (NUREG-1437). The supplement should meet the specifications set forth in Section 10, above. It should explicitly address the principles of the NIPP.

12. Bibliography

(Adam, 2005)
David Adam, "50m environmental refugees by end of decade, UN warns", *The Guardian*, 12 October 2005.

(Alvarez et al, 2003)
Robert Alvarez, Jan Beyea, Klaus Janberg, Jungmin Kang, Ed Lyman, Allison Macfarlane, Gordon Thompson and Frank N. von Hippel, "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States", *Science and Global Security*, Volume 11, 2003, pp 1-51.

(ASLB, 2001)
ASLBP No. 99-762-02-LA, "Memorandum and Order (Denying Request for Evidentiary Hearing and Terminating Proceeding)", 1 March 2001.

(ASLB, 2000)
ASLBP No. 99-762-02-LA, "Memorandum and Order (Ruling on Late-Filed Environmental Contention)", 7 August 2000.

(ASLB, 1982)
Carolina Power and Light Co. (Shearon Harris Nuclear Power Plant, Units 1 and 2), LBP-82-119A, 16 NRC 2069, 2098 (1982).

(Benjamin et al, 1979)
Allan S. Benjamin and 3 other authors, *Spent Fuel Heatup Following Loss of Water During Storage, NUREG/CR-0649* (Washington, DC: US Nuclear Regulatory Commission, March 1979).

(Beyea et al, 2004)
Jan Beyea, Ed Lyman and Frank von Hippel, "Damages from a Major Release of Cs-137 into the Atmosphere of the United States", *Science and Global Security*, Volume 12, 2004, pp 125-136.

(Brian, 2006)
Danielle Brian, Project on Government Oversight, letter to NRC chair Nils J. Diaz, 22 February 2006.

(Brzezinski, 2007)
Zbigniew Brzezinski, testimony before the US Senate Foreign Relations Committee, 1 February 2007.

(Campbell et al, 2007)
Kurt M. Campbell et al, *The Age of Consequences: The Foreign Policy and National Security Implications of Global Climate Change* (Washington, DC: Center for Strategic and International Studies, Center for a New American Security, November 2007).

(Clinton, 1993)
President William Clinton, "Executive Order 12866 – Regulatory Planning and Review", *Federal Register*, Volume 58, Number 190, 4 October 1993, pp 51735-51744.

(Collins and Hubbard, 2001)
T. E. Collins and G. Hubbard, *Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants, NUREG-1738* (Washington, DC: US Nuclear Regulatory Commission, February 2001). (This document was first released in October 2000.)

(Consolidated Edison, 1995)
Consolidated Edison Company of New York, *Individual Plant Examination of External Events for Indian Point Unit No. 2 Nuclear Generating Station* (Buchanan, New York: Consolidated Edison, December 1995).

(Consolidated Edison, 1992)
Consolidated Edison Company of New York, *Individual Plant Examination for Indian Point Unit No. 2 Nuclear Generating Station* (Buchanan, New York: Consolidated Edison, August 1992).

(Deller, 2002)
Nicole Deller, "Rule of Power or Rule of Law?", *Science for Democratic Action*, Volume 10, Number 4, August 2002.

(DHS, 2006)
US Department of Homeland Security, *National Infrastructure Protection Plan* (Washington, DC: DHS, 2006).

(Dillingham, 2003)
Gerald L. Dillingham, US General Accounting Office, testimony before the Committee on Commerce, Science and Transportation, US Senate, "Aviation Security: Progress Since September 11, 2001, and the Challenges Ahead", 9 September 2003.

(DOE, 1987)
US Department of Energy, *Health and Environmental Consequences of the Chernobyl Nuclear Power Plant Accident, DOE/ER-0332* (Washington, DC: DOE, June 1987).

(ElBaradei, 2004)
Mohamed ElBaradei, Director General, International Atomic Energy Agency, "Nuclear Non-Proliferation: Global Security in a Rapidly Changing World", keynote address, Carnegie International Non-Proliferation Conference, Washington, DC, 21 June 2004.

(Ellison et al, 1996)
P. G. Ellison and 11 other authors, *Steam Generator Tube Rupture Induced from Operational Transients, Design Bases Accidents, and Severe Accidents, INEL-95/0641* (Idaho: Idaho National Engineering Laboratory, August 1996).

(Entergy, 2007a)
Entergy, License Renewal Application, Indian Point Nuclear Generating Units Nos. 2 and 3, submitted to the NRC on 30 April 2007.

(Entergy, 2007b)
Entergy, *Indian Point Unit 2 Updated Final Safety Analysis Report, Version 20*, issued in November 2006, publicly released with redactions in July 2007.

(EPA, 2007)
US Environmental Protection Agency, Region 2, letter of 10 October 2007 to NRC from Grace Musumeci, RE: Indian Point Nuclear Generating Station, Unit Nos. 2 and 3 License Renewal.

(ERIN, 2000)
ERIN Engineering and Research Inc., "Technical Input for Use in the Matter of Shearon Harris Spent Fuel Pool Before the Atomic Safety and Licensing Board (Docket No. 50-400-LA)", November 2000.

(Fertel, 2006)
Marvin Fertel, Nuclear Energy Institute, testimony before the Subcommittee on National Security, Emerging Threats and International Relations, US House Committee on Government Reform, 4 April 2006.

(Fletcher and Beaton, 2006a)
C. D. Fletcher and R. M. Beaton, *SCDAP/RELAP5 Base Case Calculation for the Station Blackout Uncertainty Study, DRAFT* (Idaho Falls, Idaho, and Rockville, Maryland: Information Systems Laboratories, August 2006).

(Fletcher and Beaton, 2006b)
C. D. Fletcher and R. M. Beaton, *Evaluation of Uncertainties in SCDAP/RELAP5 Station Blackout Simulations, DRAFT* (Idaho Falls, Idaho, and Rockville, Maryland: Information Systems Laboratories, August 2006).

(Franceschini and Schaper, 2006)
Giorgio Franceschini and Annette Schaper, *Nuclear Weapons Research and Modernization Without Testing: The CTBT in danger?* (Frankfurt: Peace Research Institute Frankfurt, 2006).

(Flynn, 2007)
Stephen Flynn, *The Edge of Disaster: Rebuilding a Resilient Nation* (New York: Random House, 2007).

(GAO, 2007)
US Government Accountability Office, *Crude Oil: Uncertainty about Future Oil Supply Makes It Important to Develop a Strategy for Addressing a Peak and Decline in Oil Production, GAO-07-283* (Washington, DC: GAO, February 2007).

(Gilman et al, 2007)
Nils Gilman, Doug Randall and Peter Schwartz, *Impacts of Climate Change* (San Francisco: Global Business Network, January 2007).

(Hannerz, 1983)
K. Hannerz, *Towards Intrinsically Safe Light Water Reactors* (Oak Ridge, Tennessee: Institute for Energy Analysis, February 1983).

(Hart et al, 2002)
Gary Hart and Warren B. Rudman (Co-chairs), Stephen E. Flynn (project director) and Task Force members, *America Still Unprepared – America Still in Danger: Report of an Independent Task Force Sponsored by the Council on Foreign Relations* (New York: Council on Foreign Relations, 25 October 2002).

(Hebert, 2007)
H. Josef Hebert, Associated Press, "NRC rejects plan for power plants to stop airliner attacks", *The Boston Globe*, 30 January 2007.

(Hersh, 2006)
Seymour M. Hersh, "The Iran Plans", *The New Yorker*, 17 April 2006, pp 30-37.

(Hirsch et al, 2005)
Robert L. Hirsch, Roger H. Bezdek and Robert M. Wendling, "Peaking Oil Production: Sooner Rather Than Later?" *Issues in Science and Technology*, Volume XXI, Number 3, Spring 2005, pp 25-30. (That paper was adapted from a report prepared for the US Department of Energy's National Energy Technology Laboratory.)

(Holt and Andrews, 2006)
Mark Holt and Anthony Andrews, *Nuclear Power Plants: Vulnerability to Terrorist Attack* (Washington, DC: Congressional Research Service, 4 October 2006).

(Honniello and Rydell, 2007)
Anthony L. Honnellio and Stan Rydell, "Sabotage vulnerability of nuclear power plants", *International Journal of Nuclear Governance, Economy and Ecology*, Volume 1, Number 3, 2007, pp 312-321.

(Jo et al, 1989)
J. H. Jo and 5 other authors, *Value/Impact Analyses of Accident Preventive and Mitigative Options for Spent Fuel Pools, NUREG/CR-5281* (Washington, DC: US Nuclear Regulatory Commission, March 1989).

(Kugler, 1995)
Richard L. Kugler, *Toward a Dangerous World: US National Security Strategy for the Coming Turbulence* (Santa Monica, California: RAND Corporation, 1995).

(Kull et al, 2007)
Steven Kull et al, *Muslim Public Opinion on US Policy, Attacks on Civilians and al Qaeda* (Maryland: Program on International Policy Attitudes, University of Maryland, 24 April 2007).

(Lyman, 2007)
Edwin Lyman, *A Critique of the Radiological Consequence Assessment Conducted in Support of the Indian Point Severe Accident Mitigation Alternatives Analysis* (Washington, DC: Union of Concerned Scientists, November 2007).

(Maioli et al, 2004)
Andrea Maioli, David J. Finnicum, and Yuji Kumagai, "IRIS Simplified LERF Model", Paper presented at the conference: Americas Nuclear Energy Symposium, Miami, 3-6 October 2004.

(Marshall and Gurr, 2005)
Monty G. Marshall and Ted Robert Gurr, *Peace and Conflict 2005*, (College Park, Maryland: Center for International Development and Conflict Management, University of Maryland, May 2005).

(MEA, 2005)
Millennium Ecosystem Assessment, *Ecosystems and Human Well-Being: Synthesis* (Washington, DC: Island Press, 2005).

(Meadows et al, 1972)
Donella H. Meadows, Dennis L. Meadows, Jorgen Randers and William W. Behrens III, *The Limits to Growth* (London: Earth Island Limited, 1972).

(Meserve, 2002)
Richard A. Meserve, "Nuclear Security in a New World", *The Industrial Physicist*, October/November 2002, pp 20-23.

(Morris et al, 2006)
Robert H. Morris et al, "Using the VISAC program to calculate the vulnerability of nuclear power plants to terrorism", *International Journal of Nuclear Governance, Economy and Ecology*, Volume 1, Number 2, 2006, pp 193-211.

(NAS, 2006)
Committee on the Safety and Security of Commercial Spent Nuclear Fuel Storage, Board on Radioactive Waste Management, National Research Council, *Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report* (Washington, DC: National Academies Press, 2006). (This document was first released in April 2005.)

(NRC, 2007a)
US Nuclear Regulatory Commission Staff, *Supplement to the Environmental Assessment and Final Finding of No Significant Impact Related to the Construction and Operation of the Diablo Canyon Independent Spent Fuel Storage Installation*, Docket No. 72-26, Pacific Gas and Electric Company, August 2007.

(NRC, 2007b)
US Nuclear Regulatory Commission Staff, *Supplement to the Environmental Assessment and Draft Finding of No Significant Impact Related to the Construction and Operation of the Diablo Canyon Independent Spent Fuel Storage Installation*, Docket No. 72-26, Pacific Gas and Electric Company, May 2007.

(NRC, 2004)
US Nuclear Regulatory Commission, *Regulatory Analysis Guidelines of the US Nuclear Regulatory Commission, NUREG/BR-0058, Revision 4* (Washington, DC: NRC, September 2004).

(NRC, 1998)
US Nuclear Regulatory Commission, *Risk Assessment of Severe Accident-Induced Steam Generator Tube Rupture, NUREG-1570* (Washington, DC: Nuclear Regulatory Commission, March 1998).

(NRC, 1996)
US Nuclear Regulatory Commission, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants, NUREG-1437* (Washington, DC: Nuclear Regulatory Commission, May 1996).

(NRC, 1994)
US Nuclear Regulatory Commission, "10 CFR Part 73, RIN 3150-AE81, Protection Against Malevolent Use of Vehicles at Nuclear Power Plants", *Federal Register*, Volume 59, Number 146, 1 August 1994, pp 38889-38900.

(NRC, 1990a)
US Nuclear Regulatory Commission, "10 CFR Part 51: Waste Confidence Decision Review", *Federal Register*, Vol. 55, 18 September 1990, page 38474.

(NRC, 1990b)
US Nuclear Regulatory Commission, *Severe Accident Risks: An Assessment for Five US Nuclear Power Plants, NUREG-1150* (Washington, DC: Nuclear Regulatory Commission, December 1990).

(NRC, 1979)
US Nuclear Regulatory Commission, *Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel, NUREG-0575* (Washington, DC: Nuclear Regulatory Commission, August 1979).

(NRC, 1975)
US Nuclear Regulatory Commission, *Reactor Safety Study, WASH-1400 (NUREG-75/014)* (Washington, DC: Nuclear Regulatory Commission, October 1975).

(NYPA, 1997)
New York Power Authority, *Indian Point Three Nuclear Power Plant Individual Plant Examination of External Events* (White Plains, New York: NYPA, September 1997).

(NYPA, 1994)
New York Power Authority, *Indian Point 3 Nuclear Power Plant Individual Plant Examination* (White Plains, New York: NYPA, June 1994).

(Parry et al, 2000)
ASLBP No. 99-762-02-LA, "Affidavit of Gareth W. Parry, Stephen F. LaVie, Robert L. Palla and Christopher Gratton in Support of NRC Staff Brief and Summary of Relevant Facts, Data and Arguments upon which the Staff Proposes to Rely at Oral Argument on Environmental Contention EC-6", 20 November 2000.

(Prassinos et al, 1989)
P. G. Prassinos and 8 other authors, *Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear Power Plants, NUREG/CR-5176* (Washington, DC: US Nuclear Regulatory Commission, January 1989).

(Raskin et al, 2002)
Paul Raskin et al, *Great Transition: The Promise and Lure of the Times Ahead* (Boston, Massachusetts: Stockholm Environment Institute, 2002).

(Sailor et al, 1987)
V. L. Sailor and 3 other authors, *Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82, NUREG/CR-4982* (Washington, DC: US Nuclear Regulatory Commission, July 1987).

(Scarry, 2002)
Elaine Scarry, "A nuclear double standard", *Boston Sunday Globe*, 3 November 2002, page D11.

(Sdouz, 2007)
Gert Sdouz, "Radioactive release from VVER-1000 reactors after a terror attack", *International Journal of Nuclear Governance, Economy and Ecology*, Volume 1, Number 3, 2007, pp 305-311.

(Smith and Vivekananda, 2007)
Dan Smith and Janani Vivekananda, *A Climate of Conflict: The links between climate change, peace and war* (London: International Alert, November 2007).

(Thompson, 2007a)
Gordon R. Thompson, Institute for Resource and Security Studies, Cambridge, Massachusetts, Declaration of 1 October 2007 regarding the NRC Staff's August 2007 Supplement to the EA related to construction and operation of the Diablo Canyon ISFSI.

(Thompson, 2007b)
Gordon R. Thompson, *Assessing Risks of Potential Malicious Actions at Commercial Nuclear Facilities: The Case of a Proposed Independent Spent Fuel Storage Installation at the Diablo Canyon Site*, a report for San Luis Obispo Mothers for Peace (Cambridge, Massachusetts: Institute for Resource and Security Studies, 27 June 2007).

(Thompson, 2006)
Gordon R. Thompson, *Risks and Risk-Reducing Options Associated with Pool Storage of Spent Nuclear Fuel at the Pilgrim and Vermont Yankee Nuclear Power Plants*, a report for the Office of the Attorney General, Commonwealth of Massachusetts (Cambridge, Massachusetts: Institute for Resource and Security Studies, 25 May 2006).

(Thompson, 2005)
Gordon R. Thompson, Institute for Resource and Security Studies, Cambridge, Massachusetts, direct testimony before the Minnesota Public Utilities Commission regarding an application for a Certificate of Need to establish an ISFSI at the Monticello site, Docket No. E002/CN-05-123, 16 December 2005.

(Thompson, 2004)
Gordon Thompson, Institute for Resource and Security Studies, Cambridge, Massachusetts, testimony before the Public Utilities Commission of the State of California regarding Application No. 04-02-026, 13 December 2004. (This testimony, prepared for California Earth Corps, addressed the provision of an enhanced defense of Units 2 and 3 of the San Onofre Nuclear Generating Station.)

(Thompson, 2003)
Gordon Thompson, *Robust Storage of Spent Nuclear Fuel: A Neglected Issue of Homeland Security* (Cambridge, Massachusetts: Institute for Resource and Security Studies, January 2003).

(Thompson, 2002)
Gordon Thompson, Declaration of 7 September 2002 in support of a petition to the US Nuclear Regulatory Commission by Avila Valley Advisory Council, San Luis Obispo Mothers for Peace, Peg Pinard et al, regarding a license application for an ISFSI at the Diablo Canyon site, Docket No. 72-26.

(Thompson, 2001a)
Gordon Thompson, *Comments on the NRC Staff's Technical Study of Spent Fuel Pool Accident Risk at Decommissioning Nuclear Power Plants* (Cambridge, Massachusetts: Institute for Resource and Security Studies, 19 February 2001).

(Thompson, 2001b)
US Court of Appeals for the District of Columbia Circuit, No. 01-1246, "Declaration of 31 May 2001 by Dr Gordon Thompson in Support of Orange County's Stay Motion".

(Thompson, 2000)
Gordon Thompson, *The Potential for a Large, Atmospheric Release of Radioactive Material from Spent Fuel Pools at the Harris Nuclear Power Plant: The Case of a Pool Release Initiated by a Severe Reactor Accident* (Cambridge, Massachusetts: Institute for Resource and Security Studies, 20 November 2000).

(Thompson et al, 1979)
Gordon Thompson (subgroup chair), Jan Beyea, Yves Lenoir and Gene Rochlin, "Potential Accidents and their Effects", Chapter 3 of the Report of the Gorleben International Review, submitted (in German) to the government of Lower Saxony, March 1979.

(Throm, 1989)
E. D. Throm, *Regulatory Analysis for the Resolution of Generic Issue 82, "Beyond Design Basis Accidents in Spent Fuel Pools", NUREG-1353* (Washington, DC: US Nuclear Regulatory Commission, April 1989).

(Wald, 2005)
Matthew L. Wald, "Agencies Fight Over Report on Sensitive Atomic Wastes", *The New York Times*, 30 March 2005.

(Walters, 2003)
William Walters, "An Overview of the Shaped Charge Concept", paper presented at the 11th Annual ARL/USMA Technical Symposium, 5 and 7 November 2003. (That symposium was sponsored by the Mathematical Sciences Center of Excellence at the US Military Academy (USMA) and hosted by the US Army Research Laboratory (ARL) and USMA.)

(Wells, 2006)
Jim Wells, US Government Accountability Office, testimony before the Subcommittee on National Security, Emerging Threats and International Relations, US House Committee on Government Reform, "Nuclear Power Plants Have Upgraded Security, but the Nuclear Regulatory Commission Needs to Improve Its Process for Revising the Design Basis Threat", 4 April 2006.

(White House, 2007)
The White House, *National Strategy for Homeland Security* (Washington, DC: The White House, October 2007).

(White House, 2006)
The White House, *National Strategy for Combating Terrorism* (Washington, DC: The White House, September 2006).

(Yergin, 1991)
Daniel Yergin, *The Prize: The Epic Quest for Oil, Money and Power* (New York: Simon and Schuster, 1991).

Table 2-1
Cesium-137 Inventories and Other Indicators for Reactors, Spent-Fuel Pools and the ISFSI at Indian Point

Indicator	Indian Point 2	Indian Point 3
Rated power of reactor	3,216 MWt	3,216 MWt
Number of fuel assemblies in reactor core	193 assemblies	193 assemblies
Mass of uranium in reactor core	87 Mg	87 Mg
Typical period of full-power exposure of a fuel assembly (assuming refueling outages of 2-month duration at 24-month intervals, discharging 72 assemblies, capacity factor of 0.9 between outages)	4.4 yrs (during 5.4 calendar years)	4.4 yrs (during 5.4 calendar years)
Typical burnup of fuel assembly at discharge	59,370 MWt-days/MgU	59,370 MWt-days/MgU
Typical Cs-137 inventory in fuel assembly at discharge (assuming steady-state fission at 0.9x22/24 power for 5.4 yrs with an energy yield of 200 MeV per fission and a Cs-137 fission fraction of 6.0 percent)	0.082 MCi	0.082 MCi
Approx. Cs-137 inventory in reactor core (assuming 193 fuel assemblies with av. burnup = 50% of discharge burnup)	7.9 MCi	7.9 MCi
Cs-137 inventory in reactor core according to License Renewal Application	11.2 MCi	11.2 MCi
Capacity of spent-fuel pool	1,376 assemblies	1,345 assemblies
Cs-137 inventory in spent-fuel pool (assuming space for full-core unloading, av. assembly age after discharge = 15 yrs	68.6 MCi	66.8 MCi
Cs-137 inventory in ISFSI module (assuming 32 fuel assemblies, av. age after discharge = 30 yrs)	1.3 MCi	

Sources:
(a) License Renewal Application, Appendix E.
(b) Consolidated Edison Company, request to NRC for license amendment to increase capacity of spent-fuel pool at Indian Point Unit 2, 20 June 1989.
(c) New York Power Authority, request to NRC for license amendment to increase capacity of spent-fuel pool at Indian Point Unit 3, 9 May 1988.

Table 2-2
Illustrative Inventories of Cesium-137

Case	Inventory of Cesium-137
Produced during detonation of a 10-kilotonne fission weapon	0.002 MCi
Released to atmosphere during Chernobyl reactor accident of 1986	2.4 MCi
Released to atmosphere during nuclear-weapon tests, primarily in the 1950s and 1960s (Fallout was non-uniformly distributed across the planet, mostly in the Northern hemisphere.)	20 MCi
In Indian Point 2 spent-fuel pool during period of license extension	68.6 MCi
In Indian Point 3 spent-fuel pool during period of license extension	66.8 MCi
In IP2 or IP3 reactor core	11.2 MCi

Notes:
(a) 1 Tbq = 1.0E+12 Bq = 27.0 Ci
(b) Inventories in the first three rows are from Table 3-2 of: Gordon Thompson, *Reasonably Foreseeable Security Events: Potential threats to options for long-term management of UK radioactive waste*, A report for the UK government's Committee on Radioactive Waste Management, IRSS, 2 November 2005.
(c) Inventories in the fourth and fifth rows are author's estimates set forth in this report.
(d) Inventory in the sixth row is from Appendix E of the License Renewal Application.

Table 4-1
Estimated Core Damage Frequencies for Conventional Accidents at the IP2 and IP3 Reactors

Source of Estimate	Factors Included in Estimate	Estimated Core Damage Frequency (per reactor-year)	
		Indian Point 2	Indian Point 3
License Renewal Application, Appendix E, Section 4.21	Internal initiating events	1.79E-05	1.15E-05
	Internal + external initiating events	6.80E-05 (multiplier of 3.80)	6.35E-05 (multiplier of 5.52)
	Internal + external initiating events, plus uncertainty	1.43E-04 (multiplier of 8)	9.20E-05 (multiplier of 8)

Notes:
(a) Initiating events involving acts of malice are not considered in these estimates.
(b) The multipliers shown in the second and third rows are applied to the frequency estimates in the first row.

Table 5-1
Predicted Core-Damage Sequences at the IP2 Reactor in the High/Dry Category

Source of Estimate	Types of Core-Damage Sequence in the High/Dry Category	Share of Estimated Total CDF (percent)
Indian Point 2 IPE, August 1992, Section 3.4.1.1 (See also Section 3.1.6.3.6.)	Sequences 1, 3, 4, 9, 13, 17, 19, 22 and 39 of the 42 most probable core-damage sequences Comments: The 42 most probable core-damage sequences account for 80% of the estimated total CDF. Thus, the aggregate frequency of the above-listed sequences is adjusted here by a factor 1/0.8. Most of the listed sequences involve failure of primary bleed, leading to RCS pressure in the range of the pressurizer relief valve setpoints (pressure > 2350 psia).	43 (% of internal CDF)
License Renewal Application, Appendix E, Attachment E.1, Table E.1-6	Plant damage states with high RCS pressure (pressure > 2350 psia) and no secondary-side cooling prior to onset of core damage	47 (% of internal CDF)
License Renewal Application, Appendix E, Attachment E.1, Table E.1-6	Plant damage states with high RCS pressure (pressure > 2350 psia) or medium RCS pressure (2350 psia > pressure > 675 psia) and no secondary-side cooling prior to onset of core damage	71 (% of internal CDF)
Indian Point 2 IPEEE, December 1995, Section 3.1.6.4 and Table 3.1-8 (corrected version of February 1998)	Seismic damage states 35, 36, 37 and 47 Comments: Some sequences could exhibit medium RCS pressure. In some sequences, the turbine-driven AFW pump might operate, which would reduce the High/Dry share of total seismic CDF.	59 (% of seismic CDF)
Indian Point 2 IPEEE, December 1995, Section 4.6.3	Relevant sequences are not fully identified Comments: Fire scenario A3-10 is the most probable fire-initiated sequence, accounting for 9% of fire CDF. This High/Dry sequence would involve loss of all AFW and primary bleed, leading to core damage at high RCS pressure. Other fire scenarios would contribute to a substantial High/Dry share of fire CDF.	Not available (% of fire CDF)

Table 5-2
Predicted Core-Damage Sequences at the IP3 Reactor in the High/Dry Category

Source of Estimate	Types of Core-Damage Sequence in the High/Dry Category	Share of Estimated Total CDF (percent)
Indian Point 3 IPE, June 1994, Tables 3.1.5.2 and 4.4.1.1	Plant damage states with RCS pressure status RX1 (pressure > 2350 psia) and auxiliary feedwater status F1 or F3	47 (% of internal CDF)
Indian Point 3 IPE, June 1994, Tables 3.1.5.2 and 4.4.1.1	Plant damage states with RCS pressure status RX1 (pressure > 2350 psia) or RX2 (2350 psia > pressure > 675 psia) and auxiliary feedwater status F1 or F3	53 (% of internal CDF)
License Renewal Application, Appendix E, Attachment E.3, Table E.3-6	Plant damage states with high RCS pressure (pressure > 2350 psia) and no secondary-side cooling prior to onset of core damage	27 (% of internal CDF)
License Renewal Application, Appendix E, Attachment E.3, Table E.3-6	Plant damage states with high RCS pressure (pressure > 2350 psia) or medium RCS pressure (2350 psia > pressure > 675 psia) and no secondary-side cooling prior to onset of core damage	56 (% of internal CDF)
Indian Point 3 IPEEE, September 1997, Section 3.1.5.5	Seismic accident sequences 1, 4, 6 and 8 Comments: Some sequences could exhibit medium RCS pressure. In some sequences, the turbine-driven AFW pump might operate, which would reduce the High/Dry share of total seismic CDF.	56 (% of seismic CDF)
Indian Point 3 IPEEE, September 1997, Section 4.7.5	Fires in 480 V switchgear room Comments: Some sequences could exhibit medium RCS pressure. In some sequences, the turbine-driven AFW pump could operate, which would reduce the High/Dry share of total fire CDF. Conversely, other fire-initiated sequences could increase the High/Dry share.	62 (% of fire CDF)

Table 5-3
Estimated Conditional Probabilities of Categories of Atmospheric Release from a Core-Damage Event at the IP2 Reactor

Source of Estimate	Category of Radioactive Release	Conditional Probability of Release Category, Given Core Damage (percent)
License Renewal Application, Appendix E, Attachment E.1, Table E.1-9	Early High	3.6
	Other	96.4
	Total	100
Above-stated estimate corrected by accounting for containment bypass during High/Dry sequences	Early High	51.8
	Other	48.2
	Total	100

Notes:
(a) The corrected estimate in this table assumes that 50 percent of core-damage sequences are High/Dry sequences that lead to containment bypass via induced failure of steam generator tubes, leading to an Early High release.
(b) The correction is applied by re-allocating 50 percent of core-damage sequences across release categories in proportion to the previously-estimated conditional probability of each category.
(c) This table considers only those core-damage sequences that arise from "internal" initiating events.

Table 5-4
Estimated Conditional Probabilities of Categories of Atmospheric Release from a Core-Damage Event at the IP3 Reactor

Source of Estimate	Category of Radioactive Release	Conditional Probability of Release Category, Given Core Damage (percent)
License Renewal Application, Appendix E, Attachment E.3, Table E.3-9	Early High	8.2
	Other	91.8
	Total	100
Above-stated estimate corrected by accounting for containment bypass during High/Dry sequences	Early High	54.1
	Other	45.9
	Total	100

Notes:
(a) The corrected estimate in this table assumes that 50 percent of core-damage sequences are High/Dry sequences that lead to containment bypass via induced failure of steam generator tubes, leading to an Early High release.
(b) The correction is applied by re-allocating 50 percent of core-damage sequences across release categories in proportion to the previously-estimated conditional probability of each category.
(c) This table considers only those core-damage sequences that arise from "internal" initiating events.

Table 5-5
Estimated Population Dose Risk (PDR) and Offsite Economic Cost Risk (OECR) Associated with Atmospheric Release from a Core-Damage Event at the IP2 Reactor

Source of Estimate	Category Of Radioactive Release	Conditional Probability of Release Category, Given Core Damage (percent)	Population Dose Risk (person-rem/yr)	Offsite Economic Cost Risk ($/yr)
License Renewal Application, Appendix E, Attach. E.1, Table E.1-14	Early High	3.6	1.03E+01	2.22E+04
	Other	96.4	1.17E+01	2.27E+04
	Total	100	2.20E+01	4.49E+04
Above-stated estimate corrected by accounting for containment bypass during High/Dry sequences	Early High	51.8	1.48E+02	3.19E+05
	Other	48.2	5.85E+00	1.14E+04
	Total	100	1.54E+02	3.30E+05

Notes:
(a) The corrected estimate in this table assumes that 50 percent of core-damage sequences are High/Dry sequences that lead to containment bypass via induced failure of steam generator tubes, leading to an Early High release.
(b) The correction is applied by re-allocating 50 percent of core-damage sequences across release categories in proportion to the previously-estimated conditional probability of each category.
(c) This table considers only those core-damage sequences that arise from "internal" initiating events.

Table 5-6
Estimated Population Dose Risk (PDR) and Offsite Economic Cost Risk (OECR) Associated with Atmospheric Release from a Core-Damage Event at the IP3 Reactor

Source of Estimate	Category Of Radioactive Release	Conditional Probability of Release Category, Given Core Damage (percent)	Population Dose Risk (person-rem/yr)	Offsite Economic Cost Risk ($/yr)
License Renewal Application, Appendix E, Attach. E.3, Table E.3-14	Early High	8.2	1.24E+01	2.81E+04
	Other	91.8	1.21E+01	2.47E+04
	Total	100	2.45E+01	5.28E+04
Above-stated estimate corrected by accounting for containment bypass during High/Dry sequences	Early High	54.1	8.18E+01	1.85E+05
	Other	45.9	6.05E+00	1.24E+04
	Total	100	8.79E+01	1.97E+05

Notes:
(a) The corrected estimate in this table assumes that 50 percent of core-damage sequences are High/Dry sequences that lead to containment bypass via induced failure of steam generator tubes, leading to an Early High release.
(b) The correction is applied by re-allocating 50 percent of core-damage sequences across release categories in proportion to the previously-estimated conditional probability of each category.
(c) This table considers only those core-damage sequences that arise from "internal" initiating events.

Table 5-7
Estimated Present Value of Cost Risks Associated with Atmospheric Release from a Core-Damage Event at the IP2 or IP3 Reactor

Source of Estimate	Type of Cost Risk	Present Value for Indian Point 2 ($)	Present Value for Indian Point 3 ($)
License Renewal Application, Appendix E, Table 4-3	Offsite population dose	473,568	527,382
	Offsite economic costs	483,254	568,281
	Onsite dose	6,814	4,377
	Onsite economic costs	374,303	240,475
	Total	1,337,939	1,340,515
Above-stated estimate corrected by accounting for containment bypass during High/Dry sequences	Offsite population dose	3,314,973	1,892,118
	Offsite economic costs	3,551,757	2,120,291
	Onsite dose	6,814	4,377
	Onsite economic costs	374,303	240,475
	Total	7,247,847	4,257,261

Notes:
(a) Corrected estimates for population dose risk and offsite economic cost risk are drawn from Tables 5-5 and 5-6 of this report.
(b) Dose is valued at $2,000 per person-rem.
(c) Present value is determined by accumulating annual value over 20 years with a discount rate of 7 percent per year.
(d) This table considers only those core-damage sequences that arise from "internal" initiating events.
(e) The License Renewal Application (Appendix E, Section 4.21) estimates that a core-damage event at the IP2 or IP3 reactor would yield onsite dose costs of $35.4 million (M$ 6.60 for immediate doses and M$ 28.8 for long-term doses) and onsite economic costs of $1.94 billion (G$ 1.08 for cleanup/decontamination and G$ 0.86 for replacement power).
(f) The correction applied in the lower half of this table increases the estimated present value of cost risks by a factor of 5.42 for the IP2 reactor and 3.18 for the IP3 reactor.

Table 6-1
Estimated Offsite Costs Resulting from Potential Atmospheric Releases: Early High Release from a Core-Damage Event at the IP2 or IP3 Reactor; Fire in the IP2 or IP3 Spent-Fuel Pool

Source of Estimate	Type of Release	Source Term	Offsite Costs (billion $)
License Renewal Application, Appendix E, Attachment E.1, Tables E.1-10, E.1-13 & E.1-14	Early High Release from IP2 reactor	• 2.6 MCi of Cs-137 (23% of core inventory) • Various amounts of other radioactive isotopes	• Population dose: 32 • Economic costs: 34 • Total costs: 66
License Renewal Application, Appendix E, Attachment E.3, Tables E.3-10, E.3-13 & E.3-14	Early High Release from IP3 reactor	• 1.7 MCi of Cs-137 (15% of core inventory) • Various amounts of other radioactive isotopes	• Population dose: 26 • Economic costs: 30 • Total costs: 56
Study by Beyea et al	Fire in a spent-fuel pool at the IP2 or IP3 plant	• 35 MCi of Cs-137	• Total costs: 461

Notes:
(a) The License Renewal Application assigns a cost of $2,000 per person-rem of population dose.
(b) The citation for the study by Beyea et al is: Jan Beyea, Ed Lyman, Frank von Hippel, "Damages from a Major Release of Cs-137 into the Atmosphere of the United States", *Science and Global Security*, Volume 12, 2004, pp 125-136.

Table 6-2
Estimated Offsite Cost Risks Associated with Atmospheric Releases: Early High Release from a Core-Damage Event at the IP2 or IP3 Reactor; Fire in the IP2 or IP3 Spent-Fuel Pool

Indicator	**Affected Facility**		
	Indian Point 2 Reactor	**Indian Point 3 Reactor**	**Spent-Fuel Pool at the IP2 or IP3 Plant**
Type of radioactive release	Early High release from core damage	Early High release from core damage	Fire in the pool, following water loss
Estimated frequency of release, for internal + external initiating events	2.47E-06 per RY (as in License Renewal Application)	5.21E-06 per RY (as in License Renewal Application)	2.00E-06 per RY (as estimated in NUREG-1353)
Estimated total offsite costs	$66 billion (as in License Renewal Application)	$56 billion (as in License Renewal Application)	$461 billion (from study by Beyea et al)
Estimated offsite cost risk	$163,000 per yr	$292,000 per yr	$922,000 per yr

Notes:
(a) The citation for NUREG-1353 is: E. D. Throm, *Regulatory Analysis for the Resolution of Generic Issue 82, "Beyond Design Basis Accidents in Spent Fuel Pools", NUREG-1353*, NRC, April 1989.
(b) In the second row, the Early High release frequencies for the IP reactors are from Appendix E of the License Renewal Application as follows: Attachment E.1, Table E.1-14, adjusted by a multiplier of 3.80 (for IP2); and Attachment E.3, Table E.3-14, adjusted by a multiplier of 5.52 (for IP3). The License Renewal Application employs these multipliers to account for internal and external initiating events. (See Table 4-1.)
(c) The estimated total offsite costs in the third row are from Table 6-1.

Table 6-3
Estimated Present Value of Cost Risks Associated with Atmospheric Releases: Full Spectrum of Releases from a Core-Damage Event at the IP2 or IP3 Reactor; Fire in the IP2 or IP3 Spent-Fuel Pool

Indicator	**Affected Facility**		
	Indian Point 2 Reactor	**Indian Point 3 Reactor**	**Spent-Fuel Pool at the IP2 or IP3 Plant**
Type of radioactive release	Full spectrum of releases from core damage	Full spectrum of releases from core damage	Fire in the pool, following water loss
Present value of offsite cost risk, for internal + external initiating events	$3,635,924 (as in License Renewal Application)	$6,048,060 (as in License Renewal Application)	$9,923,394 (probability from NUREG-1353, offsite cost from study by Beyea et al)
Present value of onsite cost risk, for internal + external initiating events	$1,448,245 (as in License Renewal Application)	$1,351,583 (as in License Renewal Application)	Not estimated in this table
Total present value of cost risk, for internal + external initiating events	$5,084,168	$7,399,643	$9,923,394

Notes:
(a) The full spectrum of releases from each of the two reactors includes accident sequences in which the containment does not fail.
(b) For the two reactors, the estimated present values shown in Table 5-7 (not corrected for containment bypass during High/Dry sequences) are adjusted here by multipliers of 3.80 (for IP2) and 5.52 (for IP3) to account for both internal and external initiating events. Uncertainty multipliers are not used in this table.
(c) For the affected spent-fuel pool, the estimate shown in Table 6-2 for offsite cost risk ($922,000 per year) is converted to a present value by accumulating the annual value over 20 years with a discount rate of 7 percent per year.

Table 7-1
Public Opinion in Four Muslim Countries Regarding the US "War on Terrorism"

Country	**Percentage of Respondents Who Think that the Primary Goal of What the US Calls "the War on Terrorism" is to:**		
	Weaken and Divide the Islamic Religion and its People	**Achieve Political and Military Domination to Control Middle East Resources**	**Protect Itself from Terrorist Attacks**
Morocco	33	39	19
Egypt	31	55	9
Pakistan	42	26	12
Indonesia	29	24	23

Notes:
(a) Data are from: Steven Kull et al, *Muslim Public Opinion on US Policy, Attacks on Civilians and al Qaeda*, Program on International Policy Attitudes, University of Maryland, 24 April 2007.
(b) Percentages not shown in each row are "do not know" or "no response".

Table 7-2
Opinions of Selected Experts Regarding the Probability of Another 9/11-Type Attack in the United States

Time Horizon for Potential Attack	**Fraction of Interviewed Experts Holding Position (percent)**	
	Attack has No Chance or is Unlikely	**Attack is Likely or Certain**
Within 6 months	80	20
Within 5 years	30	70
Within 10 years	17	83

Notes:
(a) These and other survey data are discussed in: "The Terrorism Index", *Foreign Policy*, September/October 2007, pp 60-67. The underlying data are from: "Terrorism Survey III", June 2007, accessed from the website of the Center for American Progress <www.americanprogress.org> on 21 August 2007.
(b) The following question was posed to 108 US-based experts in international security: "What is the likelihood of a terrorist attack on the scale of the 9/11 attacks occurring again in the United States in the following time frames?"

Table 7-3
Future World Scenarios Identified by the Stockholm Environment Institute

Scenario	Characteristics
Conventional Worlds	
Market Forces	Competitive, open and integrated global markets drive world development. Social and environmental concerns are secondary.
Policy Reform	Comprehensive and coordinated government action is initiated for poverty reduction and environmental sustainability.
Barbarization	
Breakdown	Conflict and crises spiral out of control and institutions collapse.
Fortress World	This scenario features an authoritarian response to the threat of breakdown, as the world divides into a kind of global apartheid with the elite in interconnected, protected enclaves and an impoverished majority outside.
Great Transitions	
Eco-Communalism	This is a vision of bio-regionalism, localism, face-to-face democracy and economic autarky. While this scenario is popular among some environmental and anarchistic subcultures, it is difficult to visualize a plausible path, from the globalizing trends of today to eco-communalism, that does not pass through some form of barbarization.
New Sustainability Paradigm	This scenario changes the character of global civilization rather than retreating into localism. It validates global solidarity, cultural cross-fertilization and economic connectedness while seeking a liberatory, humanistic and ecological transition.

Source:
Paul Raskin et al, *Great Transition: The Promise and Lure of the Times Ahead*, Stockholm Environment Institute, 2002.

Table 7-4
Some Potential Modes and Instruments of Attack on a Nuclear Power Plant

Attack Mode/Instrument	Characteristics	Present Defense
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
Anti-tank missile	• 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:
This table is adapted from a table, supported by analysis and citations, in: Gordon Thompson, *Robust Storage of Spent Nuclear Fuel: A Neglected Issue of Homeland Security*, IRSS, January 2003. Later sources confirming this table include:
(a) Gordon Thompson, testimony before the California Public Utilities Commission regarding Application No. 04-02-026, 13 December 2004.
(b) Jim Wells, US Government Accountability Office, testimony before the Subcommittee on National Security, Emerging Threats and International Relations, US House Committee on Government Reform, 4 April 2006.
(c) Marvin Fertel, Nuclear Energy Institute, testimony before the Subcommittee on National Security, Emerging Threats and International Relations, US House Committee on Government Reform, 4 April 2006.
(d) Danielle Brian, Project on Government Oversight, letter to NRC chair Nils J. Diaz, 22 February 2006.
(e) National Research Council, *Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report*, National Academies Press, 2006.

Table 7-5
Potential Sabotage Events at a Spent-Fuel-Storage Pool, as Postulated in the NRC's August 1979 GEIS on Handling and Storage of Spent LWR Fuel

Event Designator	General Description of Event	Additional Details
Mode 1	• Between 1 and 1,000 fuel assemblies undergo extensive damage by high-explosive charges detonated under water • Adversaries commandeer the central control room and hold it for approx. 0.5 hr to prevent the ventilation fans from being turned off	• One adversary can carry 3 charges, each of which can damage 4 fuel assemblies • Damage to 1,000 assemblies (i.e., by 83 adversaries) is a "worst-case bounding estimate"
Mode 2	• Identical to Mode 1 except that, in addition, an adversary enters the ventilation building and removes or ruptures the HEPA filters	
Mode 3	• Identical to Mode 1 within the pool building except that, in addition, adversaries breach two opposite walls of the building by explosives or other means	• Adversaries enter the central control room or ventilation building and turn off or disable the ventilation fans
Mode 4	• Identical to Mode 1 except that, in addition, adversaries use an additional explosive charge or other means to breach the pool liner and 5-ft-thick concrete floor of the pool	

Notes:
(a) Information in this table is from Appendix J of: USNRC, *Generic EIS on Handling and Storage of Spent Light Water Power Reactor Fuel, NUREG-0575*, August 1979.
(b) The postulated fuel damage ruptures the cladding of each rod in an affected fuel assembly, releasing "contained gases" (gap activity) to the pool water, whereupon the released gases bubble to the water surface and enter the air volume above that surface.

Table 7-6
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 an unclassified, published report (citation is voluntarily withheld here) • Purpose is to penetrate large thicknesses of rock or concrete as the first stage of a "tandem" warhead • Configuration is a cylinder with a diameter of 71 cm and a length of 72 cm • When tested in November 2002, created a hole of 25 cm diameter in tuff rock to a depth of 5.9 m • Device has a mass of 410 kg; would be within the payload capacity of many general-aviation aircraft
A potential delivery vehicle	• A Beechcraft King Air 90 general-aviation aircraft will carry a payload of up to 990 kg at a speed of up to 460 km/hr • A used King Air 90 can be purchased in the US for $0.4-1.0 million

Source:
Gordon Thompson, Institute for Resource and Security Studies, testimony before the Public Utilities Commission of the State of California regarding Application No. 04-02-026, 13 December 2004.

Table 7-7
Estimated Present Value of Cost Risks of a Potential Atmospheric Release from a Reactor or Spent-Fuel Pool at Indian Point, Including a Release Caused by an Attack

Type of Event	Estimated Present Value of Cost Risks for Affected Facility		
	Indian Point 2 Reactor	**Spent-Fuel Pool at the IP2 or IP3 Plant**	**Indian Point 3 Reactor**
Full spectrum of releases from reactor core damage, for internal + external initiating events (excluding attack) plus uncertainty	$10.7 million (as in License Renewal Application)	Not applicable	$10.7 million (as in License Renewal Application)
Above-stated estimate corrected by accounting for containment bypass during High/Dry sequences	$58.0 million	Not applicable	$34.1 million
Fire in pool, for internal + external initiating events (excluding attack) plus uncertainty	Not applicable	$27.7 million (assuming probability as in NUREG-1353)	Not applicable
Attack on reactor assuming probability of 1 per 10,000 reactor-years	$73.2 million	Not applicable	$62.4 million
Attack on pool assuming probability of 1 per 10,000 reactor-years	Not applicable	$498 million	Not applicable
Attack on IP2 reactor and pool assuming probability of 1 per 10,000 reactor-years	$569 million		Not applicable
Attack on IP3 reactor and pool assuming probability of 1 per 10,000 reactor-years	Not applicable	$559 million	

(Notes for this table are on the following page.)

Notes for Table 7-7:

(a) Estimated present values in the first two rows are from Table 5-7, adjusted by a multiplier of 8 to account for external initiating events and uncertainty.

(b) In the third row, the probability of a pool fire is assumed, following NUREG-1353, to be 2.0E-06 per reactor-year adjusted by an uncertainty multiplier (the ratio of 95th percentile to mean probability) of 2.78. That multiplier is taken from Table 4.6.8 of NUREG-1353, for a 99% cutoff value. The fire is assumed to yield an atmospheric release of 35 MCi of Cs-137, with accompanying offsite costs of $461 billion as estimated by Beyea et al. (See Tables 6-1 and 6-2.)

(c) An attack on a reactor is assumed here to yield an atmospheric release and accompanying offsite costs as estimated in the License Renewal Application for an Early High release. (See Table 6-1.)

(d) An attack on a spent-fuel pool is assumed here to initiate a fire that yields an atmospheric release of 35 MCi of Cs-137, with accompanying offsite costs of $461 billion as estimated by Beyea et al. (See Table 6-1.)

(e) A core-damage event and/or a spent-fuel-pool fire at each unit is assumed here to yield onsite costs of $2 billion, as estimated in the License Renewal Application for a core-damage event at IP2 or IP3. (See Table 5-7.)

(f) Present value is determined by accumulating annual value over 20 years with a discount rate of 7 percent per year.

Table 8-1
Selected Approaches to Protecting US Critical Infrastructure From Attack by Sub-National Groups, and Some of the Strengths and Weaknesses of these Approaches

Approach	Strengths	Weaknesses
Offensive military operations internationally	• Can deter or prevent governments from supporting sub-national groups hostile to the US	• Can promote growth of sub-national groups hostile to the US, and build sympathy for these groups in foreign populations • Can be costly in terms of lives, money and national reputation
International police cooperation within a legal framework	• Can identify and intercept potential attackers	• Implementation can be slow and/or incomplete • Requires ongoing international cooperation
Surveillance and control of the domestic population	• Can identify and intercept potential attackers	• Can destroy civil liberties, leading to political, social and economic decline of the nation
Active defense of infrastructure facilities (by use of guards, guns, gates, etc.)	• Can stop attackers before they reach the target	• Can involve higher operating costs • Requires ongoing vigilance • May require military involvement
Resilient design, passive defense, and related protective measures for infrastructure facilities (as envisioned in the NIPP)	• Can allow target to survive attack without damage, thereby enhancing protective deterrence • Can substitute for other protective approaches, avoiding their costs and adverse impacts • Can reduce risks from accidents, natural hazards, etc.	• Can involve higher capital costs

Table 9-1
Selected Options to Reduce the Risk of a Spent-Fuel-Pool Fire at the Indian Point Nuclear Power Plants

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

Table 9-2
Estimation of Cost to Offload Spent Fuel from Pools at the IP2 and IP3 Plants After 5 Years of Decay

Estimation Step	Indian Point 2	Indian Point 3
Present licensed capacity of pool	1,376 fuel assemblies	1,345 fuel assemblies
Pool capacity needed for full-core discharge	193 fuel assemblies	193 fuel assemblies
Anticipated av. pool inventory of spent fuel during period of license extension	1,376 – 193 – 32 = 1,151 fuel assemblies (assuming periodic offload of 64 assemblies to ISFSI)	1,345 – 193 – 32 = 1,120 fuel assemblies (assuming periodic offload of 64 assemblies to ISFSI)
Av. annual discharge of fuel from reactor	36 fuel assemblies	36 fuel assemblies
Pool capacity needed to store fuel for 5-yr decay, incl. 10% buffer	36x5x1.1 = 198 fuel assemblies	36x5x1.1 = 198 fuel assemblies
Total pool capacity needed for full-core discharge and 5-yr decay	193 + 198 = 391 fuel assemblies	193 + 198 = 391 fuel assemblies
Fuel requiring offload if pool storage is limited to fuel undergoing 5-yr decay	1,151 – 198 = 953 fuel assemblies	1,120 – 198 = 922 fuel assemblies
Capital cost to offload fuel, assuming 450 kgU per assembly and capital cost of $100 to 200 per kgU for dry storage	$43 to 86 million	$41 to 83 million

Notes:
(a) Data, except capital cost per kgU, are from Table 2-1.
(b) A capital cost of $100 to 200 per kgU for dry storage of spent fuel is used by Robert Alvarez et al in their paper in *Science and Global Security*, Volume 11, 2003, pp 1-51.

COMMENTS OF RIVERKEEPER ON NYSDOS PUBLIC NOTICE F-2012-1028 – APPLICATION OF ENTERGY FOR COASTAL CONSISTENCY CERTIFICATION FOR THE PROPOSED RELICENSING OF INDIAN POINT (October 30, 2013)

Attachment 15

CHERNOBYL ON THE HUDSON?

THE HEALTH AND ECONOMIC IMPACTS OF A TERRORIST ATTACK AT THE INDIAN POINT NUCLEAR PLANT

Edwin S. Lyman, PhD
Union of Concerned Scientists
September 2004

Commissioned by Riverkeeper, Inc.

TABLE OF CONTENTS

TABLES

EXECUTIVE SUMMARY

Since 9/11, the specter of a terrorist attack at the Indian Point nuclear power plant, thirty-five miles upwind from midtown Manhattan, has caused great concern for residents of the New York metropolitan area. Although the Nuclear Regulatory Commission (NRC) ordered modest security upgrades at Indian Point and other nuclear power plants in response to the 9/11 attacks, the plants remain vulnerable, both to air attacks and to ground assaults by large terrorist teams with paramilitary training and advanced weaponry. Many question whether the NRC's security and emergency planning requirements at Indian Point are adequate, given its attractiveness as a terrorist target and the grave consequences for the region of a successful attack.

This report presents the results of an independent analysis of the health and economic impacts of a terrorist attack at Indian Point that results in a core meltdown and a large radiological release to the environment. We find that, depending on the weather conditions, an attack could result in as many as 44,000 near-term deaths from acute radiation syndrome or as many as 518,000 long-term deaths from cancer among individuals within fifty miles of the plant. These findings confirm that Indian Point poses a severe threat to the entire New York metropolitan area. The scope of emergency planning measures should be promptly expanded to provide some protection from the fallout from an attack at Indian Point to those New York area residents who currently have none. Security at Indian Point should also be upgraded to a level commensurate with the threat it poses to the region.

A 1982 study by Sandia National Laboratories found that a core meltdown and radiological release at one of the two operating Indian Point reactors could cause 50,000 near-term deaths from acute radiation syndrome and 14,000 long-term deaths from cancer. When these results were originally disclosed to the press, an NRC official tried to reassure the public by saying that the kind of accident the study considered would be less likely than "a jumbo jet crashing into a football stadium during the Superbowl."

In the post-9/11 era, the possibility of a jumbo jet crashing into the Superbowl --- or even a nuclear power plant --- no longer seems as remote as it did in 1982. Nonetheless, NRC continues to argue that the 1982 Sandia report is unrealistic because it focused on "worst-case" accidents involving the simultaneous failure of multiple safety systems, which are highly unlikely to occur by chance. But when the potential for terrorist attacks is considered, this argument no longer applies. "Worst-case" scenarios are precisely the ones that terrorists have in mind when planning attacks.

Both NRC and Entergy, the owner of Indian Point, assert that even for the most severe terrorist attack, current emergency plans will be adequate to protect residents who live in the evacuation zone within 10 miles of the plant. They also say that there will be no significant radiological impact on New York City or any other location outside of the 10-mile zone. Accordingly, NRC has opposed proposals made after 9/11 to extend the emergency planning zone around Indian Point. However, NRC and Entergy have not provided the public with any documentation of the assumptions and calculations underlying these claims.

In view of the lack of public information available on these controversial issues, we carried out an independent technical analysis to help inform the debate. Our calculations were performed with the same state-of-the-art computer code that NRC uses to assess accident consequences. We used the NRC's guidance on the radiological release from a core meltdown, current estimates of radiation risk, population data from the 2000 census, and the most recent evacuation time estimate for the 10-mile Indian Point emergency planning zone. Following the format of the 1982 Sandia report, we calculated the numbers of near-term deaths from acute radiation syndrome, the numbers of long-term deaths from cancer, and the maximum distance at which near-term deaths can occur. We evaluated the impact of both evacuation and sheltering on these outcomes. We also estimated the economic damages due to the long-term relocation of individuals from contaminated areas, and the cost of cleanup or condemnation of those areas.

The health and environmental impacts of a large radiological release at Indian Point depend strongly on the weather conditions. We have carried out calculations for over 140,000 combinations of weather conditions for the New York area and wind directions for the Indian Point site, based on a year's worth of weather data. For this data set, we have determined the average consequences, the peak consequences, and the consequences for "95th percentile" weather conditions (in other words, only 5% of the weather sequences analyzed resulted in greater consequences).

We believe that the 95th percentile results, rather than the average values, represent a reasonable assessment of the likely outcome of a successful terrorist attack, since such attacks would most likely not occur at random, but would be timed to coincide with weather conditions that favor greater casualties. Attacks capable of causing the peak consequences that we calculate would be difficult to achieve because of inaccuracies in weather forecasts, restricted windows of opportunity and other factors, but remain within the realm of possibility.

For a successful attack at one of the two operating Indian Point reactors, we find that

- The number of near-term deaths within 50 miles, due to lethal radiation exposures received within 7 days after the attack, is approximately 3,500 for 95th percentile weather conditions, and approximately 44,000 for the worst case evaluated. Although we assumed that the 10-mile emergency planning zone was entirely evacuated in these cases, this effort was inadequate because (according to Entergy's own estimate) it would take nearly 9.5 hours to fully evacuate the 10-mile zone, whereas in our model the first radiological release occurs about two hours after the attack.

- Near-term deaths can occur among individuals living as far as 18 miles from Indian Point for the 95th percentile case, and as far as 60 miles away in the worst case evaluated. Timely sheltering could be effective in reducing the number of near-term deaths among people residing outside of the 10-mile emergency planning zone, but currently no formal emergency plan is required for these individuals.

- The number of long-term cancer deaths within 50 miles, due to non-acutely lethal radiation exposures within 7 days after the attack, is almost 100,000 for 95th percentile weather conditions and more than 500,000 for the worst weather case evaluated. The peak value corresponds to an attack timed to coincide with weather conditions that maximize radioactive fallout over New York City.

- Based on the 95th percentile case, Food and Drug Administration guidance would recommend that many New York City residents under 40, and children in particular, take potassium iodide (KI) to block absorption for radioactive iodine in the thyroid. However, there is no requirement that KI be stockpiled for use in New York City.

- The economic damages within 100 miles would exceed $1.1 trillion for the 95th percentile case, and could be as great as $2.1 trillion for the worst case evaluated, based on Environmental Protection Agency guidance for population relocation and cleanup. Millions of people would require permanent relocation.

We hope that this information will be useful to Federal, State and local homeland security officials as they continue to develop plans to protect all those at risk from terrorist attacks in the post-9/11 world.

INTRODUCTION

(a) The terrorist threat to nuclear power plants

Public concern about the vulnerability of nuclear power plants to catastrophic acts of sabotage soared in the aftermath of the September 11 terrorist attacks. There is ample justification for this concern.

Soon after the 9/11 attacks, the Nuclear Regulatory Commission conceded that U.S. nuclear power plants were not designed to withstand the high-speed impact of a fully fueled, modern passenger jet. The report of the 9/11 Commission has revealed that al Qaeda considered attacks on nuclear plants as part of their original plan, but declined to do so primarily because of their mistaken belief that the airspace around nuclear power plants in the U.S. was "restricted," and that planes that violated this airspace would likely be shot down before impact.[1]

But al Qaeda is surely now aware that no such restrictions were in place on 9/11. And it is clear from press reports that even today, no-fly zones around nuclear plants are imposed only at times of elevated threat level, and are limited in scope to minimize their economic impact on the aviation industry. This policy reflects a confidence in the ability of the intelligence community to provide timely advance warning of a surprise attack that --- given the 9/11 example --- is not entirely warranted. Moreover, even when no-fly zones are in place around nuclear plants, they are not likely to be effectively enforced. For instance, the U.S. government does not require that surface-to-air anti-aircraft protection be provided at nuclear plants, although such defenses have been routinely employed in Washington, D.C. since the 9/11 attacks.

In addition to the aircraft threat, many have begun to question the adequacy of physical security at nuclear plants to protect against ground-based, paramilitary assaults, in view of revelations that thousands of individuals received sophisticated training in military tactics at al Qaeda camps in Afghanistan. Press reports have documented many security failures at nuclear plants around the country, and have called attention to the troubling statistic that during a series of security performance tests in the 1990s, guard forces at nearly 50% of US plants failed to prevent mock terrorist teams from simulating damage that would have caused meltdowns had they been real attacks. This information, which was widely available but largely ignored before 9/11, suddenly became far more alarming in the new threat environment.

Today, the danger of a terrorist attack at a nuclear power plant in the United States --- either from the air or from the ground --- is apparently as great as ever. According to a January 14, 2004 speech by Robert L. Hutchings, Chairman of the National Intelligence Council (NIC),[2]

---

[1] *The 9/11 Commission Report, Authorized Edition*, W.W. Norton, New York, 2004, p. 245.
[2] Robert L. Hutchings, "Terrorism and Economic Security," speech to the International Security Management Organization, Scottsdale, AZ, January 14, 2004.

"targets such as nuclear power plants … are high on al Qa'ida's targeting list as a way to sow panic and hurt our economy … The group has continued to hone its use of transportation assets as weapons … although we have disrupted several airline plots, we have not eliminated the threat to airplanes. There are still al Qa'ida operatives who we believe have been deployed to hijack planes and fly them into key targets … Al Qa'ida's intent is clear. Its capabilities are circumscribed but still substantial. And our vulnerabilities are still great."

More recently, the 9/11 Commission concluded that "major vulnerabilities still exist in cargo and general aviation security. These, together with inadequate screening and access controls, continue to present aviation security challenges."[3]

(b) The Nuclear Regulatory Commission: an agency in denial

Since 9/11, members of the public, non-profit groups and lawmakers across the United States have been calling for major security upgrades at nuclear power plants, including consideration of measures such as military protection against ground assault and anti-aircraft defenses against jet attack. Yet the response of the Nuclear Regulatory Commission (NRC), the agency that regulates both the safety and security of US nuclear reactors, has not been commensurate with the magnitude of the threat.[4] And the Department of Homeland Security, the agency charged with coordinating the defense of the entire US critical infrastructure against terrorist attacks, appears to be merely following NRC's lead.[5]

Notwithstanding a steady stream of FBI warnings citing nuclear power plants as potential terrorist targets, NRC continues to maintain that there is no need to consider measures that could reduce the vulnerability of nuclear plants to air attack. NRC's position is that "the best approach to dealing with threats from aircraft is through strengthening airport and airline security measures."[6]

As it became clear that NRC was not going to require the nuclear industry to protect nuclear plants from attacks on the scale of September 11, some groups began calling for plants to be shut permanently. Because many of the most dangerous fission products in a nuclear reactor core decay rapidly after shutdown, the health consequences of a terrorist attack on a shutdown nuclear reactor would be significantly lower than those of an attack on an operating reactor.[7]

---

[3] *9/11 Commission Report* (2004), op cit., p. 391.
[4] D. Hirsch, D. Lochbaum and E. Lyman, "NRC's Dirty Little Secret," *Bulletin of the Atomic Scientists*, May/June 2003.
[5] E. Lyman, "Nuclear Plant Protection and the Homeland Security Mandate," Proceedings of the 44th Annual Meeting of the Institute of Nuclear Materials Management, Phoenix, Arizona, July 2003.
[6] US Nuclear Regulatory Commission, "Frequently Asked Questions About NRC's Response to the 9/11/01 Events," revised March 15, 2004. On the NRC web site: http://www.nrc.gov/what-we-do/safeguards/911/faq.html#3.
[7] Calculations by the author, using the computer code MACCS2, indicate that for an attack occurring at twenty days after reactor shutdown and resulting in core melt and loss of containment, the number of early fatalities from acute radiation sickness would be reduced by 80% and the number of latent cancer fatalities

Public concern has been greatest for those plants seen as prime terrorist targets because of their symbolic importance or location near large population and commercial centers, such as the Indian Point nuclear power plant in Westchester County, New York, whose two operating reactors are situated only 24 miles from the New York City limits, 35 miles from midtown Manhattan and in close proximity to the reservoir system that supplies drinking water to nine million people. The post-9/11 movement to shut down Indian Point has attracted a level of support from the public and elected officials not seen since the early 1980s, including calls for shutdown by over 400 elected officials and over 50 municipalities.

In response to this challenge, NRC, Entergy (the owner of Indian Point), other nuclear utilities, and their trade group in Washington, the Nuclear Energy Institute (NEI), have undertaken a massive public relations campaign to assuage public fears about the risk of terrorism at Indian Point. First, they assert that a combination of robust nuclear plant design, physical security and redundant safety measures would be able to stop any terrorist attack from causing significant damage to the reactor core. Second, they argue that even if terrorists were to successfully attack Indian Point and cause a large radiological release, the public health consequences could be successfully mitigated by execution of the emergency plans already in place for residents within the 10-mile-radius "emergency planning zone" (EPZ). And third, they claim that outside of the 10-mile EPZ, exposures would be so low that no special precautions would be necessary to adequately protect the public from radiation, other than possible interdiction of contaminated produce and water.[8]

A typical example of the third argument can be found in a recent letter the NRC sent to Alex Matthiessen, Executive Director of Riverkeeper:[9]

> "Outside of 10 miles, direct exposure is expected to be sufficiently low that evacuation or sheltering would not be necessary. Exposure to a radioactive plume would not likely result in immediate or serious long-term health effects. Consideration of public sheltering and evacuation in emergency plans is very conservative and recommended at very low dose levels, well below the levels where health effects would be expected to occur."

---

resulting from lower exposures would be reduced by 50%, compared to an attack when the reactor is operating at full power. This calculation does not consider an attack on the storage pools for the highly radioactive spent fuel, which could result in significant long-term radiological contamination over a wide area and enormous economic consequences. For an extensive discussion of this threat, as well as an analysis of approaches for mitigating it, see R. Alvarez et al., "Reducing the Hazards from Stored Spent Power-Reactor Fuel in the United States," *Science and Global Security* **11** (2003) 1-51.

[8] The NRC defines two "emergency planning zones," or EPZs. The 10-mile "plume exposure" EPZ is the region where evacuation or other actions could be ordered to protect the public from coming into contact with an atmospheric release of radioactivity. The 50-mile "ingestion" EPZ is the region where interdiction of agricultural products and water supplies could be ordered to prevent the consumption of contaminated produce. No evacuation planning is required for individuals residing within the ingestion EPZ but outside of the plume exposure EPZ.

[9] Letter from Cornelius F. Holden, Jr., Office of Nuclear Reactor Regulation, US NRC, to Alex Matthiessen, Riverkeeper, September 30, 2003.

The purpose of this report is to address these three claims, with an emphasis on the second and third, by conducting a quantitative assessment of the potential consequences of a terrorist-induced radiological release at Indian Point for individuals both within and without the 10-mile EPZ, including residents of New York City.

There is a considerable need today for an independent study of these questions. At a time when the importance of rigorous emergency planning for catastrophic terrorist attacks is obvious, it is essential that responsible officials be fully apprised of the facts, especially if they contradict long-held assumptions and biases. The lives of many people could be put at jeopardy if emergency plans are not designed with the most accurate information at hand.

This means, in particular, that the emergency planning process should be designed to account for the full spectrum of potential consequences, including so-called "fast-breaking" release scenarios in which radioactive releases to the environment would begin within about thirty minutes after an attack. This was one of the major conclusions of the report carried out for the government of New York State by James Lee Witt Associates.[10] Certain terrorist attack scenarios could be capable of causing such rapid releases.

But NRC and the Federal Emergency Management Agency (FEMA) continue to be reluctant to require testing of fast-breaking radiological releases in emergency planning exercises, asserting that such events are highly unlikely to occur.[11] However, this argument is no longer relevant in an age when terrorists have acquired unprecedented levels of technical expertise, and are actively targeting critical infrastructure facilities with the intent to maximize casualties and economic damages. If current emergency plans cannot successfully cope with all credible terrorist-induced events, they should be upgraded. If upgrading to a sufficiently protective level is so cumbersome as to be practically impossible, then other options, including plant shutdown, should not be ruled out.

Members of the public deserve to be fully informed of the potential consequences for their health and property of a successful terrorist attack at Indian Point, so that they can prepare for an attack in accordance with their own judgment and willingness to accept risk. This principle is consistent with the guidance of the Department of Homeland Security, whose Web site www.ready.gov advises that "all Americans should begin a process of learning about potential threats so we are better prepared to react during an attack." Sources of technical information other than NRC and the nuclear industry are

[10] James Lee Witt Associates, *Review of Emergency Preparedness of Areas Adjacent to Indian Point and Millstone*, March 2003, Executive Summary, pg. x.

[11] Although it was anticipated that the widely publicized June 8, 2004 emergency planning exercise at Indian Point would involve a "fast-breaking" release, NRC in fact chose a scenario in which no release at all occurred. It was assumed that terrorists attacked the plant with a jet aircraft but missed the reactor and only managed to crash into the switchyard, causing a loss of off-site power but not enough damage to result in a radiological release. Thus the exercise provided no information as to the effectiveness of the Indian Point emergency plan in protecting residents of the EPZ from injury had the plane actually hit its target and initiated the damage scenario that is assessed in this report.

also essential to facilitate a factually accurate and honest discussion of the risks and benefits of continued operation of Indian Point in the post-9/11 era.

Some observers may criticize the public release of this report as irresponsible because they believe it (1) could assist terrorists in planning attacks, or (2) could interfere with the successful execution of emergency plans by unnecessarily frightening members of the public who the authorities claim are not at risk.

We are acutely aware of such concerns and, after careful consideration, have concluded that they do not have merit. We have reviewed this report carefully and omitted any information specific enough to be useful to terrorists seeking to attack Indian Point. Unfortunately, far more detailed information about nuclear plant design, operation and vulnerabilities than this report contains has already been --- and continues to be --- widely disseminated. For example, a paper written by staff of the Oak Ridge National Laboratory (ORNL) and the Defense Threat Reduction Agency (DTRA), published in 2004 in a technical journal and available on the Internet, contains a diagram of a generic nuclear power plant indicating where truck bombs of various sizes could be detonated in order to stage an attack with a 100% probability of core damage.

There can be little doubt that al Qaeda and other terrorist organizations are already well aware of the severity of the consequences that could result from an attack at Indian Point. It is NRC and FEMA that seem not to appreciate this risk, and it is to them above all that we direct this study. We also believe that there is a considerable cost, but no apparent benefit, to withholding information that could help people to protect themselves in the event of a terrorist attack at Indian Point. Better information will enable better coordination of all populations at risk and help to avoid situations where some individuals take inappropriate actions that endanger others.

This report would not have been necessary had we seen any indication that NRC and other government authorities fully appreciate the seriousness of the risk to the public from radiological sabotage, or if certain members of the Nuclear Regulatory Commission had not made statements regarding severe accident consequences and risks that contradicted the results of quantitative analyses developed and refined over several decades by NRC's own technical staff and contractors.

For instance, at a recent briefing on NRC's emergency preparedness program, NRC Commissioner Edward McGaffigan, comparing the radiological exposure from a reactor accident to air travel, radon and other sources of exposure to natural radioactivity, said that[12]

> "..the order of magnitude of the release is similar to all of these other things in people's lives and they should not panic over a few hundred millirem or even a couple of rem …but it's this radiation phobia, absolutely inflamed by these anti -

[12] US NRC, *Briefing on Emergency Preparedness Program Status*, Public Meeting, September 24, 2003, transcript, p. 73.

> nuclear groups putting out their misinformation that actually hurts emergency planning …"

Commissioner McGaffigan's statement is misleading on at least three counts:

(1) Current emergency planning guidance is already based on the principle that exposures of "a couple of rem" would be acceptable following a large radiological release;

(2) The potential doses from a large radiological release can greatly exceed "a few hundred millirem or even a couple of rem" far downwind of the release site, and for many individuals could result in a significant increase in their lifetime risk of cancer (10% or greater) or even pose a risk of severe injury or death from acute radiation exposure;

(3) Even if the average dose resulting from a large release were on the order of "a couple of rem," the total collective detriment (latent cancer fatalities and economic damages) could be very high if a large number of people in a densely populated area were so affected.

We believe that misinformation originating within NRC itself is the biggest obstacle to development of the robust radiological emergency planning strategies needed to cope with today's heightened threat. Statements like those cited above raise the concern that those responsible for regulating the nuclear industry and protecting it from terrorist attack are either in a chronic state of denial or actually believe the propaganda generated by the nuclear industry for public consumption. If this is indeed the case, then one cannot have confidence that emergency planning officials are basing their decisions on accurate and unbiased information. Since the departure of NRC Commissioner Greta Dicus a few years ago, the current Commission does not have any members with backgrounds in radiation protection and health issues. One wonders whether the NRC Commissioners truly understand and appreciate the full extent of the dangers posed by the facilities that they regulate.

(c) The CRAC2 Report

Given the lack of credible information from public officials on the potential consequences of a terrorist attack at Indian Point, concerned neighbors of the plant turned to one of the few sources on this subject in the public domain --- the so-called "CRAC2 Report," carried out by Sandia National Laboratories (SNL) under contract for NRC in 1981. This study, formally entitled "Technical Guidance for Siting Criteria Development," used a computer code developed by SNL known as CRAC2 ("Calculation of Reactor Accident Consequences") to analyze the consequences of severe nuclear plant accidents and to study their dependence on population density, meteorological conditions and other characteristics. The version of the CRAC2 Report that had been submitted to NRC for eventual public release only contained average values of consequence results, but the "peak" values for worst -case weather conditions were obtained by Congressman Edward Markey in 1982 and provided to the Washington Post.[13]

At many reactor sites, the CRAC2 Report predicted that for unfavorable weather conditions, a severe nuclear reactor accident could cause tens of thousands of early fatalities as a result of severe radiation exposure, and comparable numbers of latent cancer fatalities from smaller exposures. For Indian Point 3 (which at the time operated at a significantly lower power than it now does), CRAC2 predicted peak values of 50,000 early fatalities and 14,000 latent cancer fatalities, with early fatalities occurring as far as 17.5 miles downwind of the site.

The CRAC2 Report only considered accidents affecting operating nuclear reactors, and did not evaluate the consequences of accidents also involving spent fuel storage pools. Spent fuel pool loss-of-coolant accidents could themselves result in large numbers of latent cancer fatalities, widespread radiological contamination and huge cleanup bills, even if only a fraction of the fuel in the pool were damaged.

The release of the CRAC2 figures caused a great deal of consternation, but NRC was able to defuse the controversy by claiming that the peak results corresponded to accidents with extremely low probabilities (said to be one in a billion), and hence were not a cause for concern. In fact, Robert Bernero, director of the NRC's risk analysis division at the time, said (in a moment of unfortunate prescience) that such severe accidents would be less likely than "a jumbo jet crashing into a football stadium during the Super bowl."[14]

When Riverkeeper and other groups dusted off and called attention to the CRAC2 Report following the September 11 attacks, the NRC appeared unable to appreciate the new relevance of the study in a world where the possibility of a jumbo jet crashing into the Superbowl was no longer so remote. For example, in rejecting a 2001 petition filed by Riverkeeper to shut down the Indian Point plant until Entergy implemented a number of prudent security-related measures, the NRC merely repeated its old probability-based arguments, saying that[15]

> "…the reactor siting studies in the CRAC2 Report …used generic postulated releases of radioactivity from a spectrum of severe (core melt) accidents, independent of the probabilities of the event occurring or the impact of the mitigation mechanisms. The studies were never intended to be realistic assessments of accident consequences. The estimated deaths and injuries resulted from assuming the most adverse condition for each parameter in the analytical code. In the cited studies, the number of resulting deaths and injuries also reflected the assumption that no protective actions were taken for the first 24

---

[13] Subcommittee on Oversight & Investigations, Committee on Interior and Insular Affairs, U.S. House of Representatives, "Calculation of Reactor Accident Consequences (CRAC2) For U.S. Nuclear Power Plants Conditional on an 'SST1' Release," November 1, 1982.

[14] Robert J. McCloskey, "The Odds of the Worst Case," *Washington Post*, November 17, 1982.

[15] US Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Notice of Director's Decision Under 10 CFR 2.206, November 18, 2002.

> hours. The studies did not, and were never intended to, reflect reality or serve as a basis for emergency planning. The CRAC2 Report analyses used more simplistic models than current technologies."

Earlier in 2002, in a letter to the New York City Council, the NRC also said that[16]

> "The Sandia study does not factor in the numerous probabilistic risk studies that have been performed since 1982. More realistic, current inputs, assumptions, and modeling techniques would be expected to result in much smaller health consequences."

In a more recent "point paper" on homeland protection and preparedness, NRC continued to repeat these themes, although its conclusions were somewhat more equivocal: [17]

> "The Sandia Siting Study ["CRAC2"] …was performed to develop technical guidance to support the formulation of new regulations for siting nuclear power reactors. A very large radiation release and delayed evacuation, among other factors, accounts for the more severe consequences …As an overall conclusion, that report does not present an up-to-date picture of risk at nuclear plants and does not reflect current knowledge in probabilistic or phenomenological modeling.
>
> "Since September 11, 2001, the NRC has been performing assessments of the consequences of a terrorist attack on a nuclear power plant. These assessments are much more detailed than past analyses and reflect our improved understanding of severe accident phenomena. The more recent analyses have involved a more realistic assessment of the radiation release, emergency planning capabilities, radiation spreading, and health effects. More recent analysis indicates a general finding that public health effects from terrorist attacks at most sites are likely to be relatively small."

Although NRC continues to harshly criticize the CRAC2 Report and anyone who cites its results, it has not publicly identified the "more realistic, current inputs, assumptions and modeling techniques that would be expected to result in much smaller health consequences," much less demonstrated the validity of these results by providing the public with its calculations for independent review. In fact, NRC now considers that these analyses are too sensitive for public release, making it impossible for the public to verify its claims.

NRC's unwillingness to share this kind of information with the public is not unexpected. NRC (like its predecessor, the Atomic Energy Commission) has worked over its history to shield the public from estimates of the consequences of severe accidents without simultaneous consideration of the low probabilities of such accidents. By multiplying

[16] Hubert Miller, Region I Administrator, US NRC, letter to Donna De Constanzo, Legislative Attorney, New York City Council, July 24, 2002.
[17] US Nuclear Regulatory Commission, "Point Paper on Current Homeland Protection and Preparedness Issues," November 2003, on the NRC Web site, www.nrc.gov.

high consequence values with very low probability numbers, the consequence figures appear less startling to the layman but are obscured in meaning. For instance, a release that could cause 100,000 cancer fatalities would only appear to cause 1 cancer fatality per year if the associated probability of the release were 1/100,000 per year.

This issue was central to the so-called Indian Point Special Proceeding, a 1983 review conducted by a panel of NRC administrative judges that examined whether Indian Point posed unusually high risks because of its location in the densely populated New York metropolitan area. Before this proceeding, the NRC ruled that all testimony on accident consequences must also contain a discussion of accident probabilities. However, in its decision, the three-judge Atomic Safety and Licensing Board panel concluded that "the Commission should not ignore the potential consequences of severe-consequence accidents by always multiplying those consequences by low probability values."[18] One of the judges dissented from this majority opinion, insisting that singling out Indian Point "to the exclusion of many other sites similarly situated in effect raises again the question of considering consequences without their associated probabilities. This we have been restricted from doing by the Commission."[19] Today, it appears that this minority opinion ultimately prevailed at NRC.

The results of the CRAC2 Report are indeed of questionable applicability today. But the reasons for this are not the ones that NRC has identified, but include, for example, the fact that the CRAC2 Report

- used census data from 1970, at a time before rampant suburban sprawl greatly increased the population densities in formerly rural areas close to some nuclear reactor sites;

- assumed that the entire 10-mile emergency planning zone would be completely evacuated within at most six hours after issuance of a warning (contrary to NRC's assertion that the CRAC2 peak results reflect the assumption that "no protective actions were taken for the first 24 hours"), whereas the current evacuation time estimate for the Indian Point EPZ, based on updated assessments of likely road congestion, is nearly ten hours;

- assumed aggressive medical treatment for all victims of acute radiation exposure in developing estimates of the number of early fatalities, and employed a now-obsolete correlation between radiation dose and cancer risk that underestimated the risk by a factor of 4 relative to current models;

- sampled only 100 weather sequences out of 8760 (an entire year's worth), a method which we find underestimates the peak value occurring over the course of a year by 30%.

---

[18] US Nuclear Regulatory Commission, Atomic Safety and Licensing Board, Indian Point Special Proceeding, Recommendations to the Commission, October 24, 1983, p. 107.
[19] Ibid, "Dissenting Views of Judge Gleason," p. 433.

In 1990, the CRAC2 code was retired in favor of a new code known as MACCS ("MELCOR Accident Consequence Code System"), which was updated to MACCS2 in 1997. The MACCS2 code, also developed by Sandia National Laboratories, is the state-of-the-art consequence code employed by both NRC and DOE in conducting dose assessments of radiological releases to the atmosphere. It includes numerous improvements over the CRAC2 code.[20]

However, the fundamental physics models that form the basis for both the CRAC2 and MACCS2 codes have not changed in the past two decades. Nor has evidence arisen since the CRAC2 Report was issued that would suggest that the CRAC2 "source term" --- that is, the fraction of the radioactive contents of the reactor core assumed to be released to the environment during a severe accident --- significantly overestimated potential releases. On the contrary, the Chernobyl disaster in 1986 demonstrated that such large releases were possible.[21] The state-of-the art revised source term developed by NRC, as defined in the NRC report NUREG-1465, "Accident Source Terms for Light -Water Nuclear Power Plants," is little different from the source terms used in the CRAC2 Report.[22] Recent experimental work, including the Phébus tests in France, have provided further confirmation of the NUREG-1465 source term.[23] Other tests, such as the VERCORS experiments in France, have found that NUREG-1465 actually underestimates the releases of some significant radionuclides.

The NRC continues to stress the absence of consideration of accident probabilities in dismissing the results of the CRAC2 Report. However, this criticism is invalid in the post-9/11 era. Accident probabilities are not relevant for scenarios that are intentionally caused by sabotage. Severe releases resulting from the simultaneous failure of multiple safety systems, while very unlikely if left up to chance, are precisely the outcomes sought by terrorists seeking to maximize the impact of their attack. Thus the most unlikely accident sequences may well be the most likely sabotage sequences.

---

[20] D.I. Chanin and M.L. Young, *Code Manual for MACCS2: Volume 1, User's Guide,* SAND97-0594, Sandia National Laboratories, March 1997.

[21] The nuclear industry often argues that a Chernobyl-type accident could not happen in the United States because the reactor was of a different and inferior type to US plants and lacked a robust containment structure. While it is true that the specific accident sequence that led to the destruction of the Chernobyl-4 reactor and the resulting radiological release was characteristic of graphite-moderated reactors like Chernobyl and would not likely occur at a US light-water reactor (LWR), it is simply false to claim that there are no possible accident sequences that could result in consequences similar to those of Chernobyl --- namely, core melt, loss or bypass of containment, and large radiological release to the environment. In fact, because such an event is not as likely to be as energetic as the Chernobyl explosion, and the plume is not likely to be as hot as the Chernobyl plume (which was fed by the burning of a large mass of graphite), the radiological release from a severe accident at a US LWR will not rise as high or disperse as far. Therefore, radiological exposure to the public near a US LWR could be far greater than was the case at Chernobyl, because the plume would be more concentrated closer to the plant.

[22] L. Soffer, et al., *Accident Source Terms for Light-Water Nuclear Power Plants, Final Report,* NUREG-1465, US NRC, February 1995.

[23] US NRC, Memorandum from Ashok Thadani to Samuel J. Collins, "Use of Results from Phébus -FP Tests to Validate Severe Accident Codes and the NRC's Revised Accident Source Term (NUREG-1465)," Research Information Letter RIL-0004, August 21, 2000.

Other aspects that add an element of randomness to accident scenarios, such as meteorological conditions, can also be controlled through the advance planning and timing of a terrorist attack. Therefore, even if NRC were correct in claiming that the CRAC2 Report assumes the "most adverse condition" for each accident -related parameter, such an approach would still be appropriate for analyzing the potential maximum consequences of a sophisticated terrorist attack.

<u>We have not been able to identify any issues that would suggest the consequence estimates provided in the CRAC2 Report were significantly overstated.</u> But in light of the problems with the CRAC2 Report discussed earlier, we have conducted our own analysis of the consequences of a sophisticated terrorist attack at the Indian Point plant, using the MACCS2 code and the most up-to-date information available. This included the NUREG-1465 revised source term, the most current dose conversion and cancer risk coefficients recommended by the International Commission on Radiological Protection (ICRP), and the most recent evacuation time estimate (ETE) for Indian Point developed by consultants for Entergy Nuclear, the plant operator. We used the SECPOP2000 code, developed for NRC by Sandia National Laboratories, to generate a high-resolution MACCS2 site data file that includes a regional population distribution based on 2000 Census data and an economic data distribution based on 1997 government statistics.

<u>For Indian Point, we find that the MACCS2 results for peak early fatalities are generally consistent with the CRAC2 Report, but that the CRAC2 Report significantly underestimates the peak number of latent cancer fatalities that could occur.</u>

Moreover, the consequence estimates in this report are based on a number of optimistic assumptions, or "conservatisms," that tend to underes timate the true consequences of a terrorist attack at Indian Point. For example:

1. We use an evacuation time estimate that assumes the attack takes place in the summer in good weather, and does not take into account the possibility that terrorists may time their attack when evacuation is more difficult or actively interfere with the evacuation.

2. We only consider the permanent resident population of the 10-mile plume exposure EPZ, and not the daily transient population, which would increase the total population of the EPZ by about 25%.

3. We use values for the rated power of the Indian Point reactors from 2002 that are about 5% lower than the current values.

4. The only health consequences we consider are early fatalities from acute radiation syndrome and latent fatalities from cancer. We do not assess the excess mortality associated with the occurrence of other well-documented health effects of radiation such as cardiovascular disease. We also do not consider non-fatal effects of radiation, such as the reduction in intelligence quotient (IQ) of children irradiated in utero or other birth defects.

5. The NUREG-1465 source term does not represent the maximum possible radiological release from a core melt. Also, the assumed delay time between the attack and the start of the radiological release is nearly two hours, which is not nearly as short as the minimum of 30 minutes that is contemplated in NRC's emergency planning regulations.

6. The calculations assume only that the reactors itself are attacked and that the large quantity of spent fuel in the wet storage pools remains undamaged.

In the following sections, we discuss some technical issues related to severe accident and sabotage phenomena. Then we describe the methodology, tools and input parameters used to carry out the calculation. Finally, we present our results and conclusions.

ACCIDENTS: DESIGN-BASIS, BEYOND-DESIGN-BASIS, AND DELIBERATE

The NRC has traditionally grouped nuclear reactor accidents into two main categories: "design-basis" accidents, and "beyond-design-basis" or "severe" accidents.

(a) Design-basis accidents

Design-basis accidents are accidents that nuclear plants must be able to withstand without experiencing unacceptable damage or resulting in radiological releases that exceed the regulatory limits known as "Part 100" releases (because of where they can be found in the NRC regulations).

One of the more challenging design-basis accidents for pressurized-water reactors (PWRs) like those at Indian Point is a loss-of-coolant accident (LOCA). In the "primary" system of a PWR, the reactor core, which is contained in a steel vessel, is directly cooled by the flow of high-pressure water forced through pipes. In a LOCA, a pipe break or other breach of the primary system results in a loss of the water essential for removing heat from the reactor fuel elements. Even if the nuclear reactor is immediately shut down or "scrammed," an enormous quantity of heat is still present in the fuel, and cooling water must be restored before a significant number of fuel elements reach temperatures above a critical limit. If heated beyond this limit, the fuel element cladding can become brittle and shatter upon contact with cooling water. Eventually, the core geometry can become "uncoolable" and the fuel pellets themselves will reach temperatures at which they start to melt.

In a design-basis LOCA, it is assumed that the emergency core cooling system (ECCS) works as designed to provide makeup coolant water to the nuclear fuel, terminating the event before it becomes impossible to control. Even in this case, however, a significant fraction of the radioactive inventory in the core could be released into the coolant and transported out of the primary system through the pipe break. The primary system therefore must be enclosed in a leak-tight containment building to ensure that Part 100 limits are not exceeded in the event of a design-basis LOCA. To demonstrate compliance with Part 100, dose calculations at the site boundary are carried out by specifying a so-called "source term" --- the radioactive contents of the gases within the containment following the LOCA --- and assuming that the containment building leaks at its maximum design leak rate, typically about 0.1% per day. Such an event was historically considered a "maximum credible accident."

(b) Beyond-design-basis accidents

In contrast to design-basis accidents, "beyond-design-basis" accidents (also known as "severe" accidents) are those in which multiple failures occur, backup safety systems do not work as designed, the core experiences a total "meltdown" and radiological releases far greater than the Part 100 limits become possible. For example, if the ECCS does not work properly after a LOCA, the core will continue to overheat, eventually forming a molten mass that will breach the bottom of the steel reactor vessel and drop onto the containment floor. It will then react violently with any water that is present and with concrete and other materials in the containment. At this point, there is little hope that the event can be terminated before much of the radioactive material within the fuel is released in the form of gases and aerosols into the containment building.

Even worse is the potential for mechanisms such as steam or hydrogen explosions to rupture the containment building, releasing its radioactive contents into the environment. Although not the only distinguishing feature, a major distinction between design-basis and severe accidents is whether containment integrity is maintained. Even a small rupture in the containment building --- no more than a foot in diameter --- would be sufficient to depressurize it and to vent the gases and aerosols it contains into the environment in less than half an hour.[24] This would result in a catastrophic release of radioactivity on the scale of Chernobyl, and Part 100 radiation exposure limits would be greatly exceeded.

The containment building can also be "bypassed" if there is a ru pture in one of the interfaces between the primary coolant system and other systems that are outside of containment, such as the "secondary" coolant system (the fluid that drives the turbine generators) or the low-pressure safety injection system. For instance, the rupture in the steam generator that occurred at Indian Point 2 in February 2000 created a pathway in which radioactive steam from the primary system was able to pass into the secondary system, which is not enclosed in a leak-tight boundary. If that event had coincided with significant fuel damage, the radiological release to the environment could have been far greater.

NRC has always had an uncomfortable relationship with beyond-design-basis accidents. By their very definition, they are accidents that were not considered in the original design basis for the plant. In fact, according to NRC, "the technical basis for containment design was intended to ensure very low leakage under postulated loss-of-coolant accidents. No explicit consideration was given to performance under severe accidents."[25] Indeed, NRC has never instituted a formal regulatory requirement that severe accidents be prevented. In 1985, the Commission ruled by fiat in its Severe Accident Policy Statement that "existing plants pose no undue risk to health and safety" and that no regulatory changes were required to reduce severe accident risk. NRC's basic assumption is that if a plant meets design basis requirements, then it will have sufficient resistance against severe accidents, and it has devoted considerable resources to the task of "confirmatory research" to justify this assumption. NRC believes that this approach provides "adequate protection" of public health and safety because the probability of a

---

[24] US Nuclear Regulatory Commission, ***Preliminary Assessment of Core Melt Accidents at the Zion and Indian Point Nuclear Power Plants and Strategies for Mitigating Their Effects, Analysis of Containment Building Failure Modes, Preliminary Report***, NUREG-0850, Vol. 1, November 1981, p. 3-2.
[25] US Nuclear Regulatory Commission, ***Reactor Risk Reference Document (Appendices J-0),*** NUREG-1150, Draft for Comment, February 1987, p. J.10-1.

severe accident capable of rupturing or bypassing the containment prior to effective evacuation of the EPZ is so low in most cases as to be below regulatory concern.[26]

(c) "Deliberate accidents"

It is true that a spontaneous occurrence of the multiple system failures necessary to cause a severe accident and large radiological release is typically a very improbable event. However, if one considers the possibility of sabotage or "deliberate" accidents, the low-probability argument that NRC uses to justify the continued operation of nuclear plants completely breaks down. Terrorists with basic and readily available knowledge of how nuclear plants operate can design their attack to maximize the chance of achieving a core melt and large radiological release. With modest inside assistance, as contemplated by NRC in its regulations and practices, saboteurs would be able to identify a plant-specific set of components known as a "target set." If all elements of a target set are disabled or destroyed, significant core damage would result. Thus, by deliberately disrupting all redundant safety systems, saboteurs can cause a severe event that would have had only a very low probability of occurrence if left to chance.

The likelihood of a successful attack is enhanced for plants with "common-cause" failure modes. A common-cause failure is a single event that can lead to the failure of multiple redundant systems. For example, if the diesel fuel supplied to a nuclear plant with two independent emergency diesel generators from the same distributor is impure, then both generators may fail to start for the same reason if off-site power is lost and emergency power is needed. This would result in a station blackout, one of the most serious challenges to pressurized-water reactors like Indian Point. While some common-cause failure modes can be corrected, others are intrinsic to the design of currently operating nuclear plants. Common-cause failure modes make the saboteurs' job easier, as fewer targets would have to be disabled to achieve the desired goal.

In addition to causing a core meltdown, terrorists also have the means to ensure that the radioactive materials released from the melting fuel can escape into the environment by breaching, severely weakening or bypassing the containment.[27] Finally, saboteurs can maximize the harm caused by a radiological release by staging their attack when the meteorological conditions favor a significant dispersal over densely populated areas, and even interfering with the execution of emergency plans.

NRC has formally maintained for at least two decades that it does not make sense to assign probabilities to terrorist attacks. In a 2002 memorandum, NRC stated that[28]

> "the horrors of September 11 notwithstanding, it remains true that the likelihood of a terrorist attack being directed at a particular nuclear facility is not

[26] There have been situations where NRC concluded that "adequate protection" was not met at certain nuclear plants and required additional safety measures. However, such instances are rare.
[27] We have decided not to describe such means in greater detail, although we have little doubt that terrorists are already familiar with them.
[28] US NRC, Memorandum and Order, CLI-02-025, December 18, 2002, p. 17.

> quantifiable. Any attempt at quantification or even qualitative assessment would be highly speculative. In fact, the likelihood of attack cannot be ascertained with confidence by any state-of-the-art methodology …we have no way to calculate the probability portion of the [risk] equation, except in such general terms as to be nearly meaningless."

Yet at other times, NRC does not hesitate to invoke probabilities when arguing that the public has nothing to fear from terrorist attacks on nuclear plants. For example, here is what NRC has to say about the CRAC2 study in its recent "point paper" on homeland protection and preparedness:[29]

> "Over the years, the NRC has performed a number of consequence evaluations to address regulatory issues …We have considered the extent to which past analyses, often the subject of public statements by advocacy groups and the media, can be superceded [sic] by more recent analysis …Past studies usually have considered …a number of scenarios, which resulted in only minor consequences. The most limiting severe scenarios, which comprise a minority of the calculations and represent ***very low probability events*** [emphasis added], are the predictions typically cited in press accounts. These scenarios have assumed …very large radiation releases, bounding emergency response assumptions or bounding conditions (including weather) for the spread of the radiation. The combination of these factors produces large and highly unlikely results."

These two excerpts are inconsistent. If it is meaningless to quantify the likelihood of a terrorist attack, then one cannot dismiss the possibility of terrorist attacks causing the most severe consequences by claiming they are "highly unlikely." Therefore, in order to base emergency planning on the best possible information, NRC must accept the fact that the growing threat of domestic terrorism has forever altered the delicate risk calculus that underlies its approach to safety regulation. NRC can no longer shy away from confronting the worst-case consequences of terrorist attacks on nuclear power plants. And perhaps the most attractive target in the country, where the consequences are likely to be the greatest, is Indian Point.

[29] US NRC, "Point Paper on Current Homeland Protection and Preparedness Issues" (2003), op cit.

THE HEALTH CONSEQUENCES OF A RADIOLOGICAL RELEASE FROM INDIAN POINT

The Indian Point power plant is located on 239 acres on the Hudson River in the village of Buchanan in Westchester County, New York. There are two operating pressurized-water reactors (PWRs) on site, Indian Point 2, rated at 971 MWe, and Indian Point 3, rated at 984 MWe. Both reactors are operated by Entergy Nuclear.

Indian Point is located in one of the most densely populated metropolitan areas in the United States, situated about 24 miles from the New York City limits and 35 miles from midtown Manhattan. Extrapolating from 2000 Census data, in 2003 over 305,000 persons resided within the roughly ten-mile radius plume exposure emergency planning zone for Indian Point, and over 17 million lived within 50 miles of the site.[30]

The types of injury that may occur following a catastrophic release of radioactive material resulting from a terrorist attack at Indian Point fall into two broad categories. The first category, "early" injuries and fatalities, are those that are caused by short-term whole-body exposures to doses of radiation high enough to cause cell death. Early injuries include the constellation of symptoms known as **acute radiation syndrome** that should be familiar to anyone who has read *Hiroshima* by John Hersey --- gastrointestinal disturbance, epilation (hair loss) and bone marrow damage. Other early injuries include severe skin damage, cataracts and sterility. For sufficiently high doses, early fatalities --- death within days or weeks --- can occur. These so-called "deterministic" effects are induced only when levels of radiation exposure exceed certain thresholds.

Another class of injury caused by ionizing radiation exposure is genetic damage that is insufficient to cause cell death. At doses below the thresholds for deterministic effects, radiation may cause damage to DNA that interferes with the normal process of cell reproduction. This damage can eventually lead to cancer, which may not appear for years or even decades, depending on the type. Because a single radiation-induced DNA lesion is believed to be capable of progressing to cancer, there is no threshold for these so-called "stochastic" effects. [31]

The clinical response of individuals to ionizing radiation exposure is highly variable from person to person. Some individuals have a lower capability of DNA repair and thus are more susceptible to the carcinogenic effects of radiation --- a condition that is most severe in people with certain genetic diseases like ataxia telangiectasia. Children are particularly vulnerable to radiation exposure. For the same degree of exposure to a

---

[30] A figure of 20 million people within 50 miles of Indian Point has often been quoted. This value may have been obtained by summing the populations of all counties that are either totally or partially within the 50-mile zone.

[31] A small but vocal group of pro-nuclear activists continue to maintain, in the face of overwhelming scientific evidence to the contrary, that a threshold dose exists below which ionizing radiation may have no effect or even may provide health benefits. However, there is a growing body of experimental data that indicates that low-dose radiation may actually be a more potent carcinogen than high-dose radiation because of low-dose "bystander effects."

radioactive plume, children will receive a greater absorbed dose than adults because of their lower body weight and higher respiration rate, even though their lung capacity is smaller. And because children and fetuses have much higher growth rates than adults, the same radiation dose has a greater chance of causing cancer in children and fetuses than in adults.

Exposure to low-dose ionizing radiation has also been associated with excess mortality from diseases other than cancer, such as cardiovascular disease, possibly as a result of radiation-induced inflammation. There is growing evidence that the effect of low-dose radiation exposure on mortality from diseases other than cancer may be as great as its effect on mortality from cancer, implying that current, cancer-based risk estimates may be too low by a factor of two.[32]

A radiological release from a nuclear plant accident would consist of many different types of radioactive materials. Some isotopes, such as cesium-137, emit penetrating gamma rays and can cause radiation injury from outside of the body. Other isotopes do not emit radiation that can penetrate skin but are most dangerous when inhaled or ingested, where they can concentrate in internal organs and deliver high doses to surrounding tissue. Iodine-131, which concentrates in the thyroid gland, and strontium-90, which concentrates in teeth and bones, are in this category. Some isotopes have short half-lives and do not persist in the environment, while others are long-lived and can result in long-term contamination.

NRC requires that evacuation planning in the event of a radiological emergency take place only within the so-called "plume exposure" emergency planning zone (EPZ), a roughly circular area with a radius of approximately ten miles. The choice of this distance was based in part on NRC analyses indicating that in the event of a severe accident, dose rates high enough to cause early fatalities from acute radiation syndrome would be confined to a region within about ten miles of the release point. However, dose rates outside of this region, although on average not high enough to cause early fatalities, could be high enough to result in a significant risk of cancer unless effective protective measures are taken. NRC's emergency planning regulations were never designed to limit such exposures in the event of the "worst core melt sequences," for which the protection goal is that "immediate life threatening doses would generally not occur outside the zone."[33]

Thus the current emergency planning basis is not now, and never was, intended to protect the public from significant but not immediately lethal exposures in the event of the "worst core melt sequences," such as those that could result from a well-planned terrorist attack. It should therefore be no surprise that NRC's emergency planning procedures

[32] A. MacLachlan, "UNSCEAR Probes Low-Dose Radiation Link to Non-Cancer Death Rate," *Nucleonics Week*, June 17, 2004.
[33] US NRC, *Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Plants*, NUREG-0654, 1980, p. 12.

would not protect individuals either inside or outside the EPZ from such exposures in the event of an attack.

The proximity of Indian Point to New York City, its populous suburbs and its watershed, given the potential hazard it represents, has long been an issue of concern and controversy. Following the Three Mile Island accident in March 1979, the Union of Concerned Scientists (UCS) unsuccessfully petitioned the NRC to suspend operations at Indian Point, in part because of its location in a densely populated area. At the same time, the NRC formed two task forces to examine the risks posed by Indian Point and the Zion plant near Chicago "because of the high population densities surrounding those units" and initiated a formal adjudication, the Indian Point Special Proceeding, to review the issues raised in the UCS petition and others.[34]

During the Special Proceeding, three NRC administrative judges heard testimony regarding the potential impacts of a severe accident at Indian Point on New York City residents. For instance, the director of New York City's Bureau of Radiation Control testified that potassium iodide (KI), which can block the uptake of radioactive iodine by the thyroid if taken near the time of exposure, should be stockpiled for "possible immediate use in New York City," at a time when NRC did not recommend that KI be provided even for residents of the 10-mile EPZ.

The administrative judges reached some disturbing conclusions in the proceeding. They stated that "under certain meteorological conditions, delayed fatalities from cancer appear to be possible almost anywhere in the city" and that "a severe release at Indian Point could have more serious consequences than that same release at virtually any other site licensed by the Commission." And they urged the Commission "to give serious consideration to the potential costs to society of dangerous, low probability accidents. Such accidents could, as Staff testimony has shown, result in fatalities that number in the hundreds or thousands."

The Commission appears to have essentially forgotten these conclusions. Many of the technical issues resolved during the course of the Special Proceeding are being debated all over again today.

[34] US NRC, Indian Point Special Proceeding, 1983, p. 5.

THE MACCS2 CODE

MACCS2 is a computer code that was developed by Sandia National Laboratories under NRC sponsorship as a successor to CRAC2.[35] It is designed to estimate the health, environmental and economic consequences of radiation dispersal accidents, and is widely used by NRC and DOE for various safety applications. It utilizes a standard straight-line Gaussian plume model to estimate the atmospheric dispersion of a point release of radionuclides, consisting of up to four distinct plumes, and well-established models to predict the deposition of radioactive particles on the ground from both gravitational settling ("dry deposition") and precipitation ("wet deposition"). [36] From the dispersion and deposition patterns, the code can then estimate the radiation doses to individuals as a result of external and inhalation exposures to the radioactive plume and to external radiation from radionuclides deposited on the ground ("groundshine"). The code also has the capability to model long-term exposures resulting from groundshine, food contamination, water contamination and inhalation of resuspended radioactive dust.

The code also can evaluate the impact of various protective actions on the health and environmental consequences of the release, including evacuation, sheltering and, in the long term, remediation or condemnation of contaminated areas. Most parameters, such as the average evacuation speed, decontamination costs, and the dose criteria for temporary relocation and long-term habitation, can be specified by the user.

MACCS2 requires a large number of user-specified input parameters. A given release is characterized by a "source term," which is defined by its radionuclide content, duration and heat content, among other factors. The shape of the Gaussian plume is determined by the wind speed, the release duration, the atmospheric stability (Pasquill) class and the height of the mixing layer at the time of the release.

MACCS2 requires the user to supply population and meteorological data, which can range from a uniform population density to a site-specific population distribution on a high-resolution polar grid. The meteorological data can range from constant weather conditions to a 120-hour weather sequence. The code can process up to 8760 weather sequences --- a year's worth --- and generate a frequency distribution of the results.

The code allows the user to define the dose-response models for early fatalities (EFs) and latent cancer fatalities (LCFs). We use the MACCS2 default models. For EFs, MACCS2 uses a 2-parameter hazard function, with a default LD_{50} dose (the dose associated with a 50% chance of death) of 380 rem. LCFs, MACCS2 uses the standard linear, no-threshold model, with a dose-response coefficient of 0.1 LCF/person-Sievert and a dose-dependent reduction factor of 2, per the 1991 recommendations of the International Committee on

[35] Chanin and Young (1997), op cit.

[36] Much of the following section is based on a recent comprehensive review of MACCS2 by the Department of Energy, which we would recommend to readers interested in a more in-depth discussion of the capabilities and limitations of the code. See Office of Environment, Safety and Health, U.S. Department of Energy, *MACCS2 Computer Code Application Guidance for Documented Safety Analysis: Interim Report*, DOE-EH-4.2.1.4-Interim-MACCS2, September 2003.

Radiological Protection (ICRP) in ICRP 60.[37] The corresponding coefficients used in the CRAC2 model, based on now-antiquated estimates, were lower by a factor of 4.

For the calculation of the committed effective dose equivalent (CEDE) resulting from inhalation and ingestion of radionuclides, we have replaced the default MACCS2 input file with one based on the more recent dose conversion factors in ICRP 72.[38] We have shown previously that this substitution reduces the projected number of latent cancer fatalities from a severe nuclear reactor accident by about one-third.[39] (The default MACCS2 file incorporates EPA guidance based on ICRP 30, which although out of date continues to be the basis for regulatory analyses in the United States.)

When using MACCS2 several years ago, we discovered an error that resulted in an overcounting of latent cancer fatalities in the case of very large releases. After pointing this out to the code manager, SNL sent us a revised version of the code with the error corrected, which we have used for the analysis in this report.

Like most radiological consequence codes in common use, MACCS2 has a number of limitations. First of all, because it incorporates a Gaussian plume model, the speed and direction of the plume are determined by the initial wind speed and direction at the time of release, and cannot change in response to changing atmospheric conditions (either in time or in space). Consequently, the code becomes less reliable when predicting dispersion patterns over long distances and long time periods, given the increasing likelihood of wind shifts. Also, the Gaussian plume model does not take into account terrain effects, which can have a highly complex impact on wind field patterns and plume dispersion. And finally, MACCS2 cannot be used for estimating dispersion less than 100 meters from the source.

However, MACCS2 is adequate for the purpose of this report, which is to develop order-of-magnitude estimates of the radiological consequences of a catastrophic attack at Indian Point for residents of New York City and the entire New York metropolitan area, and to assess the impact of different protective actions on these consequences. We restrict our evaluations to a circular area with a radius of 50 miles centered on Indian Point, except for the calculation of long-term doses and economic impacts, which we assess out to 100 miles.

In the next section, we discuss the basis for the MACCS2 input parameters that we use in our evaluation.

---

[37] MACCS2 does not allow the user to specify different dose-response models for different radionuclides. We use a model with a dose-dependent reduction factor of 2, even though this assumption likely underestimates the carcinogenic potential of alpha-emitters, which is not reduced in effectiveness at low doses or dose rates.

[38] International Commission on Radiological Protection (ICRP*), Age-Dependent Doses to Members of the Public from Intake of Radionuclides: Part 5, Compilation of Ingestion and Inhalation Dose Coefficients*, ICRP Publication 72, Pergamon Press, Oxford, 1996.

[39] E. Lyman, "Public Health Risks of Substituting Mixed-Oxide for Uranium Fuel in Pressurized-Water Reactors," *Science and Global Security* **9** (2001), pgs. 33-79. See Footnote 48.

THE SABOTAGE SCENARIO

The scenario that we analyze is based on the so-called "revised source term" that NRC defined in 1995 in NUREG-1465. The revised source term was developed as a more realistic characterization of the magnitude and timing of radionuclide releases during a core-melt accident than the source term originally specified for use in Part 100 siting analyses. In its entirety, the PWR revised source term presented in NUREG-1465 corresponds to a severe accident in which the primary coolant system is depressurized early in the accident sequence. An example is a "large break loss-of-coolant accident" (LBLOCA), in which primary coolant is rapidly lost and the low-pressure safety injection system fails to operate properly, resulting in core melt and vessel failure. This scenario is one of the most severe events that can occur at PWRs like Indian Point, and could result in a relatively rapid release of radioactivity.

(a) The source term

A severe accident of this type would progress through four distinct phases. As the water level in the core decreases and the fuel becomes uncovered, the zirconium cladding tubes encasing the fuel rods overheat, swell, oxidize and rupture. When that occurs, radionuclides that have accumulated in the "gap" between the fuel and the cladding will be released into the reactor coolant system. If there is a break in the reactor coolant system (as would be the case in a LBLOCA), then these radionuclides would be released into the atmosphere of the containment building. These so-called "gap" releases consist of the more volatile radionuclides contained in irradiated fuel, such as isotopes of krypton, xenon, iodine and cesium. This period is known as the "gap release" phase, and is predicted to last about 30 minutes. The oxidation of the zirconium cladding by water also generates hydrogen, which is a flammable gas.

As the core continues to heat up, the ceramic fuel pellets themselves begin to melt, releasing greater quantities of radionuclides into the reactor vessel and through the breach in the reactor coolant system into the containment building atmosphere. The molten fuel mass then collapses and drops to the bottom of the reactor vessel, where it aggressively attacks the steel, melts through the bottom and spills onto the floor of the containment building.[40] The period between the start of fuel melting and breach of the reactor vessel is known as the "early in-vessel" phase, and typically would last about an hour.

When the molten fuel breaches the reactor vessel and drops to the containment building floor, it violently reacts with any water that has accumulated in the cavity and with the concrete floor itself. This "core-concrete interaction" causes further releases of radionuclides from the molten fuel into the containment building. This period is known as the "ex-vessel" phase, and would last for several hours.

[40] This scenario is not theoretical. During the 1979 accident at Three Mile Island Unit 2, part of the melted core relocated to the bottom of the reactor vessel where it began melting through the steel. The re-introduction of forced cooling water flow terminated this sequence before vessel failure.

At the same time, some portion of the molten core may remain in the reactor vessel, where it would continue to degrade in the presence of air and release radionuclides. Also, radionuclides released during the in-vessel phase that deposit on structures within the primary coolant system may be re-released into the containment building. These releases take place during the "late in-vessel" phase and could continue for many hours.

At the time when the molten core falls to the floor of the reactor vessel, steam explosions may occur that could blow apart the reactor vessel, creating high-velocity "missiles" that could rupture the containment building and violently expel the radioactive gases and aerosols it contains into the environment. This would result in a shorter in-vessel phase. If the vessel remains intact until melt-through, hydrogen or steam explosions are also possible when the molten fuel spills onto the concrete below the vessel, providing another opportunity for containment failure.

The complete revised source term (all four phases) is a general characterization of a low-pressure severe accident sequence, such as a large-break loss of coolant accident with failure of emergency core cooling systems. According to the timing of the accident phases in the revised source term, the "gap release" phase would begin within a few minutes after the initiation of the event and lasts for 30 minutes. At that time, the early in-vessel phase begins as the fuel pellets start to melt. This phase is assumed to last for 1.3 hours, and ends when the vessel is breached.

In our scenario, we assume that the attackers have weakened but not fully breached the containment, so that there is a high probability that the containment building will be ruptured by a steam or hydrogen explosion at the time of vessel breach. This results in a rapid purge of the radionuclide content of the containment building atmosphere into the environment, followed by a longer-duration release due to core-concrete interactions and late in-vessel releases.

We do not wish to discuss in detail how saboteurs could initiate this type of accident sequence. However, since NRC asserts that even in a terrorist attack these events are unlikely to occur, we need to present some evidence of the plausibility of these scenarios. One such scenario would involve a 9/11-type jet aircraft attack on the containment building, possibly accompanied by a ground attack on the on-site emergency power supplies. (One must also assume that interruption of off-site power takes place during an attack, given that off-site power lines are not under the control of the licensee and are not protected.)

The Nuclear Energy Institute (NEI) issued a press release in 2002 describing some of the conclusions of a study conducted by the Electric Power Research Institute (EPRI) that purported to show that penetration of a PWR containment by a jet aircraft attack was impossible. A study participant later acknowledged that (1) the justification for limiting the impact speed to 350 mph was based on pilot interviews and not on the results of simulator testing, and (2) even at 350 mph, their analysis actually found that the 42-inch thick reinforced concrete containment dome of a PWR suffered "substantial damage" and the steel liner was deformed.[41]

However, even if penetration of the containment does not occur, the vibrations induced by the impact could well disrupt the supports of the coolant pumps or the steam generators, causing a LBLOCA. The emergency core cooling system pumps, which require electrical power, would not be available under blackout conditions caused by the disabling of both off-site and on-site power supplies. Thus makeup coolant would not be provided, the core would rapidly become uncovered and the NUREG-1465 sequence would begin. Other engineered safety features such as containment sprays and recirculation cooling would not be available in the absence of electrical power. The damaged containment building would then be far less resistant to the pressure pulse caused by a steam spike or hydrogen explosion, and would have a much higher probability of rupture at vessel breach. We note that the steel liner of a reinforced concrete containment structure like that at Indian Point only carries 10 to 20% of the internal pressure load, and therefore may fail well before the design containment failure pressure is reached if the concrete shell is damaged.

Because the emergency diesel generators are themselves quite sensitive to vibration, a ground assault may not even be necessary to disable them, since the aircraft impact itself, followed by a fuel-air explosion, could cause them to fail.

One can find support for the credibility of this scenario in the recently leaked summary of a report prepared for the German Environment Ministry by the nuclear safety consultant GRS on the vulnerability of German nuclear reactors to aircraft attacks.[42] In the summary, GRS defined a series of credible damage scenarios and then determined whether or not the resulting accident sequence would be controllable The report considered an attack on the Biblis B PWR by a small jet (Airbus A320) or medium-sized jet (Airbus A300) travelling at speeds from 225 to 394 miles per hour, where the peak speed of 394 mph was determined through the use of simulators. GRS concluded that for an event in which the jet did not penetrate the containment, but the resulting vibrations caused a primary coolant leak, and the control room was destroyed by debris and fire (a condition similar to a station blackout), then control of the sequence of events would be "uncertain."[43] Biblis B was designed for protection against the crash of a 1960s-era Starfighter jet and as a result is equipped, like most German reactors, with a double containment. In contrast, Indian Point 2 and 3, while of the same 1970s vintage as Biblis B, were not designed to be resistant to airplane crashes, and do not have double containments.

---

[41] R. Nickell, "Nuclear Plant Structures: Resistance to Aircraft Impact," 44 th Annual Meeting of the Institute of Nuclear Materials Management, Phoenix, AZ, July 13-17, 2003.
[42] Mark Hibbs, "Utilities Expect Showdown with Trittin over Air Te rror Threat," *Nucleonics Week* **45**, February 12, 2004.
[43] Gesellschaft für Anlagen und Reaktorsicherheit, *Schutz der deutschen Kernkraftwerke vor dem Hintergrund der terroristischen Anschläge in den USA vom 11. September 2001*, (*Protection of German Nuclear Power Plants in the Context of the September 11, 2001 Terrorist Attacks in the US*), November 27, 2002.

The NUREG-1465 revised source term is shown in Table 1. The source term is characterized by grouping together fission products with similar chemical properties and for each group specifying a "release fraction"; that is, the fraction of the core radionuclide inventory released from the damaged fuel into the containment building atmosphere. Noble gases include krypton (Kr); halogens include iodine (I); alkali metals include cesium (Cs); noble metals include ruthenium (Ru); the cerium (Ce) group includes actinides such as plutonium (Pu) and the lanthanide (La) group includes actinides such as curium (Cm).

TABLE 1: NUREG-1465 radionuclide releases into containment for PWRs

	Gap	Early In-Vessel	Ex-Vessel	Late In-Vessel
Duration (hrs)	0.5	1.3	2.0	10.0
Release fractions (%):				
Noble Gases (Kr)	0.05	0.95	0	0
Halogens (I)	0.05	0.35	0.25	0.1
Alkali Metals (Cs)	0.05	0.25	0.35	0.1
Tellurium group (Te)	0	0.05	0.25	0.005
Barium, Strontium (Ba, Sr)	0	0.02	0.1	0
Noble Metals (Ru)	0	0.0025	0.0025	0
Cerium group (Ce)	0	0.0005	0.005	0
Lanthanides (La)	0	0.0002	0.005	0

It is important to note that NUREG-1465 is not intended to be a "worst-case" source term. The accompanying guidance specifically states that "it is emphasized that the release fractions for the source terms presented in this report are intended to be representative or typical, rather than conservative or bounding values…" [44] In fact, the release fractions for tellurium, the cerium group and the lanthanides were significantly lowered in response to industry comments. Upper-bound estimates, which are provided in a table in the back of NUREG-1465, indicate that "virtually all the iodine and cesium could enter the containment."[45] And experimental evidence obtained since NUREG-1465 was published in 1995 suggests that the tellurium, ruthenium, cerium and lanthanide release fractions in the revised source term may significantly underestimate actual releases of these radionuclide groups.[46] Thus our use of the NUREG-1465 source term is far from the worst possible case and may underestimate the impacts of credible scenarios.

[44] NUREG-1465, p. 13.
[45] NUREG-1465, p. 17.
[46] Energy Research, Inc., Expert Panel Report on Source Terms for High-Burnup and MOX Fuels, 2002.

We model this scenario in MACCS2 as a two-plume release. The first release begins at the time of vessel breach and containment failure, 1.8 hours after initiation of the accident, and continues over a period of 200 seconds as the containment atmosphere is rapidly vented. The second plume lasts for two hours as core-concrete interactions occur. For simplicity, only the first two hours of the late in-vessel release are included; the last eight hours are omitted, although this late release would likely make a significant contribution to public exposures, given the nearly ten-hour evacuation time estimate for the 10-mile EPZ.

We further assume that the entire radionuclide inventory released from the damaged fuel into the containment atmosphere escapes into the environment through the rupture in the containment. There is little information in the literature about realistic values for the fraction of the containment inventory that is released to the environment. In NUREG-1150, NRC states that "in some early failure cases, the [containment to environment] transmission fraction is quite high for the entire range of uncertainty. In an early containment failure case for the Sequoyah plant …the fractional release of radioactive material ranges from 25 percent to 90 percent of the material released from the reactor coolant system."[47] A review of the default values of this fraction for the Sequoyah and Surry plants used in supporting analyses for NUREG-1150 indicates that environmental releases ranging from 80 to 98% of the radionuclides in the containment atmosphere were typically assumed. The only case in which significant retention within the containment building occurs is when there is a delay of several hours between the initiation of core degradation and the time of containment failure, which is not the case for the scenario we are considering. Given that we are using only the first three phases of the NUREG-1465 source term, which may underestimate the maximum release of radionuclides like iodine and cesium by 35%, we believe it is reasonable to neglect the retention within the containment building of at most 20% of the radionuclide inventory.

Another plume characteristic that is very important for determining the distribution and magnitude of consequences is the heat energy that it contains. The oxidation of zirconium cladding during core degradation generates a large amount of heat in a short period of time, which can cause the plume to become buoyant and rise. Greater initial plume heights result in lower radionuclide concentrations close to the plant, but wider dispersal of the plume.

It is unlikely that a radiological release at any US PWR would produce a plume as high as the one released during the Chernobyl disaster. Because of the large mass of graphite moderator in the Chernobyl-4 reactor, a hot and long-duration graphite fire caused a very high plume that was responsible for dispersing radionuclides over vast distances. However, at the same time, the exposure and contamination within 50 miles of the Chernobyl site was much lower than it would have been if the plume had not risen so high. This means that the cooler plume that would be characteristic of a core meltdown at Indian Point could actually be a greater threat to the New York metropolitan area than the contamination pattern resulting from the Chernobyl accident might suggest.

[47] US NRC, *Severe Accident Risks: An Assessment for Five Nuclear Power Plants*, NUREG-1150, Volume 2, December 1990, p. C-108.

Table 2 shows the two-plume source term for input into MACCS2, adapted from the NUREG-1465 source term in Table 1. The first plume consists of the containment radionuclide inventory at the time of vessel breach (the sum of the first and second columns in Table 1). The second plume consists of the releases generated by core-concrete interactions and a fraction of the late-in-vessel releases (the sum of the third column and one-fifth of the fourth column in Table 1).

TABLE 2: Source term used in MACCS2 model

Plume	Release time (hrs)	Duration(hrs)	Energy release (MW)	Kr	I	Cs	Te	Ba	Ru	Ce	La
1	1.8	0.06	2.8	1	0.4	0.3	0.05	0.02	0.0025	0.0005	0.0002
2	1.86	2	1.6	0	0.27	0.37	0.25	0.1	0.0025	0.005	0.005

The reactor core inventory used was calculated for a representative 3565 MWt PWR at the end of an equilibrium 18-month cycle using the SCALE code, and was then scaled to the Indian Point 2 power rating of 3071 MWt.[48] Since Indian Point 2 operates on a 24-month cycle, the inventory we use here does not represent the peak inventory of the reactor core, which occurs just before refueling.

(b) Meteorology

The calculation of radiological consequences from a severe accident is strongly dependent on the meteorological conditions at the time of the release and for several days afterward. Relevant factors include the wind speed, the wind direction, the atmospheric stability, the height of the mixing layer and the occurrence of precipitation.

The MACCS2 code can utilize a weather sequence of hourly data for a 120-hour period following the initial release. The user has the option to supply a file with an entire year's worth of hourly meteorological data (8760 entries), consisting of wind speed, atmospheric stability class, and precipitation. The program can then calculate up to 8760 results, each corresponding to a release beginning at a different hour of the year. For each set of weather data, MACCS2 can also generate sixteen results by rotating the plume direction into each sector of the compass, repeating the calculation for each plume direction, and then weighting the results with the fraction of the time that the wind blows in that direction (as specified by the user-supplied "wind rose," or set of probabilities that the wind will be blowing in a certain direction at the site). Finally, the code can tabulate the results in a frequency distribution.

[48] Lyman (2001), op cit., pp. 64-66.

The MACCS2 code, like the CRAC2 code before it, has the option to sample a reduced number of weather sequences, based on a semi-random sampling method. The reason for employing a sampling scheme in the past was no doubt the length of computing time needed for each calculation; however, the program runs quickly on modern machines, so there is no need to employ the MACCS2 sampling scheme. In fact, a comparison of the results obtained from sampling, which utilizes about 100 weather sequences, and the results obtained from an entire year's worth of sequences, finds that the peak consequence values in the sampling distribution are 30% or more below the peak consequences over the entire year, if the plume rotation option is not utilized. Thus there is a significant sampling error for peak values associated with the MACCS2 sampling scheme (and presumably the CRAC2 sampling scheme as well).

We were unable to obtain the meteorological data for the Indian Point site needed for input into MACCS2. Instead, we used a meteorological data file for New York City, the location of the nearest National Weather Service weather monitoring station, that was supplied with the original CRAC2 code. This is the same approach that was taken in the CRAC2 Report, which was ostensibly a site-specific study of the 91 sites where nuclear reactors were located or planned, but did not use meteorological data files specific to those sites. Instead, the study used data derived from 29 National Weather Service stations that were "chosen as a representative set of the nation's meteorological conditions."[49] NRC later had to adopt the same approach, using the New York City meteorological data file as a surrogate for Indian Point-specific data in a CRAC2 benchmark exercise, because it was unable to obtain the Indian Point data.[50]

Use of the New York City meteorological data file in lieu of Indian Point site data is a reasonable approximation for the purposes of this report. Two of the most important factors in determining the radiological consequences of a terrorist attack at Indian Point are the wind direction and the precipitation. With regard to the first factor, we use the Indian Point site wind rose to take into account the effect of the variation in wind direction.[51] With regard to precipitation data, since the MACCS2 code only allows for uniform precipitation over the entire evaluation area, the precipitation data set from New York City is just as relevant as data from the Indian Point site for determining the consequences for the New York metropolitan area.

One phenomenon that we cannot fully account for without access to meteorological data specific to the Indian Point site is the coupling between wind direction and wind speed that results from the plant's location in the Hudson River Valley. Wind speeds below a threshold of below 4 meters per second tend to result in plumes that follow the course of the river valley, whereas greater wind speeds produce plumes that are free to travel in any direction and are better approximated by the straight-line Gaussian model. Our use of the

---

[49] R. Davis, A. Hanson, V. Mubayi and H. Nourbakhsh, ***Reassessment of Selected Factors Affecting Siting of Nuclear Power Plants***, NUREG/CR-6295, US Nuclear Regulatory Commission, 1997, p. 3-30.
[50] US Nuclear Regulatory Commission, Generic Environmental Impact Statement for License Renewal of Nuclear Plants, NUREG-1437, Vol. 1, Sec. 5.3.3.2.3.
[51] James Lee Witt Associates, *Review of Emergency Preparedness of Areas Adjacent to Indian Point and Millstone*, March 2003, Figure 3-1, p. 21.

Indian Point wind rose accounts for this effect, but to the extent that the distribution of wind speeds in the meteorological data file that we use differs from that at the Indian Point site, the calculations may include some cases that involve unrealistic wind patterns. However, any errors in the distribution resulting from this approximation are not likely to be significant in comparison to the uncertainties associated with use of the straight-line Gaussian model in MACCS2. In any event, it is likely that properly accounting for this effect would result in the channeling of a greater number of slow-moving, concentrated plumes directly downriver toward densely populated Manhattan, thereby increasing the overall radiological impact.

We have also run the calculations using the meteorological data file for the Surry site in Virginia to compare the maximum consequences obtained. We find that the values for peak early fatalities differ by less than 1% and the value for peak latent cancer fatalities differs by less than 5%. We interpret this result as an indication that the peak consequences we found for Indian Point are not due to weather conditions unique to the meteorological data file for New York City.

If Entergy were willing to provide us with data from the Indian Point meteorological monitoring station, we would be pleased to use it to assess whether it would have a significant impact on our results. However, we would expect any impact to be minor.

(c) Protective actions

Another crucial factor in determining the consequences associated with a terrorist attack at Indian Point is the effectiveness of the actions taken to protect individuals within the 10-mile emergency planning zone (EPZ).

The MACCS2 emergency planning model requires the user to input the time when notification is given to emergency response officials to initiate protective actions for the surrounding population; the time at which evacuation begins after notification is received; and the effective evacuation speed. Once evacuation begins, each individual then proceeds in a direction radially outward from the release point at a rate given by the effective evacuation speed.

We have assumed that the time at which the off-site alarm is sounded is coincident with the initiation of core melting; that is, 30 minutes after the attack. It is unlikely that the decision to evacuate could be made in much less time. This choice still provides an interval of 78 minutes between the sounding of the alarm and the initiation of the radiological release, consistent with earlier studies such as the CRAC2 Report.

We have assumed that the delay time between receipt of notification by the public within the EPZ and initiation of evacuation is two hours. This is the default parameter in the MACCS2 code, and is consistent both with earlier estimates of the "mobilization time" and with the most recent ones for the Indian Point site, which found that 100% of the public within the EPZ would be mobilized to evacuate by two hours after notification.[52]

[52] James Lee Witt Associates (2003), op cit., Figure 5-6, p. 96.

The effective evacuation speed was obtained from the mobilization time estimate of two hours and the most recent Indian Point evacuation time estimate (ETE) for good summer weather of 9 hours 25 minutes.[53] Subtracting the two-hour mobilization time leaves a maximum time of 7.42 hours for the actual evacuation. Since the maximum travel distance to leave the EPZ is approximately ten miles, this corresponds to an effective evacuation speed of 1.35 miles per hour, or 0.6 meters per second. The high value for the ETE and the correspondingly low effective evacuation speed reflect the severe traffic congestion within the EPZ that is projected to occur in the event that a crisis occurs at Indian Point requiring evacuation.

Outside of the 10-mile EPZ, the baseline dose calculations assume that individuals will take no protective actions.[54] Although this may not be realistic, we believe that it would be inappropriate to assume otherwise. Since NRC and FEMA do not require that any preparation for an emergency be undertaken outside of the 10-mile EPZ, it would not be conservative to assume that individuals outside of the EPZ would receive prompt notification of the event or would know what to do even if they did receive notification. However, to examine the impact of this assumption on the results, we consider a case where the emergency evacuation zone is extended to 25 miles, and the average evacuation speed remains the same as in the 10-mile EPZ case.

(d) Population distribution

In order to accurately calculate the consequences of a terrorist attack at Indian Point, it is necessary to have the correct spatial distribution of population in the vicinity of the site. MACCS2 has the option to use a site population data file, in which the site-specific population is provided on a grid divided into sixteen angular sectors. The user can specify the lengths of sectors in the radial direction.

Most of our analysis is focused on a circular region centered on the Indian Point site with a radius of fifty miles. The ten-mile EPZ is divided into eleven regions, with divisions at the site exclusion zone (about 0.5 miles), at the one-mile point, and nine successive mile-wide intervals. The region between the EPZ and the fifty-mile limit is subdivided into ten intervals (see Figure 1, below).

Permanent resident population data for the ten-mile EPZ was obtained from the estimates for 2003 generated by KLD Associates for the Evacuation Time Estimate study that it prepared for Entergy.[55] The total number of permanent residents within a ten-mile circular zone around Indian Point in 2003, according to KLD, was 267,099. We have not included the transient population in the region in our calculations, even though it would add another 25% to the permanent population estimate, according to KLD data.

---

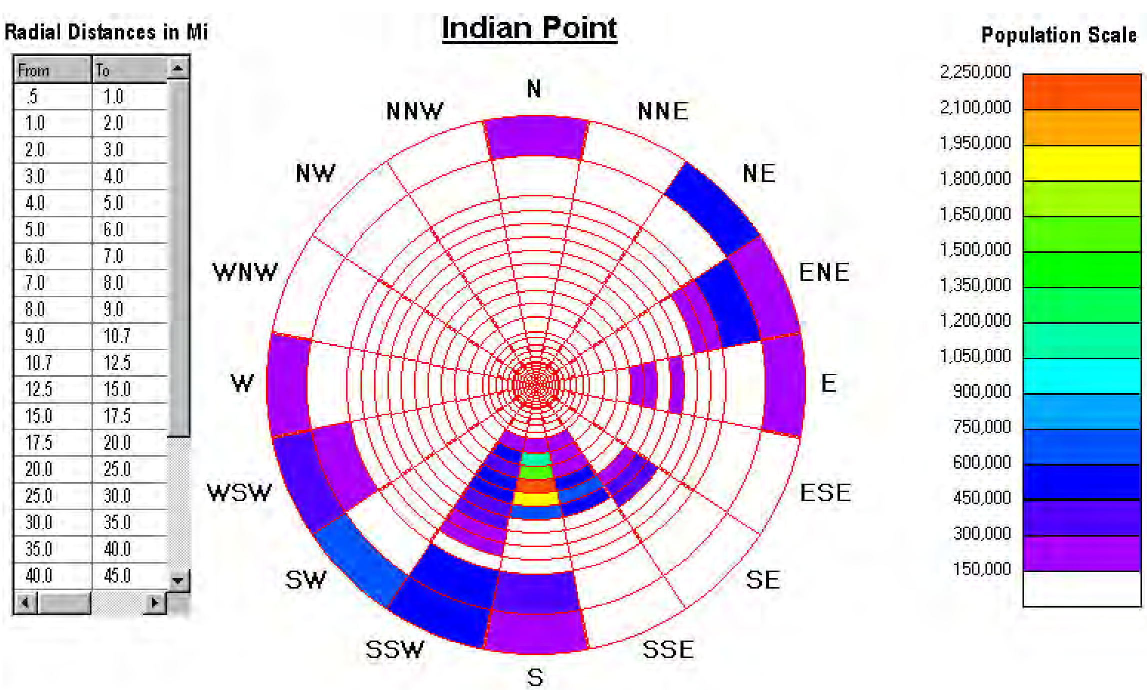
[53] KLD Associates, Inc., *Indian Point Energy Center Evacuation Time Estimate*, Rev. 0 (2003), p. 7-8.
[54] However, the calculation of doses within the EPZ does reflect the impact of "shadow evacuation" of individuals outside of the EPZ, since it uses the KLD Associates evacuation time estimate for the EPZ, which assumes that shadow evacuation occurs.
[55] KLD Associates, Inc. (2003), op cit., p. 3-7.

For the region from 10 to 100 miles from Indian Point, the MACCS2 site data file was generated with the SECPOP2000 code, which is the most recent version of the SECPOP code originally developed by the Environmental Protection Agency and later adopted by NRC for use in regulatory applications.[56] SECPOP2000 utilizes 2000 US Census data to estimate population distributions on a user-specified grid surrounding any location in the United States, drawing on a high-resolution database of over eight million census-blocks. By utilizing the 2000 Census data in SECPOP2000, we have slightly underestimated the population in this region, which appears to have increased by about 1% between 2000 and 2003.

The Indian Point plume exposure EPZ is not in the shape of a perfect circle of ten-mile radius, but includes some regions that are beyond ten miles from the plant. To account for the 38,177 individuals that reside within the EPZ but outside of the 10-mile circular zone (according to KLD estimates for 2003), we used the SECPOP2000 code to determine that an "effective" circular EPZ boundary of 10.68 miles would include the appropriate additional number of permanent residents, and adjusted the MACCS2 grid accordingly.

Figure 1 displays the population rosette generated by SECPOP2000 for Indian Point, out to a distance of 100 miles. The location of New York City is plainly visible on the grid.

FIGURE 1



[56] N. Bixler et al., *SECPOP2000: Sector Population, Land Fraction, and Economic Estimation Program*, NUREG/CR-6525, Rev. 1, Sandia National Laboratories, August 2003.

RESULTS

In this section, we present the results of the MACCS2 simulation of a terrorist attack at IP2, as previously described.

MACCS2 generates results for two distinct periods following a radiological release. First, it calculates the doses to individuals received during the "emergency" phase of the event, defined as the period extending up to the first week following the release. The doses received during this period result from direct exposure to and inhalation of the plume, as well as exposure to plume particles deposited on the ground ("groundshine"). Second, it separately calculates doses received beyond the first week after the release as a result of groundshine, inhalation of resuspended particles, and consumption of contaminated food and water. The first sets of results provided below refer only to the consequences of exposures received during a one-week emergency phase. The economic and long-term health consequences are calculated based on the evaluation of chronic exposures for a period of fifty years following the release, which are dominated by groundshine.

Following the format of the CRAC2 Report summary, our calculation considers several public health and environmental endpoints, including early fatalities, latent cancer fatalities, maximum distance for early fatalities, and total economic costs. The calculations were carried out for each of the 8760 weather sequences in the New York City meteorological data file by rotating the plume direction into each of the 16 sectors of the compass, and then generating a weighted average of the results according to the Indian Point site wind rose. For each endpoint, in addition to the mean of the distribution and the peak value corresponding to the worst-case meteorological conditions encountered during the year, we present the 95th and 99.5th percentile values of the distribution.

The results of the MACCS2 frequency distribution are based on the assumption that the radiological release would occur at random during the year, even though the timing of a terrorist attack most likely would be far from random. As we have previously discussed, one must assume that a terrorist attack intended to cause the maximum number of casualties would be timed to coincide as closely as possible with the most favorable weather conditions. In the case of Indian Point, an attack at night --- the time when a terrorist attack is most likely to be successful --- also happens to be the time when the prevailing winds are blowing toward New York City. Consequently, the mean and other statistical parameters derived from a random distribution are not characteristics of the actual distribution of consequences resulting from a terrorist attack, which would be restricted to a much more limited set of potential release times. A meteorological data set confined to the evening hours would skew the distribution in the direction of increased consequences.

In our judgment, the 95th percentile values of these distributions, rather than the mean values, are reasonable representations of the likely outcome of a well-planned terrorist attack. This choice reflects the fact that the attack time will be largely of the terrorists' choosing, but that some factors will necessarily remain out of their control --- for instance, the ability to accurately predict precipitation patterns, and the ability to launch an attack exactly as planned.

In the following tables, it is important to note that the peak results in each category do not correspond in general to the same weather sequence. For example, the weather conditions that lead to the maximum number of early fatalities are typically those that involve rainout and substantial deposition of the plume close to the plant, and thus are not the same conditions that lead to peak latent cancer fatalities, which involve rainout of the plume over New York City.

(a) Consequences of radiological exposures during "emergency phase"

Here we consider the consequences of exposures received during the 7-day "emergency phase." We calculate the number of "early fatalities" (EFs) resulting from acute radiation syndrome, both for the residents of the 10-mile EPZ, who are assumed to evacuate according to the scheme described previously, and for the entire population within 50 miles of the plant. Following the CRAC2 Report, we also provide the "early fatality distance," that is, the greatest distance from the Indian Point site at which early fatalities may occur. Finally, we provide an estimate of the number of latent cancer fatalities (LCFs) that will occur over the lifetimes of those who are exposed to doses that are not immediately life-threatening, both for residents of the EPZ and for residents of the 50-mile region.

It is important to note that these estimates are based on dose conversion factors (the radiation doses resulting from internal exposure to unit quantities of radioactive isotopes) appropriate for a uniform population of adults, and do not account for population variations such as age-specific differences. A calculation fully accounting for individual variability of response to radiation exposure is beyond the capability of the MACCS2 code and the scope of this report.

In Table 3, these results are provided for the case in which 100% evacuation of the EPZ occurs, based on the KLD evacuation time estimate and 2-hour mobilization time discussed earlier. Table 4 presents the same information for the case where the EPZ population is sheltered for 24 hours prior to evacuation. Finally, Table 5 presents the results for the extreme case where no special precautions are taken in the EPZ.

In interpreting the results of these tables, one should keep in mind that the MACCS2 code uses different radiation shielding factors for individuals that are evacuating, sheltering or engaged in normal activity. The default MACCS2 parameters (which we adopt in this study) assume that evacuees are not shielded from the radioactive plume by structures, since they are mostly outdoors or in non-airtight vehicles during the evacuation. Individuals who shelter themselves instead of evacuating are shielded to a considerable extent by structures, but may be exposed to higher levels of radiation overall because they remain in areas closer to the site of plume release. The MACCS2 default shielding parameters assume that sheltering reduces doses from direct plume exposure by 40% and doses from plume inhalation by 67%. The relative benefits of sheltering versus evacuation are obviously quite sensitive to the values of the shielding parameters. Finally, the level of shielding for individuals engaged in "normal activity" falls in between the levels for evacuation and for sheltering, with reductions in doses from direct plume exposure and plume inhalation relative to evacuees of 25% and 59%, respectively.

TABLE 3: Terrorist attack at IP 2, MACCS2 estimates of early fatalities (EFs), latent cancer fatalities (LCFs) and the EF distance resulting from emergency phase exposures, 100% evacuation of EPZ

	Mean	95th percentile	99.5th percentile	Peak
Consequence:				
EFs, within EPZ	527	2,440	11,500	26,200
EFs, 0-50 mi.	696	3,460	16,600	43,700
EF distance (mi.)	5.3	18	24	60
LCFs, within EPZ	9,200	31,600	59,000	89,500
LCFs, 0-50 mi.	28,100	99,400	208,000	518,000

TABLE 4: Terrorist attack at IP 2, MACCS2 estimates of early fatalities (EFs), latent cancer fatalities (LCFs) and the EF distance resulting from emergency phase exposures, 24-hour sheltering in EPZ

	Mean	95th percentile	99.5th percentile	Peak
Consequence:				
EFs, within EPZ	626	2,550	6,370	13,000
EFs, 0-50 mi.	795	3,250	10,200	38,700
EF distance (mi.)	6.2	18	24	60
LCFs, within EPZ	3,770	9,920	12,100	19,400
LCFs, 0-50 mi.	22,700	81,000	192,000	512,000

TABLE 5: Terrorist attack at IP 2, MACCS2 estimates of early fatalities (EFs), latent cancer fatalities (LCFs) and the EF distance resulting from emergency phase exposures, normal activity in EPZ

	Mean	95th percentile	99.5th percentile	Peak
Consequence:				
EFs, within EPZ	4,050	12,600	22,300	38,500
EFs, 0-50 mi.	4,220	13,500	27,300	71,300
EF distance (mi.)	9	18	24	60
LCFs, within EPZ	4,480	10,400	12,500	20,300
LCFs, 0-50 mi.	23,400	82,600	193,000	516,000

A comparison of Tables 3 and 4 indicates that sheltering instead of evacuation results in slightly higher mean early fatalities, but substantially lower 99.5th percentile and peak values. A possible interpretation of this counterintuitive result is that the higher percentile early fatality results for the evacuation case correspond to rare situations in which people evacuate in such a manner as to maximize their radiation exposure (for instance, if they are unfortunate enough to be traveling directly underneath the radioactive plume at the same speed and in the same direction). These situations cannot occur for the sheltering case. Overall, sheltering does appear to substantially reduce the projected number of latent cancer fatalities within the EPZ relative to evacuation, for the default MACCS2 shielding parameters.

A comparison of Table 5 to Tables 3 and 4 indicates that either evacuation or sheltering would substantially reduce the number of early fatalities within the EPZ relative to a case where no protective actions are taken. Also, by comparing Tables 3 and 5, one sees that the number of latent cancer fatalities in the EPZ is considerably lower for the normal activity case than for the evacuation case. There are two reasons for this. First, many evacuees will receive doses that are not high enough to cause early fatalities, yet will contribute to their lifetime cancer risk. In the normal activity case, some of these individuals will receive higher doses and succumb to acute radiation syndrome instead. Second, the MACCS2 default shielding factors give considerable protection to individuals engaged in normal activity compared to evacuees, and may not be realistic.[57]

The peak numbers of latent cancer fatalities for all three cases in the 50-mile zone are disturbingly high, and are more than double the number in the 99.5th percentile. But an examination of the particular weather sequence corresponding to this result indicates that

[57] The protection due to shielding has a bigger impact on the number of latent cancer fatalities, which is a linear function of population dose, than on the number of early fatalities, which is a non-linear function of dose. Shielding would only prevent early fatalities for those individuals whose acute radiation doses would be lowered by sheltering from above to below the early fatality threshold.

the rarity of the event is an artifact of the meteorological data file that we have used, and not a consequence of very extreme or unusual weather conditions for the New York City region. We are not disclosing the details of this weather sequence.

The reader may also notice that the values for the "early fatality distance" for the 95th percentile and above are the same in Tables 3-5, but the mean values are not. This is because the distances for the 95th percentile and above are all greater than 10 miles, so that they are not affected by differences in protective actions that apply only within the 10-mile EPZ.

(b) Doses received by individuals outside of the 10-mile EPZ

It is clear from the previous section that direct exposure to the radioactive plume resulting from a terrorist attack at Indian Point could have severe consequences well beyond the 10-mile EPZ, yet there is no regulatory requirement that local authorities educate residents outside of the EPZ about these risks, or undertake emergency planning to protect these individuals from plume exposures. Therefore, individuals who are now at risk do not have the information that they may need to protect themselves. This is a shortsighted policy, and in fact is inconsistent with government guidelines for protective actions in the event of a radiological emergency.

In this section, we calculate the plume centerline thyroid doses to adults and five-year-old children, and the plume centerline whole-body doses to adults, both at the EPZ boundary and in midtown New York City. (For a given distance downwind of a release, the maximum dose is found at the plume centerline.) We then compare these values to the appropriate protective action recommendations. Thyroid doses are compared to the dose thresholds in the most recent FDA recommendations for potassium iodide administration and whole-body doses are compared to the EPA protective action guides (PAGs) for emergency-phase evacuation. In both cases, the plume centerline doses received to individuals in New York City are well in excess of the projected dose thresholds that would trigger protective actions.

(i) Thyroid doses to children, their consequences, and the need for KI distribution

The statistically significant increase in the incidence of thyroid cancer observed among children exposed to fallout from the Chernobyl disaster leaves little doubt of the causal relationship between the occurrence of these cancers and the massive release of radioactive iodine to the environment resulting from the accident.[58] The effectiveness of widespread distribution of stable iodine in the form of potassium iodide (KI) to block uptake of radioactive iodine in the thyroid was also confirmed in western areas of Poland, where the timely administration of KI was estimated to have reduced peak doses from radioactive iodine by 30%.[59]

[58] D. Williams, "Cancer After Nuclear Fallout: Lessons from The Chernobyl Accident," *Nature Reviews Cancer* **2** (2002), p. 543-549.
[59] Board on Radiation Effects Research, National Research Council, *Distribution and Administration of Potassium Iodide in the Event of a Nuclear Incident*, National Academies Press, 2003, p. 58.

In the United States, after resisting public demands for many years, the Nuclear Regulatory Commission finally agreed in January 2001 to amend its emergency planning regulations to explicitly consider the use of KI, and to fund the purchase of KI for distribution within the 10-mile plume exposure EPZs of nuclear plants in states that requested it. This effort accelerated after the September 11 attacks, as more states requested the drug, but even today only fewer than two-thirds of the 34 states and tribal governments that qualify for the KI purchase program have actually stockpiled it. New York State is one of the participants.

Despite a few attempts in Congress after September 11 to require the distribution of KI in areas outside of the plume exposure EPZs, the 10-mile limit remains in effect today, and NRC continues to defend it. In a recent Commission meeting on emergency planning, NRC employee Trish Milligan said that[60]

> "...the [NRC] staff has concluded that recommending consideration of potassium iodide distribution out to 10 miles was adequate for protection of the public health and safety."

Earlier in this briefing, Ms. Milligan provided evidence of the NRC staff's thinking that led to this conclusion:[61]

> "When the population is evacuated out of the [10-mile] area and potentially contaminated foodstuffs are interdicted, the risk from further radioactive iodine exposure to the thyroid gland is essentially eliminated."

These statements again show that NRC continues to use design-basis accidents, in which the containment remains intact, as the model for its protective action recommendations. Although NRC claims that its emergency planning requirements take into account all potential releases, including those resulting from terrorist acts, it clearly is not taking into account catastrophic events such as the scenario being analyzed in this report.

These statements also suggest that NRC is committing the fallacy of using the pattern of radioactive iodine exposure that occurred after the Chernobyl accident as the model for the pattern that could occur here. In the Chernobyl event, the majority of the thyroid dose to children occurred through ingestion of contaminated milk and other foodstuffs that were not interdicted due to the failure of the Soviet authorities to act in a timely manner. However, the food pathway dominated in that case primarily because of the extremely high elevation of the Chernobyl plume, which reduced the concentration of radioactive iodine in the plume and therefore the doses received through direct inhalation.
But as pointed out earlier, the plume from a severe accident at a water-moderated PWR like Indian Point would probably not rise as high as the Chernobyl plume, and the associated collective thyroid dose would have a greater contribution from direct plume inhalation and a lower contribution from milk consumption. In this case, the importance

[60] US NRC, "Briefing on Emergency Preparedness Program Status" (2003), transcript, p. 21.
[61] Ibid, p.19.

of KI prophylaxis would increase relative to that of milk interdiction for controlling overall population exposure to radioactive iodine.

Our calculations clearly indicate that a severe threat to children from exposure to radioactive iodine is present far beyond the 10-mile EPZ where KI is now being made available. In Table 6, we present some results of the distribution for plume centerline thyroid dose to both adults and to five-year-old children at the EPZ boundary and in midtown Manhattan (32.5 miles downwind). In the last column, we provide the projected dose thresholds from the most recent guidelines issued by the FDA for KI prophylaxis.

The thyroid dose to five-year-olds due to I-131 internal exposure was calculated by using the age-dependent coefficients for dose per unit intake provided in ICRP 72, which are approximately a factor of five greater than those for adults. The calculation must also take into account the difference in the rate of intake of air for children and for adults. Children have lower lung capacities than adults, but they have higher metabolic rates and therefore breath more rapidly. The higher breathing rate of children tends to partially offset their lower lung capacity. Data collected by the California Environmental Protection Agency indicates that on average, children consume air at a rate about 75% of that of adults.[62] We have used this figure in our calculation.

TABLE 6: Terrorist attack at IP 2, MACCS2 estimates of centerline thyroid doses to 5-year-olds resulting from emergency phase exposures (all doses in rem)

Location	Age	Mean	95th percentile	99.5th percentile	Peak	FDA KI threshold
Outside EPZ (11.6 mi)	Adult	1,120	3,400	5,850	9,560	10 (ages 18-40) 500 (over 40)
	5 years	3,620	10,900	18,000	32,100	5
Midtown Manhattan (32.5 mi)	Adult	164	429	761	1,270	10 (ages 18-40) 500 (over 40)
	5 years	530	1,310	2,500	4,240	5

The results in Table 6 show that the thyroid doses to 5-year-olds are approximately three times greater than those for adults. This tracks well with information in the World Health Organization's 1999 guidelines for iodine prophylaxis, which states that thyroid doses from inhalation in children around three years old will be increased up to threefold relative to adults.[63]

[62] Air Resources Board, California Environmental Protection Agency, "How Much Air Do We Breathe?", Research Note #94-11, August 1994. On the Web at www.arb.ca.gov/research/resnotes/notes/94-11.htm.
[63] World Health Organization, *Guidelines for Iodine Prophylaxis Following Nuclear Accidents*, WHO, Geneva, 1999, Sec. 3.3.

These results make clear that both 95th percentile and mean projected thyroid doses can greatly exceed the FDA-recommended threshold for KI prophylaxis administration at locations well outside the 10-mile EPZ, for 5-year-old children and for adults of all ages. In Manhattan, KI would be recommended for children and adults under 40, based on the 95th percentile projection.

The health consequences of doses of this magnitude to the thyroid would be considerable. As the 99.5th percentile is approached, the 5-year-old doses are high enough to cause death of thyroid tissue. In fact, they are on the order of the doses that are applied therapeutically to treat hyperthyroidism and other diseases by destroying the thyroid gland. Children with this condition would require thyroid hormone replacement therapy for their entire lives. At lower doses, in which cells are not killed but DNA is damaged, the risk of thyroid cancer to children would be appreciable. According to estimates obtained from Chernobyl studies, a 95th percentile thyroid dose of 1,310 rem to a 5-year-old child in Manhattan would result in an excess risk of about 0.3% per year of contracting thyroid cancer.[64] Given that the average worldwide rate of incidence of childhood thyroid cancer is about 0.0001% per year, this would represent an impressive increase.

These results directly contradict the reassuring statements by NRC quoted earlier. But it is no secret to NRC that such severe thyroid exposures can occur as the result of a catastrophic release. Results very similar to these were issued by NRC staff in 1998 in the first version of a draft report on the use of KI, NUREG-1633.[65] This draft included a Section VII entitled "Sample Calculations," in which the NRC staff estimated the centerline thyroid doses at the 10-mile EPZ boundary from severe accidents using the RASCAL computer code. Table 5 of the draft report shows that the NRC's calculated dose to the adult thyroid at the 10-mile limit ranged from 1500 to 19,000 rem for severe accidents with iodine release fractions ranging from 6 to 35%, for a single weather sequence.[66] In the introductory section, the report states that "doses in the range of 25,000 rad are used to ablate thyroids as part of a therapeutic procedure. Such thyroid doses are possible during severe accidents."[67] NRC's results are even more severe than ours, which were obtained using the NRC revised source term, with a higher iodine release fraction of 67%.

Given NRC's reluctance to provide information of this type to the public, it is no surprise that the Commission withdrew the draft NUREG-1633 and purged it from its web site, ordering the issuance of a "substantially revised document" taking into account "the many useful public comments" that it received.[68] Lo and behold, the second draft of

[64] The average excess absolute risk per unit thyroid dose for children exposed to Chernobyl fallout has been estimated 2.1 per million children per rad. D. Williams, op cit., p. 544.
[65] F.J. Congel et al., *Assessment of the Use of Potassium Iodide (KI) As A Public Protective Action During Severe Reactor Accidents*, Draft Report for Comment, NUREG-1633, US Nuclear Regulatory Commission, July 1998.
[66] Ibid, p. 26.
[67] Ibid, p. 6.
[68] US NRC, "Staff Requirements --- Federal Register Notice on Potassium Iodide," SRM-COMSECY-98-016, September 30, 1998.

NUREG-1633, which was rewritten by Trish Milligan and reissued four years later, mysteriously failed to include Section VII, "Sample Calculations," as well as all information related to those calculations (such as the clear statement cited earlier that thyroid doses in the range of 25,000 rad are possible during severe accidents).[69] This took place even though the Commission's public direction to the NRC staff on changes to be incorporated into the revision made no explicit reference to this section.[70] However, it is clear that the expurgated information would be inconsistent with NRC's previous rulemaking restricting consideration of KI distribution only to the 10-mile zone. Even after this exercise in censorship, the Commission still voted in 2002 to block release of the revised draft NUREG-1633 as a final document.

Some insight into the level of understanding of the health impacts of a catastrophic release of radioactive iodine of the current Commission can be found in the statement of Commissioner McGaffigan in voting to delay release of the revised NUREG-1633 for public comment. In his comments, McGaffigan wrote[71]

> "Both WHO [the World Health Organization] and FDA set the intervention level on KI prophylaxis for those over 40 at 5 gray (500 rem) to the thyroid …Since we do not expect, *even in the worst circumstances*, any member of the public to receive 500 rem to the thyroid, it would be useful for FDA to clarify whether we should plan for KI prophylaxis for those over 40." [Emphasis added.]

This statement is not consistent with what is known about the potential consequences of a severe nuclear accident. Few experts would claim that such high doses cannot occur "even in the worst circumstances," and the NRC's own emergency planning guidance is not intended to prevent such doses in ***all*** accidents, but only in ***most*** accidents. Given that the Commissioner presumably read the first draft of NUREG-1633, he would have seen the results of the staff's thyroid dose calculations and other supporting material. There is no discussion in the public record that provides a rationale for Commissioner McGaffigan's rejection of the informed judgment and quantitative analysis of his technical staff.

In 2003, at the request of Congress a National Research Council committee released a report addressing the issue of distribution and administration of KI in the event of a nuclear incident.[72] Most notably, the committee concluded that[73]

> "1. KI should be available to everyone at risk of significant health consequences from accumulation of radioiodine in the thyroid in the event of a radiological incident…

[69] US NRC, "Status of Potassium Iodide Activities, SECY-01-0069, Attachment 1 (NUREG-1633, draft for comment; prepared by P.A. Milligan, April 11, 2001).
[70] US NRC, SRM-COMSECY-98-016.
[71] US NRC, Commission Voting Record on SECY-01-0069, "Status of Potassium Iodide Activities," June 29, 2001.
[72] National Research Council (2003), op cit.
[73] Ibid, p. 5.

2. KI distribution programs should consider …local stockpiling outside the emergency planning zone …"

While the committee did not itself take on the politically sensitive question of how to determine the universe of individuals who would be "at risk of significant health consequences," it did recommend that "the decision regarding the geographical area to be covered in a KI distribution program should be based on risk estimates derived from calculations of site-specific averted thyroid doses for the most vulnerable populations."[74] This is the type of information that we provide in Table 6 (and the type that NRC struck from draft NUREG-1633). We hope that the information in our report provides a starting point for state and local municipalities to determine the true extent of areas that could be significantly affected by terrorist attacks at nuclear plants in their jurisdiction and to make provisions for availability of KI in those regions. Our calculations show that New York City should be considered part of such an area.

However, even timely administration of KI to all those at risk can only reduce, but cannot fully mitigate, the consequences of a release of radioactive iodine resulting from a terrorist attack at Indian Point. The projected dose to individuals who undergo timely KI prophylaxis can be reduced by about a factor of 10. A review of the results of Table 6 shows that doses and cancer risks to many children in the affected areas will still be high even after a ten-fold reduction in received dose. And KI can only protect people from exposure to radioactive iodine, and not from exposure to the dozens of other radioactive elements that would be released to the environment in the event of a successful attack.

(ii) Whole-body doses and the need for evacuation or sheltering

In addition to KI distribution, the other major protective action that will be relied on to reduce exposures following a terrorist attack at Indian Point is evacuation of the population at risk. In Table 7, we present the results of our calculation for the projected centerline whole-body "total effective dose equivalents" (TEDEs) just outside the EPZ boundary and in downtown Manhattan, and compare those with the EPA recommended dose threshold for evacuation during the emergency phase following a radiological incident. As in the discussion of projected thyroid doses and KI prophylaxis, we find that projected centerline TEDEs would exceed the EPA Protective Action Guide (PAG) for evacuation of 1-5 rem at distances well outside of the 10-mile plume exposure EPZ within which NRC requires evacuation planning.

[74] Ibid, p. 162.

TABLE 7: Terrorist attack at IP 2, MACCS2 estimates of adult centerline whole-body total effective dose equivalents (TEDEs) resulting from emergency phase exposures (all doses in rem)

	Mean	95th percentile	99.5th percentile	Peak	EPA PAG
Location					
EPZ boundary (11.6 mi)	198	549	926	1,490	1-5
Midtown Manhattan (32.5 mi)	30	77	131	307	1-5

From the results in Table 7, it is clear that according to the EPA early phase PAG for evacuation of 1-5 rem, evacuation would be recommended for individuals in the path of the plume centerline not only outside of the EPZ boundary, but in New York City and beyond. An individual in Manhattan receiving the 95th percentile TEDE of 77 rem during the emergency phase period would have an excess absolute lifetime cancer fatality risk of approximately 8%, which corresponds to a 40% increase in the lifetime individual risk of developing a fatal cancer (which is about one in five in the United States).

We now examine the potential reduction in health consequences that could result from evacuation of a larger region than the current 10-mile EPZ by considering a case in which the boundary of the plume exposure EPZ is expanded from 10.7 to 25 miles. We calculate the impact of different protective actions in this region on the numbers of early fatalities and latent cancer fatalities among the population within the expanded EPZ but outside of the original 10-mile EPZ. The residents of the expanded EPZ are assumed either (1) to evacuate with the same mobilization time and at the same average speed as the residents of the original EPZ, or (2) to shelter in place for 24 hours and then evacuate. The results are provided in Table 8.

TABLE 8: Terrorist attack at IP 2, MACCS2 95th percentile estimates of early fatalities (EFs) and latent cancer fatalities (LCFs) resulting from emergency phase exposures; 25-mile EPZ

	Normal activity	Evacuation	Sheltering for 24 hrs
Consequence:			
EFs, 10.7-25 mi	664	0	0
LCFs, 10.7-25 mi	19,800	45,700	9,020

These results indicate that evacuation and sheltering are equally effective in eliminating the risk of early fatalities among residents of the 10.7-25 mile region for the 95th percentile case. On the other hand, one sees that evacuation also tends to increase the number of latent cancer fatalities relative to normal activity, while sheltering reduces the number. Thus for this scenario, it appears that sheltering of individuals in the 10.7-25 mile region would be preferable to evacuation of this region for the MACCS2 evacuation and sheltering models we use here. This is consistent with the results we obtained earlier when considering the comparative impacts of evacuation and sheltering of residents of the 10-mile EPZ, again indicating that evacuation tends to increase population doses by placing more people in direct contact with the radioactive plume. However, other models and other shielding parameter choices may lead to different conclusions. We would urge emergency planning officials to evaluate an exhaustive set of scenarios, and to conduct a realistic and site-specific assessment of the degrees of shielding that structures in the region may provide, to determine what types of actions would provide the greatest protection for residents of regions outside of the 10-mile EPZ.

(c) Long-term economic and health consequences

In this section we provide MACCS2 order-of-magnitude estimates of the economic costs of the terrorist attack scenario, the numbers of latent cancer fatalities resulting from long-term radiation exposures (primarily as a result of land contamination), and the number of people who will require permanent relocation. NRC has used MACCS2 to estimate the economic damages of reactor accidents for various regulatory applications.[75]

There is no unique definition of the economic damages resulting from a radiological contamination event. In the MACCS2 model, which is a descendant of the CRAC2 model, the total economic costs include the cost of decontamination to a user-specified cleanup standard, the cost of condemnation of property that cannot be cost-effectively decontaminated to the specified standard, and a simple lump-sum compensation payment to all members of the public who are forced to relocate either temporarily or permanently as a result of the attack. Although simplistic, this model does provide a reasonable estimate of the order of magnitude of the direct economic impact of a successful terrorist attack at Indian Point.

(i) EPA Protective Action Guide cleanup standard

We first employ the long-term habitability cleanup standards provided by the EPA protective action guide (PAG) for the "intermediate phase," which is the period that begins after the emergency phase ends, when releases have been brought under control and accurate radiation surveys have been taken of contaminated areas. The EPA intermediate phase PAG recommends temporary relocation of individuals and decontamination if the projected whole-body total effective dose equivalent (TEDE) (not taking into account any shielding from structures) over the first year after a radiological

[75] US NRC, Office of Nuclear Regulatory Research, ***Regulatory Analysis Technical Evaluation Handbook***, NUREG/BR-0184, January 1997, p. 5.37.

release would exceed 2 rem. The EPA chose this value with the expectation that if met, then the projected (shielded) TEDE in the second (and any subsequent year) would be below 0.5 rem, and the cumulative TEDE over a fifty-year period would not exceed 5 rem.

The MACCS2 economic consequence model evaluates the cost of restoring contaminated areas to habitability (which we define as reducing the unshielded TEDE during the first year of reoccupancy to below 2 rem), and compares that cost to the cost of condemning the property. All cost parameters, including the costs of decontamination, condemnation and compensation, can be specified by the user. We employ an economic model partly based on parameters developed for a recent study on the consequences of spent fuel pool accidents.[76] The model utilizes the results of a 1996 Sandia National Laboratories report that estimates radiological decontamination costs for mixed-use urban areas.[77] We refer interested readers to these two references for information on the limitations and assumptions of the model.

The SECPOP2000 code, executed for the Indian Point site, provides the required site-specific inputs for this calculation, including the average values of farm and non-farm wealth for each region of the MACCS2 grid, based on 1997 economic data. These values are used to assess the cost-effectiveness of decontaminating a specific element versus simply condemning it.

Table 9 presents the long-term health and economic consequences calculated by MACCS2 for a region 100 miles downwind of the release, considering only costs related to residential and small business relocation, decontamination and compensation. Since the calculation was performed using values from a 1996 study and from 1997 economic data, we have converted the results to 2003 dollars using an inflation adjustment factor of 1.10. Because of significant uncertainties in the assignments of parameters for this calculation, the results in Table 9 should only be regarded as order-of-magnitude estimates. The reader should note that the latent cancer fatality figures in Table 9 result from doses incurred after the one-week emergency phase is over, and therefore are additional to the numbers of latent cancer fatalities resulting from emergency-phase exposures reported previously in Tables 3 to 5.

---

[76] J. Beyea, E. Lyman and F. von Hippel, "Damages from a Major Release of ^{137}Cs into the Atmosphere of the United States," *Science and Global Security* 12 (2004) 1-12.
[77] D. Chanin and W. Murfin, *Site Restoration: Estimates of Attributable Costs From Plutonium Dispersal Accidents*, SND96-0057, Sandia National Laboratories, 1996.

TABLE 9: Terrorist attack at IP 2, MACCS2 estimates of long-term economic and health consequences, EPA intermediate phase PAG (< 2 rem in first year; approx. 5 rem in 50 yrs)

	Mean	95th percentile	99.5th percentile	Peak
Consequence				
Total cost, 0-100 mi (2003 $)	$371 billion	$1.17 trillion	$1.39 trillion	$2.12 trillion
People permanently relocated	684,000	3.19 million	7.91 million	11.1 million
LCFs, 0-100 mi	12,000	41,200	57,900	84,900
Plume Centerline 50-year TEDE (rem)	4.57	7.04	7.18	7.42

One can see from Table 9 that imposition of the EPA intermediate phase PAG does result in restricting the mean 50-year cumulative TEDE to below 5 rem, but that this limit is exceeded for the higher percentiles of the distribution. Thus for a terrorist attack at the 95th percentile, the subsidiary goal of the EPA intermediate phase PAG is not met.

(ii) Relaxed cleanup standard

In the recent NRC meeting on emergency planning described earlier, NRC staff and Commissioners questioned claims by activists that a severe nuclear accident would render large areas "permanently uninhabitable," arguing that the radiation protection standard underlying that determination is too stringent compared to levels of natural background radiation to which people are already exposed.

For instance, Trish Milligan said that[78]

> "There's been a concern that a radioactive release as a result of a nuclear power plant accident will render thousands of square miles uninhabitable around a plant. It is true that radioactive materials can travel long distances. But it is simply not true that the mere presence of radioactive materials are [sic] harmful…the standard applied to this particular claim has been a whole body dose of 10 rem over 30 years, or approximately 330 millirem per year. This dose is almost the average background radiation dose in the United States which is about 360 millirem per year. Some parts of the country have a background radiation dose two or more times higher than the national average. So in effect this additional 330 millirem dose is an additional year background dose or the difference in dose

[78] US NRC, Briefing on Emergency Preparedness (2003), op cit., transcript, p. 22.

between someone living in a sandy coastal area or someone living in the Rocky Mountains."

Ms. Milligan does not note that her opinion of an acceptable level of radiation is not consistent with national standards, such as the EPA PAGs. The EPA long-term goal of limiting chronic exposures after a radiological release to 5 rem in 50 years corresponds to an average annual exposure of 100 millirem above background, while she implies that even a standard of 330 millirem per year, which would double the background dose on average, is unnecessarily stringent.

However, we can evaluate the impact of weakening the EPA PAGs for long-term exposure on costs and risks. In Table 10, we assess the impact of adopting a long-term protective action guide of 25 rem in 50 years, or an average annual dose of 500 millirem per year. By comparing the 95th percentile columns in Table 10 and Table 9, one can see that relaxing the standard would modestly reduce the post-release cleanup costs by about 25% and drastically reduce the number of relocated individuals by 90%. However, weakening the standard would nearly triple the number of long-term cancer deaths among residents of the contaminated area. Cost-benefit analyses of proposals to weaken long-term exposure standards should take this consequence into account.

TABLE 10: Long-term economic and health consequences of a terrorist attack at IP 2, relaxed cleanup standard (25 rem in 50 years)

	Mean	95th percentile	99.5th percentile	Peak
Consequence:				
Total cost, 0-100 mi (2003 $)	$249 billion	$886 billion	$1.14 trillion	$1.50 trillion
People permanently relocated	118,000	334,000	1.86 million	7.98 million
LCFs, 0-100 mi	36,300	115,000	169,000	279,000

(d) An even worse case

The previous results were based on the analysis of a terrorist attack that resulted in a catastrophic radiological release from only one of the two operating reactors at the Indian Point site. However, it is plausible that both reactors could be attacked, or that an attack on one could result in the development of an unrecoverable condition at the other. Here we present the results of a scenario in which Indian Point 3 undergoes a similar accident sequence to Indian Point 2 after a time delay of just over two hours. This could occur, for example, if Indian Point 3 experienced a failure of its backup power supplies at the time that Indian Point 2 was attacked. Given the loss of off-site power at the same time, Indian Point 3 could experience a small-break LOCA and eventually a core melt, commencing about two hours after accident initiation. We assume that the attackers weaken the IP3 containment so that it ruptures at the time of vessel failure. In Table 11, we present the results of this scenario for the case of full evacuation of the EPZ.

As bad as this scenario is, it still does not represent the worst case. If any or all of the three spent fuel pools at the Indian Point site were also damaged during the attack, the impacts would be far greater, especially with regard to long-term health and economic consequences.

TABLE 11: Terrorist attack at IP 2 and 3, MACCS2 estimates of early fatalities (EFs) and latent cancer fatalities (LCFs) resulting from emergency phase exposures, 100% evacuation of EPZ

	Mean	95th percentile	99.5th percentile	Peak
Consequence:				
EFs, within EPZ	925	4,660	18,400	34,100
EFs, 0-50 mi.	1,620	8,580	30,900	78,400
EF, distance (mi.)	9.1	21	29	60
LCFs, within EPZ	14,800	42,900	75,100	122,000
LCFs, 0-50 mi.	53,400	180,000	342,000	701,000

CONCLUSIONS

In conclusion, we make the following observations.

1) The current emergency planning basis for Indian Point provides insufficient protection for the public within the 10-mile emergency planning zone in the event of a successful terrorist attack. Even in the case of a complete evacuation, up to 44,000 early fatalities are possible.

2) The radiological exposure of the population and corresponding long-term health consequences of a successful terrorist attack at Indian Point could be extremely severe, even for individuals well outside of the 10-mile emergency planning zone. We calculate that over 500,000 latent cancer fatalities could occur under certain meteorological conditions. A well-developed emergency plan for these individuals, including comprehensive distribution of potassium iodide throughout the entire area at risk, could significantly mitigate some of the health impacts if promptly and effectively carried out. However, even in the case of 100% evacuation within the 10-mile EPZ and 100% sheltering between 10 and 25 miles, the consequences could be catastrophic for residents of New York City and the entire metropolitan area.

3) The economic impact and disruption for New York City residents resulting from a terrorist attack on Indian Point could be immense, involving damages from hundreds of billions to trillions of dollars, and the permanent displacement of millions of individuals. This would dwarf the impacts of the September 11 attacks.

4) The potential harm from a successful terrorist attack at Indian Point is significant even when only the mean results are considered, and is astonishing when the results for 95th and 99.5th meteorological conditions are considered. Given the immense public policy implications, a public dialogue should immediately be initiated to identify the protective measures desired by the entire affected population to prevent such an attack or effectively mitigate its consequences should prevention fail. As this study makes abundantly clear, this population extends far beyond the 10-mile zone that is the focus of emergency planning efforts today.

We hope that this information will be useful for officials in the Department of Homeland Security as it carries out its statutory requirement to conduct a comprehensive assessment of the terrorist threat to the US critical infrastructure, as well as for health and emergency planning officials in New York City and other areas that are not now currently engaged in emergency preparedness activities related to a terrorist attack at Indian Point.

ACKNOWLEDGMENTS

The author would like to thank David Lochbaum, Kenneth Bergeron, Frank von Hippel, Jan Beyea and Lisbeth Gronlund for reading drafts of this report and providing many useful comments and suggestions. All mistakes are the responsibility of the author.