Thompson
Attachment 2

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

by
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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.

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About the Author

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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

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[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

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[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.

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[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.

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[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

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[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.

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[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.

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[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.

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[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

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[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.

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[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.

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[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

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[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]

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[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.

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[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.

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[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

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[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."

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[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"

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[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]

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[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.

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[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."

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[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

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[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

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[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]

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[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

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[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

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[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.

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[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.

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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

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

(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.