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1/12/2010

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From:	Jane Swanson [janeslo@kcbx.net]
Sent:	Tuesday, January 12, 2010 7:46 PM
To:	Rulemaking Comments
Subject:	Comments, draft revision to GEIS for License Renewal of nuclear plants
Attachments:	SLOMFP Comments on NRC Draft GEIS for License Renewal 1_12_10.pdf; ATT00007.htm; Thompson Report 6-27-07-1.pdf; ATT00008.htm; Thompson Final WasteConf Rpt 2-06-09.pdf; ATT00009.htm; Thompson Report 5-25-06-1.pdf; ATT00010.htm; IEER Waste Confidence Comments 6 Feb 09-1.pdf; ATT00011.htm; IEER DU comments 2009-1.pdf; ATT00012.htm

7:50 PM

TO: Secretary, U.S. NRC
Washington, D.C. 20555-0001
ATTN: Rulemaking and Adjudications Staff
Rulemaking.Comments@nrc.gov

FROM: **San Luis Obispo Mothers for Peace (SLOMFP)**
P.O. Box 3608
San Luis Obispo, CA 93403

RE: Draft revision to the Generic Environmental Impact Statement for License Renewal of Nuclear plants, NUREG-1437, revision 1 (GEIS)

Attached please find comments from San Luis Obispo Mothers for Peace on the NRC's proposed rule, "Revisions to Environmental Review for Renewal of Nuclear Power Plant Operating Licenses," 74 Fed. Reg. 38,117 (July 31, 2009); and on the NRC's Draft Generic Environmental Impact Statement ("GEIS") for License Renewal of Nuclear Plants (2009). The comments are followed by five attachments.

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Add = J. A. Davis (JXD10)

January 12, 2010

FROM: **San Luis Obispo Mothers for Peace (SLOMFP)**
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TO: Secretary, U.S. NRC
Washington, D.C. 20555-0001
ATTN: Rulemaking and Adjudications Staff
Rulemaking.Comments@nrc.gov

RE: Draft revision to the Generic Environmental Impact Statement for License Renewal of Nuclear plants, NUREG-1437, revision 1 (GEIS)

San Luis Oblspo Mothers for Peace ("SLOSLOMFP") hereby submits its comments on the NRC's proposed rule, "Revisions to Environmental Review for Renewal of Nuclear Power Plant Operating Licenses," 74 Fed. Reg. 38,117 (July 31, 2009); and on the NRC's Draft Generic Environmental Impact Statement ("GEIS") for License Renewal of Nuclear Plants (2009). Both the proposed rule and the draft GEIS are completely inadequate to comply with the National Environmental Policy Act and therefore they should be withdrawn.

In support of its comments, SLOMFP adopts and incorporates by reference the following additional documents, which are attached:

- Dr. Gordon R. Thompson, *Assessing Risks of Potential Malicious Actions at Commercial Facilities: The Case of a Proposed Independent Spent Fuel Storage Installation at the Diablo Canyon Site* at 15 (June 27, 2007) (Attachment 1);

- Dr. Gordon R. Thompson, *Environmental Impacts of Storing Spent Nuclear Fuel and High-Level Waste from Commercial Nuclear Reactors: A Critique of NRC's Waste Confidence Decision and Environmental Impact Determination* (February 6, 2009) (Attachment 2);

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[1] These comments were prepared with the assistance of SLOSLOMFP's attorney, Diane Curran.

- Dr. Gordon R. Thompson, *Risks and Risk-Reducing Options Associated with Pool Storage of Spent Nuclear Fuel at the Pilgrim and Vermont Yankee Nuclear Power Plants* (May 25, 2006) (Attachment 3)

- *Comments of the Institute for Energy and Environmental Research on the U.S. Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update and Proposed Rule Regarding Environmental Impacts of Temporary Spent Fuel Storage* (February 6, 2009) (Attachment 4);

- Institute for Energy and Environmental Research, *Comments on the Nuclear Regulatory Commission's Rulemaking Regarding the "Safe Disposal of Unique Waste Streams Including Significant Quantities of Depleted Uranium* (October 30, 2009) (Attachment 5)[2].

COMMENTS

Safety Standards for New Plants Should be Applied to Existing Facilities
The fact that the NRC has newer and more rigorous standards for reactor safety in the new generation of nuclear power plants is a tacit admission that those of the past are inadequate to protect human health and the environment. The NRC must apply updated and more stringent rules and regulations regarding safeguards and security for NEW reactors to existing facilities. If the new reactor standards are deemed necessary to protect human health and the environment, then such standards should be applied to any reactor given permission to operate beyond its original license.

Operation and Maintenance Deficiencies Should be Addressed in the GEIS
Recent NRC inspection reports on Diablo Canyon (August, 2009) indicate that PG&E is not meeting industry standards in its identification and resolutions of problems at the plant. In late October, 2009, it was discovered that for 18 months the plant was run with defective control of some of the valves relied upon to flood the Unit 2 reactor with essential cooling water in the event of a serious accident or sabotage. An NRC report on its findings has not yet been made available.

SLOMFP contends that a plant's mechanical and personnel history provide critical predictive information which the NRC must consider before extending the life of a nuclear facility. Yet, there is no resource area in the Draft GEIS that explores the plant's operation and maintenance record. This must be a Category 2 issue.

GEIS Should Not Exclude Need for Power
The California Public Utilities Commission (CPUC) is in the process of determining whether or not continued reliance on nuclear energy is in the best economic interests of the people of California. PG&E's decision to apply for license extensions 15 years in

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[2] Each of these expert reports has been submitted to the NRC in connection with previous rulemakings and/or adjudications.

advance of the expiration of the current licenses raises questions regarding its intentions toward the coming CPUC conclusion.

Again, the GEIS excludes the issue of the need for power. Before asking ratepayers to further invest in the continued operation of a nuclear facility, the NRC must require data-driven answers to the question of cost vs. benefit. This must be a Category 2 issue.

Availability of Uranium Fuel Should Be Addressed

Optimistic projections of the availability of uranium fuel supplies show that resource running out in about 2020 – BEFORE the period at stake in the possible Diablo license extensions. [See December 1, 2009 publication of an article by Brian Wang titled "Uranium Supplies are Likely to be Adequate until 2020," available at www.theoildrum.com/]. If this is true, all nuclear plants in the country will be affected. SLOMFP advocates that the industry apply its considerable resources toward establishing renewable sources of energy.

Spent Fuel Storage Should Be Classified as Category 2.

In the License Renewal GEIS, the NRC admits for the first time that the environmental impacts of a spent fuel pool fire are comparable to the impacts of a severe reactor accident, *i.e.,* that they may be significant. *See* Vol. 1 page 4-156 ("it is concluded that the environmental impacts from accidents at spent fuel pools (SPFs) (as quantified in NUREG-1738) can be comparable to those from reactor accidents at power.") Yet, although the License Renewal GEIS treats severe accidents as Category 2 environmental impacts (*i.e.,* subject to review in individual license renewal proceedings), it continues to treat spent fuel pool fires as Class 1 impacts, as it did in the 1996 License Renewal GEIS.

In order to rationalize its Category 1 designation of pool fires, the NRC resorts to omitting relevant information, misrepresenting previous studies, and neglecting to establish procedures that would give interested members of the public a fair chance to test the validity of its assertions. The following are just a few examples of the NRC's distortions and lack of candor:

- The NRC distorts the impacts of a pool fire by restricting its impact analysis in Table E-18 on immediate and latent fatalities and ignoring the dominant environmental impact of a pool fire: land contamination. The principal impact of a pool fire – regardless of whether it is caused intentionally or by accident -- is not death and illness through inhalation doses, but land contamination. *See* the attached report by Dr. Gordon R. Thompson, *Assessing Risks of Potential Malicious Actions at Commercial Facilities: The Case of a Proposed Independent Spent Fuel Storage Installation at the Diablo Canyon Site* at 15 (June 27, 2007) (Attachment 1).[3] A pool fire at a nuclear power plant could

[3] SLOMFP presented Dr. Thompson's report and supporting declaration to the NRC Commissioners in 2007, in San Luis Obispo Mothers for Peace's Contentions and

contaminate thousands of square miles of land, causing widespread illness and costing billions of dollars in clean-up costs. *Id. See also* Dr. Gordon R. Thompson, *Environmental Impacts of Storing Spent Nuclear Fuel and High-Level Waste from Commercial Nuclear Reactors: A Critique of NRC's Waste Confidence Decision and Environmental Impact Determination* (February 6, 2009) (Attachment 2).

For the NRC to exclude contamination effects from an analysis of the significance of the impacts of a pool fire is absurd and shows a disturbing lack of scientific integrity.

- The NRC also distorts NUREG-1738 by claiming that its results are conservative when applied to operating plants, because a plant in its decommissioning phase has "fewer protective features." GEIS p. E-34. In fact, NUREG-1738 explicitly acknowledges that it is *not* conservative for operating plants, and that the study was limited to the question of whether emergency planning measures should be required for nuclear power plants that had entered their decommissioning phases. As the Staff discussed in the report:

  > The staff found that the event sequences important to risk at decommissioning plants are limited to large earthquakes and cask drops. For emergency planning (EP) assessments this is an important difference relative to operating plants *where typically a large number of different sequences make significant contributions to risk.*

  NUREG-1738 at ix (emphasis added). Thus, in characterizing NUREG-1738 as "conservative" with respect to operating plants, the NRC completely ignores the fact that a range of severe reactor accidents may contribute to the potential for a pool fire. *See also* the attached report by Dr. Gordon R. Thompson entitled *Risks and Risk-Reducing Options Associated with Pool Storage of Spent Nuclear Fuel at the Pilgrim and Vermont Yankee Nuclear Power Plants* at 19 (May 25, 2006) (Attachment 3) (severe reactor accident could initiate or exacerbate a pool-fire scenario).[4]

- At page 4-156, the NRC states that analyses conducted and mitigative measures employed subsequent to NUREG-1738 (2001) have "lowered the risk" of spent fuel pool fires. But the NRC fails to mention that these analyses and mitigative

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Request for a Hearing Regarding Diablo Canyon Environmental Assessment Supplement (June 28, 2007).

[4] Dr. Thompson's report and supporting declaration were submitted to the NRC by the Commonwealth of Massachusetts in May 2006 in support of its requests for hearings in the license renewal proceedings for the Pilgrim and Vermont Yankee nuclear power plants. The Commonwealth also submitted Dr. Thompson's report in support of its August 25, 2006, petition for rulemaking regarding the environmental impacts of spent fuel pool storage.

measures were all *plant-specific.* NRC, Denial of Rulemaking Petition, 73 Fed. Reg. 46204, 46,208, 46,212 (Aug. 8, 2008) Therefore, under the specific terms of the NRC's regulations for implementation of NEPA in license renewal cases, the NRC may not include spent fuel pool fires in Category 1. *See* 10 C.F.R. Part 51, Appendix B, Table B-1, footnote 2 paragraph 3 (an impact may be classified as Category 1 only if "[m]itigative of adverse impacts associated with the issue has been considered in the analysis, and it has been determined that additional plant-specific mitigation measures are likely not to be sufficiently beneficial to warrant implementation."

- The NRC also fails to acknowledge that the analyses and mitigative measures described above are discussed in classified and safeguards documents which must be provided to interested parties who satisfy the NRC's procedural requirements for safeguards access and/or security clearances. 42 U.S.C. § 2231 "[I]n the case of agency proceedings or actions which involve Restricted Data, defense information, safeguards information protected from disclosure under the authority of section 2167 of this title or information protected from dissemination under the authority of section 2168 of this title, the Commission shall provide by regulation for such parallel procedures as will effectively safeguard and prevent disclosure of Restricted Data, defense information, such safeguards information, or information protected from dissemination under the authority of section 2168 of this title to unauthorized persons with minimum impairment of the procedural rights which would be available if Restricted Data, defense information, such safeguards information, or information protected from dissemination under the authority of section 2168 of this title were not involved.") The NRC recently recognized this legal obligation in the hearing notice for the proposed issuance of a uranium enrichment license. Notice of Receipt of Application for License; Notice of Consideration of Issuance of License; Notice of Hearing and Commission Order and Order Imposing Procedures for Access to Sensitive Unclassified Non-Safeguards Information and Safeguards Information for Contention Preparation; In the Matter of Areva Enrichment Services, LLC (Eagle Rock Enrichment Facility, 74 Fed. Reg. 38,052 (July 30, 2009). Here, where the NRC relies heavily on classified and safeguards documents for its conclusion that the environmental impacts of spent fuel pool fires are insignificant, its failure to establish procedures for access by authorized parties to relevant information starkly violates Section 2231 of the Atomic Energy Act.

Table S-3 is Grossly Outdated and Inadequate to Support License Renewal Decisions.

In the License Renewal GEIS, the NRC proposes to continue to rely on a generic determination, codified in Table S-3, that the human health impacts of disposing of the radioactive waste generated by that plant are insignificant. Table S-3 is now over 30 years old, and has become grossly outdated. *See* attached *Comments of the Institute for Energy and Environmental Research (IEER) on the U.S. Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update and Proposed Rule Regarding Environmental Impacts of Temporary Spent Fuel Storage* (February 6, 2009)

(Attachment 4). As discussed in IEER's comments, the findings of Table S-3 are severely outdated, and the table significantly underestimates the human health impacts of the uranium fuel cycle, including the impacts of disposing of spent fuel, greater than Class C waste, and low level radioactive waste.

For example, the assumptions on which Table S-3 depends include the assumption that spent fuel will be disposed of in a bedded salt repository. But in its Proposed Waste Confidence Decision, the NRC itself states that salt repositories are now considered suitable only for reprocessed high-level waste and not for spent fuel disposal. 73 Fed. Reg. 59,547, 59,555 (October 9, 2008). As discussed in IEER's Comments, all other repository types are now considered likely to have radioactive releases after the repository has been sealed. The hypothesis that releases from spent fuel disposal could be zero has therefore been discredited. Indeed, there are plausible circumstances in which releases could exceed the requirements of safe disposal as defined by radiation protection standards. In order to ensure that its licensing decisions for nuclear power plants comply with NEPA by fully addressing the environmental impacts of the radioactive waste they will generate, the NRC must completely overhaul Table S-3 and integrate it with a more comprehensive analysis of all of the environmental impacts and costs of the licensing of nuclear power plants, including the impacts and costs of the plants themselves and the wastes they will generate. *See* IEER Comments.

Table S-3 also erroneously concludes that it is conservative to assume gaseous releases of certain radionuclides, notably I-129, from reprocessing prior to sealing of a repository rather than to assume their release into water after disposal of spent fuel. *See* IEER Comments.

Finally, Table S-3 contains no discussion of the environmental impacts of the disposal of depleted uranium tails, which are potentially significant. *See* attached Institute for Energy and Environmental Research, *Comments on the Nuclear Regulatory Commission's Rulemaking Regarding the "Safe Disposal of Unique Waste Streams Including Significant Quantities of Depleted Uranium* (October 30, 2009).

The Scope of the GEIS Is Improperly Narrow

In a shell game of regulation, the NRC claims in Section 1.6 that some issues are adequately addressed elsewhere – by other agencies and/or proceedings - or dealt with on an ongoing basis. In its plan to review nuclear plants generically, the NRC has effectively excluded from its consideration environmental issues that have major impacts on public safety:

- Disposition of Spent Nuclear Fuel
- Emergency Preparedness
- Safeguards and Security

Additional excluded issues that would not stand up to scrutiny include:

- Changes to Plant Cooling Systems
- Need for Power

The NRC acknowledges unresolved problems, but excludes them from consideration in the GEIS. Examples include the following:

- Aging: "...operational safety issues and safety issues related to aging are considered outside the scope for the environmental review..." 1-8, lines 7,8)
- Security: "Security issues such as safeguards planning are not tied to a license renewal action..." (1-12, line 25)
- High-level waste storage: "The NRC is confident that there will eventually be a licensed high-level waste repository." (1-9, line 31)

The revised GEIS has neatly packaged the environmental issues by resource area, but there are numerous instances when these areas overlap; i.e. seismology and human health (as a result of an accident during an earthquake), waste management and human health (as a result of an accident involving high level waste storage), ecology, hydrology, and socioeconomics (the effects of damage to the marine environment on the local fishermen).

There are also limitations to the categories. What about a maintenance category? Where does the NRC look at maintenance history at each plant and analyze negative trends? The separation and restriction of environmental issues by resource area is arbitrary and ineffective.

SLOMFP objects to the elimination of critical issues in the determination of license renewal action and to the failure to acknowledge and assess the interactive and cumulative effects of overlapping issues.

Waste Management and Pollution Prevention Discussion is Inadequate

In Section 4.11, waste management is improperly labeled a Category 1 issue; SLOMFP insists that it is a large impact site-specific Category 2 issue.

Like all U.S. nuclear power plants, the Diablo Canyon facility includes the storage of all the high-level radioactive wastes generated by its reactors since it began operation. Currently, most of the spent fuel is stored in over-crowded pools. A small portion has been transferred to a few of the dry casks. To add another 20 years' worth of high level wastes at a seismically active site would significantly add to the safety and security problems at Diablo.

Furthermore, the Draft GEIS continues to promote the myth that Yucca Mountain will be available to accept high level waste from nuclear facilities. (4-166, lines 4-10) 4-167 in the GEIS provides a litany of totally unjustified "reasonable assurance" that spent fuel can be safely stored on-site until the DOE provides a long-term waste storage facility. These assurances amount to wishful thinking and nothing more. Optimistic assumptions are not an acceptable basis for allowing the continued generation of high-level wastes that will need to be stored in isolation from the biosphere for many thousands of years.

No known human civilization has remained intact for even a fraction of the length of time radioactive wastes will remain toxic. A more realistic assumption is that there is no way to assure adequate safeguarding of nuclear wastes.

Cumulative Impacts Must be Addressed

SLOMFP agrees with the License Renewal GEIS Section 4.13 that the issue of cumulative impacts is a vital one, classified as Category 2, and it must be examined in and across all resource areas. SLOMFP is particularly concerned with the consequences of cumulative impacts on the degraded marine environment, human health, and waste management.

Unavoidable Adverse Impacts Should Not Be Accepted

In Section 14.14.1, Unavoidable Adverse Impacts are specified and simply accepted. The Draft GEIS reasons that if an adverse impact can't be dealt with, the conclusion is that it is to be accepted. SLOMFP reasons that since there are so many generic unavoidable adverse impacts, license renewals should automatically be ruled out as too hazardous to the environment and the public to be acceptable.

Earthquake Risks Should be Category 2

It is contrary to current NRC regulations to license a nuclear facility next to an active, major earthquake fault. The NRC "grandfathered" the license for Diablo Canyon Nuclear Power Plant, buying into PG&E's excuse that it was unaware of the Hosgri Fault when it first invested billions of ratepayer dollars to building the plant, beginning in the late 1960's. The Hosgri Fault comes within 3.5 miles of the plant. The NRC is prohibited by its own regulations from taking into account corporate profits rather than public safety, but that is exactly what it did.

The Draft GEIS gives little attention given to seismology in the Draft GEIS except to reassure the public that the two California plants "have been designed to safely withstand the seismic effects associated with earthquakes..." (3-50, lines 23,24)

The newly-discovered Shoreline Fault, less than one mile offshore of the Diablo site, has not been thoroughly studied yet, but it clearly exacerbates an already precarious situation. Clearly, in the case of Diablo Canyon – and perhaps other plants – the impact of previously unknown seismological conditions has the potential to be quite large, and the issue should be placed in Category 2. The NRC implicitly acknowledges that it is not able to analyze earthquake risks generically in Appendix E, where it states that earthquake risks for the Diablo Canyon and San Onofre nuclear power plants were excluded from consideration of the risks of a spent fuel pool fire. Page E-33.

Aquatic Ecology Impacts Are Important and Should be Addressed

Degradation of the marine environment due to impingement and entrainment of aquatic organisms, and to thermal changes, have been long-standing problems in the waters in Diablo Cove. These waters are also prime fishing habitat, and the industry is an important one in the area.

Pacific Gas & Electric Company has been cited by the California Regional Water Quality Control Board for violations to its water permit, and the Company has been forced to take mitigation measures. SLOMFP is concerned about the cumulative impacts on the marine environment of continued operation of Diablo Canyon Nuclear Plant. It is in agreement with the Draft GEIS that Aquatic Resources and the effects of thermal discharges for once-through cooling systems are potentially large impacts that require plant-specific, Category 2 analysis.

Environmental Impacts of Attacks Should be Considered

All nuclear facilities have been identified as targets of terrorists by the NRC, as well as Homeland Security and other federal agencies. Yet this issue is excluded from consideration in the GEIS.

Furthermore, the obvious fact that a failure of security – i.e. a successful terrorist attack – has the potential for catastrophic consequences for the environment and human health is ignored.

SLOMFP is currently pursuing a legal challenge of the NRC in the Ninth Circuit of the U.S. Court of Appeals. The NRC violated both NEPA and a June, 2006 ruling by the Ninth Circuit Court in favor of SLOMFP when the regulators excluded from consideration credible attack scenarios on the dry casks at Diablo Canyon that could have devastating environmental impacts. Under NEPA, environmental impacts that are "reasonably foreseeable" and have "catastrophic consequences, even if their probability of occurrence is low" must be taken into account. The GEIS does not take into account the principles of this ruling by the second-highest court in the nation.

SLOMFP demands the NRC include acts of sabotage or terrorism in its Draft GEIS as Category 2, a large impact with site-specific needs and requirements.

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ASSESSING RISKS OF POTENTIAL MALICIOUS ACTIONS AT COMMERCIAL NUCLEAR FACILITIES:
The Case of a Proposed Independent Spent Fuel Storage Installation at the Diablo Canyon Site

by
Gordon R. Thompson

27 June 2007

A report for
San Luis Obispo Mothers for Peace
California

Abstract

This report discusses the risks of potential malicious actions at commercial nuclear facilities in the US, with a focus on actions by sub-national groups. These risks are first discussed generically, with a focus on power reactors, their spent fuel pools, and independent spent fuel storage installations (ISFSIs) at reactor sites. The report then provides a more detailed discussion of malice-related risks at a proposed ISFSI at the Diablo Canyon site in California. In May 2007 the US Nuclear Regulatory Commission Staff issued a Supplement to its October 2003 Environmental Assessment (EA) for the Diablo Canyon ISFSI. The Supplement considered malice-related risks, pursuant to a ruling by the 9th Circuit of the US Court of Appeals that these risks should have been considered in the EA. The Supplement is reviewed here.

About the Institute for Resource and Security Studies

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

About the Author

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

Acknowledgements

This report was prepared by IRSS for San Luis Obispo Mothers for Peace. The author, Gordon R. Thompson, is solely responsible for the content of the report.

Contents

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

1. Introduction

A variety of nuclear facilities are deployed across the United States and worldwide to serve commercial (non-military) purposes. These facilities contain radioactive material and fissionable material that could create adverse impacts if released to the environment or used for unauthorized purposes. Those impacts could arise as a result of conventional accidents or malicious actions. Here, the term "conventional accidents" refers to incidents caused by human error, equipment failure or natural events.[1] Other incidents could be caused by deliberate, malicious actions. The parties taking those malicious actions could be national governments or sub-national groups.[2]

This report discusses the risks of potential malicious actions at commercial nuclear facilities in the US, with a focus on actions by sub-national groups. The report also focuses on a particular set of facilities that contain large amounts of radioactive material. These facilities are reactors used for generating electrical power, and facilities at the reactor sites that store spent fuel discharged from the reactors. After discharge, spent fuel assemblies are initially stored in spent-fuel pools located adjacent to the reactors. Some years later, the assemblies could be transferred to an independent spent fuel storage installation (ISFSI) on the reactor site. ISFSIs are operating or under construction at a number of reactor sites in the US, and more are being proposed. Although this report focuses on power reactors, their spent-fuel pools, and ISFSIs at reactor sites, many of its findings are applicable to other commercial nuclear facilities.

Here, the term "risks" refers to potential adverse impacts that can be reasonably foreseen but will not necessarily occur. Such impacts can be characterized by their consequences and their probabilities of occurrence.[3] This report focuses on risks associated with potential radiological impacts arising from release to the environment of radioactive material as a result of malicious actions. Many of the report's findings are applicable to related types of risks, such as those associated with use of fissionable material for unauthorized purposes.

The Diablo EA Supplement

In October 2003 the Nuclear Regulatory Commission (NRC) Staff issued an Environmental Assessment (EA) for a proposed ISFSI at the Diablo Canyon reactor site in California. The EA did not consider malice-related risks. Pursuant to a petition by

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[1] The NRC's Glossary, accessed at the NRC web site (www.nrc.gov) on 25 June 2007, contains no definition of "accident". The term "conventional accident" is defined and used in this report to ensure precision, because the term "accident" has been used to encompass incidents caused by deliberate, malicious actions.

[2] Relevant sub-national groups could be based in the US or in other countries.

[3] Some analysts define "risk" as the arithmetic product of consequence and probability. That definition is simplistic and can be misleading, and is not used in this report. That definition is especially inappropriate for malice-related risks because there is usually no statistical basis to support quantitative estimates of the probabilities of malicious actions.

San Luis Obispo Mothers for Peace and other parties, the 9th Circuit of the US Court of Appeals ruled in June 2006 that the EA was inadequate because it did not consider malice-related environmental impacts. In May 2007 the Staff responded to that ruling by issuing a Supplement to the October 2003 EA.[4] The Supplement addresses the risks of potential malicious actions at the proposed ISFSI. Hereafter, the Supplement is described as the "Diablo EA Supplement".

Over a three-decade period, the NRC has accepted, in various contexts, that an analysis of a nuclear facility's environmental impacts, in an EA or an environmental impact statement (EIS), should consider radiological risks associated with conventional accidents. The NRC has generally refused, however, to consider malice-related risks in an EA or EIS. The Diablo EA Supplement represents a departure from that longstanding refusal. The NRC Staff has issued an analogous document in the context of an application to build and operate an industrial irradiator in Hawaii.[5] Other, analogous documents are likely to be prepared in other licensing contexts. Thus, the Diablo EA Supplement deserves careful review.

This report provides a review of the Diablo EA Supplement. To support that review, the report also discusses some broader issues. The NRC has not issued any document or statement that provides an adequate discussion of the broader issues surrounding the Diablo EA Supplement.

Preparation of EAs and EISs is governed by the National Environmental Policy Act (NEPA). A major purpose of NEPA is to ensure that options for reducing the risks and other environmental impacts of a proposed action are identified and characterized. That goal is addressed repeatedly in this report.

Sensitive information

Any responsible analyst who discusses potential acts of malice at nuclear facilities 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 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, secrecy has costs, and an entrenched culture of secrecy is not compatible with a clear-headed, science-based approach to the understanding of risks. Section 3.3 of this report provides a further discussion about identifying and managing sensitive information.

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[4] NRC, 2007a.
[5] NRC, 2007b.

Structure of this report

The remainder of this report has five sections. Section 2 provides a broad, US-wide perspective on potential malicious actions at commercial nuclear facilities. That potential is discussed within the contexts of the general threat environment and national policy on homeland security. Section 3 sets forth an appropriate framework for assessing the risks of malicious actions at nuclear facilities, and for incorporating the findings in an EA or EIS. In Section 4, the Diablo EA Supplement is reviewed, using the framework set forth in Section 3 as a standard that should be met. That review does not purport to provide analysis that corrects deficiencies in the Diablo EA Supplement. Providing such analysis is a task for the NRC Staff. Conclusions are set forth in Section 5, and a bibliography is provided in Section 6. All documents cited in the text of this report are listed in the bibliography.

2. A US-Wide Perspective on Potential Malicious Actions at Nuclear Facilities

2.1 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 Diablo Canyon nuclear generation units receive 20-year license extensions, they will operate until 2041 (Unit 1) and 2045 (Unit 2), discharging spent fuel throughout that period. The proposed Yucca Mountain repository could not accommodate more than a fraction of the Diablo units' 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 Diablo Canyon 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.[6] Thus, in assessing the risks of malicious actions at a Diablo Canyon ISFSI, 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

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[6] Thompson, 2005a.

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 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 2-1 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.[7]

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.

[7] Kull et al, 2007.

The threat environment over the coming decades

As mentioned above, an assessment of the risks of malicious actions at a Diablo Canyon ISFSI 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, if an ISFSI is constructed at Diablo Canyon, the security aspects of its design will reflect an implicit or explicit forecast of trends in the general threat environment. The forecast should be explicit, and should be global in scope, because the US cannot be insulated from broad trends in violent conflict and social disorder.

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.[8] Second, the RAND corporation has conducted a literature review and assessment of potential worldwide trends that would be adverse for US national security.[9]

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.[10] A more recent example is the work of the Global Scenario group, convened by the Stockholm Environment Institute (SEI).[11] 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 2-2. 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.

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[8] Marshall and Gurr, 2005.
[9] Kugler, 1995.
[10] Meadows et al, 1972.
[11] Raskin et al, 2002.

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 peak in world oil production within the next few decades.[12] This prediction is sobering in view of the prominent role played by oil in the origins and conduct of war in the 20th century.[13] 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.[14] 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".[15] 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.[16]

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 considering the level of security that should be built into an ISFSI, 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

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[12] Hirsch et al, 2005; GAO, 2007.
[13] Yergin, 1991.
[14] Gilman et al, 2007.
[15] MEA, 2005, page 1.
[16] Adam, 2005.

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:[17]

> "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."

2.2 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*, which was published in July 2002, and that guidance document apparently remains operative. The document sets forth three strategic objectives, in order of priority:[18]

> "• Prevent terrorist attacks within the United States;
> • Reduce America's vulnerability to terrorism; and
> • Minimize the damage and recover from attacks that do occur."

In pursuit of those objectives, the *National Strategy for Homeland Security* identifies six major mission areas: (i) intelligence and warning; (ii) border and transportation security; (iii) domestic counterterrorism; (iv) protecting critical infrastructure; (v) defending against catastrophic terrorism; and (vi) emergency preparedness and response. The fourth of those mission areas is highly relevant to nuclear reactors, spent-fuel pools, and ISFSIs, which are important elements of the nation's critical infrastructure. The other five mission areas are also relevant to nuclear facilities in various ways.

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".[19] 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

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[17] Kugler, 1995, page 279.
[18] White House, 2002, page vii.
[19] DHS, 2006, page iii.

consequences associated with an attack or other incident. The NIPP identifies a range of protective measures as follows:[20]

> "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" 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 in Section 2.1, 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.

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[20] DHS, 2006, page 7.

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.[21] 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:[22]

> "*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.[23] The White House states, in the *National Strategy for Combating Terrorism*, issued in September 2006:[24] "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 Table 2-1, that it is unbalanced and counterproductive.

A well-informed analyst of homeland security summarizes current national priorities in the following statement:[25]

> "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

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[21] 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.
[22] Hart et al, 2002, pp 14-15.
[23] Flynn, 2007.
[24] White House, 2006, page 1.
[25] Flynn, 2007, page 11.

constructed prior to that policy shift may lack the protective design features that are envisioned in the NIPP. Persons responsible for the design of currently-proposed facilities, such as the proposed ISFSI at Diablo Canyon, could anticipate a national policy shift and take design decisions accordingly.

Table 2-3 illustrates the options and issues that should be considered in developing a balanced policy for protecting US critical infrastructure from attack by sub-national groups. This illustrative table shows the potential benefits that could be gained by assigning a higher priority to protective deterrence.

2.3 Commercial Nuclear Facilities as Potential Targets of Attack

The *National Strategy for Combating Terrorism* discusses the importance of protecting critical infrastructure and key resources. Potential targets in this category are described as: "systems and assets so vital that their destruction or incapacitation would have a debilitating effect on the security of our Nation". In listing targets in this category, the Strategy includes: "nuclear reactors, materials, and waste".[26] An ISFSI at Diablo Canyon would clearly fit within that class of targets.

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.[27] Yet, the US government rejects the constraint of its own nuclear weapons by international agreements such as the Non-Proliferation Treaty.[28] As an

[26] White House, 2006, page 13.
[27] Hersh, 2006; Brzezinski, 2007.
[28] Deller, 2002; Scarry, 2002; Franceschini and Schaper, 2006.

approach to international security, this policy has been criticized by the director general of the International Atomic Energy Agency as "unsustainable and counterproductive".[29] 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 2.4, 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.

Nuclear facilities contain a variety of radioactive isotopes, but 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.[30] Cesium is a volatile element that would be liberally released during conventional accidents or attack scenarios that involve overheating of nuclear fuel.

Table 2-4 shows estimated amounts of cesium-137 in nuclear fuel in the Diablo Canyon reactors and spent-fuel pools, and in one of the spent-fuel storage modules of the proposed Diablo Canyon ISFSI. Table 2-5 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 indicate that release of a substantial fraction of the cesium-137 in a Diablo Canyon nuclear facility could create comparatively large radiological impacts.

Land contamination by cesium-137

The radiological impacts of an atmospheric release of cesium-137 arise primarily from land contamination. Small particles containing cesium-137 are deposited on soil, vegetation and buildings. These particles emit gamma radiation that affects people who travel through or reside in the contaminated area. Food and water supplies also become contaminated. Over time, the amount of deposited cesium-137 is reduced through radioactive decay (with a half-life of 30 years) and through natural processes.

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[29] ElBaradei, 2004, page 9.
[30] DOE, 1987.

(weathering) that carry cesium deeper into soil or into streams and lakes where it is deposited in sediments.

One measure of the radiological impacts attributable to deposition of cesium-137 is the area of land that would become uninhabitable. For illustration, assume that the threshold of uninhabitability is an external, whole-body dose of 10 rem over 30 years. That level of radiation exposure, which would represent about a three-fold increase above the typical level of background (natural) radiation, was used in the NRC's 1975 *Reactor Safety Study* as a criterion for relocating populations from rural areas.[31]

A radiation dose of 10 rem over 30 years corresponds to an average dose rate of 0.33 rem per year.[32] The health effects of radiation exposure at this dose level have been estimated by the National Research Council's Committee on the Biological Effects of Ionizing Radiations (BEIR V committee).[33] The committee estimated that a continuous lifetime exposure of 0.1 rem per year would increase the incidence of fatal cancers in an exposed population by 2.5 percent for males and 3.4 percent for females.[34] Incidence would scale linearly with dose, in this low-dose region.[35] Thus, an average lifetime exposure of 0.33 rem per year would increase the incidence of fatal cancers by about 8 percent for males and 11 percent for females. About 21 percent of males and 18 percent of females normally die of cancer.[36] In other words, in populations residing continuously at the threshold of uninhabitability (an external dose rate of 0.33 rem per year), about 2 percent of people would suffer a fatal cancer that would not otherwise occur.[37] Internal doses from contaminated food and water could cause additional cancer fatalities.

An average dose rate of 0.33 rem per year would be experienced at the boundary of the uninhabitable area. Within that area, the external dose rate from cesium-137 would exceed the threshold of 10 rem over 30 years. At some locations, the dose rate could exceed this threshold by orders of magnitude. Therefore, persons choosing to live within the uninhabitable area could experience an incidence of fatal cancers at a level higher than is set forth above.

For a postulated release of cesium-137 to the atmosphere, the area of uninhabitable land can be estimated from calculations done by Jan Beyea.[38] Two releases of cesium-137 are

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[31] NRC, 1975, Appendix VI, page 11-17.
[32] At a given location contaminated by cesium-137, the resulting external, whole-body dose received by a person at that location would decline over time, due to radioactive decay and weathering of the cesium-137. Thus, a person receiving 10 rem over an initial 30-year period would receive a lower dose over the subsequent 30 -year period.
[33] National Research Council, 1990.
[34] National Research Council, 1990, Table 4-2.
[35] The BEIR V committee assumed a linear dose-response model for cancers other than leukemia, and a model for leukemia that is effectively linear in the low-dose range. See: National Research Council, 1990, pp 171-176.
[36] National Research Council, 1990, Table 4-2.
[37] For males, 0.08 x 0.21 = 0.017. For females, 0.11 x 0.18 = 0.020.
[38] Beyea, 1979. Related calculations are provided in: Alvarez et al, 2003; Beyea et al, 2004.

postulated here, drawing upon data from Table 2-4. The first release is 30 million Curies, representing about one-half of the cesium-137 in a Diablo Canyon spent-fuel pool. The second postulated release is 3 million Curies, representing about one-half of the cesium-137 in the core of a Diablo Canyon reactor, or about one-half of the cesium-137 in four spent-fuel storage modules of a Diablo Canyon ISFSI. For typical weather conditions, a release of 30 million Curies of cesium-137 would render about 75,000 square kilometers of land uninhabitable, assuming that the radioactive plume travels inland rather than out to sea. A release of 3 million Curies would render uninhabitable about 7,500 square kilometers.

An atmospheric release of 50 percent of the cesium-137 in a Diablo Canyon spent-fuel pool would be a likely outcome of a conventional accident or attack that causes the water level in the pool to fall below the top of the fuel-storage racks.[39] Similarly, a release of 50 percent of the cesium-137 in a Diablo Canyon reactor would be a likely outcome of a range of potential accidents or attacks that affect the reactor. This report focuses on the Diablo Canyon ISFSI rather than the reactors and spent-fuel pools. The potential release of cesium-137 from the Diablo Canyon ISFSI is addressed in Section 4, below.

2.4 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:[40]

> "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:[41]

> "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

[39] Alvarez et al, 2003; Thompson, 2006; National Research Council, 2006.
[40] Federal Register, Vol. 32, 26 September 1967, page 13445.
[41] NRC, 1994, page 38893.

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.[42] The attacks on New York and Washington in September 2001 led the NRC to require additional protective measures.

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 (ASLB) 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:[43]

> "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.[44] At that time, the NRC described its order as follows:[45]

> "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

[42] NRC, 1994.
[43] ASLB, 1982.
[44] NRC Press Release No. 07-012, 29 January 2007.
[45] NRC Press Release No. 03-053, 29 April 2003.

> 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."

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.[46] 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".[47]

The present DBT for "radiological sabotage" at a nuclear power plant has the following published attributes:[48]

> "(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

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[46] Fertel, 2006; Wells, 2006; Brian, 2006.
[47] NRC Press Release No. 07-012, 29 January 2007.
[48] 10 CFR 73.1 Purpose and scope, accessed from the NRC web site (www.nrc.gov) on 14 June 2007.

(ii) An internal threat; and
(iii) A land vehicle bomb assault, which may be coordinated with an external assault; and
(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.[49] 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.[50]

Table 2-6 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 on an ISFSI are discussed in Section 4, 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:[51]

> "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 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

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[49] 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.
[50] Hebert, 2007.
[51] Meserve, 2002, page 22.

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.[52] An ISFSI could be designed to withstand similar threats.

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 *Generic Environmental Impact Statement on Handling and Storage of Spent Light Water Power Reactor Fuel* (NUREG-0575), which considered potential sabotage events at a spent-fuel pool.[53] Table 2-7 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.[54] Technically-informed attackers operating within this envelope of attributes could cause a fire in a spent-fuel pool at Diablo Canyon or any other operating nuclear power plant in the US.[55] 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.[56]

3. An Appropriate Framework for Assessing the Risks of Malicious Actions at Nuclear Facilities

3.1 Extending Traditional Risk Assessment to Encompass Malicious Actions

Over a three-decade period, the NRC has accepted, in various contexts, that an analysis of a nuclear facility's environmental impacts should consider a range of conventional accidents. Here, the term "conventional accidents" refers to incidents caused by human error, equipment failure or natural events, but excludes incidents caused by malicious actions. The radiological impacts of conventional accidents are examined through the

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[52] Hannerz, 1983.
[53] NRC, 1979, Section 5 and Appendix J.
[54] The sabotage events postulated in NUREG-0575 yielded comparatively small radioactive releases.
[55] Spent-fuel pools at Diablo Canyon 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.
[56] Alvarez et al, 2003; Thompson, 2006; National Research Council, 2006.

use of risk-assessment tools such as probabilistic risk assessment (PRA). The first PRA for a commercial nuclear reactor was the *Reactor Safety Study*.[57] A PRA for a nuclear facility considers a number of conventional accident scenarios, estimating both their radiological consequences and their probabilities of occurrence. In a competently-conducted PRA study, a conventional accident scenario is not screened out a priori if its probability is thought to be low. Instead, the scenario's radiological consequences and probability are systematically estimated to determine its contribution to the overall risks associated with the facility.

The traditional tools and practices of radiological risk assessment should be adapted to address the risks of malicious actions at a nuclear facility. In this application of risk assessment, conventional accident scenarios would be replaced by attack scenarios. (These are also known as threat scenarios.) Probability would be treated differently in this application, however, because there is usually no statistical basis to support quantitative estimates of the probabilities of malicious actions. To accommodate that problem, occurrence of a representative set of malicious actions would be assumed. The scenarios flowing from each postulated malicious action would then be analyzed to estimate the conditional probabilities and other characteristics of the outcomes, including radiological impacts. The resulting information would be useful for a variety of purposes. It would, for example, help to identify options to reduce the risks of malicious actions through changes in the design or mode of operation of the facility. PRA-related studies have been very helpful in this respect in the context of conventional accidents.

Information obtained by assuming the occurrence of a set of malicious actions should be combined with qualitative estimates of the probabilities of the malicious actions, to yield risk findings that have qualitative and quantitative components. The process of combination should occur in such a way that assumptions and qualitative estimates of probability can be re-visited at any time. With that provision, new information or differing professional opinions could be factored into the risk findings without difficulty. A standardized terminology should be developed to facilitate reasoned discussion of assumptions and qualitative estimates.

The NRC, in developing its 1994 ruling on protection of nuclear power plants against vehicle bombs, adopted the PRA-adaptation approach described above, stating:[58]

> "The NRC does not believe that it can quantify the likelihood of vehicle bomb attack. However, it has performed a conditional probabilistic risk analysis for an existing power reactor site, assuming an attempt to damage a nuclear power plant with a design basis vehicle bomb placed at locations within the protected area that would create the greatest risk to public health and safety. The analysis indicated that the contribution to core damage frequency could be high."

[57] NRC, 1975.
[58] NRC, 1994, page 38891.

The NRC argued that its vehicle-bomb ruling was "prudent" in view of a vehicle intrusion incident at the Three Mile Island site and a vehicle bombing of the World Trade Center in February 1993.[59] In support of this view, the NRC noted that the 1993 World Trade Center bombing was "organized within the United States and implemented with materials obtained on the open market in the United States".[60]

The vehicle-bomb ruling was a step forward in that the NRC recognized one form of threat scenario (use of a vehicle bomb) for an attack on a nuclear facility by a sub-national group. However, the NRC failed to recognize other threat scenarios that are at least as credible. Section 4.3, below, discusses other, credible scenarios in the context of an ISFSI; analogous scenarios are relevant to power reactors and spent-fuel pools. Also, the NRC failed to develop a standardized terminology for assumptions and qualitative estimates regarding the probabilities of attack scenarios. At present (June 2007), the NRC still lacks such a terminology.

Assessment of malice-related risks, as described here, would typically involve the use of sensitive information. Here, the term "sensitive" refers to detailed information that could substantially assist an attacking group to attain its objectives. Management of sensitive information is discussed in Section 3.3, below.

In reviewing a license application for a nuclear facility, the NRC considers a set of design-basis conventional accidents. That consideration occurs under the umbrella of the Atomic Energy Act. An analogous situation pertains in the security realm. There, the NRC considers a facility's ability to withstand a design-basis threat. That consideration also occurs under the umbrella of the Atomic Energy Act. However, when the NRC examines a facility's environmental impacts, it does so under the umbrella of NEPA. In performing such examinations, the NRC has repeatedly accepted that it should consider conventional accidents more severe than design-basis conventional accidents. Logic indicates, therefore, that an assessment by the NRC of the risks of malicious actions at a nuclear facility, conducted under the umbrella of NEPA, should consider reasonably foreseeable threats more severe than design-basis threats.

3.2 Examining a Full Range of Risks, Risk-Reducing Options and their Implications

A competently-performed assessment of the conventional accident risks at a nuclear facility would consider radiological risks. The assessment would also identify and characterize options for reducing those risks by modifying the facility's design or mode of operation. Articulating knowledge about such options is an important purpose of NEPA. Essentially the same requirements should apply to an assessment of the risks of malicious actions. The latter assessment should consider radiological risks and options for reducing those risks.

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[59] NRC, 1994, Summary.
[60] NRC, 1994, page 38891.

Additional risks and impacts

Risks and impacts arising from the potential for malicious actions are not limited to radiological risks. Social and economic impacts could be caused by malicious actions, the expectation of malicious actions, the choice of design options, or other factors. The term "additional risks and impacts" is used here to encompass the potential for such impacts. These additional risks and impacts deserve careful research, and it is premature to provide a taxonomy of them. Additional risks and impacts, and their relationships with risk-reducing options, should be examined in any malice-related risk assessment. The following, simplified example illustrates some additional risks and impacts, and shows the importance of considering them in a risk assessment.

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 one or more decades ago. It would have a comparatively low ability to resist an attack. To compensate for its vulnerability, it would be protected by a large 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. Option B would employ a 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 example, 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 could be higher if Option A had been chosen, because that choice would have relegated the public to a lesser role.

The preceding example, although 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 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 re-equipping the pools with low-density, open-frame racks, as was intended when the present generation of US nuclear power plants was designed.[61]

Cumulative risks of closely-associated facilities

Many nuclear facilities are closely associated with other nuclear facilities. For example, the Diablo Canyon site features two reactors and two spent-fuel pools. These four facilities are in close physical proximity and share many supporting systems. As a result, the conventional accident risks and malice-related risks associated with any one of these four facilities can only be properly understood through analyses that consider interactions among all four facilities. The proposed ISFSI at Diablo Canyon would share the guard force and other security measures that are deployed at the site. A release of radioactive material from the ISFSI could affect the operation of the reactors and pools, and vice versa. Thus, malice-related risks at the ISFSI should be considered in the context of malice-related risks across the entire site. Also, the ISFSI would be used to support continued operation of the reactors. Thus, risks arising from operation of the ISFSI over its lifetime should be viewed in the context of reactor risks.

To generalize from the Diablo Canyon example, any assessment of conventional accident risks or malice-related risks should examine the interactions among closely-associated facilities, and should assess the cumulative risks arising from operation of those facilities.

3.3 Managing Sensitive Information

A thorough assessment of malice-related risks at a nuclear facility would typically involve the use of sensitive information, defined here as detailed information that could substantially assist an attacking group to attain its objectives. Given this definition, general information about a nuclear facility, including its overall physical layout, operating principles and radioactive inventory, would not be sensitive. Information about the potential radiological impacts of a malicious action would not be sensitive. Detailed information about vulnerable points of the facility, or detailed information about attack scenarios that could exploit such points of vulnerability, could be sensitive. None of the information provided in this report is sensitive.

Sensitive information, as defined here, is not appropriate for general dissemination. Thus, processes for the assessment of malice-related risks must involve rules and practices for managing sensitive information so that its distribution is limited.

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

The costs of secrecy

Rules and practices for designating information as sensitive, and for managing information so designated, should recognize that secrecy has high costs. As stated in Section 3.2, above, secrecy is antithetical to US traditions and inconsistent with long-term national prosperity. Thus, an assessment of malice-related risks at 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 a nuclear facility. It should be remembered that nuclear facilities exist to serve society, rather than vice versa.

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.[62]

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 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

[62] Thompson, 2002, Section X.

management of sensitive information. Implementation of that policy would not necessarily require changes in NRC rules.

3.4 Ensuring Compatibility with a Comprehensive National Strategy for Homeland Security

Section 2, above, explains the need for a comprehensive, balanced strategy to reduce the risks of attack on US critical infrastructure by sub-national groups. The *National Infrastructure Protection Plan* could be a major element of that strategy, supporting a policy of enhanced protective deterrence.

The conduct of thorough assessments of malice-related risks at US nuclear facilities could make a major contribution to implementation of the NIPP. These assessments could provide models to be followed in other infrastructure sectors, such as the chemical industry. Even better, the NRC could work with other agencies to develop a risk-assessment framework that allows risks to be compared not only within an infrastructure sector (such as the nuclear industry, or the chemical industry) but also among sectors.

As an initial step, the NRC should develop malice-related risk assessments that are scientifically credible and meet the other requirements set forth above. While developing these assessments, the NRC should engage in dialogue and cooperative research with other agencies and stakeholders, seeking to develop a pan-sectoral risk-assessment framework.

3.5 Incorporating Findings into an Environmental Assessment or Environmental Impact Statement

Sections 3.1 through 3.4, above, outline a set of standards for the conduct of malice-related risk assessments. When those assessments are done, they must be incorporated into EAs or EISs, either retroactively or concurrently. During that process, provision must be made for limiting the dissemination of sensitive information. The best approach would be to place sensitive information in appendices whose dissemination is limited. The full title of each such appendix, and a general summary of its purpose, scope and findings, should be included in the body of the EA or EIS, which would be openly published.

4. The NRC Staff's Supplement to the Environmental Assessment for the Diablo Canyon ISFSI

4.1 Scope, Assumptions, Methodology and Conclusions of the Staff's Supplement

In October 2003, the NRC Staff issued an Environmental Assessment for the proposed ISFSI at Diablo Canyon. Pursuant to a ruling by the 9th Circuit of the US Court of

Appeals, the Staff issued a Supplement to that EA in May 2007.[63] Here, that Supplement is described as the Diablo EA Supplement. The Supplement addresses the risks of potential malicious actions at the proposed ISFSI. It concludes (at page 7) that "a terrorist attack that would result in a significant release of radiation affecting the public is not reasonably expected to occur".

Shortly after issuing the Diablo EA Supplement, the NRC Staff issued an analogous document related to the application by Pa'ina Hawaii, LLC, to build and operate a commercial, pool-type industrial irradiator in Honolulu, Hawaii, at the Honolulu International Airport. That document is analogous to the Diablo EA Supplement because both respond to the same ruling by the 9th Circuit of the US Court of Appeals. The document takes the form of a Supplemental Appendix to the Staff's Draft EA for the proposed irradiator, which was issued in December 2006.[64] Hereafter, the Supplemental Appendix is described as the "Pa'ina EA Appendix".

This report focuses on issues related to the Diablo EA Supplement. However, the Pa'ina EA Appendix provides additional, relevant information, and is therefore briefly examined here.

The Diablo EA Supplement is a short (8-page) document. It claims (at page 1) to address "the environmental impacts from potential terrorist acts directed at the Diablo Canyon ISFSI". It mentions technical analyses related to potential malicious actions at the Diablo Canyon ISFSI, but does not itself provide such analyses. Nor does it cite any document that describes such analyses. It provides only a partial, incomplete view of its underlying assumptions and methodology. Thus, the Supplement's conclusions cannot be linked to a technical base of evidence and analysis.

Defense of the Diablo Canyon ISFSI

The Diablo EA Supplement provides (at page 4) a brief discussion of nation-wide security measures implemented by the US government since September 2001. That discussion focuses on measures intended to prevent persons with malicious intent from taking control of commercial aircraft used to carry passengers or cargo. There is no discussion of security measures in the context of smaller, general-aviation aircraft, despite the existence of a large US-based fleet of such aircraft and the potential for such an aircraft to be used, in an explosive-laden configuration, as an instrument of attack on a nuclear facility.

The Supplement goes on to provide (at pages 4 and 5) a discussion of the security measures that the NRC requires licensees to implement at ISFSIs and other nuclear facilities. Major security measures required at ISFSIs include: (i) physical barriers; (ii) surveillance; (iii) intrusion detection; (iv) a response to intrusions; and (v) offsite

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[63] NRC, 2007a.
[64] NRC, 2007b.

assistance from local law enforcement agencies, as necessary. Measures in each category were required prior to September 2001. After September 2001, the NRC conducted what the Staff describes as a "comprehensive review" of the NRC's security program. The review considered threats such as a land-based vehicle bomb, ground assault with the use of an insider, and water-borne assaults. Subsequently, security measures at ISFSIs were enhanced in various respects.

The Diablo EA Supplement does not clearly articulate the relationship between defense of the Diablo Canyon ISFSI and defense of other facilities on the site. Elsewhere, the NRC states that its regulations do not require licensees to defend against the DBT that applies at a nuclear power plant, but, in practice, when an ISFSI is located at a reactor site, the ISFSI is typically included within the reactors' security plan. The NRC further states that the Diablo Canyon licensee has amended its reactor security plan to cover the proposed ISFSI.[65] As explained in Section 2.4, above, the DBT at a nuclear power plant is such that the NRC requires only a light defense of the plant.

Risk-assessment methodology underlying the Diablo EA Supplement

As explained in Section 3.1, above, the NRC's consideration of design-basis conventional accidents and design-basis threats in a license proceeding is governed by the Atomic Energy Act. By contrast, preparation of an EA or an EIS is governed by NEPA. The NRC has repeatedly accepted that its assessment of conventional accident risks in an EA or an EIS should consider conventional accidents more severe than design-basis conventional accidents. Logic indicates that its assessment of malice-related risks in an EA or an EIS should consider threats more severe than design-basis threats. Preparation of the Diablo EA Supplement has given the NRC Staff an opportunity to apply that logic, and to employ a credible process for assessment of malice-related risks. Section 3, above, has articulated a standard by which to judge the Staff's assessment.

The Diablo EA Supplement does not provide or cite any technical analyses to support its conclusions, nor does it provide an adequate explanation of the assumptions and methodology that underlie those conclusions. The reader is obliged to rely on a brief and incomplete explanation in the Diablo EA Supplement. Apparently, the Staff employed similar assumptions and methodology in preparing the Pa'ina EA Appendix, which provides slightly more information. Neither document provides a clear and complete explanation of the assumptions and methodology used by the Staff to identify and examine attack scenarios and their impacts. From the limited explanations that are provided, it appears that the Staff employed a crude methodology (a "screening and assessment tool") that was originally intended to determine the adequacy of security measures. That issue falls under the Atomic Energy Act, not under NEPA. Also, some of the assumptions employed by the Staff are inappropriate, as discussed below.

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[65] NRC, 2007c, Footnote 10.

The Diablo EA Supplement states (at page 6):

> "Following issuance of the 2002 security orders for ISFSIs, NRC used a security assessment framework as a screening and assessment tool, to determine whether additional security measures, beyond those required by regulation and the security orders, were warranted for NRC-regulated facilities, including ISFSIs."

Apparently, that process began by identifying a "spectrum" of threat scenarios. The Diablo EA Supplement does not describe the spectrum. From that spectrum, the Staff identified a set of "plausible" threat scenarios through a screening exercise that is not described in the Supplement. The Pa'ina EA Appendix provides slightly more information about threat screening, stating (at page B-5):

> "Remote or speculative scenarios and scenarios with insignificant consequences were screened out based on threat assessments and engineering evaluations".

Threat scenarios deemed to be "plausible" were then examined by the Staff as follows (Diablo EA Supplement, page 6):

> "For those scenarios deemed plausible, NRC assessed the attractiveness of the facility to attack by taking into account factors such as iconic value, complexity of planning required, resources needed, execution risk, and public protective measures. In addition, NRC made conservative assessments of consequences, to assess the potential for early fatalities from radiological impacts. NRC then looked at the combined effect of the attractiveness and the consequence analyses, to determine whether additional security measures for ISFSIs were necessary."

These words describe an examination that apparently combined qualitative judgments with quantitative analyses. The Diablo EA Supplement provides no further description of the examination, and does not cite any document that provides such a description. Thus, the completeness and quality of the examination cannot be determined, with one exception. That exception is the use of the "potential for early fatalities" as an indicator of radiological impacts. As explained in Section 4.3, below, the potential for early fatalities is a highly inappropriate indicator of the radiological impacts of accidents or attacks at an ISFSI.

The Diablo EA Supplement describes (at pages 6 and 7) how the Staff used its process to consider threat scenarios and radiological impacts in the context of ISFSIs in general, and in the context of the proposed Diablo ISFSI. That application of the process is discussed in Section 4.2, below.

The probability of attack

The Diablo EA Supplement addresses the probability of attack in differing, inconsistent ways. It states (at page 6) that the probability of an attack is "believed to be low", but also that it "cannot be reliably quantified". It also states (at page 6) that enhanced security measures and emergency-planning measures have been implemented at ISFSIs "without regard to the probability of an attack". The Supplement claims (at page 6) that these measures reduce the risk of attack to an "acceptable" level. The Supplement does not explain how acceptability was determined.

The Pa'ina EA Appendix takes a different approach to the probability of attack at commercial nuclear facilities, including irradiators and ISFSIs. It states (at page B-4):

> "The NRC staff operates on the premise that a general credible threat exists (i.e., the likelihood of attack has a probability of 1). However, this general credible threat should not be confused with the likelihood of a successful terrorist action (i.e., the probability of a successful attack is <1). Generally in NEPA analysis, the NRC must consider reasonable foreseeable impacts including those from potential accidents. Due to the unique nature of terrorist activities the following discussion focuses on the qualitative probability of a successful attack because at this time it is only possible to assign qualitative probabilities to these events."

The Diablo EA Supplement draws no distinction between the probability of an attack and the conditional probability that the attack will be successful. The Supplement does not indicate whether a "credible" threat or a "plausible" threat is, or is not, equivalent to a "successful attack". From the Pa'ina EA Appendix, one might infer that the "plausible" threats described in the Diablo EA Supplement are thought (by the Staff) to have a comparatively high conditional probability of success. The Supplement provides no clarity on these points.

The Supplement does not provide any framework or terminology for discussing probability in qualitative terms. The Supplement does not discuss the conditional probabilities of radiological impacts and other outcomes of assumed attack scenarios, thereby ignoring an opportunity to partially quantify malice-related risks. Overall, the Supplement provides an inconsistent and incomplete treatment of the probability of attack.

Role of emergency planning

The Diablo EA Supplement states (at page 6) that the NRC has "developed emergency planning requirements, which could mitigate potential [radiological] consequences for certain [attack] scenarios [at an ISFSI]". No further explanation is provided, and no document is cited. This statement apparently refers to security-related enhancements that licensees have made in their emergency preparedness (EP) programs, pursuant to communications from the NRC. These enhancements are not required by current NRC regulations. The NRC Staff has, therefore, sought "Commission approval to begin activities to develop a new voluntary performance-based EP regulatory regimen that could serve as an alternative approach to existing EP regulations and guidance".[66] From that information, one can infer that the Diablo EA Supplement assumes that voluntary EP enhancements would reduce malice-related risks at the Diablo Canyon ISFSI. The Supplement states (at page 7): "In some situations, emergency planning actions could provide an additional measure of protection to help mitigate the consequences, in the unlikely event that an attack were attempted at the Diablo Canyon ISFSI". Apparently, those emergency planning actions would involve voluntary, security-related enhancements.

The NRC Staff's lack of clarity in the Supplement regarding the role of emergency planning illustrates the negative effects of an entrenched culture of secrecy. Effective emergency response requires rapid, coordinated actions by many public and private entities that normally have limited or no engagement with the NRC and the licensee. Secrecy in emergency planning will almost guarantee that confusion and delay would prevail in an actual emergency. Moreover, emergency planning for reactor sites is not currently optimized to address land contamination, which would be the dominant source of radiological impacts following a successful attack on an ISFSI.

Consideration of other nuclear facilities at the Diablo Canyon site

The Diablo EA Supplement does not discuss risk-related interactions among the proposed ISFSI and other nuclear facilities at the Diablo Canyon site. The Supplement does not mention the cumulative risks arising from operation of all the nuclear facilities at the site. Section 3.2, above, explains the importance of: (i) considering risk-related interactions among nuclear facilities at a site; and (ii) assessing the cumulative risks from operation of those facilities.[67]

4.2 Threat Scenarios and Radiological Impacts Considered by the Staff

The Diablo EA Supplement provides (at page 6) brief descriptions of: (i) the type of spent-fuel storage module that would be employed at the Diablo Canyon ISFSI; and (ii) the module's purported robustness against attack. The module would function as follows: Spent fuel assemblies would be stored vertically inside a sealed, cylindrical, multi-purpose canister (MPC) made of stainless steel, which would in turn be located inside an overpack. The overpack would consist of two, coaxial, cylindrical, carbon steel shells separated by a layer of concrete, with a fixed baseplate at the bottom and a removable lid at the top. The overpack would be penetrated by cooling vents at its top and bottom, whose purpose would be to allow a flow of ambient air over the outer surface of the MPC, driven by natural convection, to remove radioactive decay heat from the fuel

[66] Reyes, 2006, page 1.
[67] Related information is provided in: Thompson, 2002.

assemblies. The module would be supplied by Holtec International. This type of module is known as the HI-STORM 100SA System.

To assess the potential for release of radioactive material from a Diablo Canyon module by malicious actions, the NRC Staff relied on generic security assessments for ISFSIs, apparently conducted around 2002. The Diablo EA Supplement states (at page 7): "Plausible threat scenarios considered in the generic security assessments for ISFSIs included a large aircraft impact similar in magnitude to the attacks of September 11, 2001, and ground assaults using expanded adversary characteristics consistent with the design basis threat for radiological sabotage for nuclear power plants." The Supplement later (at page 7) describes these two attack scenarios as "the most severe plausible threat scenarios". Section 4.3, below, addresses the merit of that statement.

The Diablo EA Supplement does not provide any analysis of the radiological impacts of threat scenarios, nor does it cite any document that provides such analysis. The Supplement does not provide any estimate of the radiation dose arising from release of radioactive material, except to say (at page 7) that the dose "would likely be below 5 rem" at the Diablo Canyon site. The Supplement strongly implies that the generic ISFSI assessments yielded the same upper range of dose. That would be consistent with the licensing role of the generic ISFSI assessments, because a dose of 5 rem is the maximum allowable dose for a design-basis accident at an ISFSI.[68]

Obtaining a dose of 5 rem would require only a small release of radioactive material from a storage module. Table 4-1 illustrates this point. It shows, for example, that creation of a hole in an MPC with an equivalent diameter of 2.3 mm would yield a dose of 6.3 rem. Most of that dose would be attributable to release of two-millionths (1.9E-06) of the MPC's inventory of radioisotopes in the "fines" category. That release corresponds to a comparatively small amount of damage to the MPC and the spent fuel within it. Clearly, therefore, the Diablo EA Supplement has not considered a threat scenario that causes substantial damage to an ISFSI module.

4.3 Threat Scenarios and Radiological Impacts that are Relevant to an ISFSI

The NRC Staff has not provided a credible analysis of threat scenarios and radiological impacts for an ISFSI at Diablo Canyon or elsewhere. Some illustrative analysis is provided here, to show deficiencies in the Diablo EA Supplement. Correcting those deficiencies is a task for the NRC Staff. The illustrative analysis provided here is abbreviated due to the author's concern about dissemination of sensitive information. A

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[68] NRC regulation 10 CFR 72.106(b) limits the radiation dose that any individual located on or beyond the nearest boundary of the controlled area of an ISFSI may receive from any design-basis accident. The dose limit is the more limiting of: (i) a total effective dose equivalent (TEDE) of 5 rem; or (ii) a 50-rem sum of the deep-dose equivalent and the committed dose equivalent to any individual organ. Separate dose limits are also specified for the lens of the eye and for skin or extremities.

much fuller analysis could be provided here, drawing from published literature and general engineering knowledge.[69]

An ISFSI module's vulnerability to attack

In some ways, the type of storage module proposed for the Diablo canyon ISFSI (the HI-STORM 100SA System) is a robust structure. The overpack has an outer diameter of 3.7 meters and a height of 5.9 meters. Its outer, carbon steel shell is about 3/4 inch (2 cm) thick, the inner shell is about 1 1/4 inch (3 cm) thick, and the space between these shells is filled by about 27 inches (69 cm) of concrete (details vary by module version).[70] That is a robust structure in terms of its resistance to natural forces (e.g., tornado-driven missiles), but not in terms of its ability to withstand penetration by weapons available to sub-national groups. In any event, the overpack is already penetrated by cooling vents, as described above. The cylindrical wall of the MPC is about 1/2 inch (1.3 cm) thick, and could be readily penetrated by available weapons. The spent fuel assemblies that would be stored inside the MPC are composed of long, narrow tubes made of zirconium alloy, inside which uranium oxide fuel pellets are stacked. The walls of the tubes (the fuel cladding) are about 0.023 inch (0.6 mm) thick and have negligible capacity to withstand penetration by available weapons. Moreover, zirconium is a flammable metal. In finely divided form, it is used in military incendiary devices.

A competent, sub-national group seeking to create offsite radiological impacts by attacking a storage module at the Diablo Canyon ISFSI would probably seek to penetrate the wall of the MPC and ignite the zirconium fuel cladding, with the intent of initiating a fire that would release radioactive material to the atmosphere. A fire could release a substantial fraction of the cesium-137 in affected fuel assemblies, because cesium is a volatile element. The presence of cooling vents at the top and bottom of the module could create a chimney effect that enhances a zirconium fire. For that reason, the attackers could prefer that the module remains upright. The type of module (HI-STORM 100SA System) that the licensee intends to use at the Diablo Canyon ISFSI would remain upright during many attack scenarios, because it is specifically designed to be anchored to its pad. The attackers could seek to exacerbate a fire by enlarging the cooling vents or creating additional holes in the overpack.

Instruments and modes of attack

Penetration of the overpack of a storage module (and penetration of the MPC) could be readily accomplished using a shaped charge.[71] These devices have many civilian applications. They are extensively used in the mining and petroleum industries, and for demolition. They have been used in military contexts for decades. Their military applications include, for example, human-carried demolition charges or warheads for anti-tank missiles. Construction and use of shaped charges does not require assistance

[69] Related information is provided in: Thompson, 2005b; Thompson, 2003.
[70] Holtec FSAR, Chapter 1.
[71] Walters, 2003.

from a government or access to classified information. Many people around the world have experience with these devices in civilian and military contexts.

Table 4-2 provides some information about the shaped charge as a potential instrument of attack. A shaped charge described in that table was designed to penetrate large thicknesses of rock or concrete, as the first stage of a "tandem" warhead (two devices in line, with differing functions). Detailed information about this device has been openly published, but the citation is not provided here. A test proved that the device could create a hole of 25 cm diameter in rock to a depth of almost 6 meters. A device of that size and capability would not be needed to penetrate an ISFSI module. For that application, competent attackers would employ smaller shaped charges, optimized for portability and diameter and depth of hole.

Penetration using a shaped charge would not be the attackers' only option for creating additional holes in the overpack. For example, attackers could use small charges or cutting devices to sever the bolts holding down the lid of the overpack, and then use charges to remove the lid. Boring into or cutting off portions of the overpack could be accomplished using a thermic lance. That device is an iron pipe through which oxygen gas is passed. When the tip is ignited, iron and oxygen react exothermically at a temperature of about 4,000 degrees C. This lance will easily cut through concrete, which melts at 1,800-2,500 degrees C. Steel plates or reinforcing bars will feed the iron-oxygen reaction. This device was developed in France after World War II, to assist the demolition of submarine pens and other large concrete structures that had been built by Nazi Germany. A thermic lance could readily penetrate the MPC in an ISFSI module and ignite the zirconium fuel cladding inside the MPC.

There are various military situations in which attackers seek to penetrate a target (e.g., an armored vehicle, or a concrete bunker) and initiate combustion inside the target. If the attackers achieve direct contact with the target, they might pursue this goal in two, separate steps. First, the target would be penetrated. Second, an incendiary device or material would be inserted through the resulting hole. Often, however, the attack would be made from a distance. For example, an anti-tank missile might be launched from a point tens or hundreds of meters from the target. To accommodate such situations, weapons laboratories and suppliers have developed warheads that combine penetration and incendiary functions. One arrangement is a tandem warhead in which the first stage penetrates the target and the second stage is an incendiary device. A variant of this arrangement employs a "thermobaric" second stage that generates blast and thermal effects.

An attack on the Diablo Canyon ISFSI could be mounted in three different modes, or in combinations of those modes.[72] First, attackers could seek to place themselves in direct contact with ISFSI modules. That mode of attack could involve the use of land vehicles

[72] Each mode of attack on the ISFSI could be accompanied by diversionary or complementary attacks at other locations.

or airborne vehicles (which could include helicopters or ultralight aircraft) to carry personnel to the ISFSI. Second, attackers could fire guided missiles or other weapons at the ISFSI from ground positions, land vehicles, airborne vehicles, or boats located at distances of hundreds of meters or more from the ISFSI. In illustration of the potential for such an attack, note that the TOW (tube-launched, optically-tracked, wire-guided) missile, which is widely used around the world and which has a proven capability against armored vehicles and bunkers, has a range exceeding 3,000 meters. Third, attackers could use aircraft as improvised cruise missiles, in a kamikaze or remotely-guided configuration.

The Diablo EA Supplement considers the third mode of attack on an ISFSI, but makes 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 an ISFSI. 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 competent group seeking to attack an ISFSI using an improvised cruise missile would probably prefer to use a smaller, general-aviation aircraft laden with explosive material, perhaps configured as a shaped charge in tandem with incendiary material. In this connection, 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:[73]

> "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."

Prudent assumptions about attack

Many people around the world are familiar with the attack principles described in the preceding paragraphs, relevant weapons are available in many countries, and the resources required for an attack are attainable by many sub-national groups. It would, therefore, be prudent to assume that: (i) a sub-national group could mount a credible attack on ISFSI modules at Diablo Canyon; (ii) the group would seek to create a release pathway from the interior of one or more MPCs to the atmosphere; (iii) the group would

[73] Dillingham, 2003, page 14.

seek to initiate a zirconium fire inside each attacked MPC, to maximize the release of radioactive material to the atmosphere; and (iv) the attack could have a substantial conditional probability of success.

Radiological impacts of attack

Given the second and third of the assumptions in the preceding paragraph, a successful attack on the Diablo Canyon ISFSI could release to the atmosphere a substantial fraction (tens of percent) of the cesium-137 in each attacked MPC, together with releases of other radioisotopes.[74] Several MPCs could be affected in this manner. Section 2.3, above, discusses a postulated release of 3 million Curies of cesium-137, representing about 50 percent of the cesium-137 in four spent-fuel storage modules. That is a reasonable assumption for the purpose of assessing the radiological impacts of a successful attack.

Land contamination and its sequelae would be the dominant radiological impacts of the release from attacked MPCs. Sequelae would include contamination of food and water, cancers and other adverse health effects that would be manifested years after the release, relocation of populations, abandonment of real estate, and various economic and social impacts. An estimate of economic loss arising from an atmospheric release of 3.5 million Curies of cesium-137, considering five US reactor sites, shows an average loss of $91 billion.[75] Factors not considered in that estimate could lead to a higher economic loss.

The radiological impacts of potential atmospheric releases from power reactors have been studied for decades. For example, the 1975 *Reactor Safety Study* discussed these impacts in detail.[76] Studies show that a release from a power reactor could lead to early fatalities among downwind populations. The fatalities would be "early" in the sense that they would be manifested within a few weeks or months after the release. Early fatalities would be almost entirely attributable to the release of short-lived radioisotopes, which are present in abundance in the core of an operating reactor. An ISFSI would contain a negligible inventory of short-lived radioisotopes, because it would contain spent fuel that has aged over a period of years. Thus, the potential for early fatalities is a highly inappropriate indicator of the radiological impacts of conventional accidents or attacks at an ISFSI. The NRC Staff's reliance on this indicator in the Diablo EA Supplement provides, by itself, sufficient grounds to reject the conclusions of the Supplement.

4.4 Options for Reducing the Risks of Malicious Actions

The Diablo EA Supplement provides (at page 3) a limited discussion of alternatives to the proposed ISFSI. These alternatives fall into three categories: (i) shipment of spent fuel offsite; (ii) other methods of storing spent fuel onsite; and (iii) no action, leading to shutdown of the Diablo Canyon reactors. In discussing other methods of storing spent

[74] The fractional release of each radioisotope would be determined by the isotope's physical and chemical properties as an element.
[75] Beyea et al, 2004.
[76] NRC, 1975, Appendix VI.

fuel onsite, the Supplement considers an increase in the capacity of the existing spent-fuel pools at the site, or construction of a new pool, and rejects both options. The Supplement does not discuss the option of constructing the ISFSI using a design that is more robust against attack than the design proposed by the licensee.

The Supplement does not mention the *National Infrastructure Protection Plan*. It does not discuss homeland-security strategy, the principles of protective deterrence, or the opportunities that the NIPP has identified for incorporating protective features into the design of infrastructure elements.

Increasing the ISFSI's robustness against attack

Options for designing a Diablo Canyon ISFSI to be more robust against attack have been identified by this author, as follows:[77] "re-design of the ISFSI to use thick-walled metal casks, dispersal of the casks, and protection of the casks by berms or bunkers in a configuration such that pooling of aircraft fuel would not occur in the event of an aircraft impact". Elsewhere, the author has provided a more detailed discussion about designing an ISFSI to be more robust against attack.[78] A factor addressed in that discussion is the possibility that society will extend the life of ISFSIs until they become, by default, repositories for spent fuel. Consideration of that possibility could favor an above-ground ISFSI whose robustness would be enhanced through a combination of the design options described above.

Holtec International has developed a design for a new ISFSI storage module that is said to be more robust against attack than present modules. The new module is the HI-STORM 100U module, which would employ the same MPC as is proposed for the Diablo Canyon ISFSI. For most of its height, the 100U module would be underground. Holtec has described the robustness of the 100U module as follows:[79]

> "Release of radioactivity from the HI-STORM 100U by any mechanical means (crashing aircraft, missile, etc.) is virtually impossible. The only access path into the cavity for a missile is vertically downward, which is guarded by an arched, concrete-fortified steel lid weighing in excess of 10 tons. The lid design, at present configured to easily thwart a crashing aircraft, can be further buttressed to withstand more severe battlefield weapons, if required in the future for homeland security considerations. The lid is engineered to be conveniently replaceable by a later model, if the potency of threat is deemed to escalate to levels that are considered non-credible today."

The design of the Holtec 100U module has been under review by the NRC Staff. The Staff has expressed concern about seismic-related structural analyses performed for this design, and in late 2006 Holtec withdrew its application for a Certificate of Compliance

[77] Thompson, 2002, paragraph XI-5.
[78] Thompson, 2003.
[79] Holtec, 2007.

for the 100U module. Further discussions were held between Holtec and the Staff on 27 March 2007, described by the Staff as follows:[80]

> "At the meeting, Holtec presented new and revised structural analyses in response to the staffs concerns. The staff responded positively to the material presented by Holtec and indicated that it appeared the staffs concerns had been addressed. A new application is scheduled to be submitted by the end of April 2007."

It appears that the Holtec 100U module may soon receive a Certificate of Compliance from the NRC. At that point, the 100U module would be available for use in the Diablo Canyon ISFSI.

Enhancing active defense of the ISFSI

As currently proposed, the Diablo Canyon ISFSI would receive an active defense involving the deployment of armed guards and related security measures. That form of defense contrasts with the passive defense provided by a facility's inherent robustness against attack.

Active defense of the ISFSI could be enhanced by employing additional security measures, such as anti-aircraft guns or missiles. The Diablo EA Supplement does not discuss that option. A thorough assessment of malice-related risks at the Diablo Canyon ISFSI should consider the merits of enhancing active defense as a risk-reducing option. In considering that option, the assessment should recognize that active defense has substantial costs, both monetary and societal, that could be avoided by enhancing the ISFSI's inherent robustness.[81]

Enhancing capabilities for damage control

As discussed in Section 4.3, above, it would be prudent to assume that a group attacking the Diablo Canyon ISFSI would seek to create a release pathway from the interior of one or more MPCs to the atmosphere, and to initiate a zirconium fire inside each attacked MPC in order to maximize the release of radioactive material to the atmosphere. To counter those ambitions, the licensee could improve its capabilities for damage control, seeking to minimize the radioactive release in the event of an attack. Relevant capabilities would include: (i) availability of personnel trained and equipped to work in a high-radiation environment; and (ii) deployment of devices and materials to suppress fires and limit releases of radioactive material. A thorough assessment of malice-related

[80] Johnson, 2007, Enclosure C.
[81] In October 2001 the French government deployed anti-aircraft missiles at the La Hague nuclear site. Deployment of anti-aircraft guns or missiles to defend the Diablo Canyon ISFSI would require the ongoing presence of US military personnel, to maintain and operate these weapons. Complex questions of command authority for firing of the weapons would need to be addressed. These factors would generate substantial monetary and societal costs.

risks at the Diablo Canyon ISFSI should consider the merits of enhancing capabilities for damage control as a risk-reducing option.

4.5 An Overall Evaluation of the Staff's Supplement

Section 2 of this report provides a broad perspective on potential malicious actions at nuclear facilities. That perspective shows the importance of conducting thorough assessments of malice-related risks and options for reducing those risks. Section 3 sets forth an appropriate framework for assessing malice-related risks, thereby providing a standard for evaluating the Diablo EA Supplement. Sections 4.1 through 4.4 review various aspects of the Supplement. Major findings of the review include:

(i) the Supplement neither provides technical analysis nor cites any document that provides such analysis;
(ii) in preparing the Supplement, the NRC Staff relied on an unexplained process to identify plausible threat scenarios;
(iii) the Staff failed to consider threat scenarios that are more severe and at least as plausible as the threat scenarios that it did consider;
(iv) the Staff relied on a crude, partially explained methodology to assess malice-related risks;
(v) the Staff employed a highly inappropriate indicator of the radiological impacts of attacks, namely the potential for early fatalities;
(vi) the Supplement greatly under-estimates the scale of radiological impacts of attacks and ignores the dominant impacts, which would arise from land contamination;
(vii) the Supplement ignores the NIPP and the potential that it articulates for increasing the inherent robustness of infrastructure facilities against attack;
(viii) the Supplement fails to consider options for reducing malice-related risks at the proposed Diablo Canyon ISFSI through measures including the use of more robust fuel storage modules; and
(ix) the Supplement fails to consider ISFSI-related risks in the context of risks associated with other nuclear facilities on the Diablo Canyon site.

These are grave deficiencies. The Diablo EA Supplement is not credible.

5. Conclusions

Major conclusions of this report are as follows:

C1. It would be prudent to assume that power reactors, spent-fuel pools and ISFSIs in the US will be attacked by capable sub-national groups during the coming decades.

C2. Given present designs and defenses of these facilities, there is a substantial probability that an attack by a capable sub-national group would cause a release to the environment of a large amount of radioactive material, yielding severe radiological consequences.

C3. Design options are available that could increase the inherent robustness of commercial nuclear facilities against attack, especially in the case of new facilities such as the proposed Diablo Canyon ISFSI.

C4. Increasing the inherent robustness of infrastructure facilities against attack is envisioned in the *National Infrastructure Protection Plan*, and would support a national strategy of protective deterrence.

C5. Present methodologies for risk assessment could be adapted to provide operationally-useful assessments of: (i) the risks of malicious actions at commercial nuclear facilities; and (ii) the potential for reducing those risks through alternative options.

C6. The Diablo EA Supplement has grave deficiencies as summarized in Section 4.5, above, and is not credible.

C7. A credible assessment of malice-related risks at the proposed Diablo Canyon ISFSI would correct the deficiencies in the Diablo EA Supplement and would consider a range of risk-reducing options, including design options that enhance robustness of the ISFSI and limits on future production of spent fuel.

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Table 2-1
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 2-2
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 2-3
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 2-4
Estimated Amounts of Cesium-137 in Nuclear Fuel Associated With Diablo Canyon Unit 1 or Unit 2

Category of Nuclear Fuel	Amount of Cesium-137 (million Curies)
One spent fuel assembly at discharge from reactor (17.5 MWt per assembly, 90% capacity factor, discharge after 44 months, 520 kgU/assembly)	0.064
One reactor core at operating equilibrium (193 assemblies, av. burnup = 50% of discharge burnup)	6.2
One spent-fuel pool at full loading, allowing space for full-core discharge (1,131 assemblies, av. age after discharge = 10 yr)	57
One ISFSI module at full capacity (32 assemblies, av. age after discharge = 20 yr)	1.3

Notes:
(a) The radionuclide inventory of Ginna spent fuel batch 16 is estimated in: V.L. Sailor et al, *Severe Accidents in Spent Fuel Pools in Support of Generic Safety Issue 82, NUREG/CR-4982*, July 1987. From Tables A.11 and A.13 of that document, one finds that the inventory of Cs-137 in newly-discharged spent fuel is 3.05 kCi per GWt-day of fission energy yield. For the assumed conditions of a Diablo Canyon fuel assembly at discharge, this inventory is 0.064 MCi. Almost the same result (0.065 MCi) can be obtained by direct calculation, assuming an energy yield of 200 MeV per fission and a Cs-137 fission fraction of 6.0 percent.
(b) The assumed conditions of a Diablo Canyon fuel assembly at discharge are equivalent to a burnup of 41 MWt-days per kgU.
(c) The mass of 1 MCi of Cs-137 is 11 kg.

Table 2-5
Illustrative Inventories of Cesium-137

Case	Inventory of Cesium-137 (Curies)
Produced during detonation of a 10-kilotonne fission weapon	1,800
Released to atmosphere during the Chernobyl reactor accident of 1986	2.4 million
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 million
Currently in reactor core of Diablo Canyon Unit 1 or Unit 2	6.2 million
Currently in spent-fuel pool of Diablo Canyon Unit 1 or Unit 2	57 million
In a typical module of a Diablo Canyon ISFSI	1.3 million

Notes:
(a) 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.
(b) Inventories in rows four through six are author's estimates set forth in Table 2-3 of this report.

Table 2-6
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 2-7
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 4-1
Estimated Release of Radioactive Material and Downwind Inhalation Dose for Blowdown of the MPC in a Spent Fuel Storage Module

Indicator		MPC Leakage Area		
		4 sq. mm (equiv. dia. = 2.3 mm)	**100 sq. mm (equiv. dia. = 11 mm)**	**1,000 sq. mm (equiv. dia. = 36 mm)**
Fuel Release Fraction	**Gases**	3.0E-01	3.0E-01	3.0E-01
	Crud	1.0E+00	1.0E+00	1.0E+00
	Volatiles	2.0E-04	2.0E-04	2.0E-04
	Fines	3.0E-05	3.0E-05	3.0E-05
MPC Blowdown Fraction		9.0E-01	9.0E-01	9.0E-01
MPC Escape Fraction	**Gases**	1.0E+00	1.0E+00	1.0E+00
	Crud	7.0E-02	5.0E-01	8.0E-01
	Volatiles	4.0E-03	3.0E-01	6.0E-01
	Fines	7.0E-02	5.0E-01	8.0E-01
Inhalation Dose (CEDE) to a Person at a Distance of 900 m		6.3 rem	48 rem	79 rem

Notes:
(a) Estimates are from: Gordon Thompson, *Estimated Downwind Inhalation Dose for Blowdown of the MPC in a Spent Fuel Storage Module*, IRSS, June 2007.
(b) The assumed multi-purpose canister (MPC) contains 24 PWR spent fuel assemblies with a burnup of 40 MWt-days per kgU, aged 10 years after discharge.
(c) The following radioisotopes were considered: Gases (H-3, I-129, Kr-85); Crud (Co-60); Volatiles (Sr-90, Ru-106, Cs-134, Cs-137); Fines (Y-90 and 22 other isotopes).
(d) The calculation followed NRC guidance for calculating radiation dose from a design-basis accident, except that the MPC Escape Fraction was drawn from a study by Sandia National Laboratories that used the MELCOR code package.
(e) CEDE = committed effective dose equivalent. In this scenario, CEDE makes up most of the total dose (TEDE) and is a sufficient approximation to it.
(f) The overall fractional release of a radioisotope from fuel to atmosphere is the product of Fuel Release Fraction, MPC Blowdown Fraction, and MPC Escape Fraction.
(g) For a leakage area of 4 square mm, the overall fractional release is: Gases (0.27); Crud (0.063); Volatiles (7.2E-07); Fines (1.9E-06). Fines account for 95 percent of CEDE, and Crud accounts for 4 percent.

Table 4-2
The Shaped Charge as a Potential Instrument of Attack

Category of Information	Selected Information in Category
General information	• Shaped charges have many civilian and military applications, and have been used for decades • Applications include human-carried demolition charges or warheads for anti-tank missiles • Construction and use does not require assistance from a government or access to classified information
Use in World War II	• The German MISTEL, designed to be carried in the nose of an un-manned bomber aircraft, is the largest known shaped charge • Japan used a smaller version of this device, the SAKURA bomb, for kamikaze attacks against US warships
A large, contemporary device	• Developed by a US government laboratory for mounting in the nose of a cruise missile • Described in 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.

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Environmental Impacts of Storing Spent Nuclear Fuel and High-Level Waste from Commercial Nuclear Reactors: A Critique of NRC's Waste Confidence Decision and Environmental Impact Determination

by
Gordon R. Thompson

6 February 2009

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Texans for a Sound Energy Policy

Abstract

The US Nuclear Regulatory Commission (NRC) issued its Waste Confidence Decision in 1984, expressing NRC's confidence that radioactive waste from commercial nuclear reactors would be safely stored and ultimately disposed of in a safe manner. The 1984 Decision was reaffirmed and revised in 1990. In October 2008, NRC issued a Draft Update to its Waste Confidence Decision. At the same time, NRC issued a Proposed Rule, confirming a previous, generic determination by NRC that interim storage of spent nuclear fuel (SNF) has no significant environmental impact, and relaxing the time limit for application of that determination.

This report provides a critical review of the findings in the Waste Confidence Decision, as modified by the Draft Update, insofar as those findings relate to the environmental impacts of interim storage of SNF or high-level radioactive waste (HLW) originating in commercial reactors. Also, this report provides a critical review of the Proposed Rule. To support its critical review of the Waste Confidence Decision and the Proposed Rule, this report provides a general summary of selected, adverse impacts on the environment that can arise from interim storage of SNF and HLW.

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

About the Author

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

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Contents

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

1. Introduction

In October 2008, the US Nuclear Regulatory Commission (NRC) issued a set of proposed findings that address, among other matters, the interim storage of radioactive waste generated by commercial nuclear reactors. This report provides a critical review of the proposed findings, insofar as those findings relate to the environmental impacts of storing radioactive waste.

An overview of radioactive waste from commercial reactors

Commercial nuclear reactors periodically discharge nuclear fuel assemblies that are "spent", in the sense that they are no longer suitable for generating power from nuclear fission. Each spent nuclear fuel (SNF) assembly contains a large amount of radioactive material, and the decay of that material generates heat. Release of radioactive material from an assembly to the environment could cause significant adverse impacts on exposed persons.

With some minor exceptions, spent fuel discharged from US commercial reactors is now being stored at the reactor sites. Initially, a spent fuel assembly is stored under water in a pool adjacent to the reactor. After some years of storage in this pool, an assembly could be transferred to an on-site, dry-storage facility known as an independent spent fuel storage installation (ISFSI). In the future, assemblies might also be shipped to ISFSIs built at off-site locations.[1]

Current national policy for managing SNF is to store spent fuel assemblies for an interim period, followed by their disposal in a mined, underground repository. The US Department of Energy (DOE) has applied to NRC for a license to operate such a repository at Yucca Mountain, Nevada. Many observers doubt that this repository will open.

As a separate initiative, DOE has established the Global Nuclear Energy Partnership (GNEP) program. That program is pursuing the development of alternative nuclear fuel cycles that would involve the physical and chemical processing of SNF to separate its components (plutonium, uranium, fission products, etc.). The separation processes would generate radioactive waste streams including streams of high-level radioactive waste (HLW).

[1] As an alternative, spent fuel assemblies generated at several reactor sites might be stored in an ISFSI located at one reactor site.

NRC findings regarding management of SNF and HLW

In 1984, NRC issued its Waste Confidence Decision, expressing NRC's confidence that radioactive waste from commercial nuclear reactors would be safely stored and ultimately disposed of in a safe manner. The 1984 Decision was reaffirmed and revised in 1990. In October 2008, NRC issued, for public comment, a draft Update to its Waste Confidence Decision.[2] Hereafter, that document is referred to as the "Draft Update". In parallel, NRC issued a proposed rule regarding consideration of the environmental impacts of temporary storage of spent fuel.[3] That document is referred to, hereafter, as the "Proposed Rule". The Proposed Rule provides a generic determination that interim storage of spent fuel has no significant environmental impact.

Table 1-1 shows the five findings set forth in the 1990 version of the Waste Confidence Decision, together with the modification of two of those findings that is proposed in the Draft Update. It is interesting to compare these two versions of the findings with each other and with the original findings, issued in 1984. Notably, Finding 2 stated in 1984 that a repository would – with "reasonable assurance" – be available by 2007-2009. In 1990, that date was extended to 2025 (within the first quarter of the 21st century), and NRC now proposes to further extend that date to 2049-2059 (50-60 years after expiration of the Dresden 1 operating license).[4] This progression invites skepticism about NRC's "reasonable assurance".[5]

The Proposed Rule proposes a revision of the NRC regulations set forth in 10 CFR Part 51. With the proposed revision, paragraph (a) of section 51.23 would read:[6]

> **"51.23 Temporary storage of spent fuel after cessation of reactor operation – generic determination of no significant environmental impact.**
> (a) The Commission has made a generic determination that, if necessary, spent fuel generated in any reactor can be stored safely and without significant environmental impacts beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor at its spent fuel storage basin or at either onsite or offsite independent spent fuel storage installations until a disposal facility can reasonably be expected to be available."

The principal difference between this language and the previous language, established in 1990, is the relaxation of the time limit for application of paragraph 51.23 (a). In the

[2] NRC, 2008a.
[3] NRC, 2008b.
[4] NRC, 2008a.
[5] NRC's estimated time horizon for repository availability has receded with each revision of its Waste Confidence Decision, beginning at 23-25 years in 1984, then receding to 35 years in 1990, and to 41-51 years in 2008.
[6] NRC, 2008b.

1990 version, there was a time limit – at least 30 years beyond a reactor's licensed life for operation.[7] The revised version contains no specific time limit for its application.

Purposes of this report

This report provides a critical review of the findings in the Waste Confidence Decision, as modified by the Draft Update, insofar as those findings relate to the environmental impacts of interim storage of SNF or HLW originating in commercial reactors. Thus, the focus here is on Findings 3, 4 and 5, as shown in Table 1-1.[8] Also, this report provides a critical review of the Proposed Rule.

To support its critical review of the Draft Update and the Proposed Rule, this report provides a general summary of selected, adverse impacts on the environment that can arise from interim storage of SNF and HLW. This summary could be useful outside the context of the Draft Update and the Proposed Rule.

Categories of environmental impacts

Two categories of adverse impacts on the environment are examined here. The first category consists of the risk of radiological harm arising from unplanned releases of radioactive material. The second category consists of adverse impacts, including social and economic impacts, that could arise from deficiencies in NRC's approach to regulating the storage of SNF and HLW.

In examining the risk of radiological harm, this report considers the potential for unplanned releases of radioactive material to the environment, especially to the atmosphere.[9] The primary focus here is on unplanned releases from spent fuel. The affected fuel could be stored in a pool adjacent to a commercial reactor, or in an ISFSI located at a reactor site or elsewhere. This report also provides a brief, limited discussion of unplanned releases from reactors. That discussion relates to potential associations and interactions between spent-fuel releases and reactor releases. Unplanned releases, as discussed in this report, are distinct from the comparatively small, planned releases that occur during operation of a nuclear power plant or a spent-fuel storage facility.

In this report, the term "risk" – used here in the context of radiological harm – encompasses the type and scale of potential adverse outcomes together with the probabilities of occurrence of those outcomes.[10] The radiological harm could be direct,

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[7] NRC, 2008b.

[8] This author has published, in other contexts, writings that relate to Findings 1 and 2. See, for example: Thompson, 2008a.

[9] Unplanned releases to ground or surface water could also yield significant adverse impacts. The spatial extent of significant impacts is likely to be greatest for atmospheric releases.

[10] 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

as measured by outcomes such as the number of radiation-induced human illnesses. Alternatively, the radiological harm could be indirect, in the form of social and economic impacts that arise from the direct harm.

Unplanned releases of radioactive material

Unplanned releases of radioactive material from a spent-fuel storage facility or a reactor could arise as a result of two types of accident. The term "conventional accidents" is used here to refer to incidents caused by human error, equipment failure or natural events.[11] 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.[12] In considering malicious actions, this report focuses on actions by sub-national groups.

Adverse impacts arising from regulatory deficiencies

As mentioned above, the second category of adverse, environmental impacts examined in this report consists of impacts, including social and economic impacts, that could arise from deficiencies in NRC's approach to regulating the storage of SNF and HLW. One factor to be examined in this context is NRC's refusal to perform any environmental impact statement (EIS) that addresses the risk of malice-induced accidents at a nuclear facility. A second factor is NRC's heavy reliance on secrecy as a protective measure, without acknowledgment that secrecy can be counterproductive, and can have adverse impacts on society and the economy. A third factor is the role of "protective deterrence" in the defense and security of the USA, and the potential to enhance protective deterrence by implementing protective measures of the type called for in the National Infrastructure Protection Plan (NIPP).

Protection of sensitive information

In examining the radiological risk associated with malice-induced accidents, this report necessarily discusses the potential for a deliberate attack on a nuclear power plant or an ISFSI. Any responsible analyst who discusses the potential for such an attack 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 report contains no such

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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.

[11] NRC's Glossary, accessed at the NRC web site (www.nrc.gov) on 23 January 2009, 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.

[12] Relevant sub-national groups could be based in the USA or in other countries.

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 facility's design and operation leave the facility 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 nuclear facilities 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 nuclear facilities, 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. Sections 2 through 10 are as listed in the table of contents. Conclusions are set forth in Section 11, and a bibliography is provided in Section 12. All documents cited in the text and tables of this report are listed in the bibliography, unless the full citation is provided directly in a footnote. Tables are provided at the end of the report.

2. Radioactive Waste from Commercial Reactors: History & Likely Future Trends

During normal operation of a commercial nuclear reactor, the reactor periodically discharges spent fuel assemblies. Also, the reactor releases a comparatively small amount of radioactive material to the environment, and generates a stream of packaged, low-level, radioactive waste. Decommissioning of the reactor generates an additional stream of radioactive waste, including wastes that are not suitable for disposal as low-level waste. Here, our focus is on spent fuel, and on HLW that may be generated by processing spent fuel.

The early assumption of reprocessing

When the commercial reactors now operating in the USA were designed, the designers assumed that spent fuel would be stored at each reactor for only a few years.[13] After that storage period, each spent fuel assembly would be transported to a "reprocessing" plant where it would be separated into its components (plutonium, uranium, fission products, etc.) through physical and chemical processes. Most of the radioactive material in the assemblies would emerge from the reprocessing plant as a stream of HLW, packaged in a solid form such as borosilicate glass in a stainless steel canister.

Reprocessing fell out of favor and was banned by President Carter in 1977.[14] Although the ban was subsequently lifted, reprocessing has not resumed. The current national policy for managing spent fuel is to store the fuel for an interim period (measured in decades), with eventual disposal of the fuel in a mined repository. The GNEP program envisions a change in that policy, as discussed below.

When a spent fuel assembly is discharged from a reactor, it is placed in a water-filled pool adjacent to the reactor. Given the expectation of reprocessing, the pools at the present generation of US reactors were originally designed so that each held only a small inventory of spent fuel. Low-density, open-frame storage racks were used.[15] Cooling fluid can circulate freely through such a rack.

Use of high-density racks in spent-fuel pools

After reprocessing was abandoned in the 1970s, 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 high-density racks have a closed-form configuration in which each fuel assembly is surrounded by neutron-absorbing plates, to suppress criticality.[16] That configuration creates the potential for auto-ignition and propagating combustion of the fuel's zirconium cladding if water were lost from the pool.[17] The resulting event can be termed a "pool fire". To date, no such event has occurred.

As shown later in this report, NRC has never properly assessed either the risk of a pool fire or the opportunities to reduce that risk. Instead, NRC has enabled and encouraged the use of high-density racks in spent-fuel pools. Such racks are now used at all

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[13] NRC, 1979.
[14] The ban reflected a widely shared view that reprocessing is uneconomic and promotes the proliferation of nuclear weapons.
[15] NRC, 1979.
[16] NRC, 1979.
[17] Alvarez et al, 2003.

commercial reactors in the USA. Licensees have naturally preferred to use high-density racks, because this is the cheapest option for storing spent fuel.

The national inventory of spent fuel, and its management

The quantity of spent fuel is often measured in terms of metric tons of heavy metal (MTHM), based on the fresh (pre-irradiation) form of the fuel. The same indicator can be used for HLW, by tracing the HLW back to the fresh fuel from which it originated.

As of early 2008, about 57,000 MTHM of commercial spent fuel was in storage across the USA, in 35 states. This stock of fuel is growing at the rate of about 2,000 MTHM annually.[18] The majority of this stock of fuel is stored in pools at operating reactors.[19] As mentioned above, those pools are equipped with high-density racks. The remainder of the fuel is stored in ISFSIs. There are 49 licensed ISFSIs across the USA, of which 45 are at reactor sites.[20] At some of those reactor sites, decommissioning activities have removed the reactor, leaving an ISFSI as the remaining major facility on the site.

ISFSIs were first established in the 1980s, and the number of ISFSIs began to grow rapidly in the mid-1990s.[21] This growth reflects the fact that spent-fuel pools are reaching their maximum capacity of spent fuel. When a pool approaches that point, and the licensee wishes to continue operating the reactor, older fuel in the pool is offloaded to an ISFSI to make room for fuel newly discharged from the reactor.[22] The offloading occurs on a batch basis, reflecting the use of modular storage at ISFSIs. Storage modules are filled one at a time, and then installed at the ISFSI.

According to NRC, all pools across the USA will be packed at full capacity by 2015.[23] From that point forward, growth in the national inventory of spent fuel from existing reactors will be accommodated entirely in ISFSIs, until a repository is opened.

When a reactor reaches the end of its operating life, storage of spent fuel in the associated pool will continue for some time thereafter. However, dry storage in an ISFSI will be a cheaper option for long-term storage. Thus, ongoing pool storage at permanently shut-down reactors will be comparatively rare.

[18] NRC, 2008c.
[19] The NRC does not publish spent-fuel inventory data broken down by reactor, site or storage mode. Other sources show that the majority of the inventory is now in pools at operating reactors. See, for example: Alvarez et al, 2003.
[20] One ISFSI license is for an away-from-reactor site in Utah. Actual establishment of that ISFSI appears unlikely.
[21] NRC, 2008c.
[22] The older fuel is appropriate for transfer to an ISFSI because it produces less heat from radioactive decay than is produced by newly-discharged fuel.
[23] Figure, "Nuclear Fuel Pool Capacity", accessed at the NRC web site (www.nrc.gov) on 27 January 2009.

To summarize, NRC has enabled and encouraged the development of a de facto, national strategy for storing spent fuel from commercial reactors. Major elements of the strategy are: (i) storage of spent fuel, after discharge from a reactor, in a pool equipped with high-density racks; (ii) placement of the pool in close proximity to the reactor, with sharing of systems; (iii) accumulation of spent fuel in the pool until the pool is packed nearly to full capacity, followed by periodic offloading of older fuel from the pool to an on-site ISFSI in order to make room for newly-discharged fuel; and (iv) after permanent shut-down of the reactor, transfer of the remaining fuel from the pool to the ISFSI.

Future trends in reactor operation and spent-fuel storage

At present, 104 commercial reactors are licensed for operation in the US. Each of these reactors was licensed for an initial 40-year period, and many have received 20-year license extensions. A number of reactors with license extensions are now licensed for operation into the 2040s, one of them (Nine Mile Point 2) being licensed to operate until 2046. If reactors that were commissioned more recently receive 20-year license extensions, which seems likely, they will be licensed into the 2050s. Watts Bar 1 would be licensed until 2055.[24]

Thus, if the present practice of high-density pool storage continues, we can expect that existing reactors will operate in close proximity to pools, packed with spent fuel at high density to nearly their full capacity, for future periods as long as 46 years. That conclusion has significant implications for the environmental impacts of spent-fuel storage, as discussed later in this report.

NRC is considering applications for operating licenses for new commercial reactors. Some people see those applications as the beginning of a "renaissance" of nuclear power. The accuracy of that perception will become clear over time. For the purpose of examining potential impacts on the environment, one can assume that a number of new reactors will enter service. A member of the initial cohort of reactors might begin commercial operation in, for example, 2020. Assuming a 60-year operating life, that reactor would shut down in 2080.

NRC has taken no action to encourage or require a spent-fuel storage strategy for new reactors that differs from the strategy now being implemented for existing reactors. Thus, for the purpose of examining potential environmental impacts, one can assume a continuation of the present strategy. Indeed, it appears that reactor vendors, license applicants and the NRC have all assumed, without any evident analysis or debate, that the present spent-fuel storage strategy will continue.

If new reactors employed spent-fuel pools similar in size to the pools at existing reactors, then a typical new pool would become packed to near its capacity in the middle of a

[24] NRC, 2008c.

reactor's 60-year operating life. Thus, if a reactor entered service in 2020, its pool would become packed to near its capacity around 2050, and would remain packed at that level until the reactor ceased operating in 2080. Given such an outcome, a cohort of new reactors would yield large, densely-packed inventories of spent fuel in their adjacent pools during the time period when existing reactors with similar spent-fuel inventories are shutting down. In that manner, new reactors would prolong the present strategy of spent fuel storage, and its environmental impacts, into the late 21st century and potentially beyond.

The Global Nuclear Energy Partnership

The US government is pursuing, through the GNEP program at DOE, the development of "alternative" nuclear fuel cycles.[25] Current national policy is to operate a "once-through" fuel cycle in which spent fuel is stored and eventually disposed of in a radioactive waste repository. One of the explicit purposes of the GNEP program is to develop fuel-cycle options that would require less repository capacity than would be required for a once-through fuel cycle producing the same amount of electrical energy. Thus, the GNEP program is relevant to NRC's Waste Confidence Decision.

Each of the GNEP fuel cycles would involve the processing of spent fuel in facilities that would produce streams of HLW. The HLW waste forms would require storage prior to their placement in a repository. The storage period could be long. For example, some fuel cycles would involve the separation of cesium and strontium isotopes from the other constituents of spent fuel. The cesium and strontium isotopes would be incorporated into some type of liquid or solid HLW waste form that would be stored for about 300 years.[26]

Separation of cesium and strontium isotopes for extended storage would be done to reduce the need for repository capacity. Over 300 years of storage, radioactive decay would substantially reduce the inventory of these isotopes, and their heat output would decline accordingly.[27] From a purely technical perspective, the construction and operation of a repository would become easier and cheaper if that approach were adopted. However, the approach raises important questions about the risk of prolonged storage and the inter-generational equity of deferred disposal.

According to DOE, the transition to an alternative fuel cycle could begin as soon as 10-15 years in the future.[28] Yet, NRC's Draft Update and Proposed Rule are silent regarding the implications of the GNEP program.

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[25] DOE, 2008.
[26] DOE, 2008.
[27] Cesium-137 has a half-life of 30 years. Over 300 years, the inventory of this isotope would decline by a factor of about 1,000.
[28] DOE, 2008.

3. Radioactive Inventories at Spent-Fuel Storage Facilities

The inventories of radioactive material at spent-fuel storage facilities are illustrated here by considering the Indian Point site as a representative site. At that site, the Indian Point 2 (IP2) and Indian Point 3 (IP3) commercial reactors remain operational, and the Indian Point 1 (IP1) reactor is permanently shut down. The IP2 and IP3 reactors are pressurized-water reactors (PWRs). An ISFSI has been established on the 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. The IP1 pool is not discussed here.

Active or spent fuel assemblies contain a variety of radioactive isotopes.[29] 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.[30] Cesium is a volatile element that would be liberally released during conventional accidents or attack scenarios that involve overheating of nuclear fuel.

Table 3-1 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. Table 3-2 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 commercial reactors 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 is discussed further in Section 5, below.

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[29] 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.
[30] DOE, 1987.

4. An Overview of Radiological Risk

As explained in Section 1, above, two categories of adverse impacts on the environment are examined in this report. The first category consists of the risk of radiological harm arising from unplanned releases of radioactive material. The radiological harm could be direct, as measured by outcomes such as the number of radiation-induced human illnesses. Alternatively, the radiological harm could be indirect, in the form of social and economic impacts that arise from the direct harm.

In considering the potential for unplanned releases, this report focuses on atmospheric releases. Such a release could cause radiological consequences at the site where the release occurs 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
(v) social and economic impacts of the above-listed consequences.

An unplanned atmospheric release could arise as a result of a conventional accident or a malice-induced accident. The potential for a conventional accident 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. 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.

Development of PRA capability

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 basic designs of the existing fleet of commercial reactors were being established in the 1960s, there was limited technical understanding of the potential for severe accidents at 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. Knowledge about the potential for core-damage accidents was substantially improved by completion of the Reactor Safety Study (WASH-1400) in 1975.[31] 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.[32]

The "high point" of PRA practice was reached in 1990 with publication by NRC of its NUREG-1150 study, which examined five different US reactors using a common methodology.[33] The study was well funded, involved many experts, was conducted in an open and transparent manner, was done at Level 3 (i.e., radiological consequences were estimated), considered internal and external initiating events, explicitly propagated uncertainty through its chain of analysis, was subjected to peer review, and left behind a large body of published documentation. Each of those features is necessary if the findings of a PRA are to be credible. There are deficiencies in the NUREG-1150 findings, which can be corrected by fresh analysis and the use of new information. The process of correction is possible because the NUREG-1150 study was conducted openly and left a documentary record.

PRA practice in the USA has degenerated since the NUREG-1150 study. Now, PRAs are conducted by the nuclear industry, and the only published documentation is a summary statement of findings. NRC formerly sponsored independent reviews of industry PRAs, but no longer does so. Thus, PRA findings have lacked credibility for at least a decade. An illustration of the degeneration of PRA practice was the disclosure, during a July 2008 hearing before the NRC Commissioners, that the NRC Staff lacks an in-house capability to use the MACCS computer code.[34] That code is used to assess the radiological consequences of an atmospheric release of radioactive material.

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[31] NRC, 1975.
[32] Relevant experience includes the Three Mile Island reactor accident of 1979 and the Chernobyl reactor accident of 1986.
[33] NRC, 1990b.
[34] NRC, 2008e.

5. Potential for a Fire in a Spent-Fuel Pool

5.1 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 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.[35] 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 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.

[35] This sentence assumes adiabatic conditions.

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.

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.[36] 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 NRC.[37] 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, NRC continued, until October 2000, to employ the erroneous assumption that complete drainage is the most severe case.

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).[38] The second document is the May 1996 GEIS on license renewal for nuclear power plants (NUREG-1437).[39] These two documents purported to provide systematic analysis of the risks and relative costs and benefits of alternative options. The third document is NRC's September 1990 review (55 FR 38474) of its Waste Confidence Decision.[40] That document did not purport to provide an analysis of risks and alternatives.

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[36] Thompson et al, 1979.
[37] Benjamin et al, 1979.
[38] NRC, 1979.
[39] NRC, 1996.
[40] NRC, 1990a.

NUREG-0575 addresses the potential for a spent-fuel-pool fire in a single sentence that cites the 1979 Sandia report. The sentence reads:[41]

> "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 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. 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:[42]

> "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 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:[43] (i) NUREG/CR-4982;[44] (ii) NUREG/CR-5176;[45] (iii) NUREG-1353;[46] and (iv) NUREG/CR-5281.[47] These documents are discussed in Section 5.2, 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.

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[41] NRC, 1979, page 4-21.
[42] NRC, 1996, pp 6-72 to 6-75.
[43] NRC, 1990a, page 38481.
[44] Sailor et al, 1987.
[45] Prassinos et al, 1989.
[46] Throm, 1989.
[47] Jo et al, 1989.

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.[48] This author submitted comments on the study to the NRC Commissioners in February 2001.[49] The study was in several respects an improvement on previous NRC documents that addressed pool fires. It reversed 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 decommissioning. Therefore, it did not address potential interactions between pools and operating reactors, such as the interactions discussed in Section 5.3, 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.[50] 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.[51] 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. NAS submitted a classified report to Congress in July 2004, and released an unclassified version in April 2005.[52] Press reports described considerable tension between NAS and NRC regarding the inclusion of material in the unclassified NAS report.[53]

Since September 2001, NRC has not published any document that contains technical analysis related to the potential for a pool fire. Instead, NRC has issued statements claiming that the risk of a pool fire has been limited by secret studies and secret actions.

NRC concedes, in the Draft Update and elsewhere, that a fire could spontaneously break out in a spent-fuel pool following a loss of water. NRC also concedes that radioactive material released to the atmosphere during a pool fire would have significant, adverse impacts on the environment. To offset those concessions, NRC argues that the probability of a pool fire is very low. NRC attributes the alleged low probability, in part, to unspecified, secret security measures and damage-control preparations that have been implemented at commercial reactors since September 2001. NRC further attributes the alleged low probability, in part, to unspecified, secret studies that find that a fire would not break out in certain scenarios for loss of water from a pool.[54] This approach by NRC is discussed further in Section 9, below.

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[48] Collins and Hubbard, 2001
[49] Thompson, 2001a.
[50] Alvarez et al, 2003.
[51] Thompson, 2003.
[52] NAS, 2006.
[53] Wald, 2005.
[54] NRC, 2008a; NRC, 2008d.

5.2 Technical Understanding of Pool Fires

Section 5.1, above, introduces the concept of a pool fire and describes the history of analysis of pool-fire risk. There is a body of technical literature on this risk, containing documents of varying degrees of completeness and accuracy. Current opinions about the risk 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.[55] Benjamin's comment is quoted in the unclassified NAS report as follows:[56]

> "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. 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 EIS. These authors stated:[57]

> "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 NRC's September 1990 review of its Waste Confidence Decision. As discussed in Section 5.1, above, four NRC documents were cited to support that review's finding regarding the risks of pool fires.[58] 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

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[55] Allan Benjamin was one of the authors of: Benjamin et al, 1979.
[56] NAS, 2006, page 45.
[57] Alvarez et al, 2003, page 35.
[58] NRC, 1990a, page 38481.

pool".[59] 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.[60] 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.[61] It postulated a pool accident involving complete, instantaneous loss 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 risk of pool fires.[62] 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 risk 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

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[59] Sailor et al, 1987.
[60] Prassinos et al, 1989.
[61] Throm, 1989.
[62] Jo et al, 1989.

undergoing decommissioning.[63] 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).[64]

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 3-1 shows that the inventory of cesium-137 in a representative pool – 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.

Secret studies by NRC

The Draft Update mentions secret studies allegedly conducted or sponsored by NRC, after September 2001, to improve technical understanding of pool fires. Aspects of those studies include "detailed and realistic analytical modeling", "extensive testing of zirconium oxidation kinetics in an air environment", and "full scale coolability and "zirc fire" testing of spent fuel assemblies".[65] If those studies were indeed carried out, and done competently, they could have yielded an improved technical understanding of pool fires. However, the Draft Update provides no citation to any document, secret or otherwise, that describes the alleged studies.

Secret studies are also mentioned in an August 2008 decision by the NRC Commissioners to deny petitions for rulemaking, filed by the Attorneys General of Massachusetts and California, regarding the environmental impacts of storing spent fuel at high density in pools.[66] In that decision, the secret studies are referred to as the "Sandia studies", because they were done at Sandia National Laboratories. The decision cites two documents that were not previously cited by NRC. One of these documents is entirely secret and the other is available in a highly redacted version.[67] The redacted

[63] Collins and Hubbard, 2001.
[64] NRC, 1990b.
[65] NRC, 2008a, page 59565.
[66] NRC, 2008d.
[67] The two citations are provided in Footnote 6 at page 46207 of the Rulemaking Petition Decision (NRC, 2008d). Both citations are to reports prepared at Sandia National Laboratories. One report, which is

document describes theoretical analyses using the MELCOR computer code, and the other document appears, from its title, to describe similar theoretical analyses. Thus, one can reasonably conclude that neither document describes empirical investigations (e.g., "full scale coolability and "zirc fire" testing of spent fuel assemblies") as mentioned in the Draft Update. (See previous paragraph.)

To summarize, the Draft Update, issued in October 2008, mentions one set of secret studies, while the rulemaking petition decision, issued in August 2008, mentions a different set of secret studies. This inconsistency represents, at a minimum, carelessness and a lack of respect for the public.

5.3 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. NRC has devoted substantial attention and resources to the examination of reactor-core-damage scenarios, through studies such as NUREG-1150.[68] Neither 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.

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entirely secret, was prepared in November 2006 and titled *Mitigation of Spent Fuel Pool Loss-of-Coolant Inventory Accidents and Extension of Reference Plant Analyses to Other Spent Fuel Pools*. It is said to be a Letter Report, implying that it is comparatively short. The other report was available from NRC's ADAMS document archive in a severely redacted version; when obtained, it was revealed to be a June 2003 draft report titled *MELCOR 1.8.5 Separate Effect Analyses of Spent Fuel Pool Assembly Accident Response*. Footnote 6 describes the latter report, illogically, as "a version of the Sandia Studies".

[68] NRC, 1990b.

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.[69] 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. 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 a typical US nuclear power plant, the spent-fuel 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 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.[70] In the ASLB's 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.

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[69] Throm, 1989, Table 4.7.1.
[70] ASLB, 2000.

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.[71] The NRC Staff submitted an affidavit by members of the Staff.[72] CP&L – the licensee – submitted a document prepared by ERIN Engineering.[73]

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.[74] Elsewhere, the author has described deficiencies in the ASLB's ruling.[75]

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."[76] 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 power 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.

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[71] Thompson, 2000.
[72] Parry et al, 2000.
[73] ERIN, 2000.
[74] ASLB, 2001.
[75] Thompson, 2001b.
[76] Parry et al, 2000, paragraph 29.

Interactions between a core-damage accident and a pool fire could be especially important in the context of an attack from outside and/or inside the plant. 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.

Sabotage analysis in NUREG-0575

IRSS is aware of one instance in which 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.

5.4 Pool Fires in a SAMA Context

When the licensee of a commercial reactor applies for a license extension, the licensee is required to examine a set of Severe Accident Mitigation Alternatives (SAMAs) that could reduce risk. For each SAMA, a "benefit" is determined by estimating the amount by which this SAMA would, if adopted, reduce the present value of cost risk 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 "present value of cost risk" is estimated as follows. First, the annual risk of core-damage events at the reactor is assessed, considering only conventional accidents. That 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. Then, the annual risk is summed (with discounting) over the 20-year period of license extension. The resulting indicator is the present value of cost risk for the reactor. Various assumptions and approximations are used during the estimation of this indicator.[77]

NRC does not require that spent-fuel-pool fires be considered in SAMA analyses. There is, however, no logical basis for that position. To illustrate, Table 5-1 shows the estimated present value of cost risk for the reactors and spent-fuel pools at the Indian Point site. The table shows that the present value of cost risk is greatest for a pool fire, even without considering the onsite impacts of such a fire.

In Table 5-1, the present value of cost risk for each reactor is an estimate by the licensee. For each pool, the present value of cost risk derives from two sources. First, it derives from an estimate of pool-fire probability that NRC set forth in NUREG-1353 and has not repudiated. Second, it derives from an estimate by Beyea et al of the offsite costs arising

[77] IRSS does not necessarily accept any of the assumptions and approximations used in SAMA analyses.

from an atmospheric release of 35 MCi of cesium-137. (See the source term discussion in Section 5.2, above.)

Beyea et al estimate the offsite costs of a 35 MCi release of cesium-137 from the Indian Point site to be $461 billion.[78] Their study identifies a number of factors that, if considered, could increase the estimated costs. 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.

Consideration of pool fires in a SAMA context is addressed further in Sections 7 and 8, below.

6. Potential for Radioactive Release from an ISFSI

At an ISFSI, spent fuel is stored in modules. The inner portion of each module is a sealed, cylindrical multi-purpose canister (MPC) made of stainless steel. Spent fuel assemblies are stored inside the MPC, in a helium atmosphere. The MPC is placed inside an overpack made of concrete and steel. The overpack is penetrated by vents that allow ambient air to circulate over the MPC by natural convection, thereby removing heat that is generated in the fuel assemblies by radioactive decay.

Holtec's HI-STORM 100SA module, scheduled for use at the Diablo canyon ISFSI, is a typical module. This module takes the form of a cylinder with a vertical axis, anchored to a concrete pad in the open air. The overpack has an outer diameter of 3.7 meters and a height of 5.9 meters. Its outer, carbon steel shell is about 3/4 inch (2 cm) thick, the inner shell is about 11/4 inch (3 cm) thick, and the space between these shells is filled by about 27 inches (69 cm) of concrete (details vary by module version).[79] That is a robust structure in terms of its resistance to natural forces (e.g., tornado-driven missiles), but not in terms of its ability to withstand penetration by weapons available to sub-national groups. The cylindrical wall of the MPC is about 1/2 inch (1.3 cm) thick, and could be readily penetrated by available weapons. The spent fuel assemblies inside the MPC are composed of long, narrow tubes made of zirconium alloy, inside which uranium oxide fuel pellets are stacked. The walls of the tubes (the fuel cladding) are about 0.023 inch (0.6 mm) thick. Zirconium is a flammable metal. In finely divided form, it is used in military incendiary devices.

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[78] Beyea et al, 2004.
[79] Holtec FSAR, Chapter 1.

One type of scenario for an atmospheric release from an ISFSI module would involve mechanical loading of the module in a manner that creates a comparatively small hole in the MPC. The loading could arise, for example, from the air blast produced by a nearby explosion, or from the impact of an aircraft or missile. If the loading were sufficient to puncture the MPC, it would also shake the spent fuel assemblies and damage their cladding.

Table 6-1 addresses the "blowdown" (escape of helium and gases) of an MPC that has been subjected to a loading pulse sufficient to cause a comparatively small hole. The table shows that, for a hole with an equivalent diameter of 2.3 mm, radioactive gases and particles released during the blowdown would yield an inhalation dose (CEDE) of 6.3 rem to a person 900 m downwind from the release. Most of that dose would be attributable to release of two-millionths (1.9E-06) of the MPC's inventory of radioisotopes in the "fines" category.

Another type of scenario for an atmospheric release would involve the creation of one or more holes in an MPC, with a size and position that allows ingress and egress of air. In addition, the scenario would involve the ignition of incendiary material inside the MPC, causing ignition and sustained burning of the zirconium alloy cladding of the spent fuel. Heat produced by burning of the cladding would release volatile radioactive material to the atmosphere. Illustrative calculations in Table 6-2 show that heat from combustion of cladding would be ample to raise the temperature of adjacent fuel pellets to well above the boiling point of cesium.

Note from Table 3-2 that a typical ISFSI module would contain 1.3 MCi of cesium-137, about half the amount of cesium-137 released during the Chernobyl reactor accident of 1986. Most of the offsite radiation exposure from the Chernobyl accident was due to cesium-137. Thus, a fire inside an ISFSI module, as described in the preceding paragraph, could cause significant radiological harm. The potential for deliberate creation of such a fire is discussed in Section 7, below.

7. Potential for Attack on a Commercial Nuclear Facility

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.

As discussed in Section 2, above, we can expect that existing commercial reactors will operate in close proximity to pools, packed with spent fuel at high density to nearly their full capacity, for future periods as long as 46 years. That situation could persist into the 22nd century if new reactors are commissioned and employ the present strategy for storing spent fuel. Thus, in assessing the risk of malice-induced accidents affecting spent fuel, 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. Sub-national groups have repeatedly attacked US and allied forces in Iraq and Afghanistan.

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 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 risk of attack by sub-national groups requires a sophisticated, multi-faceted and sustained policy. An unbalanced policy can be ineffective or counterproductive. After September 2001, the US government implemented a policy that was heavily weighted toward offensive military action. Evidence has accumulated that this policy has been significantly counterproductive. Table 7-1 provides a sample of the evidence. The table shows 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.[80]

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 risk of malice-induced accidents affecting spent fuel 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 the design and mode of operation of a nuclear facility 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.

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.[81] Second, the RAND corporation has conducted a literature review and assessment of potential worldwide trends that would be adverse for US national security.[82]

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

[80] Kull et al, 2007.
[81] Marshall and Gurr, 2005.
[82] Kugler, 1995.

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.[83] A more recent example is the work of the Global Scenario group, convened by the Stockholm Environment Institute (SEI).[84] 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 peak in world oil production within the next few decades.[85] This prediction is sobering in view of the prominent role played by oil in the origins and conduct of war in the 20th century.[86] 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.[87] 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".[88] 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.[89]

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[83] Meadows et al, 1972.
[84] Raskin et al, 2002.
[85] Hirsch et al, 2005; GAO, 2007.
[86] Yergin, 1991.
[87] Gilman et al, 2007; Campbell et al, 2007; Smith and Vivekananda, 2007.
[88] MEA, 2005, page 1.
[89] Adam, 2005.

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 a nuclear facility, 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:[90]

> "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."

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 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:[91]

"• 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."

[90] Kugler, 1995, page 279.
[91] White House, 2007, page 1.

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".[92] 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".[93] Other Federal agencies, including 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:[94]

> "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" 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.

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[92] White House, 2007, page 25.
[93] DHS, 2006, page iii.
[94] DHS, 2006, page 7.

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 risk 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.[95] 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:[96]

> "*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, priorities of the US government have not been 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.[97] The White House stated, in the *National Strategy for Combating*

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[95] 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.
[96] Hart et al, 2002, pp 14-15.
[97] Flynn, 2007.

Terrorism, issued in September 2006:[98] "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 has relied overwhelmingly on military means to reduce the risks of attacks on US assets by sub-national groups. That policy has continued 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 has summarized national priorities in the following statement:[99]

> "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."

Under the new 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 nuclear facilities could anticipate a national policy shift and take decisions accordingly.

Section 8, below, discusses 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.

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.

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[98] White House, 2006, page 1.
[99] Flynn, 2007, page 11.

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.[100] Yet, the US government rejects the constraint of its own nuclear weapons by international agreements such as the Non-Proliferation Treaty.[101] 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".[102] 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.

As explained in Section 3, above, a facility's inventory of cesium-137 provides an indicator of the facility's potency as a radiological weapon. Table 3-1 shows estimated amounts of cesium-137 in nuclear fuel in the Indian Point reactors and spent-fuel pools, and in one of the spent-fuel storage modules of the Indian Point ISFSI. Table 3-2 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 a nuclear facility, such as those at Indian Point, would create comparatively large radiological consequences.

[100] Hersh, 2006; Brzezinski, 2007.
[101] Deller, 2002; Scarry, 2002; Franceschini and Schaper, 2006.
[102] ElBaradei, 2004, page 9.

7.4 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:[103]

> "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:[104]

> "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.[105] The attacks on New York and Washington in September 2001 led the NRC to require additional protective measures.

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:[106]

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[103] Federal Register, Vol. 32, 26 September 1967, page 13445.
[104] NRC, 1994, page 38893.
[105] NRC, 1994.
[106] ASLB, 1982.

> "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.[107] At that time, the NRC described its order as follows:[108]

> "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."

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.[109] 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]

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[107] NRC Press Release No. 07-012, 29 January 2007.
[108] NRC Press Release No. 03-053, 29 April 2003.
[109] Fertel, 2006; Wells, 2006; Brian, 2006.

against airborne threats is addressed by other federal organizations, including the military".[110]

The present DBT for "radiological sabotage" at a nuclear power plant has the following published attributes:[111]

> "(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
> (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

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[110] NRC Press Release No. 07-012, 29 January 2007.
[111] 10 CFR 73.1 Purpose and scope, accessed from the NRC web site (www.nrc.gov) on 14 June 2007.

night vision.[112] 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.[113] The average US nuclear-plant site employs about 77 security personnel, covering multiple shifts.[114] Thus, comparatively few guards are on duty at any given time.[115]

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. Illustrative scenarios are discussed, in a general sense, 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:[116]

> "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 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;

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112 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.
113 Hebert, 2007.
114 Holt and Andrews, 2006.
115 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.
116 Meserve, 2002, page 22.

(ii) aerial bombardment with 1,000-pound bombs; and (iii) abandonment of the plant by the operators for one week.[117]

Consideration of malicious actions in environmental impact statements

NRC has generally refused to consider potential malicious actions in environmental impact statements. An exception is NRC's August 1979 GEIS on handling and storage of spent fuel (NUREG-0575), which considered potential sabotage events at a spent-fuel pool.[118] Table 7-5 describes the postulated events, which encompass 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 is implied.

NUREG-0575 did not recognize the potential for an attack with these attributes to cause a fire in the pool.[119] Technically-informed attackers operating within this envelope of attributes could cause a fire in a spent-fuel pool at any operating nuclear power plant in the USA.[120] 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 could initiate a fire that would release to the atmosphere a large fraction of the pool's inventory of cesium-137.[121]

Pursuant to a ruling obtained from the 9th Circuit of the US Court of Appeals by San Luis Obispo Mothers for Peace (SLOMFP), 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 risk 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.[122] IRSS prepared a detailed review of the draft version and a short review of the final version.[123] 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. In October 2008 the NRC Commissioners rejected arguments submitted by SLMOFP regarding

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

deficiencies in the EA, and ruled that an EIS is not required in this instance.[124] Commissioner Jaczko dissented strongly from the majority decision.[125] The decision may be appealed.

The NRC Staff has refused to implement the 9th Circuit ruling in regions of the USA, 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)".[126] The EPA cites the 9th Circuit ruling as requiring such an analysis.

7.5 Vulnerability of Typical Reactors, Pools and ISFSIs to Attack

Here, the vulnerability of reactors, pools and ISFSIs to attack is discussed in two parts. First, the vulnerability of reactors and pools is addressed by examining the vulnerability of nuclear power plants. Reactors and pools are, of course, components of those plants. Second, the vulnerability of ISFSIs is addressed, noting that most ISFSIs are at plant sites.

Vulnerability of nuclear power plants

Nuclear power plants in the USA were not designed to withstand an attack. Nor were they designed to withstand a conventional accident involving damage to the reactor core. However, they employ 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. To assess the potential for release, a range of attack scenarios and conventional core-damage scenarios could be articulated, and an atmospheric source term could 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.[127]

PRAs and related studies have been done for all US commercial reactors. That work could be built upon to assess the vulnerability of these reactors to attack. The analysis could be further extended to assess the risk of a pool fire arising from a conventional accident or attack, with consideration of pool-reactor interactions. If done properly, the overall analysis could provide a comprehensive assessment of the risk posed by operation

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[124] This author prepared a declaration supporting SLOMFP's arguments. See: Thompson, 2008b.
[125] NRC, 2008e.
[126] EPA, 2007.
[127] NRC, 1994.

of each US nuclear power plant. 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.[128]

Such a comprehensive assessment of risk does not exist. If that assessment did exist, parts of it would not be appropriate for publication. In the absence of such an assessment, IRSS provides here some illustrative analysis of the vulnerability of 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 that skilled attackers could readily obtain or infer a much greater depth of knowledge about a plant's vulnerability than is provided here.

Table 7-4 and the discussion in Section 7.4, above, show that a US nuclear power plant is 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 with a substantial probability of success.

Modes of attack on a nuclear power plant

Consider the Indian Point site as an example. An attack at that site 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.[129] 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 IP2 (and IP3) 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.[130] 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, Tables 7-6 and 7-7 show the capability of shaped charges.[131]

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[128] See, for example: Morris et al, 2006; Honnellio and Rydell, 2007; Sdouz, 2007.
[129] 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.
[130] Entergy, 2007, Section 5.1.2. This source describes the IP2 plant; the IP3 plant has a similar design.
[131] Also see: Walters, 2003.

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.

Arms manufacturers are actively developing tandem-warhead systems. For example, in January 2008 Raytheon tested the shaped-charge penetrating stage for its Tandem Warhead System.[132] The shaped charge penetrated 19 feet into steel-reinforced concrete with a compressive strength of 12,600 psi. The purpose of this new system is to penetrate a target protected by concrete, steel and rock barriers, and to cause damage inside the target. Development of the system was self-funded by Raytheon. The current version would have a mass of about 1,000 pounds in its tandem configuration. Raytheon states that it could scale the technology, which implies both larger and smaller versions.

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.[133] 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.[134]

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.[135] 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

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[132] Raytheon, 2008.
[133] Entergy, 2007, Table 9.5-1. This source describes the IP2 plant; the IP3 plant has a similar design.
[134] Thompson, 2000.
[135] Alvarez et al, 2003.

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.[136] 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 facility. 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:[137]

> "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."

Modes of attack on an ISFSI

Section 6, above, describes two types of potential release of radioactive material from an ISFSI module. In one type, gases and small particles are swept out of the MPC during a blowdown of gases in the MPC through a comparatively small hole. That release would expose a person downwind to a comparatively small inhalation dose. In the second type of release, air would enter and leave the MPC through one or more holes, and the zirconium alloy cladding of the spent fuel would be ignited by use of incendiary material. That release could include a large amount of cesium-137 that would cause significant

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[136] NRC, 2007a; NRC, 2007b.
[137] Dillingham, 2003, page 14.

radiological harm at distances of tens of km downwind. An attacking group seeking to maximize the impact of its attack would clearly prefer the second type of release.

Table 7-8 broadens the discussion in the preceding paragraph by considering four types of potential, attack-induced release, designated as Types I through IV. If a Type I release is set aside as a special case, examination of Types II through IV reveals two interesting trends. First, as one moves from a Type II or Type III release to a Type IV release, the release event would become less dramatic in terms of indicators such as noise, flame and smoke. Second, the environmental impact would decrease as one moves from a Type II to a Type III release, but would then increase sharply for a Type IV release.

A well-informed sub-national group planning to attack an ISFSI would be likely to aim at creating a Type IV release. That release would require a comparatively small investment of resources and could produce a comparatively large environmental impact.

The NRC Staff reluctantly prepared an EA that examines the potential for an attack on the Diablo Canyon ISFSI.[138] Most of the analyses and assumptions underlying the EA are secret. However, it is clear that the Staff limited its examination to Type III releases. The Staff may have been misled by the comparatively dramatic appearance of the attack scenarios associated with Type III releases, leading to the false conclusion that Type IV releases would yield comparatively small environmental impacts.

Further discussion of potential attacks on ISFSIs, and their treatment by NRC, is provided in other documents prepared by this author.[139] Also relevant to this issue is a dissent by Commissioner Jaczko to an October 2008 decision by the NRC Commissioners.[140] Jaczko noted, for example, that the NRC Staff lacks an in-house capability to analyze the potential for a zirconium fire.

7.6 Potential Attacks in a SAMA Context

Section 5.4, above, discusses the potential for a pool fire in the context of SAMA analyses. To illustrate that discussion, Table 5-1 shows the estimated present value of cost risk for the reactors and spent-fuel pools at the Indian Point site, for conventional accidents. The table shows that the present value of cost risk is greatest for a pool fire, even without considering the onsite impacts of such a fire.

In order to consider potential attacks 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 risk of

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[138] NRC, 2007a; NRC, 2007b.
[139] Thompson, 2007b; Thompson, 2008b.
[140] NRC, 2008e.

conventional accidents with the risk of postulated attacks; and (ii) identify and examine SAMAs that reduce both categories of risk.

Here, IRSS provides some illustrative analysis 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 analysis 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 existing nuclear power 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 7-9 shows the estimated present value of cost risk of an atmospheric release from the IP2 and IP3 plants. Attack-induced releases are considered, with a postulated probability of 1 per 10,000 reactor-years. Releases caused by conventional accidents are also considered, carrying forward the analyses summarized in Table 5-1 to include internal and external initiating events and uncertainty. Thus, Table 7-9 provides an overall summary of the present value of cost risks as estimated by the Indian Point licensee and IRSS.

8. Options for Reducing Radiological Risk

Options are available for reducing the risk of conventional accidents and malice-induced accidents during storage of spent fuel. These options would involve changes in the design and/or mode of operation of SNF storage facilities. Such risk-reducing options can be thought of as SAMAs, although in NRC licensing practice that term is currently used only in connection with conventional accidents at reactors.

Commercial nuclear facilities, such as reactors, pools and ISFSIs, are elements of the nation's critical infrastructure. Thus, options to reduce the risk of malice-induced accidents at nuclear facilities should be examined in the larger setting of national security, values and interests. Table 8-1 shows the importance of taking this broad view. The table shows how wise design of critical infrastructure can enhance protective deterrence and substitute for defense measures that are less effective and/or have significant adverse impacts. The NIPP has outlined appropriate design principles.

Options for reducing the risk of a pool fire

Table 8-2 shows some options that could reduce the risk of a fire in a spent-fuel pool. The option that is most compatible with protective deterrence and the NIPP is to re-equip the pool with low-density, open-frame racks, as was planned when the existing commercial reactors were designed. That option would dramatically reduce the probability of a pool fire, and would substantially reduce the inventory of radioactive material available for release if a fire did occur.

Table 7-9 shows that the present value of cost risk for a fire at an Indian Point pool would be about $28 million for a conventional accident (assuming probability as in NUREG-1353) and $500 million for a malice-induced accident (assuming a probability of 1 per 10,000 reactor-years). Those values are calculated according to standard practice for SAMA analyses. In that paradigm, a SAMA would be cost-effective if its benefit (reduction in the present value of cost risk) exceeds its cost.

Table 8-3 provides an estimate of the incremental cost of using low-density racks in the pool associated with a new commercial reactor. With these racks in place, SNF assemblies would be transferred to dry storage after about 5 years of cooling in the pool. An incremental cost of $3.2 million per year (equivalent to 0.04 cent per kWh of nuclear generation) would arise, beginning in the 11th year of plant operation. That incremental cost would cease at a later point, around the 30th year of plant operation, when the pool inventory of SNF would have approached the pool's capacity if high-density racks had been used. The total, undiscounted incremental cost up to that point would be about $64 million. Viewed over the entire operating life of the reactor, the total, undiscounted incremental cost would actually be zero, assuming that all SNF remaining in the pool after permanent shut-down of the reactor would be moved to dry storage.

Use of low-density racks would dramatically reduce the risk of a pool fire. Thus, the benefit of this SAMA at Indian Point would be a large fraction of the present value of cost risk shown in Table 7-9 for a pool fire. Comparison with the cost estimate in Table 8-3 shows that this SAMA would be cost-effective by a large margin, in the context of malice-induced accidents.

A more complete discussion of SAMAs related to pool fires is provided in another report by this author.[141] That discussion relates directly to the Indian Point site, but also has general application.

Options for reducing the risk of release from an ISFSI

The overall risk of a radioactive release from an ISFSI is dominated by the risk of a malice-induced accident. Options for reducing the latter risk include active defense of the site and preparations for damage control.[142] Here, we focus on design options for enhancing the robustness of the ISFSI.

Options for designing an ISFSI to resist attack have been identified by this author, as follows:[143] "re-design of the ISFSI to use thick-walled metal casks, dispersal of the casks,

[141] Thompson, 2007c.
[142] Thompson, 2007b.
[143] Thompson, 2002, paragraph XI-5.

and protection of the casks by berms or bunkers in a configuration such that pooling of aircraft fuel would not occur in the event of an aircraft impact". Elsewhere, the author has provided a more detailed discussion about designing an ISFSI to be more robust against attack.[144] A factor addressed in that discussion is the possibility that society will extend the life of ISFSIs until they become, by default, repositories for spent fuel. Consideration of that possibility could favor an above-ground ISFSI whose robustness would be enhanced through a combination of the design options described above.

Holtec has developed a design for a new ISFSI storage module that is said to be more robust against attack than present modules. The new module is the HI-STORM 100U module, which would employ the same MPC as is used in the present Holtec modules. For most of its height, the 100U module would be underground. Holtec has described the robustness of the 100U module as follows:[145]

> "Release of radioactivity from the HI-STORM 100U by any mechanical means (crashing aircraft, missile, etc.) is virtually impossible. The only access path into the cavity for a missile is vertically downward, which is guarded by an arched, concrete-fortified steel lid weighing in excess of 10 tons. The lid design, at present configured to easily thwart a crashing aircraft, can be further buttressed to withstand more severe battlefield weapons, if required in the future for homeland security considerations. The lid is engineered to be conveniently replaceable by a later model, if the potency of threat is deemed to escalate to levels that are considered non-credible today."

9. NRC Regulation of Spent-Fuel Storage

9.1 NRC's Approach to Regulating Spent-Fuel Storage

As shown in Section 2, above, NRC has enabled and encouraged the development of a de facto, national strategy for storing SNF from existing commercial reactors. This strategy is likely to persist at existing reactors until 2055, and appears poised to continue into the 22nd century at new reactors. As shown in Section 5, above, NRC has known since 1979 that the strategy creates the potential for a fire in a spent-fuel pool, and that the environmental impacts of such a fire would be severe. The Draft Update agrees that a pool fire could occur, but argues that the probability of this event has been limited by secret studies and secret actions.

Options are available for reducing the risk of a pool fire, as shown in Section 8, above. One option – use of low-density racks – would almost eliminate the risk, at a comparatively modest cost. Yet, NRC has never prepared an EIS that assesses the risk of a pool fire and the options for reducing that risk.

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[144] Thompson, 2003.
[145] Holtec, 2007.

Published NRC documents that address pool fires

Section 5, above, describes various documents published by NRC that are relevant to pool fires. One document is a 1979 GEIS on SNF handling and storage (NUREG-0575), which failed to identify the risk of a pool fire. Another document is an initial technical report (NUREG/CR-0649) published in 1979, whose introduction mis-characterized its content by erroneously stating that complete drainage of a pool is the most severe case. All subsequent documents published by NRC until October 2000 employed the erroneous assumption that complete drainage is the most severe case. For that and other reasons, none of those documents provides a credible assessment of pool-fire risk or risk-reducing options.

The October 2000 document (published in February 2001 as NUREG-1738) addressed nuclear power plants undergoing decommissioning. At such plants, the risk of a pool fire is qualitatively different, and quantitatively lower, than at operating plants. Thus, NRC should have taken the technical understanding that it had belatedly achieved in NUREG-1738, and applied that understanding to operating plants. Instead, NUREG-1738 was the last technical document published by NRC that addressed pool fires.

Secret NRC studies that address pool fires

Since September 2001, NRC has stated on various occasions that it has conducted secret studies addressing the risk of pool fires. The Draft Update, published in October 2008, mentions secret studies of this type.[146] An August 2008 decision by the NRC Commissioners to deny two rulemaking petitions also mentions secret studies of this type.[147] As shown in Section 5.2, above, the two sets of secret studies are clearly different. It appears that NRC is either confused or careless in attributing its position on pool fires to secret studies.

NRC actions to reduce the risk of pool fires

Prior to September 2001, NRC required no specific action to reduce the risk of a pool fire. Since September 2001, NRC has required licensees to take actions with the specific purpose of reducing the risk of a pool fire, while simultaneously claiming that the risk was overstated in published documents such as NUREG-1738. The new, risk-reducing actions are secret. From the Draft Update, they appear to include security measures and damage-control preparations.[148]

The NRC Commissioners' August 2008 decision to deny two rulemaking petitions mentions "internal and external strategies" for the supply of emergency water makeup or

[146] NRC, 2008a.
[147] NRC, 2008d.
[148] NRC, 2008a.

spray to spent-fuel pools. These strategies were proposed by the nuclear industry in 2006, and NRC has "approved license amendments and issued safety evaluations to incorporate these strategies into the plant licensing bases of all operating nuclear power plants in the United States". The external strategy involves the use of an "independently-powered, portable" pumping system.[149]

Adoption of these secret strategies shows that the nuclear industry and NRC are aware of the potential for a pool fire, despite their numerous claims that the risk of such a fire is very low. However, the strategies have been implemented in secrecy, without any assessment of their effectiveness and cost by an EIS or equivalent study. A credible assessment would be likely to show that these strategies would be ineffective following a well-executed attack that targets a reactor and its adjacent pool, as discussed in Section 7.5, above.

Regulation of ISFSIs

An ISFSI poses a radiological risk that is lower than the risk posed by a spent-fuel pool packed at high density. Nevertheless, options are available for reducing the risk associated with malice-induced accidents at an ISFSI, as discussed in Section 8, above. NRC refuses to consider these options in an EIS. Also, NRC attempts to hide the vulnerabilities of existing ISFSIs under a veil of secrecy.

9.2 Impacts of NRC's Regulatory Approach

The preceding discussion identifies four notable features of NRC's approach to regulating SNF storage. First, NRC has not performed any credible EIS to assess the risk of a pool fire caused by a conventional accident. Second, NRC refuses to perform any EIS that assesses the risk associated with malice-induced accidents at any nuclear facility. Third, NRC relies heavily on secrecy as a protective measure. Fourth, under the veil of secrecy, NRC has cooperated with the nuclear industry to adopt measures to reduce the risk of a pool fire, without assessing the effectiveness and costs of these measures by conducting an EIS or equivalent study.

These features of NRC's regulatory approach yield significant, adverse impacts on the environment in the following respects. First, NRC's secrecy is likely to be counterproductive, suppressing a true understanding of risk and discouraging the use of appropriate measures of risk reduction. Second, secretive behavior by a governmental agency has adverse impacts on society and the economy. Third, NRC's secrecy and refusal to prepare an EIS undermine the potential to enhance protective deterrence by implementing protective measures of the type called for in the National Infrastructure Protection Plan.

[149] NRC, 2008d, Section VI (B) (3).

The potential for secrecy to be counterproductive

An entrenched culture of secrecy will adversely affect the safety and security of nuclear facilities. Such a culture is not compatible with a clear-headed, science-based approach to the understanding of risk. 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.[150]

Moreover, secrecy is limited in its 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.

The costs of secrecy

Secrecy is antithetical to US traditions and inconsistent with long-term national prosperity. Thus, when an EIS is conducted to assess design options for a nuclear facility, the EIS should consider the social and economic impacts of secrecy. That consideration would tend to favor options involving features such as hardening, resiliency and passive protection. Secrecy can be reduced or eliminated if such features are employed. In considering the impacts of secrecy, it should be remembered that nuclear facilities exist to serve society, rather than vice versa.[151]

NRC's undermining of protective deterrence

Section 7, above, discusses the role of protective deterrence as part of a balanced policy for homeland security. That role is illustrated by Table 8-1, which shows the strengths and weaknesses of options for protecting critical infrastructure from attack by sub-national groups. Table 8-1 shows the benefits that could flow from adoption of resilient design, passive defense, and other protective measures for infrastructure elements such as SNF or HLW storage facilities. The NIPP envisions the use of such measures. Yet, NRC does not require such measures, and refuses to allow their identification and assessment in an EIS. Moreover, NRC attempts to hide the true characteristics of existing nuclear facilities under a veil of secrecy. In effect, NRC endorses the use of offensive military

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[150] Thompson, 2002, Section X.

[151] 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.

operations, surveillance of the domestic population, and related measures as the primary means of protecting critical infrastructure. NRC appears to be willing to sustain that preference into the 22nd century.

An opportunity to eliminate secrecy regarding spent-fuel pools

Secrecy and its adverse impacts could be quickly eliminated in the context of spent-fuel pools. As discussed in Section 8, above, the pools could be re-equipped with low-density, open-frame racks, as was planned when the existing commercial reactors were designed. That option would dramatically reduce the probability of a pool fire, and would substantially reduce the inventory of radioactive material available for release if a fire did occur. There would no longer be any reasonable basis for secrecy regarding spent-fuel pools.

10. A NEPA-Compliant Approach to Regulation of SNF and HLW Storage

The National Environmental Policy Act (NEPA) requires, for US government actions that significantly affect the environment, systematic consideration of impacts and alternatives in an EIS. Licensing of a facility for storage of SNF or HLW is such an action, especially given the modes of storage that NRC has licensed.

This report shows that an SNF storage facility can pose a significant radiological risk, which is a form of environmental impact. Also, deficiencies in NRC regulation of the facility can cause other, significant impacts on the environment, as discussed in Section 9, above. This combined set of impacts could be considered in an EIS without any conceptual difficulty. If NRC were to perform such an EIS, NRC would be obliged to accurately assess the impacts of its own regulatory approach.

Consideration of malice-induced accidents in an EIS would pose two challenges. First, the probabilities of such accidents cannot be quantitatively estimated. Second, some analyses related to such accidents contain sensitive information and are therefore not appropriate for general publication.

Both challenges could be readily overcome. The probabilities of malice-induced accidents could be estimated qualitatively, and a numerical range could be used for illustrative calculations. NRC has well-established procedures for handling sensitive information, including procedures whereby intervenors in a licensing process that involves sensitive information can be represented by persons with security clearances.

If necessary, an EIS could have classified appendices. However, an EIS that is consistent with the purposes of NEPA would use secrecy sparingly, not as a veil to hide inconvenient information. Notably, such an EIS would explicitly identify and examine alternatives whose assessment does not require the use of sensitive information.

11. Conclusions

C1. NRC has enabled and encouraged the development of a de facto, national strategy for storing spent fuel from existing commercial reactors. Major elements of the strategy are: (i) storage of spent fuel, after discharge from a reactor, in a high-density pool; (ii) placement of the pool in close proximity to the reactor, with sharing of systems; (iii) accumulation of spent fuel in the pool until the pool is packed nearly to full capacity, followed by periodic offloading of older fuel from the pool to an on-site ISFSI in order to make room for newly-discharged fuel; and (iv) after permanent shut-down of the reactor, transfer of the remaining fuel from the pool to the ISFSI.

C2. The strategy described in conclusion C1 creates a substantial risk of radiological harm and, therefore, has severe, adverse impacts on the environment. The dominant component of the radiological risk arises from the potential for a fire in a spent-fuel pool following a loss of water from the pool. That event could be caused by a conventional accident or a malice-induced accident. The potential for a pool fire is exacerbated by the presence of an operating reactor in close proximity to a pool. Among other components of the radiological risk, the most significant component arises from the potential for a malice-induced accident to release radioactive material from an ISFSI.

C3. NRC has conducted some analyses related to the radiological risk described in conclusion C2. The analyses that have been published, taken together, provide an incomplete and inaccurate assessment of the risk. None of the published analyses meets the standards of an EIS prepared under NEPA. NRC has issued statements about the radiological risk associated with malice-induced accidents affecting spent fuel, but has neither published any technical analysis of that risk, nor published any citation to a secret analysis that could meet the standards of an EIS prepared under NEPA.

C4. NRC has conceded, in the Draft Update and other documents, that a fire could occur in a spent-fuel pool following a loss of water. NRC has also conceded that radioactive material released during a pool fire would have significant, adverse impacts on the environment. To offset those concessions, NRC argues that the probability of a pool fire is very low. NRC attributes the alleged low probability, in part, to unspecified, secret security measures and damage-control preparations that have been implemented at commercial reactors. NRC further attributes the alleged low probability, in part, to unspecified, secret studies that find that a fire would not break out in certain scenarios for loss of water from a pool. None of the arguments advanced by NRC to support its claim of low probability cites or provides an analysis that could meet the standards of an EIS prepared under NEPA.

C5. Options are available for reducing the radiological risk now associated with storage of spent fuel. Some of those options are entirely passive, and do not rely on active systems or human action. Options of that type are especially suitable for spent-fuel storage. Notably, spent-fuel pools could be re-equipped with low-density racks, as was intended when the existing reactors were designed, the excess fuel being moved to ISFSIs. That option would be entirely passive, and would dramatically reduce the potential for a pool fire. Also, the spent-fuel storage modules that are deployed at ISFSIs could be protected from attack by berming, underground placement, and/or stronger outer containers. Those options would be entirely passive, and would significantly reduce the risk of a malice-induced release of radioactive material from an ISFSI. Passive, robust options for risk reduction, such as the options outlined here for spent-fuel pools and ISFSIs, are protective measures of the type called for in the National Infrastructure Protection Plan.

C6. NRC has published some analyses of options for reducing the radiological risk associated with storage of spent fuel. None of those analyses considers the potential for malice-induced accidents. Nor does any of those published analyses meet the standards of an EIS prepared under NEPA. Also, NRC has never published any citation to a secret analysis, meeting the standards of an EIS prepared under NEPA, that examines options for reducing the radiological risk associated with storage of spent fuel.

C7. NRC has not required the use of risk-reducing options of the type outlined in conclusion C5. Nor has NRC analyzed risk-reducing options in the manner required by NEPA, as pointed out in conclusion C6. Instead, NRC claims that the radiological risk associated with spent-fuel storage is limited by secret studies and secret actions, in the following respects. First, says NRC, secret studies show that many accident scenarios would not lead to a large release of radioactive material. Second, says NRC, secret actions significantly reduce the probability of occurrence of accident scenarios that would lead to a large release of radioactive material. NRC takes that position in regard to pool fires, as mentioned in conclusion C4, and in regard to radioactive releases from ISFSIs. NRC appears to be unaware that the use of passive, robust options for risk reduction, of the type discussed in conclusion C5, could reduce or eliminate any need for secrecy.

C8. Conclusion C7 shows that NRC relies on secrecy as a primary measure for limiting the radiological risk associated with spent-fuel storage. NRC's heavy reliance on secrecy, and its refusal to perform risk analyses that meet the standards of an EIS prepared under NEPA, are significant deficiencies in NRC's approach to regulating the storage of spent fuel. NRC's reliance on secrecy has adverse impacts on the environment in two respects. First, secrecy is likely to be counterproductive, suppressing a true understanding of risk and discouraging the use of appropriate measures of risk reduction. Second, secretive behavior by a governmental agency has adverse impacts on society and the economy. In addition, NRC's overall regulatory approach, which combines secrecy with a lack of NEPA compliance, has adverse impacts on the defense and security of the USA. NRC's approach undermines the potential to enhance protective deterrence by implementing protective measures of the type called for in the National Infrastructure Protection Plan.

C9. The de facto, national strategy for storing spent fuel, as described in conclusion C1, creates the substantial risk of radiological harm that is described in conclusion C2. In addition, NRC's approach to the regulation of spent-fuel storage exacerbates the radiological risk and has adverse impacts on society, the economy, national defense and security, as summarized in conclusion C8. Taken together, the national strategy and NRC's regulatory approach have significant, adverse impacts on the environment. In the context of a particular reactor, the combined impacts are at a comparatively high level when the reactor is in its operational period, because the potential for a pool fire is the dominant component of radiological risk, and that potential is exacerbated by reactor operation. The combined impacts then continue at a lower level after permanent shut-down of the reactor, during any remaining period of ISFSI operation.

C10. Likely trends in the operation of existing reactors show a substantial part of the fleet operating into the 2040s, with the last reactor shutting down in 2055. The combined impacts described in conclusion C9 would continue at a comparatively high level during that period, and at a lower level thereafter. If new reactors commence operating and the present fuel-storage strategy continues, the combined impacts associated with that strategy could be expected to continue at a comparatively high level into the latter part of the 21st century and, potentially, into the 22nd century.

C11. Findings 3, 4 and 5 of NRC's Waste Confidence Decision should account for the environmental impacts summarized in conclusion C9, and for likely trends in those impacts as discussed in conclusion C10. No such accounting is provided in the 1990 version of the Decision or in the Draft Update. Finding 3 states that spent fuel "will be managed in a safe manner", the proposed Finding 4 states that spent fuel "can be stored safely without significant environmental impacts", and Finding 5 states that "safe" storage of spent fuel in an ISFSI will be provided if needed. None of those statements has a basis in credible analysis by NRC. The statement in proposed Finding 4 might be shown to be correct, with an emphasis on the word "can", if risk-reducing options of the type discussed in conclusion C5 were considered through analysis that meets the standards of NEPA.

C12. NRC's Proposed Rule should account for the environmental impacts summarized in conclusion C9, and for likely trends in those impacts as discussed in conclusion C10. No such accounting is provided. The Proposed Rule's statement that spent fuel "can be stored safely and without significant environmental impacts" has no basis in credible analysis by NRC. The statement might be shown to be correct, with an emphasis on the word "can", if risk-reducing options of the type discussed in conclusion C5 were considered through analysis that meets the standards of NEPA.

C13. The US government is pursuing, through the GNEP program at DOE, the development of alternative nuclear fuel cycles. Those cycles would involve the processing of spent fuel in facilities that would produce streams of HLW. The HLW waste forms would require storage prior to their placement in a repository. The storage period could be long. For example, some fuel cycles would involve the separation of cesium and strontium isotopes from the other constituents of spent fuel. The cesium and strontium isotopes would be incorporated into an HLW waste form that would be stored for about 300 years.

C14. NRC's present approach to the regulation of spent-fuel storage could set a precedent for regulation of the storage of HLW waste forms in the future. NRC currently allows spent fuel to be stored in a manner that creates significant, adverse impacts on the environment, and appears willing to allow these impacts to continue through the 21st century. The Draft Update and the Proposed Rule do not acknowledge the potential for NRC's present regulatory approach to set a precedent for regulating the storage of HLW waste forms that are produced in the future.

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Table 1-1
NRC Waste Confidence Findings, 1990 Version and Version Now Proposed by NRC

1990 Version	Proposed Version
Finding 1: The Commission finds reasonable assurance that safe disposal of high-level radioactive waste and spent fuel in a mined geologic repository is technically feasible.	Unchanged
Finding 2: The Commission finds reasonable assurance that at least one mined geologic repository will be available within the first quarter of the twenty-first century, and that sufficient repository capacity will be available within 30 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of any reactor to dispose of the commercial high-level radioactive waste and spent fuel originating in such reactor and generated up to that time.	Finding 2: The Commission finds reasonable assurance that sufficient mined geologic repository capacity can reasonably be expected to be available within 50-60 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of any reactor to dispose of the commercial high-level radioactive waste and spent fuel originating in such reactor and generated up to that time.
Finding 3: The Commission finds reasonable assurance that HLW and spent fuel will be managed in a safe manner until sufficient repository capacity is available to assure the safe disposal of all HLW and spent fuel.	Unchanged
Finding 4: The Commission finds reasonable assurance that, if necessary, spent fuel generated in any reactor can be stored safely and without significant environmental impacts for at least 30 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor at its spent fuel storage basin, or at either onsite or offsite independent spent fuel storage installations.	Finding 4: The Commission finds reasonable assurance that, if necessary, spent fuel generated in any reactor can be stored safely without significant environmental impacts for at least 60 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of that reactor in a combination of storage in its spent fuel storage basin and either onsite or offsite independent spent fuel storage installations.
Finding 5: The Commission finds reasonable assurance that safe independent onsite spent fuel storage or offsite spent fuel storage will be made available if such storage capacity is needed.	Unchanged

Source:
NRC, 2008a

Table 3-1
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 one ISFSI module (assuming 32 fuel assemblies, av. age after discharge = 30 yrs)	1.3 MCi	

Source:
This table is adapted from Table 2-1 of: Thompson, 2007c.

Table 3-2
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
In one storage module at the Indian Point ISFSI	1.3 MCi

Source:
This table is adapted from Table 2-2 of: Thompson, 2007c.

Table 5-1
Estimated Present Value of Cost Risk Associated with Atmospheric Releases from Conventional Accidents: 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) This table is adapted from Table 6-3 of: Thompson, 2007c.
(b) The full spectrum of releases from each of the two reactors includes accident sequences in which the containment does not fail.
(c) Uncertainty in probability, and the potential for malice-induced accidents, are not considered in this table.
(d) Annual cost risk ($ per year) is converted to the present values shown here by accumulating the annual value over 20 years with a discount rate of 7 percent per year.

Table 6-1
Estimated Atmospheric Release of Radioactive Material and Downwind Inhalation Dose for Blowdown of the MPC in a Spent-Fuel-Storage Module

Indicator		MPC Leakage Area		
		4 sq. mm (equiv. dia. = 2.3 mm)	**100 sq. mm (equiv. dia. = 11 mm)**	**1,000 sq. mm (equiv. dia. = 36 mm)**
Fuel Release Fraction	**Gases**	3.0E-01	3.0E-01	3.0E-01
	Crud	1.0E+00	1.0E+00	1.0E+00
	Volatiles	2.0E-04	2.0E-04	2.0E-04
	Fines	3.0E-05	3.0E-05	3.0E-05
MPC Blowdown Fraction		9.0E-01	9.0E-01	9.0E-01
MPC Escape Fraction	**Gases**	1.0E+00	1.0E+00	1.0E+00
	Crud	7.0E-02	5.0E-01	8.0E-01
	Volatiles	4.0E-03	3.0E-01	6.0E-01
	Fines	7.0E-02	5.0E-01	8.0E-01
Inhalation Dose (CEDE) to a Person at a Distance of 900 m		6.3 rem	48 rem	79 rem

Notes:
(a) Estimates are from: Gordon Thompson, *Estimated Downwind Inhalation Dose for Blowdown of the MPC in a Spent Fuel Storage Module*, IRSS, June 2007.
(b) The assumed multi-purpose canister (MPC) contains 24 PWR spent fuel assemblies with a burnup of 40 MWt-days per kgU, aged 10 years after discharge.
(c) The following radioisotopes were considered: Gases (H-3, I-129, Kr-85); Crud (Co-60); Volatiles (Sr-90, Ru-106, Cs-134, Cs-137); Fines (Y-90 and 22 other isotopes).
(d) The calculation followed NRC guidance for calculating radiation dose from a design-basis accident, except that the MPC Escape Fraction was drawn from a study by Sandia National Laboratories that used the MELCOR code package.
(e) CEDE = committed effective dose equivalent. In this scenario, CEDE makes up most of the total dose (TEDE) and is a sufficient approximation to it.
(f) The overall fractional release of a radioisotope from fuel to atmosphere is the product of Fuel Release Fraction, MPC Blowdown Fraction, and MPC Escape Fraction.
(g) For a leakage area of 4 square mm, the overall fractional release is: Gases (0.27); Crud (0.063); Volatiles (7.2E-07); Fines (1.9E-06). Fines account for 95 percent of CEDE, and Crud accounts for 4 percent.

Table 6-2
Illustrative Calculation of Heat-Up of a Fuel Rod in a PWR Fuel Assembly Due to Combustion in Air

Indicator	Affected Material	
	Zircaloy Cladding	**UO_2 Pellets**
Solid volume, per m length	1.90E-05 cub. m (OD = 1.07 cm; thickness = 0.06 cm)	6.36E-05 cub. m (OD = 0.9 cm)
Mass, per m length	0.124 kg (@ 6.55 Mg per cub. m)	0.700 kg (@ 11.0 Mg per cub. m)
Heat output from combustion of material in air, per m length	1.48 MJ (@ 2,850 cal per g Zr)	Neglected
Equilibrium temperature rise if material receives 50% of heat output from adjacent combustion, and if heat loss from material is neglected	Neglected	approx. 2,700 deg. C (Note: The enthalpy rise if UO_2 temp. rises from 300 K to 3,000 K = 1,052 kJ per kg UO_2)

Notes:
(a) Data shown in table are from: Nero, 1979, Table 5-1; Powers et al, 1994, Table 4; and files accessed at International Nuclear Safety Center (INSC), Argonne National Laboratory, <http://www.insc.anl.gov/>, in March 2008.
(b) Melting point of UO_2 is 2,850 deg. C (from INSC files).
(c) Boiling point of elemental cesium is 685 deg. C (from: Thompson and Beckerley, 1973, Volume 2, page 527).
(d) 1 cal = 4.184 J

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 US 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 Table 7-4 of: Thompson, 2007c. Sources supporting this table include:
(a) 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.
(b) 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.
(c) Danielle Brian, Project on Government Oversight, letter to NRC chair Nils J. Diaz, 22 February 2006.
(d) 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 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:
This table is adapted from Table 7-6 of: Thompson, 2007c.

Table 7-7
Performance of US Army Shaped Charges, M3 and M2A3

Target Material	Indicator	Type of Shaped Charge	
		M3	**M2A3**
Reinforced concrete	Maximum wall thickness that can be perforated	60 in	36 in
	Depth of penetration in thick walls	60 in	30 in
	Diameter of hole	• 5 in at entrance • 2 in minimum	• 3.5 in at entrance • 2 in minimum
	Depth of hole with second charge placed over first hole	84 in	45 in
Armor plate	Perforation	At least 20 in	12 in
	Average diameter of hole	2.5 in	1.5 in

Notes:
(a) Data are from: Army, 1967, pp 13-15 and page 100.
(b) The M2A3 charge has a mass of 12 lb, a maximum diameter of 7 in, and a total length of 15 in including the standoff ring.
(c) The M3 charge has a mass of 30 lb, a maximum diameter of 9 in, a charge length of 15.5 in, and a standoff pedestal 15 in long.

Table 7-8
Types of Atmospheric Release from a Spent-Fuel-Storage Module at an ISFSI as a Result of a Potential Attack

Type of Event	Module Behavior	Relevant Instruments and Modes of Attack	Characteristics of Atmospheric Release
Type I: Vaporization	• Entire module is vaporized	• Module is within the fireball of a nuclear-weapon explosion	• Radioactive content of module is lofted into the atmosphere and amplifies fallout from nuc. explosion
Type II: Rupture and Dispersal (Large)	• MPC and overpack are broken open • Fuel is dislodged from MPC and broken apart • Some ignition of zircaloy fuel cladding may occur, without sustained combustion	• Aerial bombing • Artillery, rockets, etc. • Effects of blast etc. outside the fireball of a nuclear weapon explosion	• Solid pieces of various sizes are scattered in vicinity • Gases and small particles form an aerial plume that travels downwind • Some release of volatile species (esp. cesium-137) if incendiary effects occur
Type III: Rupture and Dispersal (Small)	• MPC and overpack are ruptured but retain basic shape • Fuel is damaged but most rods retain basic shape • No combustion inside MPC	• Vehicle bomb • Impact by commercial aircraft • Perforation by shaped charge	• Scattering and plume formation as for Type II event, but involving smaller amounts of material • Little release of volatile species
Type IV: Rupture and Combustion	• MPC is ruptured, allowing air ingress and egress • Zircaloy fuel cladding is ignited and combustion propagates within the MPC	• Missiles with tandem warheads • Close-up use of shaped charges and incendiary devices • Thermic lance • Removal of overpack lid	• Scattering and plume formation as for Type III event • Substantial release of volatile species, exceeding amounts for Type II release

Table 7-9
Estimated Present Value of Cost Risk of a Potential Atmospheric Release from a Reactor or Spent-Fuel Pool at Indian Point, Including a Release Caused by an Attack

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

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

Notes for Table 7-9:

(a) This table is adapted from Table 7-7 of: Thompson, 2007c.

(b) In the second 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.

(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.

(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.

(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.

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

Table 8-2
Selected Options to Reduce the Risk of a Spent-Fuel-Pool Fire at a Commercial Reactor

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 site	Active	Yes	No	• Implementation requires presence of US military at site
Develop enhanced onsite capability for damage control	Active	Yes	Yes	• Requires new equipment, staff and training • Personnel must function in extreme environments

Table 8-3
Estimation of Incremental Cost if Spent Fuel from a New PWR is Transferred from the Spent-Fuel Pool to Dry Storage After 5 Years of Storage in the Pool

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

Notes:
(a) This calculation employs data that apply to the Indian Point 2 nuclear power plant. Similar data apply to other US plants.
(b) Data in this table are from Tables 2-1 and 9-2 of: Thompson, 2007c.
(c) The capital cost begins in the 11^{th} year of plant operation, and continues while the plant operates.

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Risks and Risk-Reducing Options Associated with Pool Storage of Spent Nuclear Fuel at the Pilgrim and Vermont Yankee Nuclear Power Plants

by
Gordon R. Thompson

25 May 2006

A report for
Office of the Attorney General
Commonwealth of Massachusetts

Abstract

This report addresses some of the risks associated with the future operation of the Pilgrim and Vermont Yankee nuclear power plants. The risks that are addressed here arise from the storage of spent nuclear fuel in a water-filled pool adjacent to the reactor at each plant. Both pools are now equipped with high-density, closed-form storage racks. Options are available to reduce spent-fuel-pool risks. The option that would achieve the largest risk reduction at each plant, during operation within a license extension period, would be to re-equip the pool with low-density, open-frame storage racks. That option would return the plant to its original design configuration. This report describes risks and risk-reducing options, and relevant analysis that is required from the licensee and the Nuclear Regulatory Commission in the context of license extension applications for the Pilgrim and Vermont Yankee plants.

About the Institute for Resource and Security Studies

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

About the Author

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

Dr. Thompson independently identified the potential for a spent-fuel-pool fire, and articulated alternative options for lower-risk storage of spent fuel, during his work for the German state government of Lower Saxony in 1978-1979. His findings were accepted by that government after a public hearing. Since that time, Thompson has conducted several other studies on spent-fuel-storage risk, alone and with colleagues. Findings of these studies have been confirmed by a 2005 report by the National Academy of Sciences, prepared at the request of the US Congress.

Acknowledgements

This report was prepared by IRSS for the Office of the Attorney General, Commonwealth of Massachusetts. Gordon R. Thompson is solely responsible for the content of the report.

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1. Introduction

Applications have been submitted for 20-year extensions of the operating licenses of the Pilgrim and Vermont Yankee nuclear power plants. These plants began operating in 1972, and their current operating licenses expire in 2012. The designs of the two plants are broadly similar, and both are operated by Entergy Nuclear Operations Inc. (Entergy). Each plant features a boiling-water reactor (BWR) with a Mark 1 containment. The US Nuclear Regulatory Commission (NRC) has announced that interested persons can petition to intervene in the license extension proceedings for these plants. In that context, the Office of the Attorney General, Commonwealth of Massachusetts, has requested the preparation of this report.

This report addresses a particular set of risks associated with the future operation of the Pilgrim and Vermont Yankee plants. These risks arise from the storage of spent nuclear fuel in water-filled pools. Each plant's nuclear reactor periodically discharges fuel that is "spent" in the sense that the fuel is no longer suitable for power generation. The spent fuel contains a large amount of radioactive material, and is stored in a water-filled pool adjacent to the reactor. In this report, the word "risk" applies to the potential for a release of radioactive material from nuclear fuel to the atmosphere. Other risks arise from the operation of nuclear power plants, but are not addressed here. The concept of risk encompasses both the consequences and probability of an event. However, risk is not simply the arithmetic product of consequence and probability numbers, as is sometimes assumed.

Although this report focuses on the risks arising from pool storage of spent fuel, the report necessarily considers some aspects of the risks arising from operation of the reactor at each plant. Such consideration is necessary because the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. Thus, an incident involving a release of radioactive material from the pool could be initiated or exacerbated by an incident at the reactor, or vice versa, or parallel incidents at the pool and the reactor could have a common cause.

Scope of this analysis

This report does not purport to provide a comprehensive assessment of the risks arising from pool storage of spent fuel at the Pilgrim and Vermont Yankee plants. As discussed in Section 10, below, preparation of such an assessment is a duty of Entergy and the NRC. Neither party has performed this duty. In the absence of a comprehensive assessment, this report provides illustrative analysis of selected issues. Assumptions of the analysis are stated, and the author would be pleased to engage in open technical debate regarding his analysis. A companion report, prepared independently by Dr. Jan Beyea, examines the offsite consequences of releases of radioactive material. Findings in that report are consistent with scientific knowledge and experience in the field of radiological consequence assessment. Questions about the analysis in that report should be directed to Dr. Beyea.

Five major purposes are pursued in this report. The focus throughout is on the Pilgrim and Vermont Yankee plants and their license extension applications, but much of the report's discussion has wider application. First, the potential for a release of radioactive material from a spent-fuel pool is described. Second, options for reducing the probability and/or consequences of such a release are described. These descriptions provide a general picture of the risks and risk-reducing options associated with pool storage of spent fuel. Third, an integrated view of these risks and risk-reducing options is provided. Fourth, the state of knowledge about these risks and risk-reducing options is reviewed. Fifth, the technical analysis required from Entergy and the NRC to improve this state of knowledge is described.

Two classes of event could lead to a release of radioactive material from a spent-fuel pool. One class of events, typically described as "accidents", includes human error, equipment failure and/or natural forces such as earthquakes. A second class encompasses deliberate, malicious acts. Some events, which involve harmful acts by insane but cognitively functioning persons, fall into both classes. This report considers the full range of initiating events, including human error, equipment failure, natural forces, malice, and/or insanity.

Protection of sensitive information

Any responsible analyst who discusses potential acts of malice at nuclear power plants 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 report contains no such information. However, a higher standard of discretion is necessary. An analyst should not publish detailed information that will assist potential attackers, 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 Pilgrim and Vermont Yankee 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 Pilgrim and Vermont Yankee 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 can be discussed without concern about disclosure to potential attackers. Rules and practices are available so that the parties to a license proceeding can discuss sensitive information in a protected setting.

Structure of this report

The remainder of this report has eleven sections. Section 2 outlines the hazard posed by storage of spent fuel in a high-density configuration in pools at nuclear power plants, and describes the history of attention to this issue. The hazard arises from the potential for a self-ignited fire in a spent-fuel pool if water is lost from the pool. Technical aspects of this hazard are discussed in greater detail in subsequent sections of the report. Characteristics of the Pilgrim and Vermont Yankee plants and their spent fuel are described in Section 3. National trends in the management of spent nuclear fuel are described in Section 4, providing evidence that spent fuel is likely to remain at the Pilgrim and Vermont Yankee sites for at least several decades, and potentially for more than a century. The risks of spent-fuel storage will continue to accumulate over that period.

Section 5 reviews the state of technical knowledge about potential spent-fuel-pool fires. Scenarios for such a fire at the Pilgrim or Vermont Yankee plants are discussed in the two following sections. Section 6 discusses scenarios initiated by accidents not involving malice, while Section 7 discusses scenarios initiated by malicious action. Options to reduce the risks of spent-fuel-pool fires at the Pilgrim and Vermont Yankee plants are described in Section 8. An integrated view of risks and risk-reducing options at these plants is set forth in Section 9.

In Section 5 and elsewhere, this report discusses the state of technical knowledge about risks and risk-reducing options associated with spent-fuel pools. There are substantial deficiencies in present knowledge. Section 10 describes the technical analysis required from Entergy and the NRC to correct these deficiencies in the context of license extension applications for Pilgrim and Vermont Yankee. 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.

2. Recognition of the Spent-Fuel Hazard

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 Pilgrim and Vermont Yankee plants began operating in 1972, 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. The environmental impact statements (EISs) related to the operation of Pilgrim and Vermont Yankee did not consider severe reactor accidents.[1] Knowledge about the potential for such accidents was improved by completion of the Reactor Safety Study (WASH-1400) in 1975.[2] More knowledge has accumulated from analysis and experience since that time.[3]

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. Initially, pools were 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.[4] 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

[1] AEC, 1972a; AEC, 1972b.
[2] NRC, 1975.
[3] Relevant experience includes the Three Mile Island reactor accident of 1979 and the Chernobyl reactor accident of 1986.
[4] This sentence assumes adiabatic conditions.

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.

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.[5] 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.[6] 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 in Section 5, 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).[7] The second document is the May 1996 GEIS on license renewal (NUREG-1437).[8] These two documents purported to provide systematic analysis of the risks and relative costs and

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[5] Thompson et al, 1979.
[6] Benjamin et al, 1979.
[7] NRC, 1979.
[8] NRC, 1996.

benefits of alternative options. The third document is the NRC's September 1990 review (55 FR 38474) of its Waste Confidence Decision.[9] 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:[10]

> 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 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:[11]

> 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:[12] (i) NUREG/CR-4982;[13] (ii) NUREG/CR-5176;[14] (iii) NUREG-1353;[15] and (iv) NUREG/CR-5281.[16] These documents are discussed in Section 5, 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

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[9] NRC, 1990a.
[10] NRC, 1979, page 4-21.
[11] NRC, 1996, pp 6-72 to 6-75.
[12] NRC, 1990a, page 38481.
[13] Sailor et al, 1987.
[14] Prassinos et al, 1989.
[15] Throm, 1989.
[16] Jo et al, 1989.

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.[17] This author submitted comments on the study to the NRC Commissioners in February 2001.[18] 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 decommissioning. Therefore, it did not address potential interactions between pools and operating reactors, such as the interactions discussed in Section 6, 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.[19] 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.[20] 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.[21] Press reports described considerable tension between the NAS and the NRC regarding the inclusion of material in the unclassified NAS report.[22]

Since September 2001, the NRC has not published any document that contains technical analysis related to the potential for a pool fire. The NRC claims that it is conducting further analysis in a classified setting. The scope of information treated as secret by the NRC is 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.

3. Characteristics of the Pilgrim and Vermont Yankee Plants and their Spent Fuel

Basic data about the Pilgrim and Vermont Yankee plants are set forth in Table 3-1. Data and estimates about storage of spent fuel at these plants are set forth in Tables 3-2

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[17] Collins and Hubbard, 2001
[18] Thompson, 2001a.
[19] Alvarez et al, 2003.
[20] Thompson, 2003.
[21] NAS, 2006.
[22] Wald, 2005.

through 3-5. In regard to the latter tables, publicly available information is incomplete and inconsistent. Therefore, assumptions are made at various points in the tables, as is readily evident. In addition, the estimates set forth in Tables 3-3 through 3-5 involve a number of simplifying assumptions, which are also evident from the tables.

The scope and accuracy of Tables 3-1 through 3-5 could be improved using information that is held by Entergy and the NRC. Given this information, a more sophisticated analysis could be conducted to estimate the inventories and other characteristics of the Pilgrim and Vermont Yankee spent-fuel pools during the requested period of license extension. These improvements would not alter the basic findings of this report.

At the Pilgrim plant, the present configuration of the storage racks in the spent-fuel pool reflects a license amendment approved by the NRC in 1994. A report submitted by the licensee in support of that license amendment states that the existing racks in the pool and the proposed new racks had a center-to-center distance of about 6.3 inches in both directions. The new racks would, when fully installed, fill the pool tightly, wall-to-wall.[23] Equivalent detail is not available regarding the present configuration of racks in the Vermont Yankee pool. However, from the data provided in Table 3-2 regarding the capacities, inventories and dimensions of both pools, it is evident that the Vermont Yankee pool configuration is similar to that at Pilgrim.[24]

Entergy has announced its intention to establish an independent spent fuel storage installation (ISFSI) at the Vermont Yankee site, and for this purpose has requested a Certificate of Public Good from the Vermont Public Service Board. The ISFSI would store fuel in dry-storage modules. Entergy has described its planned schedule for transferring spent fuel from the pool to the ISFSI.[25] From this schedule, it is evident that Entergy plans to use the spent-fuel pool at nearly its full capacity, storing the overflow from that capacity in the ISFSI.

Extension of the Pilgrim operating license would imply the establishment of an ISFSI at the Pilgrim site. Entergy has not yet announced a plan to establish such an ISFSI. Given the continuing accumulation of spent fuel in the Pilgrim pool, and the time required to establish an ISFSI, it can reasonably be presumed that Entergy plans to use the Pilgrim spent-fuel pool at nearly its full capacity, storing the overflow from that capacity in a future ISFSI.

Inventories of cesium-137

The radioactive isotope cesium-137 provides a useful indicator of the hazard potential of the Pilgrim and Vermont Yankee spent-fuel pools. This isotope, which has a half-life of

[23] Holtec, 1993.
[24] Hoffman, 2005, states that the present Vermont Yankee racks have a center-to-center distance of 6.2 inches.
[25] Hoffman, 2005.

30 years, is a volatile element that would be liberally released during a pool fire.[26] Table 3-4 shows the estimated inventory of cesium-137 in the Pilgrim and Vermont Yankee spent-fuel pools during the period of license extension. This table shows that the pools will hold about 1.6 million TBq (Pilgrim) and 1.4 million TBq (Vermont Yankee) of cesium-137. For comparison, Tables 3-3 and 3-5 provide licensee estimates showing that the Pilgrim and Vermont Yankee reactor cores will hold 190,000 TBq and 179,000 TBq, respectively, of cesium-137. Thus, each pool will hold about 8 times as much cesium-137 as will be present in the adjacent reactor.

4. Trends in Management of Spent Fuel

Risks arising from storage of spent fuel will accumulate over time. Thus, it is important to estimate the time period during which spent fuel will be stored at the Pilgrim or Vermont Yankee site, whether in a pool or an onsite ISFSI. In testimony before the Vermont Public Service Board, an Entergy witness has stated that the US Department of Energy (DOE) could begin accepting spent fuel from Vermont Yankee as early as 2015, for emplacement in the proposed repository in Yucca Mountain, Nevada.[27]

Some decision makers have advocated a revival of spent-fuel reprocessing as an alternative to placing intact spent fuel in a repository. Reprocessing was the national strategy for spent-fuel management when the Pilgrim and Vermont Yankee plants were built, but was abandoned in the 1970s. If reprocessing were to resume, it would provide an option for removal of spent fuel from reactor sites.

This author has testified before the Vermont Public Service Board regarding the prospects for the Yucca Mountain repository, reprocessing, and other options for removal of spent fuel from the Vermont Yankee site. He concluded that spent fuel is likely to remain at the site for at least several decades, and potentially for more than a century.[28] The same arguments apply to the Pilgrim site. Here, selected arguments are summarized, to illustrate the factors that will hinder removal of spent fuel from each site.

Current national policy for long-term management of spent fuel is to establish a repository inside Yucca Mountain. Progress with this project has been slow, and many observers believe that it will be cancelled. Even if the repository does open, there will be a delay before fuel can be shipped to Yucca Mountain and emplaced in the repository. Table 4-1 shows a schedule projection by DOE, indicating that the emplacement process could occupy five decades.

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[26] A study by the US Department of Energy (DOE, 1987) shows that cesium-137 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 nuclear weapons tests in the atmosphere. Note that the particular mechanisms of the Chernobyl accident could not occur in the Pilgrim or Vermont Yankee pool.

[27] Hoffman, 2005.

[28] Thompson, 2006.

The US fleet of commercial reactors will probably produce more than 80,000 MgU of spent fuel if each reactor operates to the end of its initial 40-year license period. If each reactor received a 20-year license extension, the fleet could eventually produce a total of about 120,000 MgU of spent fuel. Yet, the capacity of Yucca Mountain is limited by federal statute to 63,000 MgU of spent fuel. DOE has investigated the option of placing 105,000 MgU of spent fuel in Yucca Mountain, which assumes a statute amendment. However, Table 4-2 shows that emplacement of 105,000 MgU of fuel could require an emplacement area of up to 3,800 acres if a lower-temperature operating mode is selected. Licensing considerations are likely to favor the selection of a lower-temperature operating mode, and there may not be enough space in the mountain to allow a total emplacement area of 3,800 acres. Thus, the physical capacity of Yucca Mountain could be less than 105,000 MgU of fuel.

As Table 4-3 shows, operation of the Yucca Mountain repository would involve a large number of spent-fuel shipments. This potential traffic poses a security concern, because there is evidence that shipping casks are more vulnerable to attack by sub-national groups than DOE has previously assumed.[29] Spent-fuel shipments could be comparatively attractive targets because they cannot be protected to the same extent as nuclear power plants.

A further impediment to shipping spent fuel to Yucca Mountain is that DOE has announced that it will receive fuel in standard canisters that are inserted, unopened, into waste packages prior to emplacement in the repository. Yet, as Table 4-4 shows, the concept of a standard canister is incompatible with the present configurations of dry-storage canisters and the proposed configurations of Yucca Mountain disposal packages. There is no clear path to resolution of this problem.

5. Technical Understanding of Spent-Fuel-Pool Fires

Section 2, 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 may be 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.[30] Benjamin's comment is quoted in the unclassified NAS report as follows:[31]

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[29] The term "sub-national group" is used in security analysis to describe a human group that is larger and more capable than an isolated individual, but is not an arm of a national government. This distinction has strategic significance because deterrence, a potentially effective means of influencing a national government, may not influence a sub-national group.
[30] Allan Benjamin was one of the authors of: Benjamin et al, 1979.
[31] NAS, 2006, page 45.

> 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. 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 EIS. These authors stated:[32]

> 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 2, above, four NRC documents were cited to support that review's finding regarding the risks of pool fires.[33] 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".[34] 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.[35] 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

[32] Alvarez et al, 2003, page 35.
[33] NRC, 1990a, page 38481.
[34] Sailor et al, 1987.
[35] Prassinos et al, 1989.

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.[36] It postulated a pool accident involving complete, instantaneous loss 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 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.[37] 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.[38] 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).[39]

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 a release of radioactive material. Present knowledge does not allow theoretical or empirically-based prediction of the source term for a postulated pool-fire scenario. Instead, informed judgment must be used.

Table 5-1 provides two versions of a source term for a pool fire at Pilgrim or Vermont Yankee. Each version assumes that a high-density pool would be almost full of spent

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[36] Throm, 1989.
[37] Jo et al, 1989.
[38] Collins and Hubbard, 2001.
[39] NRC, 1990b.

fuel, which is the expected mode of operation of each plant during the period of license extension.

One version of the source term involves a release of 100 percent of the cesium-137 in a pool. That is an upper limit. In practice, the cesium-137 release fraction would be less than 100 percent, but there is no way to determine if the largest achievable release fraction would be 90 percent or 95 percent or some other number. In any event, this large source term implies that all or most of the zirconium in the pool would oxidize. Table 5-1 assumes that the oxidation occurs over a period of 5 hours. The second version of the source term involves a release of 10 percent of the cesium-137 in the pool, with oxidation of 10 percent of the zirconium over a period of 0.5 hours.

Given present knowledge, the approximately 100-percent release and the 10-percent release are equally probable for a typical pool fire. A prudent decision maker could, therefore, reasonably use the 100-percent release to assess risks and risk-reducing options.

6. Initiation of a Pool Fire by an Accident Not Involving Malice

Section 2, above, provides a general description of the potential for a spent-fuel-pool fire. Such a fire could be caused by a variety of events. Here, accidental events not involving malice are considered, with a focus on the Pilgrim and Vermont Yankee plants. Section 7, below, considers events that involve malicious action.

At Pilgrim or Vermont Yankee, non-malicious events at the plant that could lead to a pool fire include: (i) an accidental aircraft impact, with or without an accompanying fuel-air explosion or fire; (ii) an earthquake; (iii) dropping of a fuel transfer cask or shipping cask; (iv) a fire inside or outside the plant building; and (v) a severe accident at the adjacent reactor.

Given the major consequences of a pool fire, analysis 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-melt scenarios, through studies such as NUREG-1150.[40] Neither the NRC nor the nuclear industry has conducted a comparable study of pool fires. In the absence of such a study, this report provides illustrative analysis.

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[40] NRC, 1990b.

A pool fire accompanied by a reactor accident

As mentioned in Section 1, above, at Pilgrim and Vermont Yankee the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. These plants are, therefore, comparatively likely to experience a pool fire that is accompanied by a reactor accident.

This combination of accidents is the focus of discussion here. The pool fire and the reactor accident might have a common cause. For example, a 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-melt accident occurs. In some scenarios, 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. In other scenarios, the high radiation field produced by a core-melt accident could initiate or exacerbate a pool-fire scenario, again by precluding the presence and functioning of operating personnel. Many core-melt scenarios would involve the interruption of cooling to the pool.

By focusing on a pool fire accompanied by a reactor accident, this report does not imply that other pool-fire scenarios make a smaller contribution to pool-fire risks at Pilgrim and Vermont Yankee. Such a conclusion could come only from a comprehensive assessment of pool-fire risks, and no such assessment has ever been performed.

Tables 6-1 and 6-2 provide licensee estimates of core-damage frequency (probability) and radioactive-release frequency for the Pilgrim and Vermont Yankee reactors.[41] Some of these estimates are from the Independent Plant Examination (IPE) and the Independent Plant Examination for External Events (IPEEE) that have been performed for each plant.[42] The remaining estimates are from the Environmental Report (Appendix E of the license renewal application) for each plant. In this report, the IPE and IPEEE estimates are used instead of the ER estimates, because the studies underlying the latter are not available for review.[43]

Estimates shown in Tables 6-1 and 6-2 that are of particular relevance to this report are the estimates of the probability (frequency) of an early release of radioactive material from the reactor. Table 6-3 provides a definition of "early" and other terms that are used to categorize potential radioactive releases. "High" and "medium" release scenarios, as defined in Table 6-3, are often "early" and vice versa.

[41] For present purposes, core damage is equivalent to core melt.
[42] Boston Edison, 1992; Boston Edison, 1994; VYNPS, 1993; VYNPS, 1998.
[43] NRC Public Document Room staff informed Diane Curran that the recent reactor-accident studies referenced in the Environmental Reports for Pilgrim and Vermont Yankee could not be located within the NRC.

Lessons from a license-amendment proceeding for the Harris plant

This report assumes that the conditional probability of a spent-fuel-pool fire, given an early release from the adjacent reactor, is 50 percent. That assumption is reasonable – and not necessarily conservative – for the Pilgrim or Vermont Yankee plant because the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. Support for this assumption is provided by technical studies and opinions submitted to the Atomic Safety and Licensing Board (ASLB) in a license-amendment proceeding in regard to the expansion of spent-fuel-pool capacity at the Harris nuclear power plant. All three parties to the proceeding – the NRC Staff, Carolina Power and Light (CP&L), and Orange County – reached the same conclusion on an issue that is relevant to the above-stated conditional probability of 50 percent.

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 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.[44] 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.[45] The NRC Staff submitted an affidavit by members of the Staff.[46] CP&L – the licensee – submitted a document prepared by ERIN Engineering.[47]

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. This 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

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[44] ASLB, 2000.
[45] Thompson, 2000.
[46] Parry et al, 2000.
[47] ERIN, 2000.

ASLB then terminated the proceeding without conducting an evidentiary hearing.[48] Elsewhere, the author has described deficiencies in the ASLB's ruling.[49]

A major 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. However, the Staff agreed with Orange County on some other matters. For example, the Staff reversed its previous position that comparatively long-discharged fuel will not ignite in the event of water loss from a high-density pool. 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."[50] 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 Pilgrim and Vermont Yankee plants have a different configuration than the Harris plant, because at Pilgrim and Vermont Yankee the reactor and the pool are within the same building whereas at Harris they are in different buildings. Thus, the Pilgrim and Vermont Yankee plants are analogous to the Harris pool building. Given an early release from the Pilgrim or Vermont Yankee reactor as part of a core-melt accident, hot gases and radioactive material from the reactor would spread throughout the building that encloses both. Provision of cooling and water makeup to the pool would be precluded, the radiation field and the thermal environment being even more extreme than in the Harris situation. The pool would boil and dry out, and its fuel would burn.

Thus, the three parties' agreement in the Harris proceeding implies their agreement that a pool fire would inevitably follow an early release as part of a core-melt accident at Pilgrim or Vermont Yankee. Against that background, this report's assumption of a conditional probability of 50 percent for a pool fire, given an early release, is reasonable.

7. Initiation of a Pool Fire by Malicious Action

The NRC's August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575) considered potential sabotage events at a spent-fuel pool.[51] Table 7-1 describes the postulated events, which encompassed the detonation of

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[48] ASLB, 2001.
[49] Thompson, 2001b.
[50] Parry et al, 2000, paragraph 29.
[51] NRC, 1979, Section 5 and Appendix J.

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 80 adversaries was implied.

NUREG-0575 did not, however, recognize the potential for an attack with these attributes to cause a fire in the pool.[52] Technically-informed attackers operating within this envelope of attributes could cause a fire in a pool at Pilgrim, Vermont Yankee or other plants. 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 reactor.[53] The radiation field from the reactor release would preclude personnel access, thus precluding recovery actions if command of the plant were returned to the operators after one half-hour.

The potential for a maliciously-induced pool fire at Pilgrim or Vermont Yankee is influenced by several factors. Here, the following factors are considered: (i) the present level of protection of nuclear power plants and spent fuel; (ii) options for providing greater protection; (iii) available means of attack; and (iv) motives for attack. In the context of an EIS, the first, third and fourth of these factors relate to the probability of a successful attack, and the second factor relates to alternatives.

The present level of protection of nuclear power plants and spent fuel

Site-security measures mandated by the NRC have made access to a nuclear power plant more difficult for attackers approaching on foot or by land vehicle than was the case in 1979.[54] Nevertheless, as discussed below, a successful attack could be mounted today using resources of the scale assumed in NUREG-0575 or employed to attack the United States on 11 September 2001. In light of information now available, the NRC could prepare a supplement to NUREG-0575 that updates its sabotage analysis. This supplement could employ a classified appendix to prevent public disclosure of sensitive information.

The consideration of sabotage events in NUREG-0575 is an exception. As a general rule, the NRC does not consider malicious acts 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 rejecting this contention the ASLB stated:[55]

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[52] The sabotage events postulated in NUREG-0575 yielded comparatively small radioactive releases.
[53] In some areas of the Pilgrim or Vermont Yankee reactor building, one explosive charge could potentially breach the pool wall, the reactor containment, and the reactor vessel.
[54] NRC, 2004; Thompson, 2004.
[55] ASLB, 1982.

> 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.

As indicated by the ASLB, the NRC's basic policy on protecting nuclear facilities from attack is laid down in the regulation 10 CFR 50.13. This 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:[56]

> 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.

Pursuant to 10 CFR 50.13, licensees are not required to design or operate nuclear facilities to resist enemy attack. However, events have obliged the NRC to progressively modify this position, so as to require greater protection against malicious or insane acts by sub-national groups. A series of events, including the 1993 bombing of the World Trade Center in New York, persuaded the NRC to introduce, in 1994, regulations requiring licensees to defend nuclear power plants against vehicle bombs. The attacks of 11 September 2001 led the NRC to require additional measures.

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 was promulgated in April 2003. Prior to February 2002 the DBT was published, but not thereafter. The NRC has described the present DBT for nuclear power plants as follows:[57]

[56] Federal Register, Vol. 32, 26 September 1967, page 13445.
[57] NRC Press Release No. 03-053, 29 April 2003.

> 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. It was arrived at after extensive deliberation and interaction with cleared stakeholders from other Federal agencies, State governments and industry.

From this 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.[58]

A rationale for the present level of protection of nuclear facilities was articulated by the NRC chair, Richard Meserve, in 2002:[59]

> 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.

Options for providing greater protection

Chairman Meserve's statement does not consider another approach – designing new infrastructure elements or modifying existing elements so that they are more robust against attack. It has been known for decades that nuclear power plants could 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.[60]

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[58] Fertel, 2006; Wells, 2006; Brian, 2006.
[59] Meserve, 2002, page 22.
[60] Hannerz, 1983.

As explained in Section 8, below, the spent-fuel pools at the Pilgrim and Vermont Yankee plants would be more robust against attack if they were re-equipped with low-density, open-frame storage racks. This step would restore the pools to their original design configuration.

Available means of attack

In considering the potential for a future attack on the Pilgrim or Vermont Yankee spent-fuel pool, it is necessary to consider both means and motives. Table 7-2 provides some general information about means. This table shows that nuclear power plants are vulnerable to attack by means available to sub-national groups. For example, one of the potential instruments of attack shown in Table 7-2 is an explosive-laden smaller aircraft. In this connection, 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:[61]

> 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.

Sub-national groups could obtain explosive devices that would be effective instruments of attack on a nuclear power plant.[62] Assistance from a government or access to classified information would not be required. Designs for sophisticated explosive devices capable of exploiting the vulnerabilities of the Pilgrim or Vermont Yankee spent-fuel pools are publicly available from sources including the web. Means for delivery of such devices to the target are also readily available.[63]

Motives for attack

Understanding the factors that could motivate a sub-national group to attack a civilian nuclear facility in the USA is a difficult task. Multiple, competing factors will be in play, and will affect different groups in different ways. An attacking group might be foreign, as was the case in New York and Washington in September 2001, or domestic, as was the case in Oklahoma City in April 1995 and London in July 2005. As we try to understand

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[61] Dillingham, 2003, page 14.
[62] Walters, 2003.
[63] For example: Raytheon, 2004; the website www.aircraftdealer.com, accessed 6 November 2004.

the complex issue of motives, one requirement is clear. We must set aside our own perspectives, and attempt to understand the perspectives of those who might attack us. That understanding will help us to assess risks and prepare countermeasures.

One insight from experience is that an attack by a sub-national group could be part of an action-reaction cycle.[64] Former CIA Director Stansfield Turner has recounted how the October 1983 truck bombing of a US Marine barracks in Beirut was part of such a cycle.[65] A high-level task force convened by the Council on Foreign Relations recognized the potential for an action-reaction effect in the context of US military operations with counterterrorism objectives. They recommended that this effect be offset by greater protection of domestic targets. An October 2002 report of the task force stated:[66]

> *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.

Probability of attack

For policy and planning purposes, it would be useful to have an estimate of the probability of an attack-induced spent-fuel-pool fire. The record of experience does not allow a statistically valid estimate of this probability. A decision maker or risk analyst must, therefore, rely on prudent judgment.[67] In the case of an attack-induced spent-fuel-pool fire in the USA, prudent judgment indicates that a probability of at least one per century is a reasonable assumption for policy purposes.

8. Options to Reduce the Risks of Pool Fires

Various options are available to reduce the probability and/or magnitude of an atmospheric release from a spent-fuel-pool fire at Pilgrim or Vermont Yankee. A useful option must achieve one or more of the following five effects: (i) reduce the probability of a loss of water; (ii) reduce the potential for ignition of fuel following a loss of water; (iii) reduce the potential for fire propagation following ignition of one or more fuel

[64] Davis, 2006.
[65] Turner, 1991.
[66] Hart et al, 2002, pp 14-15.
[67] The NRC has used qualitative judgment about the probability of attack as a basis for the 1994 vehicle-bomb rule and the present design basis threat.

assemblies; (iv) reduce the inventory of spent fuel in the pool; or (v) suppress a fire in the pool.

The fifth effect – fire suppression – would be extremely difficult to achieve. Spraying water on a fire could feed a zirconium-steam reaction. In principle, an air-zirconium reaction in the pool could be smothered, perhaps by spreading large amounts of a non-reactive powder. In practice, the high radiation field surrounding the pool would preclude the approach of firefighters. Here, the focus is on the first four effects.

Table 8-1 describes selected risk-reducing options that could, to some degree, achieve one or more of the first four effects. This table does not purport to identify a comprehensive set of risk-reducing options, or to provide a complete assessment of the listed options. Instead, this table illustrates the range of options and their properties.

The option that would achieve the largest risk reduction, during plant operation within a license extension period, would be to re-equip the pool with low-density, open-frame storage racks. Implementation of this option would return the plant to its original design configuration. Excess spent fuel would be placed in dry storage at the plant site. This option would not reduce the probability of a loss of water. Instead, it would allow the pool to survive a loss of water without damage to the fuel. It would prevent ignition of fuel in almost all scenarios of water loss. For the few, unlikely scenarios that would remain, it would inhibit fire propagation across the pool. By reducing the inventory of radioactive material in the pool, this option would limit the magnitude of the greatest possible release.

Re-equipping a spent-fuel pool with low-density, open-frame racks would be an entirely passive measure of risk reduction. Successful functioning of this option would not require electricity, a water supply, the presence of personnel, or any other active function. Passive risk-reduction measures of this type represent good practice in nuclear engineering design. Reactor vendors are seeking to use passive-safety principles in the design of new commercial reactors.

Nuclear power plants are important elements of the nation's critical infrastructure. Other elements of that infrastructure also offer opportunities to use passive measures of risk reduction. Passive measures can be highly reliable and predictable in their effectiveness. They can substitute for other measures to protect critical infrastructure, as shown in Table 8-2, yielding monetary and non-monetary benefits.

Table 8-3 provides an estimated cost for offloading spent fuel from the Pilgrim or Vermont Yankee pool, to allow the pool to be re-equipped with low-density, open-frame racks. There would be an additional, smaller cost for replacing the racks, which is neglected here. Note that Table 8-3 does not purport to provide a definitive specification for re-equipment of the pools, or a final estimate of the cost of this option. The analysis presented in Table 8-3 is illustrative. A more sophisticated analysis would not alter the basic findings of this report.

From Table 8-3 one sees that the estimated cost of a transition to low-density, open-frame racks would be $54-109 million at Pilgrim and $43-87 million at Vermont Yankee. Approximately the same cost would otherwise be incurred during decommissioning of the plant, when spent fuel would be offloaded from the pool to dry storage. The net additional cost of the option would reflect the comparative present values of approximately equal expenditures now or two decades in the future.

9. An Integrated View of Risks and Risk-Reducing Options

Preceding sections of this report have discussed particular aspects of the risks and risk-reducing options associated with pool storage of spent nuclear fuel. To produce useful policy findings, these separate discussions must be integrated.

Section 6 of this report provides, in Tables 6-1 and 6-2, licensee estimates of the probability of an early release as part of a severe reactor accident – of non-malicious origin – at Pilgrim or Vermont Yankee. Also, Section 6 develops the reasonable assumption that the conditional probability of a spent-fuel-pool fire, given an early release from the reactor, is 50 percent. Section 7 sets forth a judgment that the probability of a successful, attack-induced spent-fuel-pool fire in the USA can be assumed, for policy purposes, to be at least one per century. Section 8 provides an estimate that the cost of a transition to low-density, open-frame racks in a spent-fuel pool would be $54-109 million at Pilgrim and $43-87 million at Vermont Yankee.

Table 9-1 combines the findings of Sections 6 and 7, yielding an estimate that the total probability of a pool fire at Pilgrim or Vermont Yankee is 1.2 per 10,000 years at each plant. A number of simplifying assumptions are employed in Table 9-1, as is evident from the table. A more sophisticated analysis would not alter the general findings of this report.

Entergy's Environmental Reports for Pilgrim and Vermont Yankee present a cost-versus-benefit analysis as a means of evaluating Severe Accident Mitigation Alternatives. Table 9-2 illustrates this type of analysis. The table shows that an investment of $110-200 million (depending on discount rate) is justified to prevent a radioactive release with a probability of one per 10,000 years and a consequence cost of $100 billion.

A companion report by Dr. Jan Beyea shows that the consequence cost attributable to a spent-fuel-pool fire at Pilgrim or Vermont Yankee would exceed $100 billion across a range of release scenarios.[68] This report estimates that the probability of a pool fire at Pilgrim or Vermont Yankee is more than one per 10,000 years at each plant. Re-equipping the Pilgrim or Vermont Yankee pool with low-density, open-frame racks would substantially reduce the probability of a pool fire and the magnitude of its

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[68] The findings in Dr. Beyea's companion report are consistent with previous analysis provided in: Beyea et al, 2004.

consequences. To a first-order approximation, re-equipping a pool in this manner would eliminate the risk of a pool fire. The cost of re-equipping a pool would be less than $110 million. Thus, a SAMA-type analysis shows that re-equipping both pools with low-density, open-frame racks is justified.

The analysis underlying this conclusion does not purport to be comprehensive. This analysis is, however, sufficient to show that Entergy and the NRC are obliged to perform new studies, as described in Section 10, below.

Probabilistic analysis, of the type that is used in Table 9-1 and in Entergy's Environmental Reports, should not be the only means of evaluating Severe Accident Mitigation Alternatives. People who are unfamiliar with probabilistic risk assessment may place unwarranted faith in the numerical values that it generates. A closer look at probabilistic risk assessment for nuclear power plants shows that its findings are plagued by incompleteness and uncertainty.[69] These findings cannot substitute for prudent, informed judgment. In exercising that judgment, decision makers should be aware of strategic considerations, such as those addressed in Table 8-2.

10. Analysis Required From Entergy and the Nuclear Regulatory Commission

Entergy's Environmental Reports for the Pilgrim and Vermont Yankee plants do not examine the potential for a radioactive release from a fire in a spent-fuel pool. Nor do they consider SAMA-type options that could reduce the probability and/or magnitude of such a release. Similarly, the NRC does not consider such options in its GEIS for re-licensing of nuclear power plants.

Yet, the NRC has determined that the potential for a reactor core-melt accident must be considered in a re-licensing EIS. Moreover, a spent-fuel-pool fire at Pilgrim or Vermont Yankee has, according to this report, a probability comparable to the probability of a reactor core-melt accident. Finally, the offsite radiological impact of the pool fire could be substantially greater than the impact of the core-melt accident, because the pool has a larger inventory of cesium-137. Therefore, the potential for a pool fire should be considered in an Environmental Report or EIS for re-licensing. Such studies should use at least the depth of analysis that is employed to consider the potential for a core-melt accident.

Entergy should withdraw, revise and re-submit its Environmental Reports. In addressing the potential for pool fires, each revised ER should consider the full range of potential initiating events, including acts of malice. Options for reducing the risks of pool fires should be considered to at least the depth of analysis that is employed for SAMAs in the context of reactor accidents.

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[69] Hirsch et al, 1989.

The NRC should prepare generic supplements to its August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575), and its May 1996 GEIS on license renewal (NUREG-1437). These supplements should address the risks of spent-fuel-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).[70] In addition, the supplements should identify a range of options to reduce the risks of pool fires, and should comprehensively assess the benefits and costs of these options. An EIS prepared for re-licensing of Pilgrim or Vermont Yankee should incorporate the findings of the new, generic supplements to NUREG-0575 and NUREG-1437.

11. Conclusions

Discussions in preceding sections of this report lead to the following major conclusions:

C1. At the Pilgrim and Vermont Yankee plants, large amounts of spent nuclear fuel are stored in water-filled pools equipped with high-density, closed-form storage racks. Entergy plans to continue this practice during the period of license extension, operating the pools at near to full capacity.

C2. The radioactive isotope cesium-137 provides a useful indicator of the hazard potential of the Pilgrim and Vermont Yankee spent-fuel pools. During the period of license extension, it is likely that these pools will hold about 1.6 million TBq (Pilgrim) and 1.4 million TBq (Vermont Yankee) of cesium-137. Each pool will hold about 8 times as much cesium-137 as will be present in the adjacent reactor.

C3. Various studies by the NRC and other bodies have shown that loss of water from a spent-fuel pool equipped with high-density, closed-form storage racks would, over a range of scenarios, lead to self-ignition of some of the fuel assemblies in the pool, leading to a fire that could propagate across the pool. Burning of fuel assemblies would lead to a large atmospheric release of cesium-137 and other radioactive isotopes. These findings have been confirmed by a 2005 report prepared by the National Academy of Sciences at the request of the US Congress.

C4. Entergy has submitted an Environmental Report (ER) as part of each license extension application. Each ER examines potential reactor accidents involving damage to the reactor core and release of radioactive material to the atmosphere. That examination supports the ER's evaluation of Severe Accident Mitigation Alternatives (SAMAs) – options that could reduce the probability and/or magnitude of a radioactive release from the reactor. Neither ER examines the potential for a radioactive release from a fire in a spent-fuel pool, or considers SAMA-type options that could reduce the probability and/or magnitude of such a release.

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[70] NRC, 1990b.

C5. The NRC has published various documents that discuss aspects of the potential for a spent-fuel-pool fire. Only three of these 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 document is the August 1979 Generic Environmental Impact Statement (GEIS) on handling and storage of spent fuel (NUREG-0575). The second document is the May 1996 GEIS on license renewal (NUREG-1437). These two documents purported to provide systematic analysis of the risks and relative costs and benefits of alternative options. The third document is a September 1990 review (55 FR 38474) of the NRC's Waste Confidence Decision. That document did not purport to provide an analysis of risks and alternatives. None of the three documents provides a technically defensible examination of spent-fuel-pool fires and the associated risks and alternatives. The findings in each document are inconsistent with the more recent and more credible findings of the National Academy of Sciences, set forth in its 2005 report, and the findings of other studies conducted since 1996.

C6. The August 1979 GEIS (NUREG-0575) considered potential sabotage events at a spent-fuel pool. The GEIS did not recognize the potential for an attack with the postulated attributes to cause a fire in the pool. Technically-informed attackers operating within this envelope of attributes could, with high confidence, cause an unstoppable fire in a pool.

C7. Site-security measures mandated by the NRC have made access to a nuclear power plant more difficult for attackers approaching on foot or by land vehicle than was the case in 1979. Nevertheless, a successful attack could be mounted using resources of the scale assumed in NUREG-0575 or employed to attack the United States on 11 September 2001. The NRC has not prepared any environmental impact statement or comparable study that updates the sabotage analysis set forth in NUREG-0575.

C8. The record of experience does not allow a statistically valid estimate of the probability of an attack-induced spent-fuel-pool fire in the USA. Prudent judgment indicates that a probability of at least one per century is a reasonable assumption for policy purposes. This translates to a probability of one per 10,000 years at Pilgrim or Vermont Yankee, which is comparable to the estimated probability of a reactor core-melt accident according to probabilistic risk studies done for these plants.

C9. Probabilistic risk studies done by licensees for the Pilgrim and Vermont Yankee plants can support an estimate of the probability of a spent-fuel-pool fire that is caused by or accompanies a core-melt accident at the adjacent reactor. The connection between these events is particularly strong at these plants because the pool and the reactor are in close physical proximity within the same building, and some of their essential support systems are shared. A provisional estimate of the probability of a spent-fuel-pool fire associated with a core-melt accident, not involving malice, is about two per 100,000 years at each plant.

C10. Options are available to reduce the probability and/or magnitude of an atmospheric release from a spent-fuel-pool fire at Pilgrim or Vermont Yankee. The option that would achieve the largest risk reduction, during plant operation within a license extension period, would be to re-equip the pool with low-density, open-frame racks. This step would return the plant to its original design configuration. Excess spent fuel would be placed in dry storage at the plant site. The estimated cost of this option would be $54-109 million at Pilgrim and $43-87 million at Vermont Yankee. Approximately the same cost would otherwise be incurred during decommissioning of the plant, when spent fuel would be offloaded from the pool to dry storage. The net additional cost of the option would reflect the comparative present values of approximately equal expenditures now or two decades in the future.

C11. Re-equipping a spent-fuel pool with low-density, open-frame racks would be a passive measure that would eliminate most scenarios for a pool fire and greatly reduce the atmospheric release for the few, unlikely scenarios that would remain. Passive risk-reduction measures of this type represent good practice in nuclear engineering design. Substantial benefits, both monetary and non-monetary, could arise from the deployment of passive risk-reduction measures at nuclear power plants and other elements of critical infrastructure.

C12. Entergy's Environmental Reports present a cost-versus-benefit analysis as a means of evaluating Severe Accident Mitigation Alternatives. This type of analysis should not be the only basis for evaluating SAMAs, but can provide useful information. The analysis shows that an investment of $110-200 million (depending on discount rate) is justified to prevent a radioactive release with a probability of one per 10,000 years and a consequence cost of $100 billion. A companion report by Dr. Jan Beyea shows that the consequence cost attributable to a spent-fuel-pool fire at Pilgrim or Vermont Yankee would exceed $100 billion across a range of release scenarios. Given the pool-fire probability found in this report (at least one per 10,000 years), and the estimated cost of re-equipping the Pilgrim or Vermont Yankee pool with low-density, open-frame racks (less than $110 million), re-equipment of both pools in this manner is justified.

C13. The NRC has determined that the potential for a reactor core-melt accident must be considered in an environmental impact statement for the re-licensing of a nuclear power plant. Thus, the NRC has determined that such an accident is neither remote nor speculative. A spent-fuel-pool fire at Pilgrim or Vermont Yankee has, by estimation in this report, a probability comparable to the probability of a reactor core-melt accident. The offsite radiological impact of the pool fire could be substantially greater than the impact of the core-melt accident. Therefore, the potential for a pool fire should be considered in a re-licensing EIS to at least the depth accorded the consideration of a core-melt accident.

C14. Entergy should withdraw, revise and re-submit its Environmental Reports for Pilgrim and Vermont Yankee. The revised ERs should address the potential for pool fires to at least the depth of analysis that is employed for reactor accidents. The pool-fire analysis should consider the full range of potential initiating events, including acts of malice. Options for reducing the risks of pool fires should be considered to at least the depth of analysis that is employed for SAMAs in the context of reactor accidents.

C15. The NRC should prepare supplements to its August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575), and its May 1996 GEIS on license renewal (NUREG-1437). These supplements should address the risks of spent-fuel-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). Acts of malice should be considered. In addition, the supplements should identify a range of options to reduce the risks of pool fires, and should comprehensively assess the benefits and costs of these options.

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Table 3-1
Selected Characteristics of the Pilgrim and Vermont Yankee Plants

Characteristic	Pilgrim	Vermont Yankee
Reactor type	BWR Mark 3	BWR Mark 4
Containment type	Mark 1: Drywell and free-standing torus	Mark 1: Drywell and free-standing torus
Rated power	2,028 MWt	1,593 MWt; application pending for 20% uprate to 1,912 MWt
Number of fuel assemblies in reactor core	580	368
Date of first commercial operation	December 1972	November 1972
Date of expiration of present operating license	June 2012	March 2012
Heat sink	Ocean	Connecticut River and/or cooling towers
Inventory of cesium-137 in reactor core	1.90E+17 Bq (Assumed power: 2,028 MWt)	1.79E+17 Bq (Assumed power: 1,912 MWt)

Sources:
(a) Jay R. Larson, *System Analysis Handbook, NUREG/CR-4041*, USNRC, November 1985.
(b) License renewal application, Appendix E (for each plant).

Table 3-2
Selected Characteristics of the Spent-Fuel Pools at the Pilgrim and Vermont Yankee Plants

Characteristic	Pilgrim	Vermont Yankee
Licensed capacity	3,859 fuel assemblies	• In 1988: 2,870 fuel assemblies; unused floor space could hold racks with potential additional capacity of about 360 assemblies • At present: 3,355 fuel assemblies, incl. temporary, 266-cell rack in cask position
Inventory at end of 2002	2,274 fuel assemblies	2,671 fuel assemblies
Capacity needed for full-core discharge	580 fuel assemblies	368 fuel assemblies
Floor dimensions	40 ft 4 in by 30 ft 6 in; 5 ft 8 in thick	40 ft 0 in by 26 ft 0 in; 5 ft 0 in thick including 11 in of grout
Depth	38 ft 9 in	38 ft 9 in
Wall thicknesses	Reactor shield wall forms one face; thicknesses of other walls range from 4 ft 1 in to 6 ft 1 in.	Reactor shield wall forms one face; thicknesses of other walls range from 4 ft 6 in to 6 ft 0 in.
Typical spent fuel assembly	General Electric 8x8; 210 kgU per assembly	General Electric 8x8; 210 kgU per assembly

Sources:
(a) USNRC documentation of Amendment No. 155, Pilgrim operating license.
(b) USNRC documentation of Amendment No. 104, Vermont Yankee operating license.
(c) P. G. Prassinos et al, *Seismic Failure and Cask Drop Analyses of the Spent Fuel Pools at Two Representative Nuclear Power Plants, NUREG/CR-5176,* USNRC, January 1989.
(d) Vermont Yankee Nuclear Power Corporation, *Vermont Yankee Spent Fuel Storage Rack Replacement Report,* April 1986.
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(g) Anthony Andrews, *Spent Nuclear Fuel Storage Locations and Inventory, CRS Report for Congress,* 21 December 2004.
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Table 3-3
Estimation of Cesium-137 Inventory in a Spent-Fuel Assembly and the Reactor Core, for the Pilgrim and Vermont Yankee Plants

Estimation Step	Pilgrim	Vermont Yankee
Fuel burnup at discharge	B MWt-days per kgU	B MWt-days per kgU
Discharge burnup assuming each fuel assembly has a mass of 210 kgU	210xB MWt-days per assembly	210xB MWt-days per assembly
Reactor characteristics	• Rated power: 2,028 MWt • 580 fuel assemblies	• Rated power: 1,912 MWt • 368 fuel assemblies
Av. rated power per assembly	2,028/580 = 3.50 MWt	1,912/368 = 5.20 MWt
Av. full-power days per assembly	210xB/3.50 = 60.0xB days	210xB/5.20 = 40.4xB days
Av. full-power days per assembly, assuming B = 30	1,800 days = 4.93 yr	1,212 days = 3.32 yr
Av. actual days of exposure per assembly, assuming plant capacity factor = 0.90	2,000 days = 5.48 yr	1,347 days = 3.69 yr
Cesium-137 inventory in av. fuel assembly at completion of exposure	7.24E+14 Bq	7.39E+14 Bq
Approx. core inventory of cesium-137	((7.24E+14)/2)x580 = 2.10E+17 Bq	((7.39E+14)/2)x368 = 1.36E+17 Bq
Core inventory of cesium-137 as reported in Appendix E of license renewal application	1.90E+17 Bq	1.79E+17 Bq

Notes:
Here, calculation of the cesium-137 inventory in an average fuel assembly assumes steady-state fission of uranium-235 with an energy yield of 200 MeV per fission and a cesium-137 fission yield of 6.2 percent, over the actual days of exposure with a constant power level of 0.90 times the rated power level.

Table 3-4
Estimated Future Inventory and Selected Characteristics of Spent Fuel in Pools at the Pilgrim and Vermont Yankee Plants

Estimation Step	Pilgrim	Vermont Yankee
Licensed capacity	3,859 fuel assemblies	3,089 fuel assemblies (Not including temporary, 266-cell rack in cask position)
Capacity needed for full-core discharge	580 fuel assemblies	368 fuel assemblies
Assumed periodic offload of older fuel assemblies to onsite dry-storage modules	Offload to fill 3 modules, each of 68-assembly capacity: 204 assemblies	Offload to fill 3 modules, each of 68-assembly capacity: 204 assemblies
Average inventory of spent fuel, assuming pool used at near-full capacity	3,859 – 580 – 204/2 = 3,177 fuel assemblies	3,089 – 368 – 204/2 = 2,619 fuel assemblies
Av. period of exposure of assembly in core, assuming burnup of 30 MWt-days per kgU and plant capacity factor of 0.90	5.48 yr	3.69 yr
Av. age of fuel assemblies after discharge to pool	(3,177/(580/5.48))/2 = 15.0 yr	(2,619/(368/3.69))/2 = 13.1 yr
Cesium-137 in av. fuel assembly at discharge	7.24E+14 Bq	7.39E+14 Bq
Cesium-137 in pool, assuming all assemblies at average age	1.63E+18 Bq (44.1 MCi)	1.43E+18 Bq (38.6 MCi)
Mass of zirconium in pool, assuming 60 kg per fuel assembly	191,000 kg	157,000 kg

Notes:
Data on a General Electric 8x8 fuel assembly are provided in Table G.4 of: USNRC, *Generic EIS on Handling and Storage of Spent Light Water Power Reactor Fuel, NUREG-0575*, August 1979. The total mass of an assembly is 275 kg and the mass of uranium is 210 kg. If all non-U mass were Zr, then the mass ratio of Zr to U would be 0.31. For comparison, masses of U and Zr in the core of the Peach Bottom BWR are provided in Table 4.7 of: M. Silberberg et al, *Reassessment of the Technical Bases for Estimating Source Terms, NUREG-0956*, USNRC, July 1986. The U mass is 138 Mg and the Zr mass is 64.1 Mg. Thus, the mass ratio of Zr to U in the core is 0.46. In the table above, it is assumed that each fuel assembly contains 60 kg of Zr, representing a Zr-to-U mass ratio of 0.29.

Table 3-5
Illustrative Inventories of Cesium-137

Case	Inventory of Cesium-137 (TBq)
Produced during detonation of a 10-kilotonne fission weapon	67
Released to atmosphere during Chernobyl reactor accident of 1986	89,000
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.)	740,000
In Pilgrim spent-fuel pool during period of license extension	1,630,000
In Vermont Yankee spent-fuel pool during period of license extension	1,430,000
In Pilgrim reactor core	190,000
In Vermont Yankee reactor core	179,000

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) Inventories in the sixth and seventh rows are from Appendix E of the license renewal application for each plant.

Table 4-1
Estimated Duration of Phases of Implementation of the Yucca Mountain Repository

Phase of Repository Implementation		Duration of Phase (years)	
		If Yucca Mountain Total Inventory of Commercial Spent Fuel = 63,000 MgU	If Yucca Mountain Total Inventory of Commercial Spent Fuel = 105,000 MgU
Construction phase		5	5
Operation and monitoring phases	Development	22	36
	Emplacement	24-50	38-51
	Monitoring	76-300	62-300
Closure phase		10-17	12-23

Notes:
(a) These estimates are from the Final EIS for Yucca Mountain, DOE/EIS-0250F, Volume I, February 2002, pages 8-8 and 2-18.
(b) The Development and Emplacement phases would begin on the same date. Other phases would be sequential.
(c) The Construction phase would begin with issuance of construction authorization, and end with issuance of a license to receive and dispose of radioactive waste.

Table 4-2
Potential Emplacement Area of the Yucca Mountain Repository for Differing Spent-Fuel Inventories and Operating Modes

Total Inventory of Commercial Spent Fuel in Repository (MgU)	Emplacement Area (acres)	
	Higher-Temperature Operating Mode	Lower-Temperature Operating Modes
63,000	1,150	1,600 to 2,570
105,000	1,790	2,480 to 3,810

Source: Final EIS for Yucca Mountain, DOE/EIS-0250F, Volume I, February 2002, page 8-9.

Table 4-3
Estimated Number of Radioactive-Waste Shipments to the Yucca Mountain Site

Category of Radioactive Waste	Total Number of Shipments			
	If Yucca Mountain Total Inventory of Commercial Spent Fuel = 63,000 MgU		If Yucca Mountain Total Inventory of Commercial Spent Fuel = 105,000 MgU	
	By Truck	By Rail	By Truck	By Rail
** *If shipment mostly by truck* **				
Commercial spent fuel	41,000	0	80,000	0
All wastes	53,000	300	109,000 to 110,000	300 to 360
** *If shipment mostly by rail* **				
Commercial spent fuel	1,100	7,200	3,100	13,000
All wastes	1,100	9,700	3,100	18,000 to 19,000

Source: Final EIS for Yucca Mountain, DOE/EIS-0250F, Volume I, February 2002, page 8-8.

Table 4-4
Characteristics of BWR-Spent-Fuel Storage Canisters or Disposal Packages Proposed for Use at the Monticello or Skull Valley ISFSIs, or at Yucca Mountain

Category	Characteristics of Storage Canister or Disposal Package		
	NUHOMS 61BT Storage Canister (proposed for Monticello ISFSI)	**HI-STORM 100 MPC-68 Storage Canister (proposed for Skull Valley)**	**Proposed Disposal Package for Emplacement in Yucca Mountain**
Vendor	Transnuclear West	Holtec	Unknown
Capacity (number of BWR fuel assemblies)	61	68	24 or 44
Wall thickness	0.5 in. (stainless steel)	0.5 in. (stainless steel)	2.0 in. (stainless steel) plus 0.8 in. outer layer (Alloy 22)
Length	196.0 in.	190.3 in.	201.0 in. (for 24 assemblies) or 203.3 in. (for 44 assemblies)
Diameter	67.2 in.	68.4 in.	51.9 in. (for 24 assemblies) or 65.9 in. (for 44 assemblies)
Neutron absorber material	Boral	Boral	Borated stainless steel
Fill gas	Helium	Helium	Helium
Presence of aluminum thermal shunts to transfer interior heat to wall of vessel ?	No	No	No for 24 assemblies, Yes for 44 assemblies

Notes:
(a) NUHOMS data are from: Xcel Energy's Application to the Minnesota PUC for a Certificate of Need to Establish an ISFSI at the Monticello Generating Plant, 18 January 2005, Section 3.7; and Transnuclear West's FSAR for the Standardized NUHOMS system, Revision 6, non-proprietary version, October 2001.
(b) HI-STORM data are from Holtec's FSAR for the HI-STORM 100 system, Holtec Report HI-2002444, Revision 1.
(c) Characteristics of the Yucca Mountain package are from the Yucca Mountain Science and Engineering Report, DOE/RW-0539, May 2001, Section 3.

Table 5-1
Estimated Source Term for Atmospheric Release from Spent-Fuel-Pool Fire at the Pilgrim or Vermont Yankee Plant

Indicator	Pilgrim	Vermont Yankee
	** *Large Release* **	
Release to atmosphere of 100% of cesium-137 in pool	1.63E+18 Bq	1.43E+18 Bq
Thermal power of fire, assuming oxidation of 100% of Zr over 5 hrs	191,000x12.1/(5x60x60) = 128 MW	157,000x12.1/(5x60x60) = 106 MW
	** *Smaller Release* **	
Release to atmosphere of 10% of cesium-137 in pool	1.63E+17 Bq	1.43E+17 Bq
Thermal power of fire, assuming oxidation of 10% of Zr over 0.5 hrs	19,100x12.1/(0.5x60x60) = 128 MW	15,700x12.1/(0.5x60x60) = 106 MW

Notes:
(a) Pool inventories of cesium-137 and zirconium are from Table 3-4.
(b) The heat of reaction of Zr with oxygen or water is provided in Table 3-1 of: Louis Baker Jr. and Robert C. Liimatainen, "Chemical Reactions", Chapter 17 in T. J. Thompson and J. G. Beckerley (editors), *The Technology of Nuclear Reactor Safety*, MIT Press, 1973. The heat of reaction with oxygen is 12.1 MJ/kg, and the heat of reaction with water (steam) is 6.53 MJ/kg. In the table above, it is assumed that Zr reacts with air (oxygen).

Table 6-1
Licensee Estimates of Core Damage Frequency and Radioactive Release Frequency, Pilgrim Plant

Indicator	Source of Estimate	Estimated Frequency	Est. Frequency Adjusted (by factor of 6) to Account for External Events & Uncertainty
Core damage freq. (internal events)	License renewal application, App. E	6.4E-06 per yr	3.8E-05 per yr
Core damage frequency (fires)	License renewal application, App. E	1.9E-05 per yr	Not relevant
Core damage freq. (earthquakes)	License renewal application, App. E	3.2E-05 per yr	Not relevant
Large, early release frequency (internal events)	License renewal application, App. E	1.1E-07 per yr	6.8E-07 per yr
Medium, early release frequency (internal events)	License renewal application, App. E	6.5E-08 per yr	3.9E-07 per yr
Core damage frequency (internal events)	IPE, September 1992	5.8E-05 per yr	This adjustment not used in this source
Core damage frequency (fires)	IPEEE, July 1994	2.2E-05 per yr	Not relevant
Core damage frequency (earthquakes)	IPEEE, July 1994	5.8E-05 per yr (EPRI) 9.4E-05 per yr (LLNL)	Not relevant
Early release frequency (internal events)	IPE, September 1992	1.3E-05 per yr	This adjustment not used in this source
Early release frequency (earthquakes)	IPEEE, July 1994	1.6E-05 per yr (EPRI) 3.2E-05 per yr (LLNL)	Not relevant

Table 6-2
Licensee Estimates of Core Damage Frequency and Radioactive Release Frequency, Vermont Yankee Plant

Indicator	Source of Estimate	Estimated Frequency	Est. Frequency Adjusted (by factor of 10) to Account for External Events & Uncertainty
Core damage frequency (internal events)	License renewal application, App. E	5.0E-06 per yr	5.0E-05 per yr
Core damage frequency (fires)	License renewal application, App. E	5.6E-05 per yr	Not relevant
Core damage frequency (earthquakes)	License renewal application, App. E	Not estimated in this source or in IPEEE of June 1998	Not relevant
Large, early release frequency (internal events)	License renewal application, App. E	1.6E-06 per yr	1.6E-05 per yr
Medium, early release frequency (internal events)	License renewal application, App. E	2.1E-06 per yr	2.1E-05 per yr
Core damage frequency (internal events except intl. floods)	IPE, December 1993	4.3E-06 per yr	This adjustment not used in this source
Core damage frequency (internal floods)	IPEEE, June 1998	9.0E-06 per yr	Not relevant
Core damage frequency (fires)	IPEEE, June 1998	3.8E-05 per yr	Not relevant
Large, early release frequency (internal events except intl. floods)	IPE, December 1993	9.4E-07 per yr	This adjustment not used in this source
Medium, early release frequency (internal events except intl. floods)	IPE, December 1993	8.0E-07 per yr	This adjustment not used in this source

Table 6-3
Categories of Release to Atmosphere by Core-Damage Accidents at Pilgrim and Vermont Yankee Nuclear Plants

Release Magnitude		Release Timing	
Category	**Release of Cesium from Reactor Core to Atmosphere**	**Category**	**Timing of Release Initiation After Accident Begins**
High	Greater than 10%	Early	Less than 6 hrs
Medium	1% to 10%		
Low	0.1% to 1%	Intermediate	6 hrs to 24 hrs
Low-Low	0.001% to 0.1%		
Negligible	Less than 0.001%	Late	Greater than 24 hrs

Notes:
These release categories are set forth in Appendix E of the license renewal application for Vermont Yankee. In the license renewal application for Pilgrim, the same categories are used except that: (i) the Early and Intermediate categories shown in the table above are combined into one category designated as 'Early'; and (ii) the Low and Low-Low categories are combined into one category designated as 'Low'.

Table 7-1
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 7-2
Potential Modes and Instruments of Attack on a Nuclear Power Plant

Mode of Attack	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 8-1
Selected Options to Reduce Risks of Spent-Fuel-Pool Fires at the Pilgrim and Vermont Yankee 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 8-2
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 USA	• Can promote growth of sub-national groups hostile to the USA, 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 elements	• Can stop attackers before they reach the target	• Can involve higher operating costs • Requires ongoing vigilance
Passive defense of infrastructure elements	• Can allow target to survive attack without damage • Can substitute for other approaches, avoiding their costs	• Can involve higher capital costs

Table 8-3
Estimation of Cost to Offload Spent Fuel from Pools at the Pilgrim and Vermont Yankee Plants After 5 Years of Decay

Estimation Step	Pilgrim	Vermont Yankee
Present licensed capacity of pool	3,859 fuel assemblies	3,089 fuel assemblies
Pool capacity needed for full-core discharge	580 fuel assemblies	368 fuel assemblies
Anticipated av. pool inventory of spent fuel during period of license extension	3,177 fuel assemblies	2,619 fuel assemblies
Av. period of exposure of fuel assembly in core	5.48 yr	3.69 yr
Av. annual discharge of fuel from reactor	580/5.48 = 106 fuel assemblies	368/3.69 = 100 fuel assemblies
Pool capacity needed to store fuel for 5-yr decay, incl. 10% buffer	106x5x1.1 = 583 fuel assemblies	100x5x1.1 = 550 fuel assemblies
Total pool capacity needed for full-core discharge and 5-yr decay	580 + 583 = 1,163 fuel assemblies	368 + 550 = 918 fuel assemblies
Fuel requiring offload if pool storage is limited to fuel undergoing 5-yr decay	3,177 – 583 = 2,594 fuel assemblies	2,619 – 550 = 2,069 fuel assemblies
Capital cost to offload fuel, assuming 210 kgU per assembly and capital cost of $100-200 per kgU for dry storage	$54-109 million	$43-87 million

Notes:
A capital cost of $100-200 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.

Table 9-1
Provisional Estimate of the Probability of a Spent-Fuel-Pool Fire at the Pilgrim or Vermont Yankee Plant

Estimation Step	Pilgrim	Vermont Yankee
CDF (internal events)	2.8E-05 per yr	4.3E-06 + 9.0E-06 = 1.3E-05 per yr
CDF (fires + earthquakes)	2.2E-05 + (5.8E-05 + 9.4E-05)/2 = 9.8E-05 per yr	3.8E-05 + (5.8E-05 + 9.4E-05)/2 = 1.1E-04 per yr
CDF (internal events + fires + earthquakes)	1.3E-04 per yr	1.2E-04 per yr
Early release frequency (internal events + fires + earthquakes)	1.3E-05 + (1.3/5.8)x2.2E-05 + (1.6E-05 + 3.2E-05)/2 = 4.2E-05 per yr	1.7E-06 + (1.7/4.3)x(9.0E-06 + 3.8E-05) + (1.6E-05 + 3.2E-05)/2 = 4.4E-05 per yr
Conditional probability of a pool fire, given an early release from the reactor (internal events + fires + earthquakes)	0.5 (Author's assumption)	0.5 (Author's assumption)
Probability of a pool fire initiated by events not including malice	(4.2E-05)x0.5 = 2.1E-05 per yr	(4.4E-05)x0.5 = 2.2E-05 per yr
Probability of a maliciously-induced pool fire in the USA (99 pools)	1 per 100 yr (Author's assumption)	1 per 100 yr (Author's assumption)
Probability of a maliciously-induced pool fire at this plant	1.0E-04 per yr	1.0E-04 per yr
Total probability of a pool fire at this plant	2.1E-05 + 1.0E-04 = 1.2E-04 per yr	2.2E-05 + 1.0E-04 = 1.2E-04 per yr

Notes:
(a) CDF = core damage frequency
(b) Estimates in the first four rows are drawn from the IPEs and IPEEEs for each plant, except that the Pilgrim internal-events CDF is drawn from: Willard Thomas et al, *Pilgrim Technical Evaluation Report on the Individual Plant Examination Front End Analysis*, Science and Engineering Associates, prepared for the USNRC, 9 April 1996. Earthquake findings shown for Pilgrim are the average of the EPRI and LLNL values, and are used for both plants. The conditional probability of an early release, given core damage, is assumed to be the same for events initiated by fires and by internal events including internal flooding.
(c) The probability of a maliciously-induced pool fire in the USA is assumed to be uniformly distributed across all pools.

Table 9-2
Present Value of Cumulative (20-year) Economic Risk of a Potential Release of Radioactive Material

Selected Characteristics of the Potential Release		**Present (Initial) Value of Cumulative (20-year) Economic Risk, for various Discount Rates (D)**		
Economic Cost of the Release	**Probability of the Release**	**D = 7% per yr**	**D = 3% per yr**	**D = 0% per yr**
$100 billion	1.0E-03 per yr	$1.1 billion	$1.5 billion	$2 billion
	1.0E-04 per yr	$110 million	$150 million	$200 million
	1.0E-05 per yr	$11 million	$15 million	$20 million
	1.0E-06 per yr	$1.1 million	$1.5 million	$2 million

Notes:
(a) The discounted cumulative-value function is: (1-exp(-DT))/D, where T = 20.
(b) The present values shown in the table can be scaled linearly for alternative values of the economic cost or probability of the potential release.

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Comments of the Institute for Energy and Environmental Research on the U.S. Nuclear Regulatory Commission's Proposed Waste Confidence Rule Update and Proposed Rule Regarding Environmental Impacts of Temporary Spent Fuel Storage[1]

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6 February 2009

The following are the comments of the Institute for Energy and Environmental Research (IEER) on the Nuclear Regulatory Commission's (NRC's) proposed Waste Confidence Decision Update[2] and the associated Consideration of Environmental Impacts of Temporary Storage of Spent Fuel after Cessation of Reactor Operation.[3]

The proposed Waste Confidence Decision warrants careful examination, because it serves as the underpinning to several key safety and environmental findings regarding the operation of nuclear power plants and the disposal of the wastes that they generate.

- First, the Waste Confidence Decision presents a safety finding, under the Atomic Energy Act, that the NRC has reasonable assurance that disposal of spent fuel will not pose an undue risk to public health and safety. It does so via the finding that disposal is technically feasible and can be done in conformity with the assumption of zero releases in Table S-3 at 10 CFR 51.51, which specifies the environmental impacts associated with nuclear reactor operation, including those associated with nuclear wastes and emissions.
- Second, the Waste Confidence Decision provides the basis for a key assumption in the uranium fuel cycle rule that spent fuel can be isolated in a repository, with no radioactive releases. That finding, in turn, is key to the NRC's conclusion that the environmental impacts of the entire uranium fuel cycle are insignificant.[4]

[1] These comments were prepared at the request of Texans for a Sound Energy Policy.
[2] NRC 2008
[3] NRC 2008b
[4] 10 CFR 51.51 2008 and its Table S-3 2008

- Finally, the Waste Confidence Decision provides the basis for the NRC's Finding of No Significant Impact (FONSI) regarding the environmental impacts of temporary spent fuel storage pending its disposal in a repository.

As discussed below, IEER believes that the NRC lacks adequate support for the Waste Confidence Decision's first and second proposed findings. The NRC has simply failed to address currently available information which shows that the NRC currently does not have an adequate technical basis for a reasonable level of confidence that spent fuel can and will be isolated in a geological repository.

The NRC's lack of support for Findings 1 and 2 of the Waste Confidence Decision also fatally undermines the viability of the uranium fuel cycle rule promulgated in 1979.[5] In that rule, the NRC declared that the environmental impacts of the entire uranium fuel cycle would be negligible. The finding was based in part on the assumption that spent fuel would have no radioactive releases after it was placed in a repository. That assumption was based in turn on two other assumptions: (i) that disposal of spent fuel or reprocessing high-level waste would be in a salt repository, and (ii) that releases of radioactivity from that repository would be zero. In its draft Waste Confidence Decision, the NRC has acknowledged that salt is not a suitable medium for spent fuel disposal. Investigations of Yucca Mountain and other non-salt repositories have concluded that there are likely to be some releases of radioactivity due to spent fuel disposal. This invalidates the basis of the uranium fuel cycle rule and the Waste Confidence Decision that is associated with it. Other assumptions and findings contained in the 30-year-old uranium fuel cycle rule are also demonstrably invalid today, such as the assumption that greater than class C (GTCC) waste and depleted uranium (DU) tails can be disposed of in a shallow land burial as low-level radioactive waste (LLRW) under present rules. On the contrary, special permitting processes, including environmental impact evaluations will be necessary to dispose of these wastes. The NRC must re-evaluate all of these assumptions and findings in light of new information which shows that they are incorrect. And the NRC must re-evaluate its overall conclusion that the health impacts of the uranium fuel cycle are negligible.

In addition, the NRC's lack of an adequate basis for Findings 1 and 2 undermines the NRC's basis for a finding that spent fuel can be safely stored on reactor sites pending the opening of a repository. The NRC must conduct a new environmental analysis that examines the impacts of onsite spent fuel storage for a much longer period than 50 to 60 years after the cessation of reactor operations. This must include considerations relating to the potential deterioration of onsite storage canisters and the potential for transfers to new onsite storage canisters.

Finally, taken together, the Waste Confidence Decision, the uranium fuel cycle rule, and the NRC's environmental analysis of the impacts of temporary fuel storage completely fail to address one of the key environmental questions raised by the proposed licensing and re-licensing of nuclear plants: what does it cost to manage and dispose of the radioactive waste generated in the process of operating nuclear plants, and is the cost

[5] NRC 1979

justifiable in comparison to renewable energy alternatives such as wind and solar power? The lack of a credible cost analysis for waste means that alternatives to nuclear power cannot be fairly evaluated as required by NEPA.

A. Comments on Finding 1

The NRC proposes to reaffirm Finding 1 unchanged from 1990. Finding 1 reads as follows:

> Finding 1: The Commission Finds Reasonable Assurance That Safe Disposal of High-Level Radioactive Waste and Spent Fuel in a Mined Geologic Repository Is Technically Feasible.[6]

Three terms in Finding 1 are critical:

- "reasonable assurance"
- "safe disposal", and
- "technically feasible"

The term "safe disposal" involves (i) the safety of building the repository, putting the waste in it, and backfilling and sealing it, and (ii) the performance relative to health and environmental protection standards for a long period after the repository is sealed. It should be noted that the requirements of showing that there is "reasonable assurance" that "safe disposal" of "high-level waste and spent fuel" is "technically feasible" are much greater than would be the case if the problem were simply to show that it is possible to dig a deep mine, put spent fuel in it, and backfill it. That would be nothing more than dumping. In the case of a geologic repository system, it is essential to show a reasonable basis for confidence that the public and the environment far into the future will be adequately protected from the effects of disposal at a specific site and a specific engineered system built there.

A scientific explanation of the term "reasonable assurance" requires either physical proof that such a facility exists and has operated within expected performance rules or a statistically valid argument based on real-world data that would show (i) that all the elements for a repository system exist and (ii) that they would work together as designed, as estimated by validated models. The evidence must be sufficient to provide a reasonable basis to conclude that the durability of the isolation arrangements would be sufficient to meet health and environmental standards for long periods of time – hundreds of thousands of years with a high degree of assurance, or in other words, with a high probability. In statistical terms, this means that the upper bound estimate of health and environmental damage should be below the maximum allowable limit with a high level of confidence. At present these uncertainties are very large, which means that it is reasonable to conclude that under some circumstances the damage could be higher than the norms of radiation protection. See below for examples.

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[6] NRC 2008, p. 59553.

The task of determining whether there is an adequate basis for a reasonable assurance of technical feasibility is very difficult. A large part of the difficulty so far as assessing long-term integrity and performance arises from the fact that three elements of a mined system that is highly perturbed thermally, chemically, and mechanically from its original geologic state must be shown to work together to provide "safe disposal" – that is to provide disposal that will conform to an agreed and settled radiation protection standard for the public and that will also protect workers during the construction period of the repository according to prevailing norms for worker protection. The three elements are:

- The waste and the waste encapsulation system.
- The backfill and sealant system.
- The near- and far-field perturbed geologic environment.

We will show that it is a very difficult and complex task to assess the performance of each of these elements under the conditions of spent fuel disposal in a repository and that a wide range of radiation doses can be estimated from the same general repository type and location, including doses that are above regulatory limits.

1. Lack of realistic demonstration of the technical feasibility of a thermally perturbed, sealed repository system

To date, no large-scale demonstration of a system that has been thermally perturbed by spent fuel and then back-filled and sealed has been carried out even for a limited period of time. Much less has there been a demonstration over a few decades that a highly thermally perturbed and sealed system with large amounts of spent fuel would function in the long-term as estimated on paper or via the results of limited experiments. Moreover, many of the experiments that have been proposed, even in highly regarded repository programs, are simply inadequate or inappropriate for estimating performance. For instance, an expert team of geologists put together by IEER[7] concluded that both the thermal and mechanical aspects of the research designed to study the suitability of the French repository location were deficient in essential respects, despite the fact that the program had many strong points:

> A crucial problem for research is that the model must estimate performance not of the natural setting but of a geologic system that has been considerably disturbed by a large excavation, which may induce fractures not originally present, by the introduction of (thermally) hot wastes, and by the addition of various backfill materials and seals. *Hence, the system being modeled is no longer the original geologic system, but a profoundly perturbed system. ....* Estimation of performance of a system under these conditions with some confidence poses challenges that are, in many ways, unparalleled in scientific research.
>
> In the specific case of the Bure site, the host rock is argillite, a hard rock consisting of clayey minerals, carbonates (mainly calcites), and quartz. The in-tact rock is not very porous, leading to expectation of diffusive flow in the

[7] See Attachment B for the Curriculum Vitae of the team members.

> absence of fractures and in the absence of disturbance by mining. Such flow would be very slow and the expected travel time of radionuclides released from waste packages could be very long.
>
> However, the IEER team's evaluation of (i) the documents, (ii) argillite rock properties under conditions of heat and humidity, and (iii) the research done to model the site performance indicated that the actual conditions prevailing in an actual repository could be very different from diffusive flow. Failure of certain components, notably repository seals, could result in rapid (in geological terms) transport of radionuclides to the human environment.
>
> ANDRA's own estimate of dose under conditions of seal failure was higher than the allowable limit of 0.25 millisieverts (25 millirem) per year. In this context, IEER concluded that ANDRA's scenario for human exposure was not necessarily conservative, in that doses to an autarchic farmer family (also called "subsistence farmer family") using groundwater in certain locations could be even higher than the dose at the surface water outcrop estimated by ANDRA.[8]

Note that as of the date of the IEER report on the Bure site in France, ANDRA's own estimate of dose exceeded its regulations in the event of seal failure. In this context, research on characterizing the long-term integrity of seals becomes critically important. And IEER found ANDRA's research program in this very area to be deficient. One of its principal conclusions about the research on seals was that it seemed to of "marginal value" and was far from adequate to enable a sound determination of repository performance:

> One crucial problem is that the simulated slot sealing test in the underground laboratory may be of marginal value and utility. The test is planned to be done very early on after excavation and only over a very short period of time relative to the duration of performance requirements and even relative to the time lapse over which the actual EDZ [Excavated Damaged Zone] will develop, prior to seal installation. This is neither convincing nor satisfactory. It is difficult to see how and why increasing the stress component parallel to the gallery walls will reduce the permeability in that direction or how a flatjack can simulate a bentonite seal, except in the most crude of approaches.[9]

Similarly, there has been considerable skepticism about the DOE's proposed disposal configuration for Yucca Mountain. DOE proposes disposal in the unsaturated zone in a configuration in which boiling of water is expected for "the first few hundred years after closure...in the drift vicinity."[10] The DOE expects the effects to be as follows:

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[8] Makhijani and Makhijani 2006. Italics in the original. This article is based on the full report, which is in French: *Examen critique du programme de recherche de l'ANDRA pour déterminer l'aptitude du site de Bure au confinement géologique des déchets à haute activité et à vie longue : Rapport Final.* Hereafter cited as IEER 2005. The qualifications of the team members are found in Attachment C.

[9] IEER 2005, p. 59, in Chapter 2. Retranslated from the final French report by Annie Makhijani.

[10] DOE 2008 p. 2.3.3-58 in Chapter 2

> Thermal expansion of the rock matrix induces thermal stresses and associated changes in flow properties near emplacement drifts.... Thermally-driven effects also cause dissolution and precipitation of minerals, which may affect flow properties (thermal-hydrologic-chemical effects).[11]

While the DOE believes that these processes will not prevent satisfactory repository performance, Dr. Don Shettel, an expert geochemist and consultant for the State of Nevada, has concluded that a hot temperature design is "fatally flawed."[12] This was extensively discussed at the May 18, 2004, meeting of the U.S. Nuclear Waste Technical Review Board (NWTRB):

> We've talked about thermal concentration of brines and boiling point elevation. We can get fingering of concentrated solutions in fractures, thereby increasing the probability and percentage of thermal seepage waters that might reach the drift on the EBS [Engineered Barrier System]. We have mixed salt deliquescence [absorption of water vapor by solid salts so as to dissolve them], not so much from the dust that's on the canisters, but from the increased amount of thermal seepage water that we believe can reach the EBS. And, if these evaporated or concentrated solutions can reach the EBS before the thermal peak, then they can become, even after the thermal peak, get hydrated salts with thermal decomposition, with the evolution of acidic solutions and vapors. And, **one of the most important aspects of this model is the wet-dry cycling or intermittent seepage**. If you get some seepage on the canisters, and it evaporates to some extent, dries out, the addition of water to that can generate acid.
>
> ....We believe that the **high temperature design for the repository is fatally flawed** for the number of reasons that I've discussed, and that **emplacement in the saturated zone would be much better, because that's essentially where DOE has tested their metals at.** And, the saturated zone is also the much less complicated in terms of processes and modeling.[13]

It is clear from the above, that there are scientists who have carefully studied the problem who believe that DOE has tested the metals mainly in an environment [saturated] that is fundamentally different than the proposed disposal environment [unsaturated]. According to them the proposed DOE design is "fatally flawed" and the Yucca Mountain repository site is "not adequate." Dr. Shettel also stated that an entirely different disposal concept in the saturated zone would be "much better."[14]

Testing, experiments, and models that seem to bypass essential questions were a problem that the IEER team discovered in relation to sealants, as quoted above (proposed tests were "neither convincing nor satisfactory"). Moreover, the problem of wet-dry cycling and inadequate modeling was also cited by the IEER team as a significant problem in the French repository research program:

[11] DOE 2008 p. 2.3.3-58 in Chapter 2
[12] Don Shettel is Chairman and Geochemist, Geoscience Management Institute, Inc.
[13] Shettel 2004. Emphasis added.
[14] Also see below for further discussion of the corrosion problem.

> No evidence is found for any model evolution from simple, scoping, or conceptual models into design base models that result in conceptual design and site evaluation. Model evaluation potentials against direct, experimental results have been omitted. The simple models described in the documents do not seem to be adequate for the evaluation/verification of thermophysical site properties.
>
> It is not clear why one-dimension model results are included in the inverse modeling of in situ experiments; the heat flow is not remotely a linear, one-dimensional problem. Even the two-dimensional, analytical model result for an infinite heater length is a very poor model for the arrangement involving a 2 m-long heater only. The large difference between the two-dimensional, analytical, and three-dimensional, numerical models disqualifies the other models. It is even questionable whether the model condition of a three-dimensional domain assuming homogeneous and isotropic material/physical properties is adequate, since the stratigraphy of the Bure site is layered with different properties in different directions.
>
> The thermal conductivity, one of the most important thermophysical site characteristic, has not been adequately established. The standard deviation of this parameter is unusually high, leaving a large margin of uncertainty in the heat-rejecting capacity of the site. The number of samples used for establishing thermophysical site properties based on laboratory samples appears to be low, especially considering the potential spatial variation of these properties over the proposed storage area.
>
> Although the temperature regime according to the baseline design is below-boiling, above-boiling operation is not impossible. A bi-stable system, involving either below boiling or above boiling conditions in the emplacement area, is quite possible under some circumstances. A steam cycle therefore is possible under certain heat load conditions, namely, if the backfill buffer material cannot saturate and the damaged zone cannot re-saturate due to vapor-phase water loss caused by the condensing zones of the emplacement area.
>
> Since above-boiling point temperatures are expected in the Type C and spent fuel modules for long periods of time in the preferred design selection, these modules may develop continuous steam cycles within the emplacement area for centuries.[15]

There is experimental evidence that result of wet-dry cycling at Yucca Mountain could result in very rapid corrosion of the C-22 alloy containers. While the DOE believes the contrary, Dr. Roger Staehle, who worked as a consultant for the State of Nevada with a research team including other experts and Catholic University of America faculty, made a presentation to the NWTRB during which he went through the team's experimental findings for the NWTRB; he concluded with a set of stark "warnings":

[15] IEER 2005, pp. 101-102, Chapter 3. Retranslated from the final French report by Annie Makhijani.

Warnings

1. There is an abundance of warnings as well as solid quantitative data that demonstrate that corrosion of the C-22 alloy is *inevitable and rapid.*

2. A good paradigm for the warnings about C-22 can be found with Alloy 600 that was widely used in the nuclear industry as tubing in steam generators and as structural components. Alloy 600 has broadly failed in these applications, and present failures could easily have been predicted from past occurrences.

3. There are now *abundant warnings that that C-22 alloy is not adequate nor is the present design of the repository adequate.* Such warnings are founded on warnings, some of which are 15 years old.

4. Further, there is abundant evidence that the YM site itself is not adequate.

5. The analogies of warnings from the present nuclear industry are abundant and apply directly to whether the present design at YM is adequate. *The answer is that it is not.*

6. Some of the warnings from experience of the water cooled nuclear reactor industry apply directly to the design and development of the Yucca Mountain facility. These should be carefully assessed, e.g. as they apply to heated surfaces.

7. Finally, the incapacity to inspect the YM containers requires assurances of reliable performance that are higher than those of normal industrial expectations.[16]

The problem of adequacy of the research program or lack thereof points up the critical need to have confidence in each of the three elements of geologic disposal. In the above examples, we have shown that in the case of Yucca Mountain the behavior of the containers as well as the rest of the Engineered Barrier System has not been characterized to the point that independent scientists could agree that Yucca Mountain is a suitable disposal site, even though the DOE believes it is. On the contrary, there is quite a bit of evidence that Yucca Mountain is not a suitable site, and may even be "fatally flawed," since the containers are essentially the only effective barrier preventing radionuclide releases to the environment.

The Nuclear Waste Technical Review Board considered the question of the potential for severe corrosion due to deliquescence at length following the May 2004 meeting from which the above presentation is drawn. While the twists and turns that the issue took are technically interesting and illustrate the uncertainties, the most important point to note here is that, in the end, the DOE decided to entirely ignore the issue because it believes it to be "insignificant":

> Although deliquescence of salts on the waste package surface is expected to occur, this process has been excluded from TSPA [Total System Performance Assessment] because the effects of such deliquescence have been determined to be insignificant to performance (Table 2.2-5, FEP 2.1.09.28.0A, Localized corrosion on waste package outer surface due to deliquescence). The physiochemical characteristics of brines produced through deliquescence of minerals in deposited dusts are not expected to generate an environment favorable for the initiation of localized corrosion and

[16] Staehle 2004. Italics added.

> propagation for Alloy 22 (UNS N06022) waste packages. In addition, at elevated temperatures (greater than 120°C), only small quantities of brine will form from the available dust, and brine volume will limit the extent of localized corrosion damage should it initiate.[17]

And again:

> Modeling of evaporative evolution of potential seepage waters shows that corrosive calcium and magnesium-chloride brines are not expected to form. As noted above, although deliquescence-induced brine formation is expected to occur, this process has been excluded from TSPA because the effects of such deliquescence have been determined to be insignificant to performance.[18]

The Nuclear Waste Technical Review Board, the expert oversight body appointed by Congress to oversee the Yucca Mountain program, came to a somewhat different conclusion regarding whether deliquescence-induced corrosion should be excluded from DOE's license application:

The NWTRB's report was sent to Congress with a letter dated August 2008, two months after the DOE had submitted its license application concluding that deliquescence-induced corrosion could be ignored in performance assessment because it was judged to be insignificant. For this very reason, the report is worth quoting at length:

> The Board's January 12, 2007, letter [to the DOE Office of Civilian Radioactive Waste Management] and its attached report contained the following additional findings:
>
> - *Cumulative damage due to the combined effects of deliquescence-induced localized corrosion and seepage-based localized corrosion merits some analysis.*
> - *Including seepage-based localized corrosion in TSPA-LA while excluding deliquescence-induced localized corrosion is incongruous because the process (localized corrosion) is the same in both cases.*
> - *Deliquescence-induced general corrosion of Alloy 22 should be included in TSPA-LA.*
> - Anomalies among recent experiments at high temperatures, such as unexpectedly high general corrosion rates and a maximum of general corrosion rate with respect to temperature, require explanation.
> - Effects of waste package surface condition on the corrosion of the waste package surface may need more investigation.
> - *Including deliquescence-induced localized corrosion in TSPA-LA would add to its completeness, robustness, and credibility.*
>
> In a follow-up letter to OCRWM dated July 10, 2007 (Garrick 2007c), the Board pointed out that the dust settling on waste package surfaces during ventilation would contain significant amounts of organic materials and that reactions between these materials and nitrate in the dust could affect the amount of nitrate, which inhibits

[17] DOE 2008, p. 2.3.5-10
[18] DOE 2008, p. 2.3.5-12

> localized corrosion if present in large enough quantities relative to chloride. The Board stated that the Project should analyze the effects of the full range of factors (e.g., organics in dust, acid-gas devolatilization, and radiolysis) that could influence whether inhibitive nitrate-to-chloride ratios persist under repository conditions.
>
> OCRWM responded to the Board's January 12, 2007, and July 10, 2007, letters in a November 20, 2007, letter (Sproat 2007c). Although the Board agrees with some of the points mentioned in the letter, **in several instances OCRWM did not address points brought up by the Board. For example, in its January 12 letter, the Board addressed the apparent incongruity of excluding deliquescence-induced localized corrosion while including seepage-based localized corrosion despite the fact that both are the same process, i.e., localized corrosion**. In its November 20, 2007, letter, the Project reiterated the differences in the environments between deliquescence-induced and seepage based localized corrosion. The Board concurs that the environments are quite different, but the processes are not. **Regardless of whether NRC regulations allow a process to be split in two and one part to be discarded, doing so still remains incongruous.**
>
> In addition, the Project refers to components of the dust deposited on waste package surfaces as "reactants" or "limited reactants" in several places in its November 20 letter. Although the Board agrees that many components in the dust could be reactants, it seems that the principal reactants in general or localized corrosion would be either the water component of deliquescent brines or oxygen dissolved in the brines. Both water and oxygen are essentially limitless in supply. If they are consumed by the brine in corrosion reactions, they simply will be replenished rapidly by dissolution or deliquescence. The Board would welcome additional information from the Project about what other components of the dust undergo reactions. **Finally, although OCRWM claimed that it had addressed Board concerns about the effects of organic materials on the nitrate-to-chloride ratio in the November 20 letter, the basis for this claim is unclear.**
>
> **In sum, despite the workshop in September 2006 and the exchange of letters in 2007, the issue of deliquescence-induced localized corrosion, although apparently tractable, remains open.**[19]

In other words, on perhaps the most critical scientific uncertainty for the entire Yucca Mountain program, the DOE has

- failed to follow the advice of the Congressionally mandated Technical Review Board
- submitted a license application that dismisses as "insignificant" the very process that the NWRTB asked it to include and address further and that has led some scientists with considerable expertise to conclude that Yucca Mountain is not an adequate site or that the design is "fatally flawed."

There is no evidence in the draft Waste Confidence Decision that the NRC has taken any of this information and analysis into account in reiterating Finding 1 that there is "Reasonable Assurance That Safe Disposal of High-Level Radioactive Waste and Spent Fuel in a Mined Geologic Repository Is Technically Feasible." Further, the NRC draft

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[19] NWTRB 2008, pp. 27-28, italics and bold emphasis added.

Decision also notes that salt repositories are unsuitable for disposal of spent fuel (see below).

2. Uncertainty in performance results and the question of technical feasibility

The technical feasibility of "safe disposal" of waste in a geologic disposal system with "reasonable assurance" must be judged according to technically sound and legally valid performance criteria. There are two issues that relate to "technical feasibility" in this context

a. What is the nature of the performance standards that must be met? This relates to the radiation protection standard set to protect the health and environment of future generations from the effects of waste disposal.
b. Is there reasonable assurance that the performance standard can be met and that other safety goals, such as worker safety during constructing, waste emplacement, and sealing, can also be met? This relates to a reasonable level of scientific and statistical confidence that the performance standard in terms of health and environmental protection will be met in practice.

a. Nature of the Performance Standard

The history of the process of specifying the standards of performance, such as maximum allowable dose, the pathways via which that dose must be assessed, and the period over which performance must be evaluated, in the United States undermines the NRC's claim of technical feasibility. The claim is also undermined by estimates of performance that cover a wide range and include at the upper limit large exceedance of the current EPA radiation dose requirement.

EPA standards for disposal of spent fuel, high-level waste, and transuranic waste were first promulgated in 1985 and amended later on to include drinking water protection.[20] The rule specified a period of protection of 10,000 years. Yet the National Research Council study done for the DOE in 1983[21] had already criticized the EPA proposal before its finalization and advocated extending the period of performance for all time, judging compliance for the proposed period of 10,000 years to be "rather easy."[22] The National Research Council also advocated a maximum individual dose approach rather than a population dose approach.

The EPA essentially ignored the National Research Council's advice and adopted the 10,000 year limit and limits on total releases of certain radionuclides including carbon-14. The EPA standard was to be the fundamental performance criterion for public health and environmental protection for spent fuel, high-level waste, and transuranic waste disposal.

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[20] The regulation is 40 CFR 191, and can be found on the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr191_08.html.
[21] NAS-NRC 1983 Chapter 8.
[22] NAS-NRC 1983 p. 236.

Further study showed that the National Research Council's conclusion that a 10,000 year limit would make compliance "rather easy" to be incorrect with respect to unsaturated repositories like Yucca Mountain with respect to the specific standard adopted by the EPA. Specifically, the EPA set a limit of carbon-14 emissions of 100 curies per 1,000 metric tons of heavy metal in spent fuel or equivalent high-level waste.

An EPA panel was convened to examine the question of carbon-14 releases from unsaturated repositories like Yucca Mountain. In 1993, the Science Advisory Board of the EPA cast considerable doubt on whether Yucca Mountain, a proposed unsaturated repository, could meet the carbon-14 emission limit in the EPA standard:

> ...[I]t is not possible on the basis of presently available information to predict with reasonable confidence whether releases from an unsaturated repository would be less than or greater than the Table 1 (40 CFR 191) release limits. (The Table 1 release limit is one-tenth of the inventory.)[23]

Instead of looking for a new repository that might meet the standard, Congress mandated special standards for Yucca Mountain, which may, in light of the process, be fairly called a double-standard-standard. The scientific basis of these standards was to be provided by the National Academy of Sciences.

The National Research Council of the National Academies issued a report in 1995 advocating a period of performance extending to the peak dose and a rather complex method of estimating the peak dose.[24] The latter itself generated sufficient controversy that one of the panel members, Professor Thomas Pigford, one of the most prominent nuclear engineers in the United States (and one of the authors of the 1983 National Research Council report), wrote a dissent. He concluded that the methods of dose calculation "in Appendix C are not mathematically valid."[25] He concluded that the method adopted

> would introduce unjustified and unprecedented leniency in public health protection from radioactive waste.

and that

> probabilistic exposure scenario [in Appendix C of the National Research Council's 1995 report] will be perceived by many as a disguised means of reducing the calculated individual doses below the high values (ca. 10 rem per year) that were presented to the committee. **Better repository design is the proper means of obtaining low doses, not by nonscientific policy fixes. Policy makers must reject pressures for short-term expediency and economy, lest, by enacting policy that compromises scientific**

[23] Loehr, Nygaard, and Watson 1993
[24] NAS-NRC 1995, Appendix C.
[25] NAS-NRC 1995, Appendix E, p. 177.

> **validity and credibility, it undermines public confidence** and puts and end to all further nuclear development and research.[26]

In 2001, the EPA proposed a new standard that applied only to Yucca Mountain. Contrary to the advice of the National Research Council report of 1995, it limited the period of performance to 10,000 years.[27] This was invalidated in court and then the EPA proposed a revised draft standard in 2005.[28] That proposed standard was far more lax for the period from 10,000 to 1 million years than any radiation protection standard protecting today's population. At 350 millirem per year, the lifetime risk of fatal cancer to women would be as high as 1 in 62. Higher doses to some people were permitted. For a small minority, doses as high as 2 rem would be permitted leading to a lifetime fatal cancer risk of 1 in 10.[29]

The EPA published its final rule in 2008. It limits doses in the first 10,000 years to 15 millirem per year committed effective dose equivalent, and to 100 millirem per year in the 10,000 to 1 million year period.[30]

The State of Nevada has sued the EPA over these final standards.[31] It should be noted in this context that the courts have twice before invalidated EPA "final" rules in regard to deep geologic repositories. Further the NRC has also changed its rules. In the early stages, following the 1980 DOE EIS on geologic disposal it was assumed that the containers would be the main barrier for an initial period, such as 1,000 years, but that the geologic setting would perform the main job of preventing long-lived radionuclides from reaching the human environment.

In sum, after more than a quarter of a century of trying to come up with a standard that would apply to spent fuel disposal at a proposed repository (40 CFR 191 applies to spent fuel disposal but no repository is proposed to which it might apply and it does not apply to the only one that is proposed), the matter of a final standard is still unsettled in that it is under litigation. Without a final standard that is clear of court challenges, performance assessment must necessarily rest on guesses about what it might be; this is not a basis on which "reasonable assurance" of the technical feasibility of "safe disposal" can be given, for the simple reason that there is no accepted definition of safe in relation to Yucca Mountain as yet. This is the current situation even if it could be shown that Yucca Mountain could conform to postulated rather than actual settled dose limits.

And, as it happens, there is no reasonable assurance as yet that Yucca Mountain can meet the final standard that the EPA has now in place at 40 CFR 197.

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[26] Pigford 1995, emphasis added.
[27] EPA 2001.
[28] EPA 2005
[29] Makhijani and Smith 2005. The original standard 40 CFR 191 has no specified public health protection beyond 10,000 years.
[30] EPA 2008
[31] Nevada v. EPA 2008 (State of Nevada v. Environmental Protection Agency (D.C. Cir., No. 08-1327, consolidated with No. 08-1345))

b. Evaluating performance

We will assume for the purpose of this section that the EPA standard for Yucca Mountain at 40 CFR 197 is the one against which "safe disposal" is to be judged as it concerns protection of future generations. In this limited context, a reasonable assurance of the technical feasibility of safe disposal at Yucca Mountain must show that there is a high probability that the standard will be met. This requires that the performance assessment that estimates the dose be generally accepted in the scientific community and that reasonable technical questions raised by experts on critical issues have been resolved. This is not the case with Yucca Mountain.

Analysis provided to the Nuclear Waste Technical Review Board indicates that the geologic setting of Yucca Mountain contributes essentially nothing to the performance of the site. This can be seen from the set of DOE graphs in Attachment A, which is a part of these comments. Specifically, Graph A, the first one in Attachment A, shows that in the absence of the container, a dose limit of 15 millirem would be greatly exceeded in much less than 10,000 years. Graph A shows that a 25 millirem per year dose limit, which was the norm against which the DOE was assessing compliance at the time, would be exceeded as soon as 2,000 years after closure and the peak dose would be on the order of 1,000 millirem well before 10,000 years. This is more than 60 times the EPA dose limit for the period less than 10,000 years. All of the other graphs show that if the container stays intact, the failure of another part of the overall system would not affect doses much in the first 10,000 years. (The peak dose beyond 10,000 years exceeds the limit in 40 CFR 197 in all cases in this set of DOE graphs – see below).

This puts a premium on the integrity of the container because it is the one element that would ensure compliance (according to the DOE model) in the period less than 10,000 years. This DOE conclusion that the container is practically the only barrier to the release of radioactivity has also been expressed before the Nuclear Waste Technical Review Board by an independent expert, Roger Staehle (also quoted above):

> The central question that we're all considering here is really the integrity of the container. So, whatever we're thinking about has to be directed toward the integrity of the container, because that's **the primary or virtually the only barrier to release of radioactivity**. [32]

As we have noted above, the question of whether the containers will endure for very long is, at best, an open one. There is clear evidence that they may corrode quickly relative to time scales required for assessing performance.

If they do corrode quickly, then the situation described in Graph A of Attachment A, that is, doses tens of times greater than the present final EPA standard prior to 10,000 years will prevail. The DOE itself has calculated doses for the repository that vary widely, indeed, wildly. For instance, the most recent estimate, in DOE's license application for the Yucca Mountain repository shows peak doses that would be more than 100 times

[32] Staehle 2004 p. 241.

lower than the final EPA standard of 100 millirem per year (beyond 10,000 years) discussed above.[33] But the peak doses shown in Attachment A (base case), prepared by the DOE for the NWTRB, are about an order of magnitude higher than the 100 millirem standard – that is, they are a thousand times bigger than the estimate in the DOE license applications. As another example, the DOE had estimated doses as high as 10 rem in a presentation to the National Research Council, or ten thousand times higher than the estimate in the license application (see Dr. Pigford's quote above). Finally, DOE's peak dose estimates in its 2002 Final Environmental Impact Statement for Yucca Mountain are also much higher than the 100 millirem per year dose to the maximally exposed individual. The Table below is reproduced from DOE's Final EIS for Yucca Mountain. Even the mean dose to the "reasonably maximally exposed person (RMEI)" is greater than 100 millirem. The 95 percentile dose for the "reasonably maximally exposed person" is far higher – 510 millirem. Should the population 18 kilometers from Yucca Mountain be in the thousands, many individuals would be expected to have doses considerably in excess of 500 millirem, since this value is a 95th percentile estimate. We note that even 30 kilometers away, where people live today, the 95 percentile peak dose is much greater than 100 millirem per year.

Table 5-12. Impacts for an individual from groundwater releases of radionuclides during 1 million years after repository closure for the lower-temperature repository operating mode.

Individual	Mean		95th-percentile	
	Peak annual individual dose (millirem)	Time of peak (years)	Peak annual individual dose (millirem)	Time of peak (years)
At RMEI location[a]	120[b]	480,000	510[c]	410,000
At 30 kilometers[d]	83[e]	NC[f]	350[e]	NC
At discharge location[g]	48[e]	NC	240[e]	NC

a. The RMEI location is approximately 18 kilometers (11 miles) downgradient from the repository.
b. Based on 300 simulations of total system performance, each using random samples of uncertain parameters.
c. Represents a value for which 285 out of the 300 simulations yielded a smaller value.
d. 30 kilometers = 19 miles.
e. Estimated using scale factors as described in Section 5.4.1.
f. NC = not calculated (peak time would be greater than time given for the RMEI location).
g. 60 kilometers (37 miles) at Franklin Lake Playa.

Source: "Chapter 5: Environmental Consequences of Long-Term Repository Performance," p. 5-29, in Volume I of *Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel and High-Level Radioactive Waste at Yucca Mountain, Nye County, Nevada*, DOE/EIS-0250 (U.S. Department of Energy, February 2002), on the Web at http://www.ocrwm.doe.gov/documents/feis_a/vol_1/eis05_bm.pdf.

In sum, at the present juncture, it is impossible to say with any reasonable assurance what the radiation doses to the public from a Yucca Mountain repository would be. The DOE itself has in the last few years calculated doses that are different by a factor of 1,000, ranging from compliance to non-compliance. The DOE has dismissed the potential for severe corrosion due to deliquescence as insignificant. But that possibility cannot be ruled out on the basis of present scientific evidence. As discussed above, the DOE chose to disregard the advice of the NWTRB on this matter.

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[33] DOE 2008, Table 2.4-2, p. 2.4-357.

This demonstrates that there is not enough scientific basis for "reasonable assurance" that waste can be disposed of at Yucca Mountain safely for the durations envisaged. On the contrary, the uncertainties continue to be high and the possibility that Yucca Mountain could suffer a complete failure (be "fatally flawed") cannot be reasonably excluded. The NRC does not assume that Yucca Mountain will be licensed. But its draft Finding 1 has not taken into account the data and analysis that indicate the potential that it may not meet EPA's standard and therefore cannot be any part of the basis for its Finding.

Another example throws considerable light on the issue. For decades it was assumed that salt was a suitable medium for high-level waste and spent fuel disposal. Salt sites were part of the DOE's first round set under the Nuclear Waste Policy Act (NWPA). Over the decades DOE has investigated several sites in salt formations. One of the top three sites that DOE selected for characterization for spent fuel disposal was a salt site (in Texas); the others were on federally controlled land in Washington State (the basalt site at Hanford) and Nevada (the volcanic tuff site at Yucca Mountain).[34] But now the NRC itself considers salt as unsuitable for spent fuel disposal. According to the draft waste confidence rule:

> Salt formations currently are being considered as hosts only for reprocessed nuclear materials because heat-generating waste, like spent nuclear fuel, exacerbates a process by which salt can rapidly deform. This process could potentially cause problems for keeping drifts stable and open during the operating period of a repository.[35]

The problem of salt being an inappropriate medium for spent fuel disposal is linked to a larger problem of waste confidence as it relates to assessment of the environmental impact from the licensing of reactors. This issue concerns the obsolescence and incorrectness of the governing regulation for reactor licensing, 10 CFR 51, which sets forth "environmental protection regulations applicable to NRC's domestic licensing and related regulatory functions."[36] It is connected to the Waste Confidence Rule and is discussed in Section C below.

The NRC also did not consider the third geologic formation that was in the DOE's top three: the basalt formation at the Hanford Washington site. Many serious defects of the site, including very serious problems in safety, were noted by one of the leading geologist in the United States, Donald E. White, who was a member of the National Research Council panel that wrote a report for the DOE on geologic isolation. In regard to safety Dr. White noted three "threatening effects" including "rock bursting," "costly and troublesome drainage problems" and the following:

> Construction of the repository at very high in-site temperatures, estimated by Rockwell to be 57°C but possibly considerably higher. Refrigeration on a scale seldom if ever attempted in world mining may be necessary. **The costs in time, money, energy, and lives of men are likely to be very high.**

[34] See Nevada timeline 1999
[35] NRC 2008, p. 59555.
[36] 10 CFR 51.1 2008

> **Even if each of the above [threatening effects] is individually tractable, all in combination may be intolerable.** More satisfactory alternatives probably can be found elsewhere.[37]

The DOE ignored this 1983 analysis and went ahead and selected basalt at Hanford as one of the top three sites it would characterize.

In the case of granite, the medium in which DOE hoped to find second repository locations for characterization, the DOE proceeded with a screening program that was so technically deficient that the ranking results were not credible. Essentially, the scoring system adopted by the DOE in its Delphi consultation gave zero weight to criteria for which no information was available. This made them equivalent to criteria which were "unimportant" or "judged to be poorly measured." In other words, if the DOE did not know anything about it then it could be ignored. As a result, the sites for which the least was known would tend be ranked higher than those about which there were more data and adverse as well as positive or partly positive characteristics could be evaluated. In other words, the DOE essentially used an "ignorance is bliss" approach to site ranking in order to determine which sites it would characterize."[38] The second repository program was abandoned in 1986.

We may also cite the example of France in regard to performance, which has the second largest number of reactors of any country in the world (after the United States) and which has a repository program that has been attempting to characterize a site. We have already noted that the program's research in regard to seals and thermal effects is deficient in certain critical aspects. We note here than ANDRA, the French agency charged with repository characterization and development, itself had found that doses would be greatly exceeded in the event of a seal failure. Calculated peak doses in that scenario due to chlorine-36 in Class B waste (the approximate equivalent of U.S. Greater Than Class C waste) would be 300 millirem per year and those from due to iodine-129 in spent fuel would be 1,500 millirem per year.[39] Both of these are greatly in excess of the French limit of 25 millirem per year and even of the more lax U.S. final EPA standard for Yucca Mountain of 100 millirem per year beyond 10,000 years.

These examples illustrate that it is essential to take into account the specific aspects of repository research that are important to assessing whether a given disposal system can perform to specified standards for health and environmental protection.

With the exception of salt sites, which the NRC itself rejects for spent fuel, the NRC has failed to take the specific scientific evidence about the U.S. repository program and the potential for it to meet performance, safety, and health criteria for protecting public health, worker safety, and the environment into account. By failing to examine the available evidence in regard to the elements of a repository system relevant to the United

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[37] White 1983, p. 25, reprinted as an appendix to Makhijani and Tucker 1984, emphasis added.
[38] See Makhijani 1986
[39] ANDRA 2001, p. 139.

States, the NRC has not met the minimal requirements of a scientifically based analysis that is necessary to arrive at a conclusion that there is "reasonable assurance" that safe disposal of spent fuel in a repository is technically feasible.

We are not persuaded by the NRC appeal to the fact that 24 countries have repository programs..[40] The fact that all countries with nuclear power programs have to deal with the intractable problem of nuclear waste and have chosen to believe that disposing it of in deep underground will solve the problem is not a scientific demonstration of technical feasibility of safe disposal of nuclear spent fuel in a geologic repository. In its Waste Confidence Decision Update, the NRC has used information from other countries to argue the unexceptionable point that social and political factors are important. The fact remains that no country has a repository for spent fuel or even high-level waste disposal. Further, the NRC has not presented technical evidence from the many repository programs to show that there are enough data for each of the three elements described above – the waste and waste packages, the back fill and sealing system, and the near- and far-field environment – in these programs to come to a reasonable conclusion that each is sound and that they will function together as modeled with reasonable assurance. Nor has it presented any scientific analysis of how these programs are technically relevant to the specific conditions in the United States in terms of assisting the NRC's ability to buttress Finding 1 in regard to the three elements and the modeling of their functioning together.

By contrast, we have shown that the U.S. Yucca Mountain site may well not meet established radiation protection norms and may even be fatally flawed. The geologic setting is not likely to play a significant role in containment of radionuclides, even according to the DOE's own assessment. Among other things, the basalt site at Hanford presents severe safety issues, which the NRC did not address. The second round repository investigation for granite sites in the United States was a failure, for a variety of reasons.

IEER's detailed review of the French repository program research indicated that the research was significantly deficient in certain critical areas – seals and thermal perturbation modeling. And we have shown that ANDRA's own estimates of doses in case of failure of seals would result in doses that would greatly exceed both French and U.S. disposal standards. The NRC itself has deemed salt unsuitable for spent fuel. Yet it did not explore the implications of that conclusion for the Waste Confidence Decision Update or for its reactor licensing program (see Section C below). The NRC mentions that the German salt dome repository program at Gorleben was suspended "[a]fter decades of intense discussions and protests,"[41] but mentioned none of the adverse technical factors that made the choice of Gorleben controversial or the fatal accident that occurred in 1987.[42]

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[40] NRC 2008, p. 59559.
[41] NRC 2008, p. 59559.
[42] For a discussion of some of the technical factors and the accident see Franke and Makhijani 1987.

3. Conclusions regarding Finding 1

In sum, in reiterating Finding 1, the NRC has not taken into account a mountain of data and analysis that are relevant to it that show that it is far from assured that safe disposal of spent fuel in a geologic respistory is technically feasible. The NRC has not met either of the criteria we set forth at the beginning of this section for assessing whether there was reasonable assurance that safe disposal is technically feasible. In the absence of data from a repository that has been sealed after spent fuel has actually been disposed of – and such data does not exist because no such repository exists – the NRC must provide data on and analysis of the major elements of a site that could be developed in the United States and show that the three elements required in any repository system would work together satisfactorily (i.e., meet radiation protection standards) and that such a repository could be safely built. The NRC has not done this. It has not evaluated the severe problems that the U.S. repository program has encountered and the many twists and turns that rules and regulations have taken as a result, notably with respect to Yucca Mountain. Indeed, the NRC has provided no scientific evidence in its Draft Decision that there is reasonable assurance in the scientific and statistical sense of the term that there is reasonable assurance safe disposal of spent fuel in a geologic repository is technically feasible.

In view of the above, we conclude that the NRC's Finding 1 should be modified. This is necessary on its own, but it is especially necessary in view of the fact that Finding 2 depends on Finding 1. We recommend that Finding 1 be modified to read:

1. While some of the elements of deep geologic disposal have been studied to a sufficient degree that they may be viable elements of a disposal system, an entire thermally and mechanically perturbed system has never been tested. The data on the individual elements of the perturbed and sealed system and for their combined functioning are not yet sufficient to determine the performance of a repository for safe spent fuel disposal with reasonable assurance.
2. The DOE has been pursuing study and characterization of repositories for decades and essential technical questions in relation to performance continue to be in doubt. Under some circumstances, the impact of disposing of spent fuel in a geologic repository could be significant.
3. Considerable further work remains to be done before there can be reasonable assurance that safe disposal of spent fuel and high-level waste in a deep geologic repository in the United States is technically feasible.

We have also concluded that a new generic environmental impact statement is needed to address the fundamental deficiencies of Table S-3. Licenses for new reactors and extension of licenses of existing reactors cannot be properly granted on the basis of the existing Table S-3.

B. Comments on Proposed Finding 2

The proposed Finding 2 states:

> The Commission finds reasonable assurance that sufficient mined geologic repository capacity can reasonably be expected to be available within 50–60 years beyond the licensed life for operation (which may include the term of a revised or renewed license) of any reactor to dispose of the commercial HLW and spent fuel originating in such reactor and generated up to that time.[43]

The NRC has made an unwarranted leap from its "Finding 1"[44] that a geologic repository for disposal of high-level waste and spent fuel is technically feasible to the conclusion that there is "reasonable assurance" of the actual availability of a repository within 50 or 60 years beyond the operating license of any commercial reactor in the United States.

In order to proceed from a finding that a geologic repository is technically feasible to the conclusion that one will be available within a specified time frame (in this case ~100 to 150 years), at least three additional demonstration elements are necessary. First, it must be shown that the requisite work of finding, characterizing, licensing and developing an actual site suitable for disposal of the actual amounts of waste to be generated is possible within the stipulated time. Second, a demonstration of financial feasibility and reasonableness is needed. And thirdly, a demonstration of political and social acceptability is also necessary. We will consider this last question first.

1. Social and Political Acceptability

The NRC has provided a survey of various country programs in order to review the issue of social and political acceptability.[45] This survey itself shows that there can be no confidence that the necessary social and political conditions exist in the United States to provide any assurance that a repository can be developed in any foreseeable time frame. Second, the NRC's survey is partly inaccurate. Third, the NRC's survey is essentially incomplete in that it omits the country that is often held up as being exemplary for nuclear power – France.

We discuss the NRC's survey before proceeding to the specific discussion of the situation in the United States.

1. *United Kingdom:*

The NRC appears to believe that the United Kingdom had a repository program for high level waste and spent nuclear fuel in the 1990s. Specifically the draft rule states the following

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[43] NRC 2008, p. 59561.
[44] NRC 2008, p. 59553. See below for comments on Finding 1.
[45] NRC 2008, pp. 59559-59561.

> In the United Kingdom, in 1997, an application for the construction of a rock characterization facility at Sellafield was rejected, leaving the country without a path forward for long-term management or disposal of HLW or SNF. In 1998, an inquiry by the UK House of Lords subsequently endorsed geologic disposal, but specified that public acceptance was required.[46]

The NRC appears to have its facts about the UK repository program wrong. According to a timeline and status report by Alan Hooper of Nirex, Britain's waste management company, the geological investigations for a high-level waste repository were short-lived; they did not involve an application for a rock characterization facility:

- 1976—The Royal Commission on Environmental Pollution (Flower's Report) recommended the creation of a National Waste Disposal Corporation.
- 1979—Start of program of geological investigations for HLW disposal.
- 1981—**Termination of the geological investigations and suspension of a decision on high-level waste disposal for 50 years.**
- 1982—Nuclear Industry Radioactive Waste Executive (NIREX) created to implement Government policy on intermediate-level waste (ILW) and low-level waste (LLW).
- ...
- 1987—Abandonment of the near-surface program and adoption of new policy that all ILW and LLW should go deep...; new deep site selection process started.
- ...
- 1991—Nirex decides to focus investigations on Sellafield in Cumbria.
- 1992—Nirex announces plans for a Rock Characterisation Facility (RCF) at Sellafield; the plans were eventually considered at a public inquiry which ended in 1996.
- 1997—Decision by Government not to allow Nirex to proceed with the RCF, thus terminating the UK's siting program.[47]

As can be seen, the UK terminated its HLW geologic disposal investigations in 1981. The rock characterization facility to which the NRC refers was for Intermediate Level Waste (similar to Greater Than Class C waste in the United States), which is also mandated for deep geologic disposal. However, the geologic requirements for disposal of ILW are much less stringent than for high-level waste or spent fuel, because the characteristics of these wastes are very different. For instance, the specific activity of high-level waste and spent fuel is generally much higher, as is the heat generation.

The UK formed a Committee on Radioactive Waste Management as a vehicle for public consultation and exploration of the issue of long-term waste management. As the NRC

[46] NRC 2008, p. 29559.
[47] Hooper 2006, pp. 249- 250. Emphasis added.

noted, the most recent evidence is that this is also failing. According to the draft waste confidence rule:

> This [program] led to the initiation of a national public consultation, and major structural reorganization within the UK program. In 2007, the Scottish Government officially rejected any further consultation with the UK Government on deep geologic disposal of HLW and SNF. Discussions may continue on issues of interim storage only. This action by the Scottish Government effectively ends more than 7 years of consultations with stakeholders from communities near Scottish nuclear installations and represents another major setback for the UK program.[48]

Actually, the Scottish government press release does not mention high-level waste or spent nuclear fuel explicitly, but "higher activity" waste,[49] which includes intermediate level waste in the UK. In point of fact, the UK has no active repository program that is looking at a specific site for high-level waste or spent nuclear fuel and has not had any since 1981.

In other words, even though British nuclear waste authorities may believe that a repository is technically feasible, the program is at a dead end and only interim storage is on the table. So far the public consultation program has failed to elicit any progress towards a high-level waste repository. In the meantime, the decommissioning and clean-up of its main reprocessing site (Sellafield) is estimated to take more than 100 years and costs have skyrocketed to 73 billion pounds (roughly $100 billion).[50] While Sellafield was born as a nuclear weapons materials production site, most of the work there and most of the waste there has been generated in the past few decades from reprocessing of British and (more recently) foreign spent fuel. These costs do not include waste disposal or repository development costs.

2. Germany

The German repository program began investigating a salt dome at Gorleben in 1977. Major construction and characterization activities were carried out. The NRC described its status as follows:

> After decades of intense discussions and protests, an agreement was reached in 2000 between the utilities and the government to suspend exploration of Gorleben for at least three, and at most, ten years. In 2003, the Federal Ministry for the Environment set up an interdisciplinary expert group to identify, with public participation, criteria for selecting new candidate sites.[51]

There is as yet no specific site being characterized. After more than three decades, the program is moribund.

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[48] NRC 2008, p. 59559.
[49] Scottish Government 2007
[50] Irish Times 2008
[51] NRC 2008, p. 59559-59560.

3. Switzerland

The Swiss have done a quarter century of geologic repository research. In 1998, the Swiss was authorities found that a repository was technically feasible and that it has been successfully demonstrated, the repository was rejected in a referendum in the canton.[52] The Swiss authorities have no firm date for the opening of a repository, but, according to the NRC, they "do not expect [that] a deep geologic repository will be available in their country before 2040."

4. Canada

An independent commission, empanelled by the Canadian government found in 1998 that a geologic repository was technically feasible and that the concept had been sufficiently demonstrated. Yet, public acceptance is not assured. Canadian law requires public consultation. In 2007, Canada adopted an approach of public consultation with communities, which will supposedly be "community-driven" and "collaborative." No site has been selected as yet for characterization. The authorities recognize that the process will take time. According to the NRC, the Canadian waste authority "*assumes* the availability of a deep geological repository in 2035"[53] An assumption is clearly not the same as a reasonable assurance. It simply allows financial calculations to be made. Given that the authorities are still on square-one in regard to public acceptance after 37 years of implementing a program and considerably more than that of nuclear reactor experience, the date of 2035 can only be considered notional. It is not based on an actual program of characterization on the ground or the acceptance of a particular community located at a specific site.

5. Finland

Finland is the only country with an active nuclear power program and an active repository program where the host community government has approved of the repository site and agreed to host it. The opening of the deep repository is expected in 2020.[54]

6. Sweden

Two municipalities in Sweden have agreed to be potential hosts of a geologic repository and an application for repository development is estimated to be filed in 2009.[55] However, it should be noted that Sweden has had a national moratorium on the construction of new nuclear power plants.[56] Therefore, its entire public consultation process has been carried out in the context that the waste stream would be limited to that

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[52] NRC 2008, p. 59560.
[53] Both quotes are from NRC 2008, p. 59560, italics added.
[54] NRC 2008, p. 59560.
[55] NRC 2008, p. 59560.
[56] Lundqvist 2006 p. 227

from its existing reactor fleet. It is an open question whether public acceptability would be forthcoming should Sweden reconsider its moratorium and rescind it.

7. France

The NRC has described the above six cases as part of its discussion of Finding 2 and the proposed update of this finding. It is interesting that the NRC did not discuss the French program (other than a passing mention in a footnote). In fact, the French program has faced serious public opposition and its history is somewhat similar to the one in the United States. The original intent was to characterize more than one site. Only one site, in north-eastern France is being characterized. It has faced considerable local opposition. The selection of a second site (in western France) for characterization was abandoned after serious public opposition.[57] The French appear to be as averse to having high-level nuclear waste in their backyards as people in other countries. Further, as noted above, there are serious technical questions about how ANDRA, the French nuclear waste agency, is proceeding to characterize the site and whether the results will be adequate to provide a satisfactory scientific basis for performance assessment. In other words, the public's skepticism about official technical work may not be misplaced, contrary to the NRC's implication that public and political non-acceptance of a geologic repository is somehow not based in science.[58]

2. Political and Social Acceptance Issues in the United States

Political and social acceptance is as essential in a democracy as technical feasibility. We have already discussed that the NRC has not provided the basis for its finding that there is reasonable assurance that a repository is technically feasible. We discuss here the social and political aspects of feasibility, which are also important for estimating a schedule. The NRC now acknowledges that in developing a repository schedule:

> The Commission's proposed revision of Finding 2 is based on its assessment not only of our understanding of the technical issues involved, but also **predictions of the time needed** to bring about the necessary societal and political acceptance for a repository site.[59]

The U.S. program has been beset with difficulties that are well known. Some of them are described in the discussion of the proposed update to the NRC's waste confidence findings. Some others have been discussed above. The failure of the second repository program provides another example. It was, in large measure, due to public opposition; but at least some of that opposition was technically well-founded since there were many technical problems with the approach that the DOE used to select the sites in its Draft

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[57] CNE 2001, pp. 53-55.

[58] The proposed waste confidence rule states "International developments have made clear that technical experience and confidence in geologic disposal, on their own, have not sufficed to bring about the broader societal and political acceptance needed to realize the authorization of a single national repository." NRC 2008, p. 59559.

[59] NRC 2008, p. 59561, emphasis added.

Area Recommendation Report. (An unscientific element in the DOE's approach to site ranking, an essential technical element of site section, is briefly discussed above as an example of the problems in the report). The narrowing of site characterization to one site in Nevada was also political. As discussed above and below, the Yucca Mountain site has characteristics that make it unsuitable for a repository. But in the present context of a discussion of the proposed revision to Finding 2, it is sufficient to note that the State of Nevada and its representatives have been vigorously opposed to it on a bipartisan basis. Further, the political position of those representatives is considerably stronger today than it was when the 1987 amendments to the 1982 Nuclear Waste Policy Act (NWPA) were passed. Senator Harry Reid of Nevada is now Majority Leader of the U.S. Senate.

The Yucca Mountain Project also faces serious budgetary constraints. DOE's announced timetable of an opening by 2020 is contingent on Congressional appropriations. There is no basis in present political reality to assume that the DOE would get what it wants for site development. The United States program is also mired in litigation. Though a final EPA standard has been issued, it is not a given that it will hold up in the courts or that the Yucca Mountain site can meet the limits that the EPA has set.

The vigorous opposition of the people of Nevada and also of many along the transportation routes to Nevada is a fact that does not bode well for the eventual operation of the Yucca Mountain repository. Only one repository program is proceeding with a specific site where a repository may be assumed to open with reasonable assurance. That is the Finnish program, which was undertaken with both national and local approval. There is no other repository program that is on a road that would allow a conclusion that a repository would open with "reasonable assurance." Indeed, the NRC's revision of Finding 2 is not now dependent on the opening of Yucca Mountain, but on the opening of some repository within 50 to 60 years of the termination of the license of any operating reactor.[60]

We now have a President of the United States who is on the record as having stated that the Yucca Mountain site is unsuitable. President Obama has written:

> I want every Nevadan to know that I have always opposed using Yucca Mountain as a nuclear waste repository, and I want to explain the many reasons why I've held that view.
>
> In my state of Illinois, we have faced our own issues of nuclear waste management. There are some who believe that Illinois should serve as a repository for nuclear waste from other states. My view on this subject was made clear in a 2006 letter to Sen. Pete Domenici, who at the time was chairman of the Senate Energy Committee. "States should not be unfairly burdened with waste from other states," I wrote. "Every state should be afforded the opportunity to chart a course that addresses its own interim waste storage in a manner that makes sense for that state."
>
> That is a position I hold to this day when it comes to both Illinois and Nevada.

[60] NRC 2008, p. 59558 and p. 59561.

> After spending billions of dollars on the Yucca Mountain Project, there are still significant questions about whether nuclear waste can be safely stored there. I believe a better short-term solution is to store nuclear waste on-site at the reactors where it is produced, or at a designated facility in the state where it is produced, until we find a safe, long-term disposal solution that is based on sound science.
>
> In the meantime, I believe all spending on Yucca Mountain should be redirected to other uses, such as improving the safety and security of spent fuel at plant sites around the country and exploring other long-term disposal options.[61]

But if Yucca Mountain fails, it is not at all evident that a second program could be successfully put into place, as the NRC assumes. Besides the repeated delays, cost overruns, and technical problems that have plagued the Yucca Mountain program, there are other historical facts that need to be taken into account here. For instance, the DOE's Nuclear Waste Negotiator program, which aimed to find a community by consent, was eventually a failure. President George H.W. Bush appointed David H. Leroy as the Nuclear Waste Negotiator in 1990.[62]

Some attempts to locate a "temporary storage" facility at Native American reservations failed outright. The Private Fuel Storage proposed for Goshute reservation in Utah has also essentially failed, despite approval by the NRC, because of state opposition and opposition of people within the Goshute tribe to a tribal council decision to host it. A legal challenge remains.[63] It is highly unlikely that PFS will get to use the license that the NRC has granted it.

There is nothing in the history of the U.S. high-level waste program, from the first characterization program near the Lyons, Kansas, site in the 1960s to the Yucca Mountain site in 2009, that encourages the view that a repository would gain state approval. In its discussion of Finding 2, the NRC itself has acknowledged that "technical experience and confidence" are not enough to create a successful repository program:

> It is important to note, however, that broader institutional issues have emerged since 1990 that bear on the time it takes to implement geologic disposal. International developments have made clear that technical experience and confidence in geologic disposal, on their own, have not sufficed to bring about the broader societal and political acceptance needed to realize the authorization of a single national repository.[64]

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[61] Obama 2007
[62] Wald 1991
[63] Two agencies of the Department of the Interior have issued decisions effectively ending the proposed Private Fuel Storage facility. See BIA 2006 and BLM 2006. Discussion of the opposition to the PFS in Nevada can be found at http://deseretnews.com/article/content/mobile/1,5620,645199671,00.html?printView=true and at http://healutah.org/nuclearutah/waste/pfs, among other sources. Not all challenges have ended. In July 2007, Private Fuel Storage made a claim against the Department of the Interior, hoping to reverse the decision. See NRC 2008, p. 59566 (footnote 24) – the claim has not been settled.
[64] NRC 2008, p. 59559.

The entire history of the program, from Lyons Kansas, to the second round repository sites, to PFS, to the continuing legal, technical, and political challenges to Yucca Mountain, including now from the President of the United States, lends support to the view that both state and local consent are necessary (and consent of the people and governments of the tribes in the case of Native Americans) in the United States to the opening of a spent fuel repository.[65] With this history and with the strong U.S. tradition of state political prerogatives and rights, a statement that there is "reasonable assurance" that a repository would open in the foreseeable future without both state and local consent is unwarranted and unjustified. This conclusion would stand even if Yucca Mountain were a technically suitable site. And, as discussed above, there are many indications that Yucca Mountain is not a technically suitable site.

Yucca Mountain could not even accommodate spent fuel from existing reactors without new legislation, much less spent fuel from any new reactors that might be built. A second repository would also require new legislation and, as the proposed update acknowledges, it may require new NRC regulations.[66] There needs to be reasonable assurance that workable legislation would be passed before the NRC can conclude that there is "reasonable assurance" that a repository will be available in some general time frame. To fail to provide a basis for assuming that there would be such legislation is to fail to provide a satisfactory basis for the central claim in the proposed Finding 2.

The NRC stated in its Draft Waste Confidence rule that its revision of Finding 2 is based in part on "**predictions of the time needed** to bring about the necessary societal and political acceptance for a repository site."[67] But the NRC has not provided any political, historical, legislative, or social fact, much less an analysis, to support its prediction that that there will be sufficient political or societal support for a repository by 50 to 60 years after the license of any reactor has expired. Under the present circumstances, with opposition from the President of the United States and from the Majority Leader of the U.S. Senate, it is reasonable to conclude that the Yucca Mountain project will sputter along with inadequate funds or be ended entirely.

In the absence of action to lift the 70,000 metric ton cap, legislation to authorize a second repository is needed. Moreover, such legislation should be workable. The history of nuclear waste programs around the world indicates that state, local, and (when applicable) tribal consent is one essential ingredient of a successful program (though by no means the only one). Further, the federal government must be of one mind in pursuing the project over a long period of time. The history of the NWPA shows that not one of these societal and political conditions has been met. There is no indication in political reality that they will be met. The history of the second repository, which was abandoned in 1986, and the Nuclear Waste Negotiator program also points in the same direction.

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[65] This does not mean state and local support would be sufficient; it is just one necessary condition. Technical, legal, environmental and health criteria also needed to be satisfied.

[66] See footnote 3, NRC 2008, p. 59555.

[67] NRC 2008, p. 59561, emphasis added.

Even though it recognizes the important of social and political factors, the NRC proposes to find that there is reasonable assurance that there will be a repository any underlying legislative or political feasibility analysis. In effect, the NRC is assuming that the Executive Branch of government can confront the Legislative Branch with a *fait accompli* of granting license extensions to existing reactor licensees and licenses to new applicants. The implicit assumption is that Congress must then act to create a repository program that will accommodate all the waste and that new legislation will actually result in a repository.

The NRC apparently recognizes the weakness of its position regarding Finding 2 in that it explicitly solicits comment as to whether it should find instead that storage on site is safe "until a disposal facility can reasonably be expected to be available."[68] There is even less reasonableness in punting to the indefinite future, when the uncertainties and risks become greater. A large part of the very notion of spent fuel disposal is that it is far too risky to leave spent fuel lying around at dozens of sites for the indefinite future. This matter cannot be settled within the framework of dates or simply indefinite deferral of decisions. After repeatedly incorrect Waste Confidence Decisions regarding reasonable assurance of repository availability, the reasonable thing now is to do an Environmental Impact Statement that properly considers all the alternatives. This is necessary in any case, since a large part of the environmental impact evaluation done in the reactor licensing process is either obsolete or wrong or both (see below).

3. Financial considerations

There is also no fiscal or economic basis for concluding that there is a reasonable assurance that a repository will be available. The Nuclear Waste Policy Act requires nuclear utilities to collect 0.1 cents per kilowatt-hour from ratepayers and provide them to the federal government for spent fuel disposal in a repository. Annual nuclear electricity generation was about 787 billion kWh in 2006,[69] making that year's contribution to the Nuclear Waste Fund of about 787 million dollars. About 56,000 metric tons of spent fuel have already been generated as of April 2008. The figure is expected to rise to 119,000 metric tons by 2035.[70] However, reactor relicensing is continuing so this quantity is likely to increase, for instance, if nearly all operating reactors are relicensed.

In addition, the geologic repository must also accommodate Department of Energy reprocessing high-level waste disposal. As discussed above, it is highly unlikely that the 70,000 metric ton cap for the Yucca Mountain site will be lifted by Congress. The financial consequences of these facts must be taken into account in any waste confidence ruling dealing with both existing and new reactors.

The DOE's cost estimate for Yucca Mountain has escalated from about 57.5 billion dollars in 2001 to 96 billion dollars in 2008 for a variety of reasons, including more waste

[68] NRC 2008, p. 59561.
[69] Data from the U.S. Energy Information Administration (DOE EIA 2009)
[70] DOE OCRWM 2008.

and inflation.[71] This estimate is based on a smooth functioning of the program from here on out. This is highly unlikely given that program funds are highly likely to be cut, if it is not terminated altogether. It would be prudent and reasonable to assume that the costs of Yucca Mountain likely to be well over $100 billion, if it opens. At 0.1 cent per kWh, and 90 percent capacity factor for 60 years, the present U.S. reactor fleet will generate about $50 billion in revenue.[72] Moreover, this revenue is in current dollars, since the fee is not adjusted for inflation. But the costs are subject to inflation, one reason that they keep going up with every delay. Note that the cost estimate of $96 billion is in constant 2007 dollars. While there is some additional revenue from DOE defense high-level waste and some revenue from interest, this is unlikely to keep pace with rising costs.

It is not reasonable to assume that the present 0.1 cent per kWh fee will suffice to pay for the U.S. repository program. Further, given the political and legislative situation and the history of Nevada's opposition to Yucca Mountain, it is not reasonable to assume that the 70,000 metric ton cap will be lifted. Hence a second repository may well be necessary to accommodate spent fuel from existing reactors, and the problem will be worse if most or all of the reactors are relicensed. This would be true even if no new reactors are built.

There is at present no way to estimate the costs of a second repository, since the cost escalations for the first have been large and the program may fail altogether for one or more of a variety of reasons. In the interim, governmental liabilities for failing to meet its statutory deadline for beginning the process of taking ownership and disposing of the spent fuel are mounting. With no reasonable date for Yucca Mountain or a second repository in sight, the government's liabilities may become huge and must be taken into account in the overall cost of spent fuel storage and disposal. The penalty costs cannot at present be charged to ratepayers, since the government is in contractual default. The costs are nonetheless real to the people of the United States as a whole and much of the money is coming from ratepayers via federal taxes, and the rest from other taxpayers who are not now consuming nuclear electricity.

The NRC needs to address the financial uncertainties, legislative difficulties, and other political and social problems in making its estimate of the time in which a repository might become available. While political situations are subject to change, there is nothing in the past that encourages the view that it is becoming easier to find political acceptance for a repository in any part of the country.

In view of the above, the Institute for Energy and Environmental Research makes the following recommendations regarding the update of Finding 2. This finding should be change to explicitly state that:

1. It is far from assured that a second repository site can be successfully opened in the United States without the acceptance of the host state and local community.

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[71] DOE 2008b

[72] Some of this has already been generated, of course, since ratepayers have been paying into the fund for the past quarter of a century.

Such acceptance may or may not be forthcoming. The history of the U.S. repository program is not encouraging in this regard.

2. It is far from assured that the cap of 70,000 metric tons of heavy metal that is imposed by the Nuclear Waste Policy Act will be lifted.
3. In view of 1 and 2 above, commercial nuclear reactor licensees should make financial, security, and technical provisions for indefinite, secure, and hardened storage of spent fuel at reactor sites. These provisions should include infrastructure for transferring spent fuel bundles from one dry cask to another.
4. In view of 1, 2, and 3 above a generic EIS on spent fuel management and disposal including the alternatives mentioned above needs to be prepared, along with cost estimates and estimates of comparative security risks.

C. Requirements for a Generic Environmental Impact Statement on Spent Fuel Waste Confidence

The Waste Confidence Decision Update is being proposed in the context of NRC relicensing reactors in the existing fleet and of the applications for licenses for new reactors that it is considering. This update has major implications for safety and environmental impact. It will commit generations far into the future to potential harm if the NRC does not properly consider all relevant aspects of "safe disposal" and of environmental and health impacts of the wastes and radioactivity releases associated with reactor operations.

1. Need for a Generic EIS on Waste and Reactor-Related Emissions

As set forth in Section A above, the NRC has not presented a scientific analysis to support its claim that there is "reasonable assurance" that "safe disposal" of spent fuel in a geologic repository is "technically feasible" (Finding 1) or that it can be opened within the time frame set forth in the proposed revision of Finding 2. On the contrary, it far from assured that such safe disposal is technically feasible. It is important to note in this context that the prior Commission bases, on which its earlier findings were based, have been invalidated by experience, time, and new scientific understandings, many of which have been discussed above. Consider Yucca Mountain, which should provide the strongest case for a technical feasibility determination. Deadlines have repeatedly slipped. New data on corrosion have emerged. Some experts have deemed this site as inadequate and even "fatally flawed.' Most of the DOE dose estimates made since 1990 show exposures in excess of the current EPA standard of 100 millirem beyond 10,000 years. As a result, there is considerable scientific basis to doubt that Yucca Mountain is a suitable repository or that it should be licensed. We have discussed a critical problem with DOE's license application in that it sidestepped a key recommendation of the NWTRB by declaring it insignificant. There is also no real basis to estimate a future time, either as a date or in relation to expiry of reactor licenses, when there can be reasonable assurance that a repository can be opened.

The escalation of costs without an actual result in the form of a repository as well as the escalation of penalties for the government's failure to begin disposing of existing wastes is causing waste management costs to escalate well beyond what was projected when the program was put into place. There is no clear current cost estimate of what it will cost to dispose of all the spent fuel currently scheduled to be produced from existing licenses and license extensions that have already been granted. This means that it is impossible to make a reasonable comparison with alternatives methods of electricity production that do no involve the creation of long-lived radioactive waste such as spent fuel and Greater Than Class C waste and depleted uranium.

In view of these facts, it is essential for the NRC to prepare a thorough generic environmental impact statement on spent fuel that would be generated by new reactors as well as from relicensing of existing reactors.

The NRC also needs a current and coherent analysis of the health impacts of the nuclear waste that will be created incident to the licensing of new nuclear plants and re-licensing of existing nuclear plants. The need for such a statement is further demonstrated by the fact that much of the basis for the assessment of the environmental impacts of reactor operation, which is part of the reactor licensing process, is obsolete and/or wrong. Specifically, Table S-3 at 10 CFR 51.51, is obsolete or incorrect in many respects, especially in regard to assumptions about the impacts of disposal of spent fuel, Greater than Class C Waste, Depleted Uranium as well as about other impacts (see below). Since the NRC is now engaged in a sweeping process, via relicensing existing reactors and considering new reactor licensees, to allow the creation of vast amounts of new waste, a generic EIS is needed.

Finally, the prior EIS on geologic disposal, prepared by the DOE is, like Table S-3, hopelessly out of date and also incorrect in essential parts about its estimates of environmental and health impacts.

No pre-existing EIS, already prepared by the NRC or the U.S. Department of Energy ("DOE"), is sufficient to support the Waste Confidence Decision. For instance, the EIS prepared by the DOE in 1980 is insufficient in scope and grossly out of date. As one example, the DOE EIS does not anticipate any releases from a properly constructed repository in the absence of extraordinary and rare events. In fact, it stated that:there was "every expectation that long-term radiological impacts will be nonexistent."[73] As discussed at length above, this is contrary to present understanding of any medium but salt, which the NRC itself now says is unsuitable for spent fuel disposal.

As another example, the DOE did not even examine a repository in tuff, which is the rock at Yucca Mountain and has been the only repository being characterized since 1987. It was written before there was an adequate understanding of the complexities of the three elements of the disposal system, discussed above in Section A, and the difficulties of estimating their joint performance. For instance, at the time, containers were expected to perform the role of a barrier for the early period of disposal, while the geologic system would take care of the long-term:

[73] DOE 1980, p. 5.72. The DOE only considered long-term radiological releases in case of improbable events such as meteorite impacts

> The multiple barriers that could contain nuclear waste in deep mined repositories fall into two categories: 1) geologic or natural barriers and 2) engineered barriers. Geologic barriers are expected to provide isolation of the waste for at least 10,000 years after the waste is emplaced in a repository and probably will provide isolation for millenia [sic] thereafter. Engineered barriers are those designed to assure total containment of the waste within the disposal package *during an initial period* during which most of the intermediate-lived fission products decay. This time period might be as long as 1,000 years...[74]

It is clear that when DOE prepared this EIS in 1980, engineered barriers, including containers, were not expected to fulfill the main long-term function of containment for 10,000 years or more. But the NRC now only requires only an overall performance assessment which combines the performance of all elements together and does not put any sublimits on the performance of any particular element. As we have noted in Section A, in the case of Yucca Mountain, the essential performance burden in the sense of compliance with regulations rests with the containers. Indeed, the NRC's rules in this regard have also changed since the DOE's EIS was issued. The NRC's first rules corresponded more to the DOE's EIS concept that engineered barriers were to contain the waste in an initial period with the geology taking up the function after that. Those rules, which apply to geologic repositories to be licensed by the NRC, are at 10 CFR 60, but they Yucca Mountain was exempted from them, just as it was exempted from 40 CFR 191, Subpart B, which applies to all other repositories. 10 CFR 63, which requires only a combined performance assessment, was promulgated specially for Yucca Mountain.

Finally, a central part of licensing of new reactors and of the relicensing of existing reactors is as it concerns light water reactors (that is, all licensed power reactors in the United States) is the requirement that the license applicant prepare an Environmental Report that addresses:

> Table S-3, Table of Uranium Fuel Cycle Environmental Data, as the basis for evaluating the contribution of the environmental effects of uranium mining and milling, the production of uranium hexafluoride, isotopic enrichment, fuel fabrication, reprocessing of irradiated fuel, transportation of radioactive materials, and management of low level wastes and high level wastes related to uranium fuel cycle activities to the environmental costs of licensing the nuclear power reactor.[75]

In the sections below we show that Table S-3 is obsolete and incorrect in a number of critical areas and needs revision, correction, and updating.[76] Since this is the main vehicle for assessing the environmental impacts of nuclear energy, a revision of this table and of the corresponding parts of 10 CFR 51, needs to be a part of the generic EIS on waste and the environmental impacts of nuclear energy.

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[74] DOE 1980, p. 5.1

[75] 10 CFR 51.51(e) 2008. [N.B.: formerly 51.20(e) 1984]

[76] The comments below on Table S-3 apply as well to Table S-3A, which is in WASH-1248 and provides more detail for Table S-3, when applicable.

2. Solid high-level waste and spent fuel disposal impacts

This requirement applies to "any applicant's environmental report submitted on September 4, 1979, or thereafter."[77] In regard to high-level waste or spent fuel, Table S-3 purports to provide environmental impacts that "are maximized to either of the two fuel cycles (uranium only and no recycle)."[78] While this purports to be the maximum impact from spent fuel disposal (either with or without reprocessing), the claim is either wrong, obsolete, or both.

First, the Nuclear Waste Policy Act envisions disposal of spent fuel. The reprocessing impact calculations are therefore irrelevant for present licensing and environmental impact considerations. Second, the Statements of Consideration associated with the promulgation of the final rule effective on September 4, 1979, explain the regulation note the following in regard to storage and disposal as follows:

> In determining the impacts associated with waste management and disposal, the [Nuclear Regulatory Commission] staff assumed that high-level waste (or reactor spent fuel treated as waste) would be stored in interim facilities (water basins and retrievable surface storage facilities) for about twenty years and then disposed of by burial in a bedded salt repository.[79]

In a footnote to this passage, the NRC noted that the original rulemaking had not extensively covered deep geologic disposal but subsequent work, published in NUREG-0116 has remedied that problem:

> ...NUREG-0116, Section 4.4, provides a 30-page quantitative discussion of disposal of long-lived wastes in a bedded salt repository, with citations to many relevant technical documents prepared since 1973.[80]

Thus, in 1979, the NRC had considered bedded salt as suitable for disposal either of reprocessed high-level waste or unreprocessed spent fuel. Yet, the draft waste confidence rule of 2008 states that salt formations are not being considered for spent fuel disposal for technical reasons (see quote above). Hence, Table S-3 is completely outdated and inappropriate according to current law, which requires spent fuel disposal, and the NRC's own understanding of salt repositories.

To wit, disposal in salt, which is the basis for estimating the environmental impact of high-level waste or spent fuel disposal, is only considered suitable for high-level waste resulting from reprocessing, but reprocessing is not the current policy. Rather, direct disposal of spent fuel, for which the NRC would not consider salt formation, is now the current policy.

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[77] 10 CFR 51.51(e) 2008.

[78] 10 CFR 51.51 2008, Table S-3, Footnote 1. Uranium only means a reprocessing cycle in which only the recovered uranium is reused as a fuel.

[79] NRC 1979

[80] NRC 1979, footnote 19

Moreover, Table S-3 assumes that there will be no releases whatsoever from solid high-level waste disposal.[81] According to WASH-1248, which is the underlying document developed for promulgating the rule:

> The most significant solid radiological waste consists of the fission products separated from the spent fuel of an annual fuel requirement in the reprocessing operation. These high level wastes will be stored onsite for a maximum of 10 yrs., and will ultimately be shipped, probably by rail, to a Retrievable Surface Storage Facility (RSSF). The RSSF will be established to store and manage high level solid wastes under constant surveillance for up to 100 years, or until such time as a more permanent Federal repository can be established. The facility will be designed to prevent the release of significant amounts of radioactive material to the environment under all credible environmental conditions and human actions. *Therefore, such waste will not be released as effluents to the environment.*[82]

The same assumption of essentially zero release and zero impact has evidently been applied to spent fuel as well. The NRC's 1981 background information on Table S-3 affirms this as well:

> It has been assumed that a geologic repository will be designed and operated so as to retain solid radioactive waste indefinitely.[83]

And again:

> The high-level radioactive waste from the once-through fuel cycle is the spent fuel assemblies, which will be packaged and disposed of in a geologic repository. The radioactive waste from the uranium-only recycle option consists of the fuel assembly hulls, the high-level and intermediate-level wastes from reprocessing, and the plutonium waste. These wastes will be disposed of in a geologic repository in the form of solids which will have chemical and physical properties that mitigate the release of radionuclides to the environs. It is assumed that *the geologic repository will be designed and operated so that the solid radioactive wastes are confined indefinitely.*[84]

Table S-3 does not show any releases from a deep geologic repository though ten million curies per reactor-year would be disposed of. Nor are any adverse health impacts estimated. Of course, these are implicitly zero as well, corresponding to the assumed zero release of radionuclides from the repository.

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[81] Table S-3 was revised in 1979 when 10 CFR 51 was promulgated. It has not been changed since. The references to Table S-3 are from 10 CFR 51 as it currently stands and to Table S-3A in so far as it is compatible with the present Table S-3.
[82] WASH-1248, p. S-23, italics added.
[83] NRC 1981
[84] NRC 1981, p. 13, italics added.

In 1983, the Supreme Court affirmed the reasonableness of the zero releases assumed in Table S-3 (BG&E v. NRDC, 462 U.S. 87). This decision was rendered in the context of the assumption of disposal of reprocessing high-level waste or spent fuel in a bedded salt repository. As noted above, the assumption of disposal of reprocessing waste from commercial spent fuel is obsolete; current law requires disposal of spent fuel. There is no commercial reprocessing facility in the United States. The assumption of disposal of spent fuel in salt has been is no longer scientifically supportable due to the thermo-mechanical properties of salt. The NRC itself has concluded that only reprocessing high-level waste is suitable for disposal in salt. Further, the assumption of zero release of radioactivity due to disposal of spent fuel is contrary to the established scientific understanding of the expected performance of all other geologic settings. For instance, all of the DOE documents cited above as well as the graphs shown in Attachment A to these comments show positive doses due to disposal of spent fuel in Yucca Mountain. Of course, positive doses can only be the result of positive releases of radionuclides into the human environment. As far back as 1983, the report on geologic isolation prepared for the DOE by the National Research Council concluded that radiation doses would be positive doses for spent fuel and high level reprocessing waste disposal in all settings other than salt that were evaluated – tuff, granite, and basalt.[85]

The Supreme Court's 1983 finding that an assumption of zero release from high-level waste or spent fuel disposal has therefore been rendered obsolete by the combination of following three considerations:

1. The Nuclear Waste Policy Act requires the disposal of waste from commercial nuclear power plants in the form of spent fuel rather than reprocessing waste.
2. Spent fuel cannot be safely disposed of in a salt repository, as acknowledged by the NRC (see above)
3. All other repository settings are now acknowledged to have some releases of radioactivity.

10 CFR 51 therefore is no longer valid and as the basis for determining the environmental performance of nuclear power plants so far as releases from spent fuel are concerned. As a result it does not provide a satisfactory basis for licensing new nuclear power plants or relicensing existing ones. It also does not provide the basis for confidence that a suitable repository will be available that will keep the environmental impacts within the limits assumed by Table S-3.

Instead of addressing the substantive issues that it faces in regard to waste confidence in the licensing of new reactors or the relicensing of existing reactors under the technical and legal conditions that exist today, the NRC has wrongly assumed the problem away in its draft waste confidence findings by implicitly assuming that Table S-3 is still valid. A new and valid estimate of the set of environmental impacts from high-level waste and

[85] NAS-NRC 1983, Chapter 9. Estimates of doses from spent fuel disposal are only presented for basalt along with the statement that the conclusions for basalt "will apply as well to the other repository media." p. 282.

spent fuel disposal is evidently needed as part of any waste confidence rule. A generic environmental impact statement is needed in order to establish the basis on which new reactors can be licensed or existing reactors can be relicensed.

We note here that there are other parts of Table S-3 that is obsolete or wrong or both that do not concern high-level waste or spent fuel, but relate to the impacts from other parts of the fuel cycle. These also needed to be covered in the new, generic environmental impact statement. Some additional requirements for revision of Table S-3 are discussed in below.

As noted above, Table S-3 is either incorrect or obsolete or both in regard to high-level waste and spent fuel disposal in a geologic repository. There are other ways in which these tables do not properly or adequately assess the impact of wastes and effluents associated with nuclear reactor operation. A thorough revision of these tables and the associated analysis is necessary to correct them and to assess the environmental impact from relicensing existing commercial reactors or licensing new reactors, both of which will result in the generation of large amounts of new waste and radioactivity. We will first cover the ways in which Table S-3 is deficient in matters other than high-level waste and spent nuclear fuel disposal. Then we will provide recommendations for the scope of the generic environmental impact statement that is needed to address those aspects of environmental and health impacts of reactor licensing and re-licensing.

3. Releases of volatile radionuclides from spent fuel

Volatile radionuclides are mainly released to the atmosphere from spent fuel when it is reprocessed if not captured.[86] For instance, iodine-129 would be released to the atmosphere in this way, if not captured. There are also liquid effluents as a result of reprocessing.

In constructing Table S-3, the NRC assumed that I-129 would be released to the atmosphere prior to spent fuel disposal in a repository even though, physically this would not occur. The NRC claimed that this was a "conservative" assumption:

> For spent fuel disposal the staff made the conservative assumption that fission-product gases in the spent fuel, including all tritium, krypton-85, carbon-14, and iodine-129, would be released during handling and emplacement of the waste prior to sealing of the repository. This assumption reflects the possibility that the spent fuel storage canisters and the fuel rod cladding will be corroded by the salt during the period the repository is open (roughly 6 to 20 years, and volatile materials in the fuel will escape to the environment. The staff assumed, however, that after the repository is sealed there would be no further release of radioactive materials to the environment.[87]

[86] The release of carbon-14 as carbon-14 dioxide gas is covered separately below.
[87] NRC 1979.

The NRC made this assumption in the context of disposal in a bedded salt repository, which, as noted, is obsolete for spent fuel. It is also not conservative for any other geologic setting, since iodine-129 releases into groundwater could cause much higher doses either via groundwater or where the groundwater is discharged into surface water.

For instance, the largest dose calculated by the French nuclear waste agency ANDRA, was due to I-129 in spent fuel. As noted in Section A, the whole body effective dose equivalent from I-129 in the event of seal failure was estimated to be 1,500 millirem, greatly in excess of both the French and current U.S. EPA performance requirements. Since the main organ that is irradiated is the thyroid, the implied dose to the thyroid is about 30,000 millirem.[88]

It is clear that under present circumstances, with present technical information, and under current law, Table S-3 is not conservative. On the contrary, by assuming that I-129 is dispersed into the atmosphere, the doses are implicitly assumed to be quite low. For instance, WASH-1248, the document underlying 10 CFR 51, estimates the thyroid dose due to the release of volatile radionuclides (mainly I-129) as only 6.3 millirem from one-reactor year of operation.

This dose appears to be well with compliance limits and hence the NRC can proceed to liecense reactors on this basis. However, if it is assumed that spent fuel will be disposed of in a geologic repository where groundwater could become contaminated, then the performance measure to be used is not longer that applying to one reactor for one eyar, but whther the geologic repository system is suitable for disposal of all the spent fuel that is created in the program as a whole. In the French case, the spent fuel disposed of is much less than will be required in the U.S., since the French have fewer reactors and they have reprocessing. It is plausible that the U.S. impacts from iodine disposal could therefore be far in excess of the limits set in 40 CFR 197 for geologic disposal.[89] Therefore the cumulative impact of licensing new reactors and re-licesing existing reactors would be far in excess of that estimated in Table S-3, which assumes zero releases into the environment from disposal of solid spent fuel.

Other parts of Table S-3 relating to volatile or gaseous radionuclides are also obsolete. For instance, Table S-3 assumes a release of 400,000 curies of krypton-85 into the atmosphere per reactor-year. While this may be conservative, it is greatly in excess of the EPA's maximum allowable release of krypton-85 from one-gigawatt-year[90] of operation as specified in 10 CFR 190.10(b):

[88] Calculated using thyroid and committed dose equivalent dose conversion factors for ingestion of iodine-129 in EPA 1999 and 2002 suppl. The weighting factor used for the thyroid is 0.03, according to 40 CFR 191.

[89] The DOE's license application for Yucca Mountain estimates low doses only because it assumes near-total container integrity for very long periods of time and treats deliquescence-induced corrosion as insignificant.

[90] This is equal to one 1,000 megawatt reactor operating for one year at 100 percent capacity factor. Table S-3 assumes a "Reference Reactor Year" which is the same reactor operating at 80 percent capacity factor,

> (b) The total quantity of radioactive materials entering the general environment from the entire uranium fuel cycle, per gigawatt-year of electrical energy produced by the fuel cycle, contains less than 50,000 curies of krypton-85, 5 millicuries of iodine-129, and 0.5 millicuries combined of plutonium-239 and other alpha-emitting transuranic radionuclides with half-lives greater than one year.[91]

Hence, the assumed release of Kr-85 in Table S-3 is far in excess of that allowed under current EPA rules, demonstrating yet another aspect of the obsolescence of Table S-3. We understand that these releases would occur mainly in the case of the reprocessing option being chosen and that reprocessing is not the current law for spent fuel management and disposal. But Table S-3 is designed to cover both the reprocessing and non-reprocessing cases. The releases it estimates, as an upper bound, are not in compliance with current regulations.

Table S-3's estimate of 1,300 millicuries (1.3 curies) of iodine -129, and 203 millicuries (0.203 curies) of fission products and transuranic radionuclides not otherwise specified are also not aligned with 40 CFR 190.10(b).

It is clear that some of the NRC assesses releases from reactor operations to be insignificant that are far in excess of those allowed by the EPA. The fact that these releases would be primarily from reprocessing operations and that reprocessing is no longer envisaged as the basis for disposal only highlights the obsolescence of Table S-3.

Further, it is possible that reprocessing may become the basis for spent fuel management for some or all of spent fuel. While we have concluded that such a course would create far more serious problems than it solves, it is nonetheless within the realm of possibility. For instance, it is part of a set of options being considered under the Global Nuclear Energy Partnership.[92]

As of April 2008, U.S. nuclear power plants had created 56,000 metric tons of spent fuel. The DOE anticipates that 119,000 metric tons of spent fuel will be created by existing reactors by 2035. There is some uncertainty about waste generation per reactor for new reactors, since it will depend on enrichment, burn-up etc. But 30 new reactors would likely generate in excess of 600 metric tons per year of spent fuel, or 24,000 metric tons over 40 years.

In sum, just considering spent fuel alone, there are a many ways in which Table S-3 is obsolete and/or incorrect. Hence revision of operational norms and release estimates in both the reprocessing and non-reprocessing cases is essential as is a reevaluation of the impacts and costs in a new generic EIS.

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see NUREG-0116, Table 3.2, p. 3-14. When translated into the same basis as the EPA regulation, the krypton-85 emissions would be 500,000 curies per gigawatt-year.

[91] 40 CFR 190.10(b) 2008

[92] GNEP PEIS draft 2008, see Section S.2.4 for a summary of options the DOE is considering. A Final EIS has not yet been prepared.

4. Greater than Class C (GTCC) waste and low-level waste

Table S-3 is severely outdated with respect to GTCC waste. It is also outdated with respect to Class A, B, and C low-level waste.

a. GTCC waste

There was no GTCC waste category when the 10 CFR § 51.51 and Table S-3 was revised in the late 1970's.[93] NRC regulations regarding GTCC waste were part of low-level waste regulations, which were not issued until 1982 and revised periodically after that.[94] The Part 61 low-level waste regulations generally require disposal of GTCC in a deep geologic repository and prohibit shallow land burial unless a specific exemption is obtained.[95] At present Table S-3 assumes all solid radioactive waste, except high-level waste, including what is now called GTCC waste, will be buried in a shallow land burial facility.[96] This is clearly incorrect. GTCC waste cannot be disposed of in shallow low-level waste facilities unless a specific exemption to do so is provided by the NRC. None has been provided; nor is there any application for such an exemption.

GTCC waste has a relatively high radioactivity per unit volume and many components of GTCC waste have long half-lives. The impacts in the absence of repository disposal could therefore be considerable – though the amounts would be site specific. Therefore, Table S-3, which was prepared prior to the understanding that led to the creation of a GTCC category, cannot be relied upon for estimating the environmental impact of GTCC disposal. We note here that Table S-3 has been republished in the same way since the late 1970s without change, including after the low-level waste regulations requiring deep geologic disposal of GTCC waste (unless specifically exempted). The current version of 10 CFR 51 also contains this same provision for disposal "on site."[97] The following is copied from the present Table S-3 at 10 CFR 51.51[98]:

Solids (buried on site):		
Other than high level (shallow)	11,300	9,100 Ci comes from low level reactor wastes and 1,500 Ci] comes from reactor decontamination and decommissioning--buried at land burial facilities. 600 Ci comes from mills--included in tailing returned to ground. Approximately 60 Ci comes from conversion and spent fuel storage. No significant effluent to the environment.

Table S-3 is therefore legally wrong in its *a priori* assumption of shallow land burial (on site or at any site) of GTCC waste.

[93] NRC 1979. Table S-3 was first published in WASH-1248 and revised in the late 1970s, in which form it has been republished since that time.
[94] 10 CFR Part 61 2008
[95] See 10CFR 61.55(a)(2)(iv) 2008 and 10 CFR 61.55(a)(4)(iv) 2008.
[96] 10 CFR 51.51 2008. Table S-3 mentions onsite burial (i.e., "buried on site"). This would clearly not be allowed for any of the wastes discussed here.
[97] Disposal on site at reactors would not be permitted since none have a license do to so and no applications have been made. There are other issues as well in relation to low-level waste compacts see below.
[98] 10 CFR 51.51 2008.

The Department of Energy (DOE) is preparing an Environmental Impact Statement (EIS) regarding GTCC disposal.[99] This EIS is being prepared because the DOE considers the development of capability to dispose of GTCC waste as a "major Federal action."[100] A full evaluation of the impacts of options of GTCC disposal has never been done. The impacts of GTCC disposal as evaluated in this EIS need to be incorporated into a revised Table S-3. .

Table S-3 is also incorrect in another respect. As can be seen, above, it assumes that there will be "[n]o significant effluent to the environment" and no health impact is estimated. In other words, the assumption here is the same as that for high-level waste and spent fuel disposal – zero environmental impact.

The more stringent requirement for GTCC waste disposal is because the specific activity of the waste is higher than for the Class A, B, and C low-level waste categories as defined in 10 CFR 61.55. No difference in the types of radionuclides or their chemical composition is assumed to exist. The technical inference clearly is that shallow land burial would produce greater impacts than Class A, B, and C waste disposal. The radiation doses estimated by the NRC for these latter waste categories in its low-level waste EIS are greater than zero for all disposal cases, even those in conformity with the 10 CFR 61 regulations, over a period of 500 years.[101] *A forteriori*, the impacts associated with GTCC disposal in shallow land burial at the same reactor site or at some other site would likely be greater.

While the impacts of Disposal of GTCC waste disposal have not been evaluated in the United States, they are required to be disposed of in a deep repository in France. The French evaluation of Class B waste (corresponding approximately to GTCC waste) provides some interesting evidence. According to ANDRA's assessment, the dose from Class B waste disposal at the French Bure site could exceed allowable limits due to exposure to chlorine-36 in the scenario that assumes a failure of the repository seals.[102]

There is no explicit discussion of transuranic waste in Table S-3. Yet NUREG-0116, which supplements WASH-1248, and which is referred to in the notes to Table S-3 explicitly mentions that transuranic waste, mainly generated during reprocessing, should be disposed of in a deep geologic repository. Table S-3 does not even consider chlorine 36.

There will be a considerable amount of GTCC waste even if there is no reprocessing. The DOE estimated that a Boiling Water Reactor would generate 47 cubic meters and a

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[99] See DOE 2007 and DOE 2007b.

[100] According to the GTCC EIS website set up by Argonne National Laboratory for the GTCC EIS process, "The Secretary of Energy has determined that development of disposal capability for GTCC LLW is a major Federal action that may have a significant impact upon the environment within the meaning of the National Environmental Policy Act of 1969 (NEPA)." On the Web at http://www.gtcceis.anl.gov/eis/why/index.cfm.

[101] NRC 1982, v. 1, Table 4.6 (pp. 4-30 to 4-32).

[102] ANDRA 2001, p. 139.

Pressurized Water Reactor would generate 133 cubic meters upon decommissioning.[103] On this basis the existing reactor fleet would generate in excess of 10,000 cubic meters of GTCC waste upon decommissioning.

Again, it clear that Table S-3 is obsolete or incorrect in a number of respects in regard to GTCC waste. The impact of this needs to be assessed either by the NRC as part of the impacts associated with nuclear energy production.

b. Class A, B, and C low-level waste

10 CFR 61 allows disposal of Class A, B, and C low-level waste in shallow land disposal facilities. However, such facilities must be licensed and must meet the dose limits specified at 10 CFR 61 Subpart C. Table S-3 mentions "on site" disposal. WASH-1248, the underlying document supporting Table S-3 also mentions on site diposal. No current reactor sites have such licenses. No application for a new reactor contains provision for obtaining a license for on-site disposal of low-level waste. The table needs to revised and clarified in this regard.

Table S-3 also assumes that shallow land disposal of waste will have not environmental and health impact. This is incorrect. The low-level waste EIS recognizes that some impacts may occur. The standard computational model used for assessing the radiation dose impact of land contamination (and disposal of radioactive waste in shallow land burial facilities is a form of land contamination) generally produces non-zero radiation doses under any reasonable assumption of technical site parameters. This is especially so as 10 CFR 61 Subpart C contains no time limit for performance. That is, the dose limits specified there must be met for the durations that are multiples of the longest lived radionuclides disposed of at the facility. Hence Table S-3 is obsolete and wrong in its assumption of essentially zero release from shallow land burial of low-level waste as well. .

5. Depleted Uranium

Table S-3 makes no mention of the large amounts of depleted uranium that will be generated in the course of enrichment of uranium to produce fuel for the proposed nuclear reactors. Large amounts of DU from uranium enrichment plants were not regarded as a waste when Table S-3 was created. But the Nuclear Regulatory Commission has declared depleted uranium as a low-level waste. However, the classification of large amounts of DU from enrichment plants within the low-level waste scheme (Class A, B, C or GTCC) has yet to be decided. The NRC as asked its staff to conduct a generic proceeding to determine such a classification.[104]

[103] DOE data as cited in Makhijani and Saleska 1992, Table 6.

[104] "...the Commission directs the NRC staff, outside of this adjudication, to consider whether the quantities of depleted uranium at issue in the waste stream from uranium enrichment facilities warrant amending section 61.55(a)(6) or the section 61.55(a) waste classification tables." (NRC 2005).

The NRC staff has recently begun that assessment. It has determined that 10 CFR 61 does not automatically apply to DU in large amounts such as those created by enrichment plants. In fact, it has decided that DU from enrichment plants differs essentially from other low-level wastes in some respects in that it has a much higher level of specific activity, the radionuclides are exceptionally long-lived, and there is in-growth of thorium-230 and radium-226 (which emits radon-222) over hundreds of thousands of years.[105]

DU has radiological characteristics similar to Greater than Class C low-level waste, containing long-lived, alpha-emitting transuranic radionuclides at concentrations greater than 100 nanocuries per gram. Shallow land disposal of over 10,000 metric tons of DU would cause substantial health and environmental impacts in the long run. An assessment done by the Institute for Energy and Environmental Research in the context of evaluating the disposal of 133,000 metric tons of DU from an enrichment plant proposed for New Mexico, concluded that peak doses from the disposal would be in the hundreds of rem per year to the maximally exposed individual under a variety of shallow land disposal conditions, including disposal in dry or wet areas.[106] In contrast, the maximum allowable dose from low-level radioactive waste disposal is only 0.025 rem per year.[107] This means that DU from enrichment plants, over the life of the plant, if disposed of in shallow land burial, would produce doses thousands of times greater than the allowable limit at the time of peak dose.

The NRC staff paper has itself estimated that the disposal of DU in shallow land burial will cause non-zero radiation doses.[108]

Table S-3 does not take any of these realities into account. Indeed, at the time it was published in its present form, in the late 1970s, DU was not even considered a waste. However, the NRC now requires it to be considered as waste in the context of the licensing of uranium enrichment plants.[109] Hence Table S-3 is obsolete in not explicitly considering the impacts of DU.

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[105] Borchardt 2008 Enclosure 1.

[106] Makhijani and Smith 2004, Table 5 (p. 24). "Version for Public Release Redacted March 20, 2007."

[107] 10 CFR 61.41 2008

[108] Borchardt 2008, See Enclosure 1. Note that we do not agree with the results of the NRC staff's calculations. For instance, the NRC staff has assumed that "there will not be significant releases of waste to the environment from fluvial or aeolian erosion." This is completely unrealistic and in general scientifically incorrect for the time periods evaluated – well over 1,000 years and up to one million years. As a result, the quantitative impacts assessed by the NRC for arid sites are serious underestimates (since erosion is the main pathway for long-term dose, which is external dose, in arid areas). See Makhijani and Smith 2004. The NRC's conclusion that that some shallow land burial sites may be suitable for DU disposal is based on the incorrect assumption of zero erosion rates, is therefore also incorrect. There has been no scientifically credible demonstration that there would be essentially zero impact from erosion at shallow burial sites, even if these are more than three meters deep, given the time scales involved.

[109] NRC 2005

The 56,000 metric tons of spent fuel that have been created so far correspond to more than 300,000 metric tons of DU.[110] There will be hundreds of thousands of metric tons of additional DU due to future fuel production for the existing reactor fleet. Relicensing the rest of existing reactors and licensing new reactors will commit to production of further large amounts.[111]

DU cannot be buried at the reactor site or the enrichment plant site without an appropriate license. Under the current path, DU from an enrichment plant or even more than one enrichment plant may be disposed of at a single facility.

The impacts of DU management and disposal and whether such safe disposal of DU – that is disposal of DU in conformity with low-level waste disposal standards at 10 CFR 61 Subpart C – is possible needs evaluated in the generic EIS on waste that would include a revision of Table S-3. The costs of disposal that would conform to 10 CRF 61 Subpart C also need to be estimated.[112]

6. Radon

The matter of doses from radon-222 due to emissions from mill tailings had not been included in Table S-3. On March 20, 2008, the NRC denied a petition by the New England Coalition on Nuclear Pollution, which had requested that a value for the impact of radon-222 be included in Table S-3. In denying the petition, the NRC concluded that "the radiological impacts of the uranium fuel cycle, including those from radon-222 emissions, on individuals off-site will remain at or below the Commission's regulatory limits, and as such, are of small significance."[113] The NRC referred to Chapter 6 of NUREG-1437 for technical details about the denial.

Limiting radon-222 emissions from uranium mill sites requires the maintenance of the mill tailings site. This includes maintenance of a cover to prevent radon emissions:

> The design and implementation of the radon cover and erosion protection features are the primary reliance for maintaining radon emissions within the [10 CFR] Part 40 limits; significant failure of the covers is considered highly unlikely. However, the indefinite licensed long-term custody and care provide additional assurances.[114]

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[110] This is an approximate figure. It is much greater than the amount used in the illustrative calculation in the paragraph before. The exact figure attributable to commercial nuclear power plants is difficult to estimate, since the U.S. has had dual use enrichment plants for its civilian and military enrichment requirements and because in recent years the U.S. has also imported enrichment services from Russia in the form of Russian highly enriched uranium that was downblended into low enriched reactor fuel.

[111] The exact amounts are difficult to estimate since some depleted uranium tails may be used as enrichment feedstocks and the assay of U-235 in the tails may vary as uranium prices change.

[112] See for instance Makhijani and Smith 2004.

[113] NRC 2008c. The quote is on p. 14947

[114] NRC 1996, Vol. 1, pp. 6-9 and 6-10.

This assumption that there will be custody and maintenance for the indefinite future in NUREG-1437 is patently absurd. While the decay of radium-226, which has a half-life of 1,600 years, is the proximate source of radon-222 emissions from mill tailings, radium-226 itself is the decay product of thorium-230.

So long as there is thorium-230 in the tailings, the amount of radium-226 will be about the same (excepting that part accounted for by differential environmental mobilization). Thorium-230 has a half-life of over 75,000 years. Hence, there will be significant amounts of radium-226 in the tailings ponds for about ten half-lives or about three quarter of a million years. No human institution has lasted even one percent of this time. The United States, which has had a long political continuity, is not even 300 years old, and it has had a Civil War less than a hundred years after its creation. While the Atomic Energy Act may require institutional control and maintenance of mill tailings, an environmental impact assessment is a technical matter. That assessment cannot rely on a legal requirement that is patently out of touch with any reasonable expectation or technical judgment. For instance, the National Research Council has advised that long-term institutional control should not be assumed in waste disposal or matters relating to the use of contaminated sites:

> *The committee believes that the working assumption of DOE planners must be that many contamination isolation barriers and stewardship measures at sites where wastes are left in place will eventually fail, and that much of our current knowledge of the long-term behavior of wastes in environmental media may eventually be proven wrong. Planning and implementation at these sites must proceed in ways that are cognizant of this potential fallibility and uncertainty.*[115]

The NRC has done exactly the opposite of the recommendation of the National Research Council. Instead of being "cognizant of this potential fallibility and uncertainty" arising from the failure of stewardship and the possibility of incorrect assumptions, it has simply reckoned that all of its essential assumptions and all the necessary institutions and finances will be in place for three quarters of a million years. While this time frame is not specified in NUREG-1437, it is implicit in it because radon-222 emissions ultimately originate in the thorium-230 present in the mill tailings. Indeed, over the long periods considered, the potential for high population doses due to erosion and airborne radioactive particles from the mill tailings should be explicitly considered.

Further, radon releases will also occur from DU disposal, which was not considered in Table S-3. DU disposal is now acknowledged by the NRC to create risks for a million years or more.[116] Since U-238 decay will create radium-226 buildup over time, radon-222 risks from DU disposal will persist for the indefinite future.

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[115] NAS-NRC 2000, p. 5. Italics in the original.

[116] Borchardt 2008. See for instance Figure 7. While this Figure stops at one million years, it is evident from the charts that non-zero doses continue after that time.

Finally, it should also be noted that EPA's Federal Guidance Report 13, which provides dose conversion and risk factors for persons by age does not provide any data for radon-222. In updating Table S-3 the NRC will need to consider whether children or women get a higher dose than men under specified environmental conditions.

7. Carbon-14

While Table S-3 makes an estimate of 24 curies of carbon-14 releases as gaseous effluents from one reactor year of operation, WASH-1248 does not provide an analysis of the dosimetric consequences. Carbon-14 is oxidized either during reprocessing or in an unsaturated oxidizing environment like Yucca Mountain. While the individual doses from C-14 releases can be expected to be very small, the population doses integrated over time would be very large. This is because carbon-14 has a very long half-life (5,730 years); it will continually be recycled through the biosphere along with non-radioactive carbon. Over ten thousand years, the population doses could be very high in an oxidizing environment. The SAB report cites a population dose of 14 million person rem over 10,000 years assuming that half the carbon-14 is released. This corresponds to 4,000 cancer fatalities over 10,000 years.[117] The total amount of spent fuel considered in this calculation was 70,000 metric tons of heavy metal, the present legal limit for repository disposal. The corresponding estimate per reactor-year, assuming 20 metric tons per reactor-year, would be 1.14 cancer fatalities over 10,000 years. This amounts to 45 fatal cancers due to carbon-14 releases from spent fuel generated over a 40-year operating life and twice that if the license is extended by another 40 years.

Such consequences would be estimated only for unsaturated oxidizing repositories, which is the description that fits the Yucca Mountain site as presently designed and characterized. They would also be estimated in reprocessing scenarios. Hence, the estimates of C-14 fatalities and corresponding estimates of cancer incidence need to be included in a revised Table S-3. We note here that the dose conversion factors have been updated since the EPA carbon-14 report, cited above, was published. Doses and cancer risks need to be calculated on an age-specific, gender-specific basis in the generic waste EIS.

8. Conclusions regarding aspects of Table S-3 other than Spent Fuel and High-Level Waste

Table S-3 is obsolete and/or wrong in its legal, technical, environmental and health assumptions and estimates in regard to spent fuel, gaseous releases from spent fuel, GTCC waste, Class A, B, and C low-level waste, DU, radon-222, and carbon-14. In light or more rigorous requirements for waste management and the fact that repository costs have escalated without a repository having been commissioned as previously envisaged, a thorough revision of the cost basis of nuclear power in regard to its waste aspects is also

[117] Loehr, Nygaard, and Watson 1993, p. 21

needed. This is essential because without such estimates, the costs of nuclear energy with alternative options cannot be fairly made.

A generic environmental impact statement must compare the environmental impacts and costs of the present course with the following alternatives in regard to spent fuel:

1. At reactor storage for the indefinite future, including periodic replacement of storage containers and inter-container transfer.
2. Consolidated monitored storage in one or more locations for the indefinite future, including replacement and transfer as in Item 1 above.
3. Yucca Mountain at 70,000 metric tons with no second repository.
4. Yucca Mountain at a higher capacity than 70,000 metric tons.
5. Yucca Mountain with a second repository.
6. Yucca Mountain fails as a program and one or more other sites in a new program to accommodate all spent fuel.
7. Reprocessing of spent fuel with fast reactor reuse of plutonium and uranium, plus a waste repository for high-level waste and Greater Than Class C waste.
8. Reprocessing with light water reactor re-use of plutonium (including costs of reactor modification), with a repository as in Item 7 above.
9. Reprocessing of spent fuel without fast reactor reuse of plutonium and uranium, with a repository as in Item 7 above.
10. Uranium only fuel recycle, with a repository as in Item 7 above.
11. Partial reprocessing, with repository disposal of uranium and mixed uranium-plutonium oxide spent fuel, uranium spent fuel, high-level waste and Greater Than Class C waste.

The risk of terrorist attacks and proliferation risks must be included in the generic EIS. These risks are different for the various options and those differentials need to be factored into the process of choosing a preferred alternative in the EIS process.

It must also consider the various options for GTCC disposal and DU disposal that would conform with existing low level waste dose limits specified at 10 CFR 61 Subpart C.

A waste confidence rule as well as a generic EIS on spent fuel must consider the above alternatives and provide cost estimates for them. These costs must be added to reactor costs for new reactors in the licensing process and in the re-licensing process of existing reactors. The costs must be added to nuclear power costs when evaluating alternatives when preparing environmental impact statements for new reactors. Without a realistic estimate of costs and a generic waste confidence EIS, the EIS process for new reactor licenses and the adjudicatory process for re-licensing reactors will remain fundamentally deficient. If the costs of repository alternatives cannot be realistically estimated based on present U.S. data and history (including technical, legal, regulatory, political, social, and fiscal aspects), then the waste confidence finding must be that there is no reasonable assurance that a repository for spent fuel can be opened in the United States at any time in the foreseeable future. Specifically, if a well-founded upper bound cannot be attributed to waste management and disposal costs, then there is no basis on which to compare the total costs of nuclear with various combinations of renewable energy, storage, combined heat and power, and efficiency alternatives as a part of the EIS process of licensing new reactors.

D. Conclusions

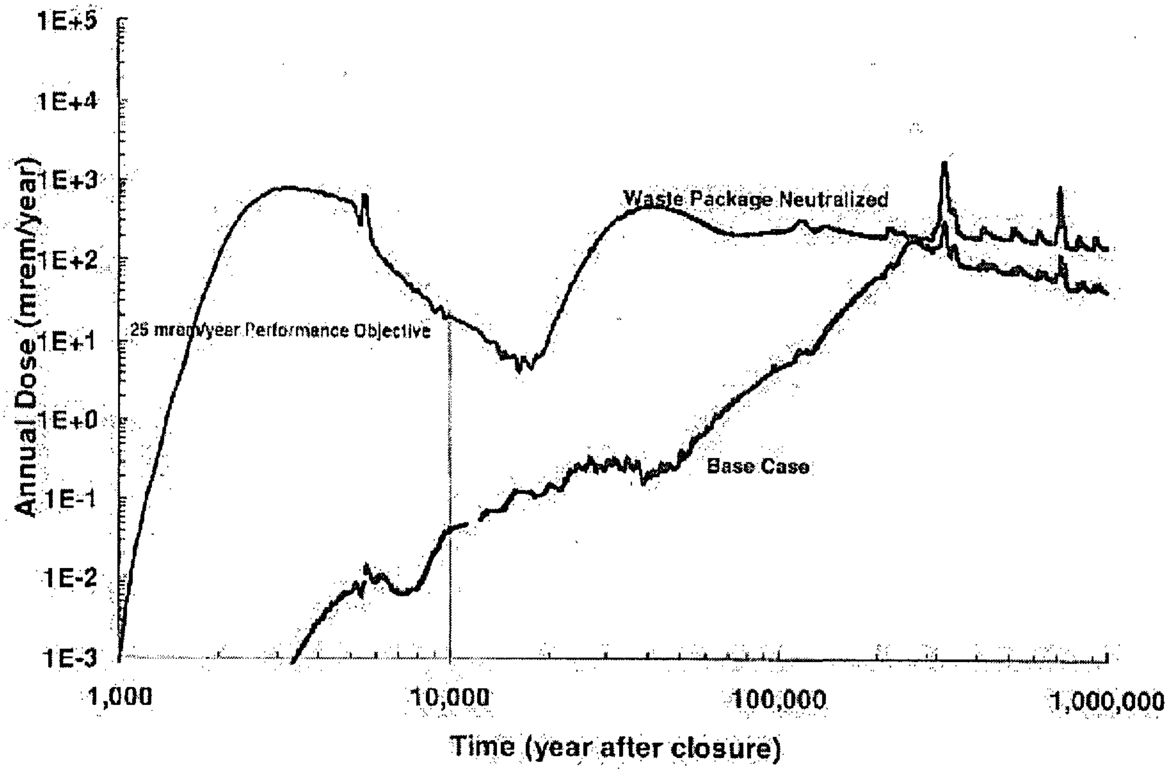
The NRC has not provided a sound scientific, technical, legal, political, social financial, or fiscal basis for its conclusions that (i) a geologic repository for disposal of spent fuel is technically feasible, (ii) it can state with reasonable assurance that a geologic repository to accommodate the required waste volumes can be opened within 50 to 60 years after the license expiry of any U.S. nuclear power plant, including new plants.

Further, Tables S-3 is either obsolete or wrong needs to be fundamentally revised to take into account new scientific and legal realities. We have concluded that at present there is no reasonable assurance that a repository in the United States can be opened within the time frame specified in the revised Finding 2 or indeed at any time. A generic EIS on nuclear spent fuel management, including a revision of Tables S-3, is required before new reactors can be licensed or existing reactors can be relicensed.

This generic EIS should include consideration of the impacts of the various options described above. It should include consideration of costs of the various options. Compliance with regulations limiting public exposure should be the fundamental basis for assessing whether the impact is small or not. Note that compliance with annual dose limits needs to be estimated for the most exposed individual, who may be a male or female, infant, or a male or female of any other age, using dose conversion factors that are specific to that age and gender. Population doses should also be estimated as this is important for understanding the full extent of the health risks over time. Other aspects of waste management and disposal to be considered as part of the process of licensing new reactors or relicensing existing reactors are discussed below.

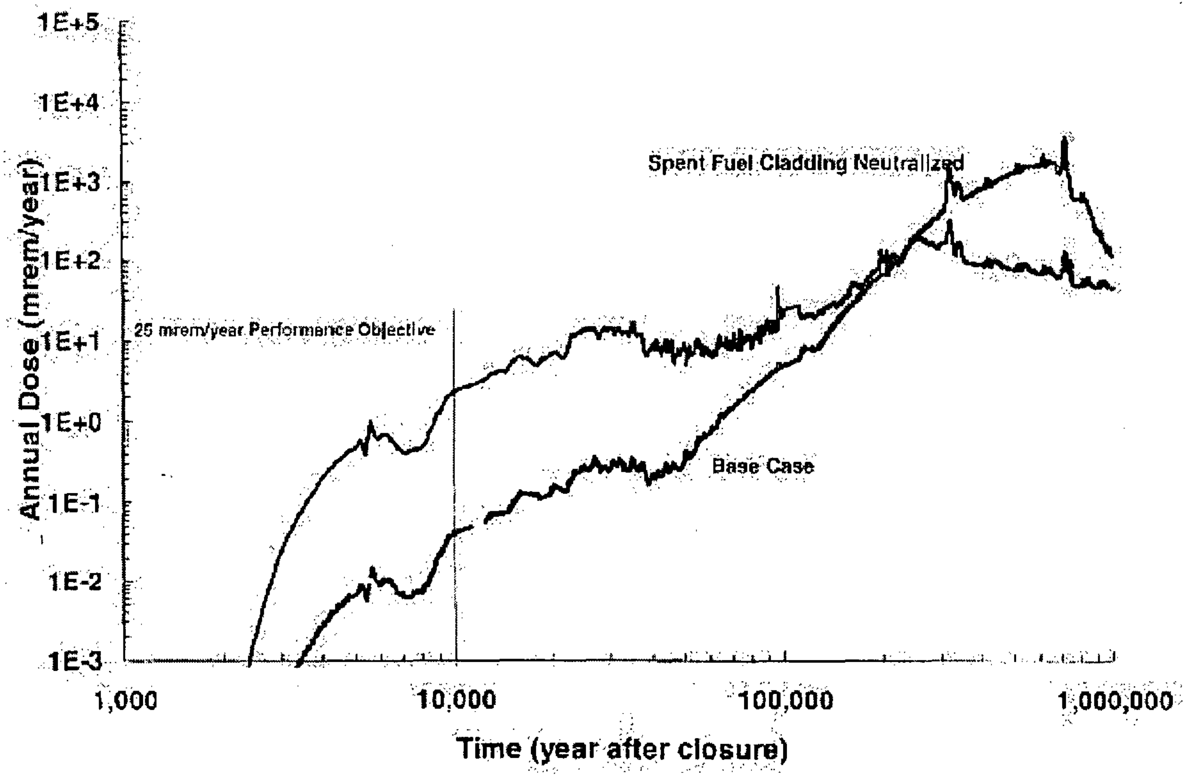
Attachment A[118]

Graph A: Neutralize Waste Package

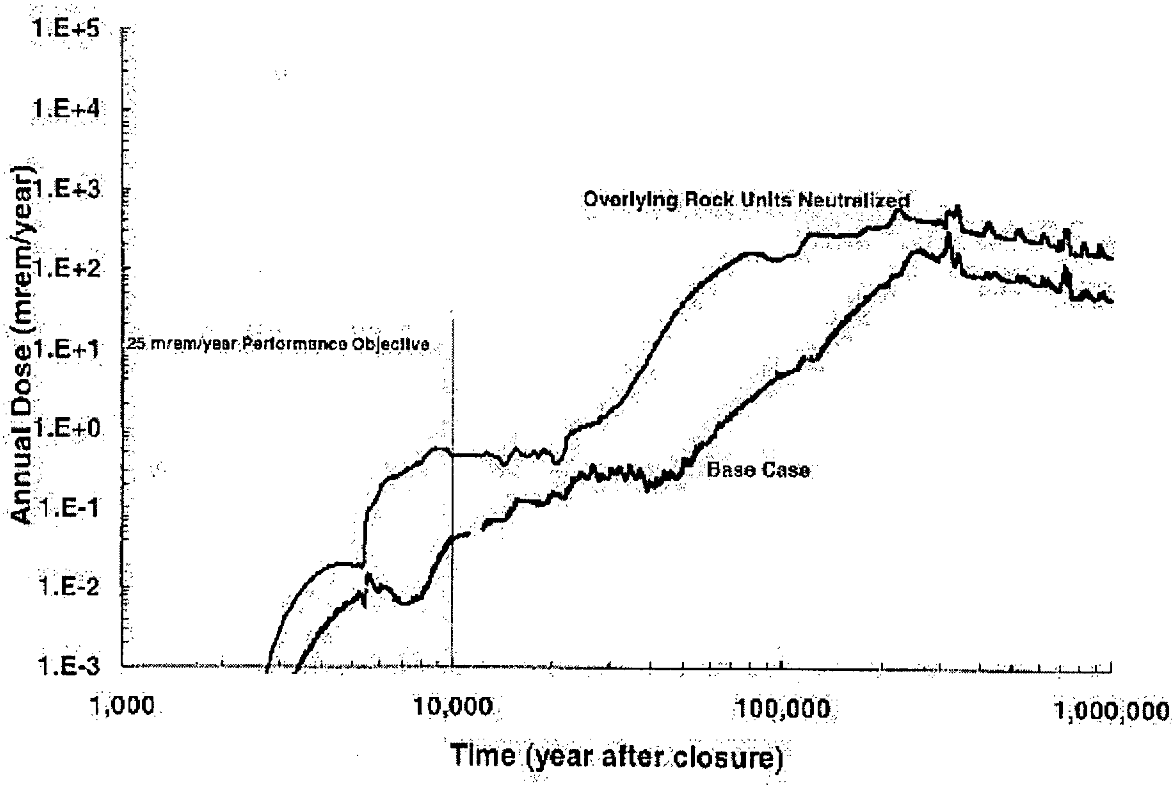


[118] Source for all graphs: DOE OCRWM 1999.

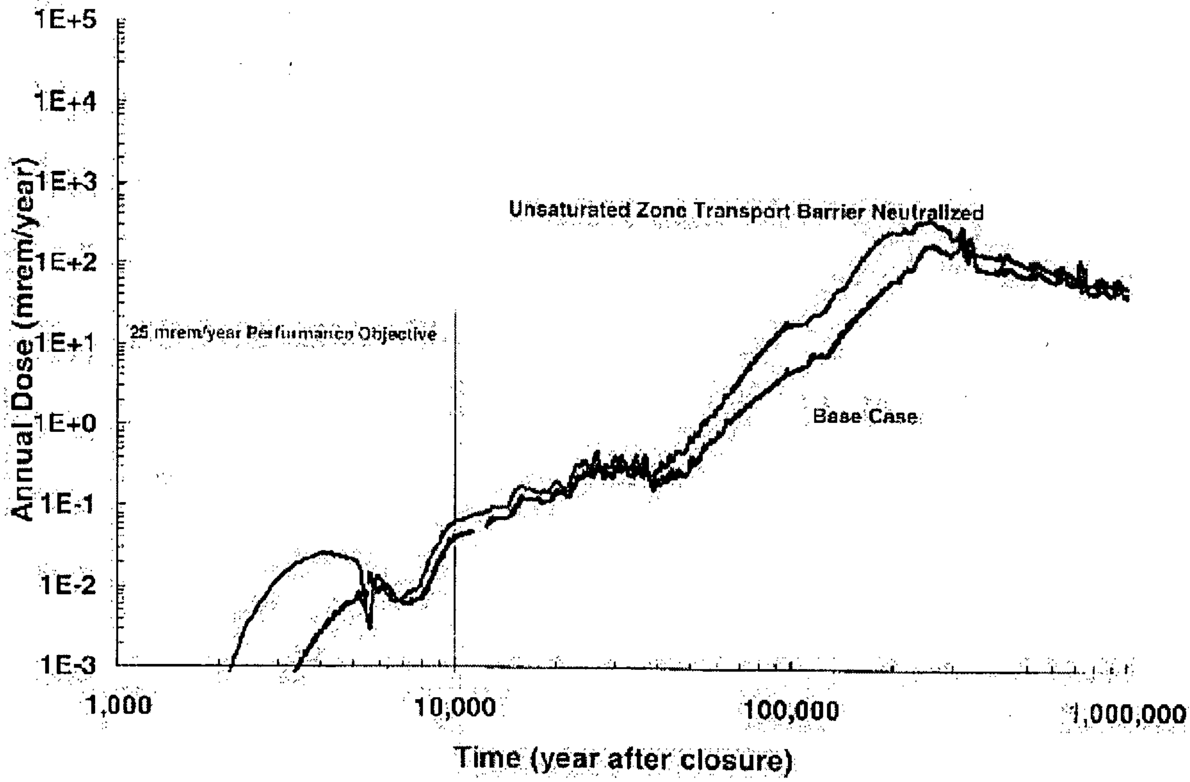
Graph B: Neutralize Spent Fuel Cladding



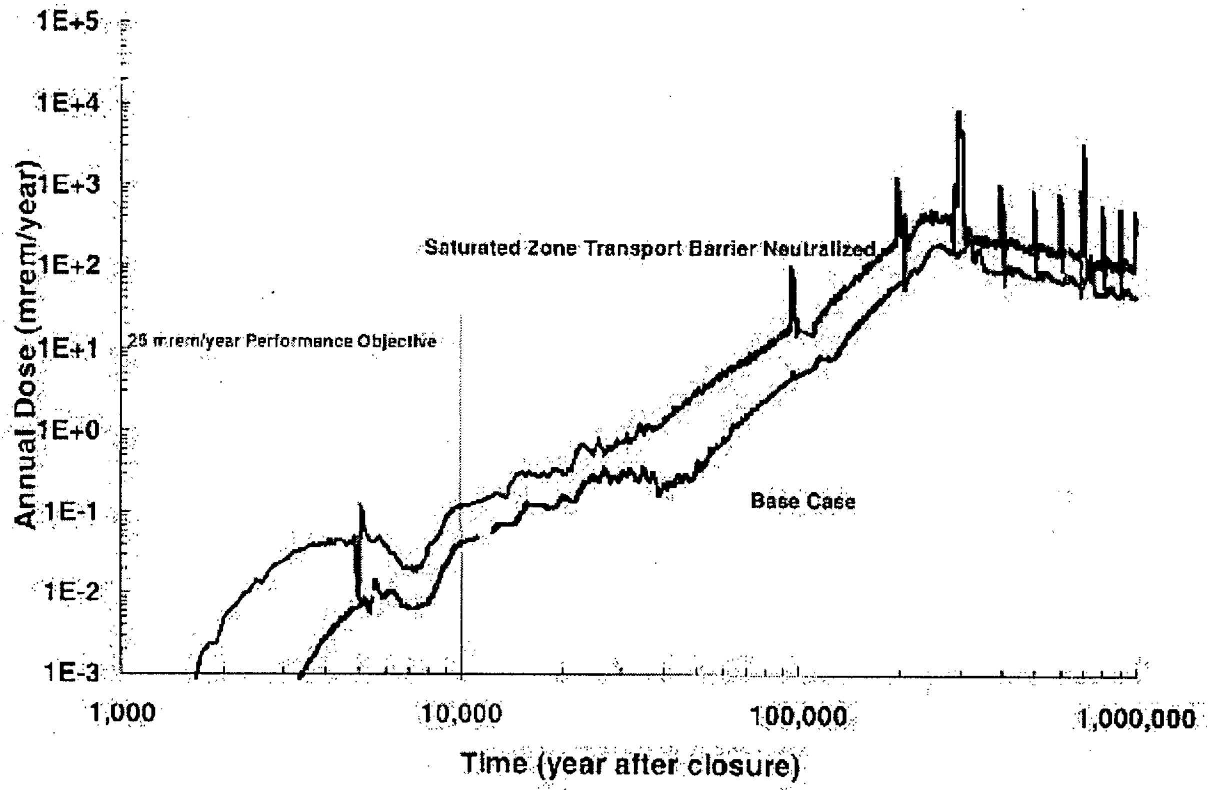
Graph C: Neutralize Overlying Flow Barriers



Graph D: Neutralize Unsaturated Zone Transport Barrier



Graph E: Neutralize Saturated Zone Transport Barrier



Source for all graphs: U.S. DOE Office of Civilian Radioactive Waste Management, "NWTRB Repository Panel meeting: Postclosure Defense in Depth in the Design Selection Process," presentation for the Nuclear Waste Technical Review Board Panel for the Repository, January 25, 1999. Presented by Dennis C. Richardson. Online at http://www.nwtrb.gov/meetings/1999/jan/richardson.pdf.

Attachment B

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des membres de l'équipe IEER et un relecteur

présent à l'IEER 29-30 novembre 2004

Examen critique du programme de recherche de l'ANDRA pour déterminer l'aptitude du site de Bure au confinement géologique des déchets à haute activité et à vie longue

RAPPORT FINAL

préparé par
l'Institut pour la recherche sur l'énergie et l'environnement (IEER)

pour
Le Comité Local d'Information et de Suivi

Directeur du Projet
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27 décembre 2004
avec corrections 11 janvier 2005

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Les différents membres de l'équipe ont eu la responsabilité des disciplines scientifiques suivantes et ont rédigé les chapitres correspondants :

Chapitre 1: Principes de confinement géologique - Arjun Makhijani. Yuri Dublyansky a contribué à la section sur la paléoclimatologie
Chapitre 2: Mécanique des roches - Jaak Daemen
Chapitre 3: Aspects thermiques de la conception et de la construction du site de stockage - George Danko
Chapitre 4: Programme de recherches sur le terme source et le champ proche - Rod Ewing
Chapitre 5: Hydrogéologie - Detlef Appel
Chapitre 6:Aspect minéralogiques et géochimiques dans la formation hôte - Yuri Dublyansky
Chapitre 7: Sismologie et déformation - Gerhard Jentzsch et Horst Letz

Traduction: Annie Makhijani
Relecture de traduction: Annike et Jean-Luc Thierry
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Curriculum Vita of
Arjun Makhijani

Education:

Ph.D. University of California, Berkeley, 1972, from the Department of Electrical Engineering. Area of specialization: plasma physics as applied to controlled nuclear fusion. Dissertation topic: multiple mirror confinement of plasmas.

M.S. (Electrical Engineering) Washington State University, Pullman, Washington, 1967. Thesis topic: electromagnetic wave propagation in the ionosphere.

Bachelor of Engineering (Electrical), University of Bombay, Bombay, India, 1965.

Current Employment:

1987-present: President and Senior Engineer, Institute for Energy and Environmental Research, Takoma Park, Maryland. (part-time in 1987).

February 3, 2004-present, Associate, SC&A, Inc., one of the principal investigators in the audit of the reconstruction of worker radiation doses under the Energy Employees Occupational Illness Compensation Program Act under contract to the Centers for Disease Control and Prevention, U.S. Department of Health and Human Services.

Professional Societies:

Institute of Electrical and Electronics Engineers and its Power Engineering Society
American Physical Society
Health Physics Society
American Association for the Advancement of Science

Official positions

Subcommittee on carbon-14 emissions from Yucca Mountain of the Radiation Advisory Committee, U.S. Environmental Protection Agency, 1992-1993

Radiation Advisory Committee, U.S. Environmental Protection Agency, 1992-1994

Technical Advisory Panel, Hanford high level waste tanks, early 1990s (ex-officio)

Consultant to the Office of Technology Assessment of the U.S. Congress

Consulting Experience, 1975-1987

Consultant on a wide variety of issues to various organizations including:

Tennessee Valley Authority
Lower Colorado River Authority
Federation of Rocky Mountain States
Environmental Policy Institute
Lawrence Berkeley Laboratory
Food and Agriculture Organization of the United Nations
International Labour Office of the United Nations
United Nations Environment Programme

United Nations Center on Transnational Corporations
The Ford Foundation
Economic and Social Commission for Asia and the Pacific
United Nations Development Programme

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Makhijani, A., K.M. Tucker, with Appendix by D. White, *Heat, High Water, and Rock Instability at Hanford*, Health and Energy Institute, Washington, D.C., 1985.

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Annie Makhijani

Education:

M.S. (Chemistry, with emphasis on Physical Chemistry) University of Maryland, College Park, Maryland, 1994. Research topic: the physical properties of nanostructures.
Bachelor of Science (Chemistry) University of Maryland, College Park, 1985.
Studied Hindi at the Institut des Langues Orientales in Paris (1980).
Bachelor of Arts (Psychology) Université de Tours, France (1972)

Employment:

- 1994-present: Project Scientist, Institute for Energy and Environmental Research, Takoma Park, Maryland.
- Staff Scientist, Institute for Energy and Environmental Research, Takoma Park, Maryland.
- Consultant for the White House Council on Environmental Quality (1979).
- French teacher, Alliance Française, Bombay, India (1977-1979)

Publications:

- Makhijani, Arjun and Annie Makhijani, *Fissile Materials in a Glass Darkly:* Technical *and Policy Aspects of the Disposition of Plutonium and Highly Enriched Uranium,* IEER Press, Takoma Park, 1995.
- Hisham Zerriffi and Annie Makhijani, *An Assessment of Transmutation as a Nuclear Waste Management Strategy,* Institute for Energy and Environmental Research, Takoma Park, 2000.

Some accomplishments

- Did research on the management of depleted uranium for the proposed Claiborne uranium enrichment plant in Louisiana (1996).
- Did research on the decommissioning or the Sequoyah uranium conversion plant in Oklahoma.
- Was responsible for some of the background research for the Institute for Energy and Environmental Research technical report: *Radiation Exposures in the Vicinity of the Uranium Facility in Apollo, Pennsylvania* (1998).

RESUME
JAAK J.K. DAEMEN

Education: Ph.D. Geo_Engineering, University of Minnesota, June 1975
Mining Engineer (Honors), University of Leuven, Belgium, July 1967

Registration: State of Arizona: Registered P.E. Civil Engineering (AZ 12158) and Mining Engineering (AZ 12980)

Professional:
American Institute of Mining Engineers, American Society of Civil Engineers, International Society for Soil Mechanics and Foundation Engineering, American Society for Engineering Education, International Society for Rock Mechanics, Royal Flemish Engineering Association, Royal Belgian Society of Engineers and Industrialists, American Geophysical Union, American Rock Mechanics Association.

Past Member, National Tunneling Committee, U.S. National Rock Mechanics Committee and Committee on Geological and Geotechnical Engineering of the National Research Council of the National Academy of Sciences; Reviewer for National Science Foundation, Geotechnical Engineering Program; U.S. Geological Survey; Mining Engineering, Society of Mining Engineers of AIME; International Journal of Rock Mechanics and Mining Sciences; Water Resources Research; Canadian Geotechnical Journal

Employment Record:

October 2001 - Present Professor, Mining Engineering, Mackay School of Mines, University of Nevada, Reno.

July 1990 - Sept.2001 Professor and Chair, Mining Engineering, Mackay School of Mines, University of Nevada, Reno.

September 1976 _ June 1990 Assistant and Associate Professor, University of Arizona, Department of Mining and Geological Engineering.

Summer 1980, 1981 Visiting Associate Research Engineer, Research Associate, University of California, Berkeley.

Summer 1977 Occidental Research Corporation. Investigations of roof control problems, Island Creek Coal Company.

April 1975 - September 1976 Research Engineer, E. I du Pont de Nemours & Co., Potomac

River Development Laboratory, Martinsburg, West Virginia 2504.

Sept. 1967 - March 1975 Research Assistant, Teaching Assistant, Teaching Associate, Research Fellow and Post_Doctoral Research Associate, Univ. of Minn, Minneapolis, Department of Civil & Mineral Engineering.

Sponsored Research:
Mechanics of Fully Grouted Bolts in Bedded Mine Rook (United Engineering Foundation); Rock Mass Sealing (U.S. Nuclear Regulatory Commission); Numerical Analysis of the influence of Bench Stiffness on Rock Fragmentation in Surface Blasting (AZ MMRRI); Ground and Air Vibrations Induced by Large Surface Blasts (Office of Surface Mining; U.S. Bureau of Mines); Mechanical Characterization of Welded Tuff (Center of Nuclear Waste Regulatory Analyses); Permeability-Strain Measurements in Rock Salt (Sandia National Laboratories); Sealing Studies for WIPP (SNL); Sealing Studies for Yucca Mountain, (SNL), Rock
Movement Induced by Blasting (Placer Dome); Long Term Drift Sability (DOE).

Courses Taught:
University of Arizona: Rock Excavation Practice; Tunneling and Underground Construction; Surface Mining; Coal Mining; Geomechanics; Applied Geomechanics: Underground Construction; Advanced Geomechanics; Design of Underground Structures; Rock Fracture and Flow; Subsidence Engineering; Rock Dynamics: Drilling, Blasting; Key Block Theory; Boundary Element Analysis.
University of Nevada, Reno: MINE 210 Mining Methods; MINE 301 Coal Mining; MINE 380 Quarry Engineering; MINE 445 Rock Excavation; MINE 448 Rock Mechanics; MINE 658 Rock Mechanics for Underground Mining and Construction.

Consulting: Morrison_Knudsen, Inc.; Sandia National Laboratories; Anaconda Minerals Company; Golder Associates; E.I. du Pont de Nemours & Co.; Fluor Mining & Metals; Cia Minera Las Cuevas, San Luis Potosi; Engineers International, Inc.; Itasca Consulting Group, Inc.; Nuclear Waste Management Consultants, Inc.; GRC Consultants, Inc; Hargis and Associates, Inc.; Southwest Research Institute; Asarco Mining Co., Inc.; Getchell Gold , Inc.; Petroplug, Inc.; U.S. DOE, J.S. Redpath.

CURRICULUM VITAE OF DR. GEORGE DANKO

EDUCATION:

Ph.D.	(Candidacy Degree in Technical Sciences), 1985, Hungarian Academy of Sciences. Thesis: Measurement and Model-building for the Convective Heat Transfer Examinations.
Dr. Tech.	(Doctor's Degree in Fluid Dynamics), 1976, Department of Fluid Dynamics, University of Technology, Budapest. Thesis: Matrix Analysis of Hydraulic Transients in Pipeline Flow.
M.S.	Applied Math, 1975, Eotvos University of Sciences, Budapest
M.S.	Mechanical Engineering, 1968, University of Technology, Budapest

EMPLOYMENT HISTORY:

7/95-present	Professor, Mining Engineering Department, Mackay School of Mines, University of Nevada, Reno.
8/90-6/95	Associate Professor, Mining Engineering Department, Mackay School of Mines, University of Nevada, Reno.
09/87-8/90	Lecturer in Mechanical Engineering, College of Engineering, University of Nevada, Reno.
11/86-8/90	Research Associate, Mining Engineering Department, Mackay School of Mines, University of Nevada, Reno.
1/79-11/86	Associate Professor, Institute of Thermal Energy and Systems Engineering, University of Technology, Budapest.
8/78-1/79	Visiting Postdoctoral Associate, Department of Mechanical Engineering, University of Minnesota.
9/75-8/78	Fellow of Hungarian Academy of Sciences.
8/68-9/75	Assistant Professor, Department of Mechanical Engineering, University of Technology, Budapest.

Selected recent publications relevant to nuclear waste disposal:

Danko, G., (1999), "In Situ REKA Probe Measurements at Yucca Mountain," Proceedings, International Bureau of Mining Thermophysiscs, St. Petersburg, pp 1-12.

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G. Danko, D. Bahrami, and A. Adu-Acheampong, (2001), "In Situ Thermophysical Properties Measurements Under Hydrothermal Disturbances at DST," Proceedings, 9th International high-Level Radioactive Waste Management Conference , April 29th-May 3rd.

G. Danko and D. Bahrami, (2002), "The Application of CFD to Ventilation Calculations at Yucca Mountain", Proceedings, WM 02' Conference, February 24-28, 2002, Tucson, AZ, Session 39B, Paper 12, Abs. 243, pp. 1-11.

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Danko, G., Jain, A., (2002). "Parameter Identification of a Numerical Transport Code," Proceedings, WM' 02 Conference, February 24-28, Tucson, AZ. pp.1-7.

Danko, G., and Bahrami, D., (2003). " Sensitivity Analysis of Ventilation Parameters and Site Input Properties," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

Danko, G., and Bahrami, D., (2003). "Natural Ventilation of a Deep Geologic Nuclear Waste Storage Facility," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

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Danko, G., Shah, N., and Bahrami, D., (2003). "In Situ Thermophysical Properties Variation at DST, Yucca Mountain," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

Danko, G., Bahrami, D., Leister, P., and Croise, J., (2003). "Temperature and Humidity Control for Underground Spent Fuel Storage," Proceedings, 10th Int. High-Level Radioactive Waste Management Conference, pp.1-8.

RODNEY C. EWING

Rod Ewing is a professor in the Department of Nuclear Engineering and Radiological Sciences at the University of Michigan, responsible for the program in radiation effects and nuclear waste management. He also holds appointments in Geological Sciences and Materials Science & Engineering and is an Emeritus Regents' Professor at the University of New Mexico in the Department of Earth and Planetary Sciences, where he was a member of the faculty from 1974 to 1997 and chair of the department from 1979 to 1984. He is also an *Adjungeret Professor* at the University of Aarhus in Denmark.

Ewing received a B.S. degree in geology from Texas Christian University (1968, summa cum laude) and M.S. (1972) and Ph.D. (1974, with distinction) degrees in mineralogy from Stanford University where he held an NSF Fellowship. His graduate studies focused on an esoteric group of minerals, metamict Nb-Ta-Ti oxides that are unusual because they have become amorphous due to radiation damage caused by the presence of radioactive elements (U and Th) and radionuclides in their decay series. This radiation-induced phase transformation from a crystalline to amorphous (periodic-to-aperiodic) structure can have significant effects on the properties of materials, such as the decreased durability of radioactive waste forms. Over the past twenty years, the early study of these unusual minerals has blossomed into a broadly based research program on radiation effects in complex ceramic materials. Such studies have lead to the development of techniques to predict and confirm the very long-term behavior of materials, such as those used in radioactive waste disposal. The key to such studies has been the use of natural phases of great age in designing highly durable nuclear waste forms. Present research includes: radiation effects caused by heavy-particle interactions with crystalline materials (e.g., ion-beam modification of ceramics and minerals); the structure and crystal chemistry of complex Nb-Ta-Ti oxides; the crystal chemistry of actinide and fission product elements, the application of "natural analogues" to the evaluation of the long-term durability of radioactive waste forms and the release and transport of radionuclides; the low-temperature corrosion of silicate glasses; the neutronics and geochemistry of the natural nuclear reactors in Gabon, Africa. The research has utilized a wide variety of solid-state characterization techniques, such as x-ray diffraction, x-ray absorption spectroscopy and high-resolution electron microscopy. The work of the research group has been supported not only by U.S. funding agencies but also from sources abroad (Sweden, Germany, Australia and Japan, as well as by the European Union and NATO). Ewing is the author or co-author of approximately 400 research publications and the editor or co-editor of seven monographs, proceedings volumes or special issues of journals. He was recently granted a patent for the development of a highly durable material for the immobilization of excess weapons plutonium. He received a Guggenheim Fellowship in 2002.

Ewing is a fellow of the Geological Society of America and the Mineralogical Society of America and has served the Materials Research Society as a Councilor (1983-1985; 1987-1989) and Secretary (1985-1986). He was president of the Mineralogical Society of America (2002) International Union of Materials Research Societies (1997-1998) and the New Mexico Geological Society (1981). He was a member of the Board of Directors of the Caswell Silver Foundation (1980-1984) and Energy, Exploration, Education, Inc. (1979-1984). He has served as a guest scientist or faculty member at Battelle Pacific Northwest Laboratories, Oak Ridge National Laboratory, the Hahn-Meitner-Institut in Berlin, the Department of Nuclear Engineering in the Technion University at Haifa, the Centre D'Etudes Nucléaires de Fontenay-Aux-Roses, Commissariat A L'Énergie Atomique in France, Charles University in Prague, the Japan Atomic Energy Research Institute, the Institut für Nukleare Entsorgungstechnik of the Kernforschungszentrum Karlsruhe, Aarhus University in Denmark, Mineralogical Institute of Tokyo University and the Khlopin Radium Institute in St. Petersburg, Russia.

The involvement in issues related to nuclear waste disposal has proceeded in parallel with the basic research program most notably in association with the activities of the Materials Research Society where he has been a member of the program committee and the editor or associate editor for the proceedings volumes for the symposia on the "Scientific Basis for Nuclear Waste Management" held in Berlin-82, Boston-84, Stockholm-85, Berlin-88, Strasbourg-91, Kyoto-1994, Boston-1998 and Sydney-2000. He is co-editor of and a contributing author of *Radioactive Waste Forms for the Future* (published by North-Holland Physics, Amsterdam, 1988). Professor Ewing has served on National Research Council committees for the National Academy of Sciences that have reviewed the Waste Isolation Pilot Plant in New Mexico (1984 to 1996), the Remediation of Buried and Tank Wastes at Hanford, Washington and INEEL, Idaho (1992 to 1995), and the INEEL High-Level Waste Alternative Treatments (1998-1999), as well as a subcommittee on WIPP for the Environmental Protection Agency's National Advisory Council on Environmental Policy and Technology (1992 to 1998). He has served as an invited expert to the Advisory Committee on Nuclear Waste of the Nuclear Regulatory Commission and a consultant to the Nuclear Waste Technology Review Board. He is presently a member of the Board of Radioactive Waste Management of the National Research Council.

Dr. Detlef Appel

Professional background
Born 1943

1965-1971
study of geology at the University of Hannover, Lower Saxony, Germany, and the University of Vienna, Austria - diploma thesis on tectonical aspects of the Asse salt-structure in Lower Saxony (test site for radioactive waste disposal in West-Germany).
1971-1983
scientific employee: Institute of Geology and Paleontology of the University of Hannover - doctoral thesis on sedimentological questions of Upper Triassic sandstone formation in Lower Saxony.

Since 1983

freelancing consultant

Numerous expert opinions / publications in applied (hydro)geology and methodology (mostly in cooperation with other authors):

- selection, assessment and licensing of sites for final disposal of "conventional" and radioactive waste,
- risk assessment of (abandoned industrial) contaminated sites,
- site-specific and conceptual groundwater and soil protection in environmental impact assessment, water and soil management and planning,

Main clients: state authorities, regional/local water and environmental authorities, environmental NGOs (Greenpeace) and local environmental organizations.
Advisory activity

for German federal and state governments, environmental NGOs and local citizen action groups:

- Advisory Board on "Questions of Nuclear Power Phase-Out" of the Lower Saxony Ministry of the Environment (1992-1998),
- Committee on Site Selection Procedure of the Federal Ministry of the Environment, Nature Protection and Reactor-Safety (1999-2002),
- Working Group Fuel and Waste Management of the German Commission on Reactor-Safety,
- Radiation Protection Commission of BUND - Friends of the Earth,
- Scientific Advisory Board of the Konrad Mine Working Group.

International activities and cooperation

- Swiss Expert Group on Disposal Concepts for Radioactive Waste,

- Cantonal Working Group Wellenberg (Advisory Board of the Canton Nidwalden on safety aspects of the formerly planned LWA/MAW repository, Switzerland; until September 2002),
- Forum on Stakeholder Confidence (OECD/NEA),
- EC-Project COWAM (Community Waste Management),

Membership of scientific / professional associations

- German Geological Society,
- Society of Environmental Geosciences,
- Engineering-Technical Association on Contaminated Sites,
- Professional Society of German Geoscientists.

YURI V. DUBLYANSKY

EDUCATION	University of Perm, Russia: PhD (Candidate of Sciences) in Geosciences, 1987 University of Odessa, Ukraine: M.S. in Geological Engineering and Hydrogeology, 1982
WORK PLACE	Fluid Inclusion Lab. Institute of Mineralogy and Petrography, Russian Academy of Sciences, Siberian Branch, since 1985 to present
POSITION	Senior Scientist
WORK ADDRESS	Russia, 630090, Novosibirsk, 3, Koptyuga Ave. IM&P SB RAS Phone: +8-913-920-5263 (cel); FAX: +7-3832-332792 e-mail: kyoto_yuri@hotmail.com
SPECIALIZATION AND FIELD OF INTEREST	Geological disposal of nuclear waste; low temperature hydrothermal processes; fluid inclusions, isotope geochemistry. Analysis of the scientific and regulatory issues related to the geological disposal of the high-level nuclear waste.
LANGUAGES	English (fluent) and French (somewhat rusty)

PROFESSIONAL EXPERIENCE

2002 By request of the State of Nevada Attorney General Office, with the group of co-authors from USA, UK and Russia, writing a scientific monograph, providing independent evaluation of the suitability of the U.S. proposed site for geological disposal of the high-level nuclear waste at Yucca Mountain, Nevada. Monograph will be used by the State of Nevada as part of legal deposition in the forthcoming litigations, court hearings and licensing proceedings related to the Yucca Mountain high-level nuclear waste disposal site.

1999-2001 Official representative of the State of Nevada in the three-lateral (U.S. Department of Energy, State of Nevada and University of Nevada) research project on the paleo-hydrology of the proposed geological disposal site for the high-level nuclear waste at Yucca Mountain, Nevada. In this capacity testified before the presidential Nuclear Waste Technical Review Board and before the Advisory Committee on Nuclear Waste of the U.S. Nuclear Regulatory Commission.

Scientific leader and manager of the research project commissioned by the Government of the State of Nevada studying critical issues of the geological suitability of the proposed high-level nuclear waste site in Nevada.

1997 - 1998 Served as an expert to TACIS (a EC program), assessing geological issues of the nuclear waste disposal in the Northwest Russia. Performed critical evaluation of the concept of the nuclear waste disposal in permafrost on the Novaya Zemlia archipelago.

1994 - 1998 Consulting the State of Nevada's Nuclear Waste Project Office and the Attorney General Office on the issues of the geological suitability of the high-level nuclear waste repository at Yucca Mountain. Submitted 19 technical reports.

1993 - 1994 International Scientific Fellowship Award from NSERC, Canada, taken up at McMaster University, Hamilton, Ontario, Canada. Fluid inclusion and stable isotope geochemistry research.

1992 - 1993 Consulting the Hungarian National Authority for Nature Conservation on fossil hydrothermal systems and caves in Budapest and the Transdanubian Range.

RECENT PROFESSIONAL PUBLICATIONS PERTINENT TO THE NUCLEAR WASTE DISPOSAL

1. Dublyansky Y.V., Smirnov, S.Z., and Pashenko S.E. 2003 Identification of the deep-seated component in paleo fluids circulated through a potential nuclear waste disposal site: Yucca Mountain, Nevada, USA. *Journal of Geochemical Exploration*, **4013**, pp. 1-5. (*In press*)
2. Dublyansky, Y., Ford, D., and Reutski, V. 2001 Traces of epigenetic hydrothermal activity at Yucca Mountain, Nevada: preliminary data on the fluid inclusion and stable isotope evidence. *Chemical Geology*. **173**, pp. 125-149.
3. Dublyansky, Y. 2001 Paleohydrogeology of Yucca Mountain by Fluid Inclusions and Stable Isotopes. Proc. Int. Con., Amer. Nucl. Soc. "High-Level Radioactive Waste Management". La Grande Park, Illinois. CD ROM
4. Dublyansky, Y., Szymanski, J., Chepizhko, A., Lapin, B., and Reutski, V. 1999 Paleohydrogeology of Yucca Mountain (Nevada, USA): Key to the Site Suitability Assessment for Planed Nuclear Waste Repository. *Geoecology*. **1**, pp. 77-87. (In Russian)
5. Dublyansky, Y., Szymanski, J., Chepizhko, A., Lapin, B. and Reutski, V. 1998 Geological History of Yucca Mountain (Nevada) and the Problem of a High-Level Nuclear Waste Repository. *Defence Nuclear Waste Disposal in Russia*. NATO Series. Kluwer Academic Publishers, The Netherlands. pp. 279-292.
6. **Hill, C., Dublyansky, Y., Harmon, R., and Schluter, C. 1995 Overview of calcite/opal deposits at or near the proposed high-level nuclear waste site, Yucca Mountain, Nevada: pedogenic, hypogene, or both? *Environmental Geology*, 26(1), pp. 69-88.**

Prof. Dr. Gerhard Jentzsch Institute for Geosciences,
University of Jena

Born in 1946 in Taucha near Leipzig, Germany

Education:

Habilitation for Geophysics, Free University of Berlin, 1985, Institute for Geophysical Sciences, Free University of Berlin.

Doctoral examination, Technical University of Clausthal, Germany, 1976, from Faculty for Geosciences, Institute for Geophysics.

Exam (Diploma) in Geophysics, 1972, same institute.

Current Employment:

1996-present: Full Professor for Applied Geophysics at the Institute for Geosciences of the University of Jena

Professional Societies:

German Geophysical Society (currently President of this society), Geologische Vereinigung, European Geophysical Union, American Geophysical Union

Employment history:

1990 - 1996: Professor for General Geophysics at the Institute for Geophysics, Technical University of Clausthal.

1987 – 1990: Professor for Applied Geophysics (Angewandte Geophysik) at the Geological Institute of the University of Bonn.

1977 – 1987: Assistant at the Institute for Geophysical Sciences, Free University of Berlin, Assistence Professor (Hochschulassistent)

1972 – 1977: scientific co-worker of Prof. Dr. O. Rosenbach, Institute for Geophysics

Consulting Experience, 1990 – present:

Seismic hazard assessment for the sites of different nuclear power plants and nuclear industry in Germany, in the form of:

- check of reports
- own calculations
- member of advisory board

1999 – 2002 Member of the German siting committee to develop a procedure for the search for a site of the German nuclear repository (appointed by the German Federal Ministry of the Environment)

1993 – 1998 Member Advisory Board for the Termination of Nuclear Energy Use (Provincial Ministry for the Environment of Lower Saxony)

Additional information:

Research Interests: deformation and seismology (Earth tides, global dynamics, seismological network in East-Thuringia, Geodynamic Observatory Moxa), seismic hazard assessment, physical volcanology

Publications: more than 40 papers during the past 5 years; 15 of them in reviewed journals

National and international activities:

Chairman of working groups (IAG), convenor of special sessions (EGS Meetings, Earthtide Symposium, national meetings), reviewer for the German Research Soc. and different scientific journals

Currently: President of the German Geophysical Society

Publications relating to seismicity / deformation and nuclear waste repository:

1. Nuclear waste repositories:

AKEnd: Arbeitskreis Auswahlverfahren Endlagerstandorte des BMU, 2000. 1. Zwischenbericht, Stand: Juni 2000. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Referat RS III 4 (A), 54 S. First intermediate report.

Bräuer, V. und G. Jentzsch, 2001. Abgrenzung von Gebieten mit offensichtlich ungünstigen geologischen Verhältnissen. Bericht an den AkEnd. Separation of areas with obvious unfavourable geological conditions.

Jentzsch, G., 2001. Vulkanische Gefährdung in Deutschland. Bericht an den AkEnd. Volcanic hazard in Germany.

AKEnd: Arbeitskreis Auswahlverfahren Endlagerstandorte des BMU, 2001. 2. Zwischenbericht – Stand der Diskussion. Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Referat RS III 4 (A), 179 S. Second intermediate report.

Appel, D., V. Bräuer, G. Jentzsch und K.-H. Lux, 2002. Geowissenschaftliche Kriterien zur Endlagerstandortsuche für radioaktive Abfälle – Ergebnisse des Arbeitskreises Auswahlverfahren Endlagerstandorte. Z. Angew. Geol, 2/2002, 40 – 47. Geoscientific criteria for the seek of a repository for radioactive waste – results of the AkEnd.

AKEnd: Arbeitskreis Auswahlverfahren Endlagerstandorte des BMU, 2002. Auswahlverfahren für Endlagerstandorte – Empfehlungen des AkEnd. Abschlussbericht, Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Referat RS III 4 (A), 260 S. Final report.

Jentzsch, G., 2002. Temperaturverträglichkeit der Gesteine - Neigung zur Ausbildung von Wasserwegsamkeiten. Bericht an den AkEnd. Temperature acceptance of rocks – tendency to open transport paths for fluids.

2. Seismology and deformation

Kracke, D., R. Heinrich, G. Jentzsch, and D. Kaiser, 2000. Seismic Hazard assessment of the East Thuringian Region / Germany – case study. Studia Geophysica et Geodaetica, 44/4, 537 – 548.

Kracke, D., R. Heinrich, A. Hemmann, G. Jentzsch, and A. Ziegert, 2000. The East Thuringia Seismic Network. Studia Geophysica et Geodaetica, 44/4, 594 – 601.

Hemmann, A., T. Meier, G. Jentzsch and A. Ziegert, 2000. A similarity of wave-forms at stations Moxa and Plauen for the 1985/86 swarm. Studia Geophysica et Geodaetica, 44/4, 602 – 607.

Kroner, C., T. Jahr, G. Jentzsch, W. Zürn, R. Widmer-Schniedrig, and B. Heck, 2000. BFO and Moxa: Two observatories for seismological broadband observations. Orfeus Newsletter, Dez. 2000, Vol. 2, No. 3.

Jahr, T., Jentzsch, G., Kroner, C., 2001. The Geodynamic observatory Moxa / Germany: Instrumentation and purposes. Proc. 14th International Symposium on Earth Tides, Special Issue J. Geodetic Soc. of Japan, 47/1, 34 – 39.
Ishii, H., Jentzsch, G., Graupner, S., Nakao, S., Ramatschi, M. and Weise, A., 2001. Observatory Nokogiriyama / Japan: Comparison of different tiltmeters. Proc. 14th International Symposium on Earth Tides, Special Issue J. Geodetic Soc. of Japan, 47/1, 155 – 160.
Jentzsch, G., Malischewsky, P., Zaddro, M., Braitenberg, C., Latynina, A., Bojarsky, E., Verbytzkyy, T., Tikhomirov, A. and Kurskeev, A., 2001. Relations between different geodynamic parameters and seismicity in areas of high and low seismic hazards. Proc. 14th International Symposium on Earth Tides, Special Issue J. Geodetic Soc. of Japan, 47/1, 82 – 87.
Gutdeutsch, R., D. Kaiser, and G. Jentzsch, 2002. Estimation of earthquake magnitudes from epicentral intensities and other focal parameters in Central and Southern Europe. Geophys. J. Int., 151(3), 824 - 834.
Jentzsch, G. S. Graupner, A. Weise, H. Ishii, and S. Nakao, 2002. Environmental effects in tilt data of Nokogiriyama Observatory (extended abstract). Bulletin d'Information Marees Terrestres, 137, 10931 - 10936.
Jentzsch, G., M. Korn, and A. Špičák (eds.), 2003. The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 258 p.
Jentzsch, G., M. Korn, and A. Špičák, 2003. Editorial. In: Jentzsch, G., M. Korn, and A. Špičák (eds.): The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 1 -3.
Kurz, J., T. Jahr und G. Jentzsch, 2003. Geodynamic modelling of the recent stress and strain field in the Vogtland swarm earthquake area using the finite-element method. In: Jentzsch, G., M. Korn, and A. Špičák (eds.): The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 247 – 258.
Hemmann, A., T. Meier, G. Jentzsch, and A. Ziegert, 2003. Similarity of waveforms and relative relocation of the earthquake swarm 1997/98 near Werdau. In: Jentzsch, G., M. Korn, and A. Špičák (eds.): The swarm earthquakes in the area Vogtland / NW-Bohemia: Interaction of tectonic stress and fluid migration in a magmatic environment. Special Issue J. Geodyn., 35, 1 / 2, 191 – 208.

Curriculum Vita of Mike Thorne

Qualifications PhD FSRP

KEY SKILLS

- Radiological protection
- Assessing the radiological safety of disposal of radioactive wastes
- Distribution and transport of radionuclides in the environment
- Expert elicitation procedures
- Probabilistic safety studies
- Development of safety criteria
- Pharmacodynamics

CAREER HISTORY

2001- **Mike Thorne and Associates Limited**

Review Studies for the Proposed Australian National Radioactive Waste Repository

Client – RWE NUKEM

Reviews of reports on animal transfer factors and of the potential effects of climate change on the repository plus development of a model for the biokinetics of the ^{226}Ra decay chain in grazing animals.

Support for development of the Drigg Post-closure Radiological Safety Assessment

Client - BNFL

Support in the areas of FEP analysis, biosphere characterisation, human intrusion assessment and the effects of natural disruptive events. In addition, provision of advice of future research initiatives that should be pursued by BNFL.

Co-ordination of biosphere research and participation in BIOCLIM

Client – UK Nirex Ltd

Review of Parameter Values: Review of biosphere parameter values for use in the ANDRA assessment model AQUABIOS.

Effects of Radiation on Organisms Other Than Man

Client: Study for ANDRA to identify appropriate indicator organisms and develop appropriate dosimetry and effects models for those organisms.

Evaluation of Unusual Pathways for Radionuclide Transport from Nuclear Installations
Client – Environment Agency

Review of literature and conduct of formal elicitation meetings to determine potential pathways and evaluate their radiological significance.

Support Studies on the Drigg Post-closure Performance Assessment
Client - BNFL
Biosphere Research Co-ordination and Assessment Studies
Client - United Kingdom Nirex Ltd

Continuation of a programme of work originally undertaken at Electrowatt Engineering (UK) Ltd

Site Investigation and Risk Assessment - Hilsea Lines
Client - Portsmouth City Council
Radiological assessment of a radium-contaminated site.

PROFESSIONAL ACTIVITIES AND MEMBERSHIP

- Fellow of the Society for Radiological Protection and Immediate Past President
- Member of the Eco-ethics International Union
- Visiting Fellow at the Climatic Research Unit, University of East Anglia

SELECTION OF PUBLICATIONS

The biosphere in post-closure radiological safety assessments of solid radioactive waste disposal, M C Thorne, Interdisciplinary Science Reviews, Vol. 23, 258-268, 1998.

Modelling radionuclide distribution and transport in the environment, K M Thiessen, M C Thorne, P R Maul, G Prohl and H S Wheater, Environmental Pollution, 100, 151-177, 1999.

Validation of a physically based catchment model for application in post-closure radiological safety assessments of deep geological repositories for solid radioactive wastes, M C Thorne, P Degnan, J Ewen and G Parkin, Journal of Radiological Protection, 20(4), 403-421, 2000.

Development of a solution method for the differential equations arising in the biosphere module of the BNFL suite of codes MONDRIAN, M M R Williams, M C Thorne, J G Thomson and A Paulley, Annals of Nuclear Energy, 29, 1019-1039, 2002.

Modelling sequential BIOsphere Systems under CLIMate change for radioactive waste disposal. Project BIOCLIM, D Texier, P Degnan, M F Loutre, D Paillard and M Thorne, Proceedings of the 10th International High-level Radioactive Waste Management Conference (IHLRWM), March 30th – April 2nd, Las Vegas, Nevada.

References

10 CFR 20 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 – Energy. Part 20 – Standards for Protection Against Radiation.* 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr20_08.html.

10 CFR 51 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy. Part 51 – Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions.* 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr51_08.html. § 51.51 Uranium fuel cycle environmental data--Table S-3, is on the Web at http://www.nrc.gov/reading-rm/doc-collections/cfr/part051/part051-0051.html. Viewed on 1 February 2009.

10 CFR 60 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy: Chapter I Nuclear Regulatory Commission; Part 60 – Disposal Of High-Level Radioactive Wastes In Geologic Repositories.* 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr60_08.html.

10 CFR 61 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy: Chapter I Nuclear Regulatory Commission; Part 61 – Licensing Requirements For Land Disposal Of Radioactive Waste.* 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr61_08.html.

10 CFR 63 2008 — U.S. Nuclear Regulatory Commission. *Code of Federal Regulations. Title 10 Energy: Chapter I Nuclear Regulatory Commission; Part 63 – Disposal Of High-level Radioactive Wastes In A Geologic Repository At Yucca Mountain, Nevada.* 1-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/10cfr63_08.html.

40 CFR 190 2008 — U.S. Environmental Protection Agency. *Code of Federal Regulations. Title 40 – Protection of Environment. Chapter I Environmental Protection Agency. Part 190 – Environmental Radiation Protection Standards For Nuclear Power Operations.* 7-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr190_08.html.

40 CFR 191 2008 — U.S. Environmental Protection Agency. *Code of Federal Regulations. Title 40 – Protection of Environment. Chapter I – Environmental Protection Agency. Part 191 – Environmental Radiation Protection Standards For Management And Disposal Of Spent Nuclear Fuel, High-Level And Transuranic Radioactive Wastes.* 7-1-08 Edition. Washington, DC: Office of the Federal Register, National Archives and Records Administration; United States Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr191_08.html.

40 CFR 197 2008	U.S. Environmental Protection Agency. *Code of Federal Regulations. Title 40 – Protection of the Environment. Chapter I Environmental Protection Agency. Part 197 – Public Health and Environmental Radiation Protection for Yucca Mountain, Nevada.* 7-1-08 Edition. Washington, D.C.: Office of the Federal Register, National Archives and Record Service; U.S. Government Printing Office, 2008. On the Web at http://www.access.gpo.gov/nara/cfr/waisidx_08/40cfr197_08.html.
ANDRA 2001	Agence nationale pour la gestion des déchets radioactifs. *Dossier 2001 Argile, sur l'avancement des études & recherches relatives à la faisabilité d'un stockage de déchets à haute activite et à vie langue en formation géologique profonde. Rapport de synthèse.* Châtenay-Malabry: ANDRA, Décembre 2001.
BIA 2006	U.S. Bureau of Indian Affairs. "Notice of Availability of the Record of Decision (Rod) for a Proposed Lease of Tribal Trust Lands Between Private Fuel Storage, L.L.C. (PFS) and Skull Valley Band of Goshute Indian (Band) in Tooele County, UT," *Federal Register* v. 71, no. 192, October 4, 2006, pp. 58629 to 58630. On the Web at http://edocket.access.gpo.gov/2006/pdf/06-8484.pdf
BLM 2006	U.S. Bureau of Land Management, "Notice of Availability of the Record of Decision for the Right-of-Way Applications Filed by Private Fuel Storage, L.L.C., for an Independent Spent Fuel Storage Installation on the Reservation of the Skull Valley Band of Goshute Indians and the Related Transportation Facility in Tooele County, UT," *Federal Register* v. 71, no. 188, September 28, 2006, pp. 57005 to 57006. On the Web at http://edocket.access.gpo.gov/2006/pdf/E6-15734.pdf
Borchardt 2008	R.W. Borchardt. Subject: *Response to Commission Order CLI-05-20 Regarding Depleted Uranium*, Rule Making Issue. SECY-08-0147. Washington, DC: NRC, October 7, 2008. On the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2008/secy2008-0147/2008-0147scy.pdf.
CNE 2001	Commission Nationale d'Evaluation relative aux recherches sur la gestion des déchets radioactifs. *Rapport d'évaluation No 7.* Paris: CNE, juin 200. On the Web at http://lesrapports.ladocumentationfrancaise.fr/BRP/014000485/0000.pdf.
Deseret News 2006	Suzanne Struglinski. "Interior Department decisions stop nuclear-waste storage plans, Hatch says," *Deseret News*, September 7, 2006. On the Web at http://deseretnews.com/article/content/mobile/1,5620,645199671,00.html?printView=true
DOE 1980	U.S. Department of Energy. Final Environmental Impact Statement: Management of Commercially Generated Radioactive Waste. DOE/EIS-0046F. Washington, DC: DOE, Assistant Secretary for Nuclear Energy, Office of Nuclear Waste Management, Octor 1990. Vol. 1 on the Web at http://www.ocrwm.doe.gov/documents/1980_FEIS/33515/33515.pdf.
DOE 2007	U.S. Department of Energy. "Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste," *Federal Register*, v. 72, no. 140, July 23, 2007, pp. 40135-40139. On the Web at http://edocket.access.gpo.gov/2007/pdf/E7-14139.pdf.
DOE 2007b	U.S. Department of Energy. "Notice of Intent to Prepare an Environmental Impact Statement for the Disposal of Greater-Than-Class-C Low-Level Radioactive Waste: Correction," *Federal Register*, v. 72, no. 146, July 31, 2007, p. 41819. On the Web at http://edocket.access.gpo.gov/2007/pdf/Z7-14139.pdf.

DOE 2008	U.S. Department of Energy, Office of Civilian Radioactive Waste Management, *Safety Analysis Report: Yucca Mountain Repository License Application*, DOE/RW-0573, Rev. 0, Las Vegas, NV: OCRWM, June 2008. Links on the Web at http://www.nrc.gov/reading-rm/adams/web-based.html, searching for ML081560400.
DOE 2008b	U.S. Department of Energy. Office of Public Affairs. *U.S. Department of Energy Releases Revised Total System Life Cycle Cost Estimate and Fee Adequacy Report for Yucca Mountain Project*. [Press Release]. Washington, DC: DOE, August 5, 2008. On the Web at http://www.ocrwm.doe.gov/info_library/newsroom/documents/8_5_08_FINAL_TSLCC_PR.pdf.
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DOE OCRWM 1999	U.S. Department of Energy. Office of Civilian Radioactive Waste Management. "NWTRB Repository Panel meeting: Postclosure Defense in Depth in the Design Selection Process," presentation for the Nuclear Waste Technical Review Board Panel for the Repository, January 25, 1999. Presented by Dennis C. Richardson. Online at http://www.nwtrb.gov/meetings/1999/jan/richardson.pdf.
DOE OCRWM 2008	U.S. Department of Energy. Office of Civilian Radioactive Waste Management. How Much Nuclear Waste Is In The United States? Washington, DC: DOE, last reviewed: 04/08. On the Web at http://www.ocrwm.doe.gov/ym_repository/about_project/waste_explained/howmuch.shtml.
EPA 2001	U.S. Environmental Protection Agency. "40 CFR Part 197: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV: Proposed Rule." *Federal Register*, v. 66, no. 114, June 13, 2001. pp. 32074-32135. On the Web at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=2001_register&docid=01-14626-filed.pdf.
EPA 2005	U.S. Environmental Protection Agency. "40 CFR Part 197: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, NV: Proposed Rule." *Federal Register*, v. 70, no. 161, August 22, 2005. pp. 49014-49065. On the Web at http://edocket.access.gpo.gov/2005/pdf/05-16193.pdf.
EPA 2008	U.S. Environmental Protection Agency. "40 CFR Part 197: Public Health and Environmental Radiation Protection Standards for Yucca Mountain, Nevada, Final Rule." *Federal Register*, v. 73, no. 200, October 15, 2008. pp. 61256-61289. On the Web at http://edocket.access.gpo.gov/2008/pdf/E8-23754.pdf.
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GNEP PEIS draft 2008 — U.S. Department of Energy and Global Nuclear Energy Partnership. *Draft Global Nuclear Energy Partnership Programmatic Environmental Impact Statement.* DOE/EIS-0396. Washington, DC: DOE, October 2008. Links on the Web at http://www.gnep.energy.gov/peis.html. Summary on the Web at http://www.gnep.energy.gov/peis/Draft_PEIS/Summary.pdf.

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IEER Comments on the Nuclear Regulatory Commission's Rulemaking Regarding the "Safe Disposal of Unique Waste Streams Including Significant Quantities of Depleted Uranium"[1]

Arjun Makhijani
October 30, 2009

On March 18, the Nuclear Regulatory Commission (NRC) directed its staff to proceed with a rulemaking to amend the low-level waste rule to take into account the gap in the existing rule,[2] which does not address depleted uranium waste created in large amounts, such as at uranium enrichment plants. This followed the preparation by the staff of a paper, SECY-08-147,[3] which presented the Commission with four options. The March 18, 2009, decision was to proceed with Option 2 as specified in SECY-08-147.

> Previously, in the adjudicatory proceeding for the Louisiana Enrichment Services (LES) license application, the Commission determined that depleted uranium is properly classified as low-level radioactive waste. Although the Commission stated that a literal reading of 10 CFR 61.55(a)(6) would render depleted uranium a Class A waste, it recognized that the analysis supporting this section did not address the disposal of large quantities of depleted uranium. Outside of the adjudication, the staff was tasked to evaluate this complex issue and provide specific recommendations to the Commission. SECY-08-0147 is the result of the Commission's direction and provides recommendations for a path forward.

[1] U.S. Nuclear Regulatory Commission, "Notice of Public Workshop on a Potential Rulemaking for Safe Disposal of Unique Waste Streams Including Significant Quantities of Depleted Uranium," *Federal Register* v.74, no.120 (June 24, 2009), pages 30175-30179, on the Web at http://edocket.access.gpo.gov/2009/pdf/E9-14820.pdf. Hereafter referred to as NRC FR Notice 2009. Hereafter NRC FR Notice 2009.
[2] Annette L. Vietti-Cook (Secretary [of the Commission]), Memorandum to R. W. Borchardt (Executive Director for Operations), *Staff Requirements – SECY-08-0147 – Response to Commission Order CLI-05-20 Regarding Depleted Uranium*, Nuclear Regulatory Commission, March 18, 2009, on the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/srm/2008/2008-0147srm.pdf. The Commission's approval of the staff's recommendation was not unanimous. Commissioner Gregory Jaczko dissented. See below.
[3] R.W. Borchardt (Executive Director for Operations), to the Commissioners [of the NRC], *Response to Commission Order CLI-05-20 Regarding Depleted Uranium*, Rulemaking Issue, SECY-08-0147, October 7, 2008, on the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/secys/2008/secy2008-0147/2008-0147scy.pdf. Hereafter referred to as SECY-08-0147 2008.

> As an initial approach to addressing this complicated issue, the Commission has approved the staff's recommended Option 2 to 1) proceed with rulemaking in 10 CFR Part 61 to specify a requirement for a site-specific analysis for the disposal of large quantities of depleted uranium (DU) and the technical requirements for such an analysis; and 2) to develop a guidance document for public comment that outlines the parameters and assumptions to be used in conducting such site-specific analyses.
>
> In revising 10 CFR 61.55(a)(6) in this limited scope rulemaking, the Commission is not proposing to alter the waste classification of depleted uranium. Eventual changes to waste classification designations in the regulations must be analyzed in light of the total amount of depleted uranium being disposed of at any given site. However, the Commission is stating that for waste streams consisting of significant amounts of depleted uranium, there may be a need to place additional restrictions on the disposal of the depleted uranium at a specific site or deny such disposal based on unique site characteristics and those restrictions should be determined by a site specific analysis which satisfies the requirements of the proposed new 61.55(a)(9). This thought should be clearly indicated in the proposed rulemaking package seeking public comment. As part of this rulemaking, the staff should promptly conduct a public workshop inviting all potentially affected stakeholders, including licensees, state regulators and federal agencies. At this workshop, the staff should discuss the issues associated with the disposal of depleted uranium, the potential issues to be considered in rulemaking, and technical parameters of concern in the analysis so that informed decisions can be made in the interim period until the rulemaking is final.[4]

The first thing to note here is that the Commission is proposing only to revise 10 CFR 61.55(a)(6) and to add a new paragraph 10 CFR 61.55(a)(9), which does not now exist. Specifically, it is *not* proposing within this limited rulemaking to modify any part of 10 CFR 61 outside of 10 CFR 61.55(a). This intention is also clear from the Federal Register notice announcing the workshops.[5] The second critical thing to note is that the vote was not unanimous. Commissioner Jaczko, who has since been appointed the Chairman of the NRC, voted against Option 2, having earlier stated his preference for Option 3:

> In my original vote on SECY-08-0147, I approved Option 3 (determine classification for depleted uranium within existing classification framework) and I disapproved the staff's recommendation for Option 2 (rulemaking to specify requirement for site-specific analyses for the disposal of large quantities of depleted uranium). Since that vote, which was dated November 3, 2008, more information has come to light that I would like to address in my vote.
>
> The disposal of large quantities of depleted uranium (DU) is a unique challenge because, unlike typical low-level waste, the doses increase over time rather than decrease. The technical analysis included with SECY-08-0147 indicates that

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[4] Annette L. Vietti-Cook (Secretary [of the Commission]), Memorandum to R. W. Borchardt (Executive Director for Operations), *Staff Requirements – SECY-08-0147 – Response to Commission Order CLI-05-20 Regarding Depleted Uranium*, Nuclear Regulatory Commission, March 18, 2009, on the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/srm/2008/2008-0147srm.pdf.

[5] NRC FR Notice 2009.

additional requirements are likely needed for disposal of large quantities of DU in order to protect public health and safety; for example, increased waste disposal depth or robust radon barriers may be required. However, Option 2 does not explicitly change the classification of DU as presently provided for in 10 CFR 61.55 and therefore the waste would remain classified as Class A. I do not believe that it is logical to argue that that waste that requires additional requirements for disposal (similar to those required for Class C waste) can still be labeled as Class A waste.[6]

As directed by the Commission, , the NRC staff held a two day workshop in Bethesda, Maryland, in which I was an invited participant, as well as one in Salt Lake City.[7] The proceedings were transcribed. The transcript and slide presentations have been posted on the NRC's website.

I will first provide comments on the DU portion of the rulemaking and then provide briefer comments relating to other unique waste forms and the NRC's proposal for a longer term risk-informed revision of the entire low-level waste rule.

A. SECY-08-147 Is Fundamentally Deficient in Concept

Option 2, as described in SECY-08-147, is to keep the existing designation of DU as Class A waste based on the default paragraph in the low-level waste rule 10 CFR 61.55(a)(6). This paragraph states: "If radioactive waste does not contain any nuclides listed in either Table 1 or 2, it is Class A." Since this was recognized as insufficient for ensuring health and safety, Option 2 proposes the addition of a new paragraph. The proposal is summed up in SECY-08-147 as follows:

> Proposed Change: Modify paragraph 61.55(a)(6) to include a statement that, for unique waste streams including, but not limited to, large quantities of depleted uranium, the requirements of § 61.55(a)(9) of this part must be met. Section 61.55(a) would then be modified to include a paragraph (a)(9), which would include a requirement that *the disposal facility licensee must perform, and the Commission must approve, a site specific analysis demonstrating that the unique waste stream, including large quantities of depleted uranium, can be disposed of at the site in conformance with the performance objectives in subpart C to Part 61.*[8]

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[6] *Commissioner Jaczko's Revised Comments on SECY-08-0147 Response to Commission Order CLI-05-20 Regarding Depleted Uranium*, March 6, 2009, on the Web at http://www.nrc.gov/reading-rm/doc-collections/commission/cvr/2008/2008-0147vtr.pdf. See pdf pp. 7 and 8.

[7] The transcripts for both the Maryland (September 2 and 3, 2009) and the Utah (September 23 and 24, 2009) Workshops, the slide presentations, and background documents are available on the NRC's web page: *Unique Waste Streams*, on the Web at http://www.nrc.gov/about-nrc/regulatory/rulemaking/potential-rulemaking/uw-streams.html. Hereafter cited as NRC DU meeting transcript, September 2, 2009, and NRC DU meeting transcript September 3, 2009.

[8] SECY-08-0147 2008, p. 8. Italics, in the original, provide the text of the proposed new paragraph.

There are is a fundamental problem with this paragraph. It *assumes* that there exist sites that can comply with the performance requirements of 10 CFR 61, Subpart C. SECY-08-0147 provides no site-specific analysis to prove this in even one case. As we will see, the generic analysis of various types of sites and scenarios performed are fundamentally deficient in their assumptions and in their modeling. The NRC staff did not take into account even the possibility that no site would be found suitable under the performance requirements of Subpart C. Option 2 contains no fallback provision to examine alternative methods of managing large amounts of DU that could meet the performance requirements. Specifically, it does not consider deep disposal.

But the problem goes even deeper. The NRC staff failed even in its generic and deficient analysis to examine whether shallow land burial (at sufficient depth but less than 30 meters) could meet the performance requirements of Subpart C. So far as limiting dose to the general public are concerned, those performance requirements are specified at 10 CFR 61.41 as follows:

> Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

SECY-08-0147 did not calculate organ doses at all despite the fact that the main radionuclides in question – uranium-238, uranium-234, thorium-230, radium-226, radon-222 (and its daughters) – have dose conversion factors for particular organs that are much greater than for the equivalent dose to the whole body. For instance, the bone surface dose due to radium-226 per unit intake by ingestion is about 44 times larger than the whole body dose equivalent. As another example, the target organ for radon-222 (and its decay products) is the lung and other organs get minimal doses. When organ dose to whole body equivalent ratios for inhalation are considered (important in case waste is uncovered by erosion, especially in dry areas), the differences can be even greater. The ratio of bone surface dose to the whole body effective dose equivalent for inhalation of medium solubility thorium-230 is more than 50.[9]

Other examples are easy to provide. For instance, the bone surface dose from drinking water contaminated with lead-210 (a decay product of radon-222) is more than 30 times bigger than the committed whole body equivalent dose.

At the Bethesda, Maryland, workshop, I asked why the performance assessment was not according to the criteria in 10 CFR 61 Subpart C. Dr. Esh, the principal author of the analysis in SECY-08-147, stated that the NRC staff had used a "modern" approach and used TEDE as the performance criterion:

> Primarily because in more recent evaluations; in particular, for waste incidental to reprocessing, we have had direction from the Commission to use more modern methods, instead of those old methods. So we followed that direction.[10]

[9] Dose conversion factors are from EPA's Federal Guidance Report 13.
[10] NRC DU meeting transcript, September 2, 2009, p. 104.

I pointed out that human beings still have organs, and 10 CFR 61 Subpart C requires organ dose calculations, so it is not a question of "modern" methods of calculation. Further, the most recent EPA method of internal dose calculation, published as Federal Guidance Report 13, allows for both organ dose and whole body effective dose equivalent calculations. So it is not even a question of "modern" methods versus obsolete methods.

Also, whether a certain method is "modern" or not or whether only whole body equivalent doses are used in other parts of the NRC's work is irrelevant. The plain language of the present DU rulemaking process requires an evaluation relative to the performance requirements of 10 CFR 61, and those requirements are in Subpart C. In turn, Subpart C requires, among other things, limitation of organ dose. Hence, in every circumstance where organ dose may exceed whole body effective dose equivalent, as is the case with DU disposal, the rule *requires the calculation dose to the critical or most exposed organ.*

As noted above, the Commission is proposing only to revise 10 CFR 61.55(a)(6) and add a new paragraph that would specify disposal requirements for DU. The Commission has not authorized modification of 10 CFR 61 Subpart C. Specifically, it has not anywhere mentioned that the organ dose requirement of 10 CFR 61.41, which is in Subpart C, is to be ignored or changed. Further, SECY-08-0147 itself states that it will examine whether compliance with 10 CFR 61 Subpart C can be achieved with shallow land burial:

> The technical analysis addressed whether amendments to § 61.55(a) are necessary to assure large quantities of DU are disposed of in a manner that meets the performance objectives in Subpart C of 10 CFR Part 61.[11]

Dr. Esh, the principal NRC staff author of SECY-08-0147, explicitly stated during the Bethesda, Maryland, workshop that the NRC was not proposing to modify Subpart C.[12]

But SECY-08-0147 did not evaluate performance of DU disposal in shallow land facilities according to a principal element of the requirements of Subpart C. Rather SECY-08-0147 entirely ignored the organ dose calculation requirements of Subpart C as specified in 10 CFR 61.41. This is a central problem with the present proceeding without any other factor. Further, were organ doses to be calculated, even with the fundamentally deficient modeling in SECY-08-0147 (see below), that, contrary to the conclusions of the SECY-08-0147, the model may show that the performance requirements of Subpart C would not be met by shallow land disposal.

The decision of the NRC instructing the staff to proceed with the rulemaking based on Option 2 is basically flawed since it depends centrally on the technical analysis of the NRC staff in SECY-08-0147 actually showing that it was, at least in theory, possible that some imaginable shallow land configuration could meet the performance requirements of Subpart C. But SECY-08-0147 is fundamentally incomplete since it did not even attempt to calculate organ doses, which are most important, under the circumstances, for evaluating disposal performance.

[11] SECY-08-0147 2008, p. 1.

[12] NRC DU meeting transcript, September 2, 2009, p. 105.

Recommendation 1: Since the entire premise of proceeding is fundamentally flawed in regard to the performance requirements of Subpart C, and since the staff paper on which the NRC made its decision to proceed with this rulemaking did not even attempt to calculate organ doses, as required by Subpart C, the NRC should stop the present process immediately and begin a new rulemaking that properly specifies the parts of the rule that are being considered for revision and that provides the relevant NRC analysis to the public so that it may comment upon it.

B. Scientific Deficiencies in SECY-08-0147

The main technical premise on which the proposed rule change in regard to disposal of significant amounts of DU as Class A waste is that it can be shown that certain low-level waste shallow land disposal facilities would meet the performance requirements of 10 CFR 61. In this section we will leave aside the basic problem that SECY-08-147 did not evaluate the most important part of the performance requirement (dose to the critical organ) and focus on the model and the assumptions that the staff used in SECY-08-147 to analyze performance.

The following are features of the analysis of performance in SECY-08-0147:

- It considers sites in various climatic zones, but is not site specific.
- It assessed doses for one million years – the approximate period during which the decay products of U-238, the main ingredient of DU, continue to build up. This approximates a peak dose calculation.
- As radium-226 builds up over thousands of years, radon-222 emissions increase. Radon-222 doses were included in the analysis. A clay layer that would inhibit radon migration was included. Given the assumption of no erosion, this layer would essentially stay intact over a million years.
- Shallow burial (defined as less than 30 meters depth) at various depths was considered.
- Chronic intruder as well as offsite resident doses were considered.
- Various exposure pathways were considered.
- Both air and water induced erosion were assumed to be zero for one million years.
- An ad hoc model, consisting of a commercial Monte Carlo package and an in-house spreadsheet, was developed.
- The dose assessment was based on TEDE, which is Total Effective Dose Equivalent (defined as the sum of deep external dose and committed effective dose equivalent for internal dose).
- For the offsite resident a 25 millirem annual TEDE dose limit was applied as the performance objective. For the chronic intruder who builds a house above the disposal site, a 500 millirem annual dose limit (TEDE) was applied as the performance objective.[13]

[13] It should be noted that 10 CFR 61 requires assurance that an inadvertent intruder be protected after institutional control expires, but does not specify a dose limit. 10 CFR 61.42 states in its entirety: "Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal

The results of the modeling were as follows:

- Using the TEDE approach, the analysis concluded that shallow land burial, less than 3 meters deep, was not suitable for DU, except for "small quantities" defined as 1 to 10 metric tons.[14]
- Disposal of DU in large amounts at humid sites "with viable water pathways is probably not appropriate."[15]
- For disposal at 5 meters or deeper, up to 30 meters, SECY-08-0147 concluded that disposal at arid sites could meet performance criteria:

> Depleted uranium can be disposed of under arid conditions and meet the Part 61 performance objectives for 1,000 to 1 million years performance periods, if the waste disposal depth is large, or robust barriers are in place to mitigate radon.[16]

Besides the failure to evaluate doses to organs, the following limitations of the analysis should be noted (most came up during the presentations or the discussion at the Bethesda, Maryland, workshop):

1. Climate change was not considered – that is, a constant climate was assumed for one million years.
2. Changes to the chemical form of uranium over one million years were not considered.
3. Colloidal transport of radionuclides was not included.
4. The clay barrier to radon migration into a home built over or near the disposal area was assumed to stay intact over a million years (e.g., no cracks would develop that may allow more migration of radon into the house). The effects of aeolian or fluvial erosion were not considered. The assumption was that the site would be stable for one million years. (The assumption is stated as follows in SECY-08-0147: "Site stability requirements would be achieved. There will not be significant releases of waste to the environment from fluvial or aeolian erosion."[17]

Let us consider these problems one by one.

1. Climate change

It is scientifically unsound and contrary to the available data to assume that climate will not change for one million years. Even without the anthropogenic emissions that are currently accelerating climate change, climate has changed naturally on times scales of thousands of years. For instance, Dr. Peter Burns of the University of Notre Dame, a geochemist invited by the NRC to participate in both workshops, and who participated in both of them, noted that Death Valley

site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed." A figure of 500 mrem per year is often used for performance assessment.

[14] SECY-08-0147 2008, Enclosure 1, p. 16.

[15] SECY-08-0147 2008, Enclosure 1, p. 16.

[16] SECY-08-0147 2008, Enclosure 1, p. 16. Emphasis in the original.

[17] SECY-08-0147 2008, Enclosure 1, p. 9.

was underwater 10,000 years ago and that climate projections could not be relied on for 10,000 or 100,000 or 1 million years.

Climate affects practically every environmental factor relevant to the performance assessment from the integrity of the cap to erosion rates to dilution of radionuclides in groundwater. As one example, the model results in SECY-08-0147 show that "[r]adon fluxes to the environment are very sensitive to the long-term moisture state of the system."[18] Since rainfall is one critical parameter to vary in climate, the radon dose results would evidently also be affected. Similarly, radon dose results would be affected if the integrity of the clay liner is damaged or destroyed by variations in rain, snow, temperature, and/or wind that are greater than those assumed in the modeling. (SECY-08-0147 assumes no erosion even from the present climate – see below).

In fact, the record of the Bethesda, Maryland, workshop shows that even the NRC staff agreed that ignoring climate change for such long periods was not appropriate. The terms "silly" and "silliness" came up in the context of trying to describe attempts to model shallow land burial for a million years, but it was suggested by the moderator, Chip Cameron, that this was perhaps not the best language to use in a regulatory context.[19] Whatever, the term used to describe the fact that the modeling ignored climate change, the essence of the matter is that there was general agreement that climate change should not be ignored for shallow land burial for periods much shorter than one million years – for instance over 10,000 years. This is not as important in the context of radionuclides with half-lives that are much shorter than 10,000 years, but in a context of DU, where the specific activity of the material is growing due to the build up of daughter products, it is essential to consider climate change.

Recommendation 2: Future modeling for disposal of significant amounts of DU should include climate change.

2. Chemical changes to the form of DU

SECY-08-0147 considered only shallow land burial, with a clay cap being put over the waste. By its very nature, the environment of the DU would be oxidizing. Elementary considerations show that there would be considerable chemical changes, especially over long periods of time in the proposed waste form, U_3O_8, that the NRC has accepted as suitable for disposal in its licensing process of the two uranium enrichment plants (LES and USEC) that were granted licenses in 2006 and 2007 respectively. Ignoring chemical changes in U_3O_8 in an oxidizing environment is not only scientifically unsound, but it also leads to potential underestimates of uranium mobilization in groundwater. Such mobilization may be enhanced by the presence of complexing compounds. The dose estimates in SECY-08-0147 may therefore be considerable underestimates, notably via the water pathway (including radon via the water pathway).

Recommendation 3: A technical discussion of the expected changes in chemical forms in the specific environment in which disposal is proposed is essential. Specifically, the effects of an oxidizing environment on the specific waste form proposed, including U_3O_8, needs to be analyzed in detail.

[18] SECY-08-0147 2008, Enclosure 1, p. 15.

[19] NRC DU meeting transcript September 2, 2009, at various places in pp. 98 to 116 and also pp. 185, 195, and 251.

3. Colloidal transport

In the modeling in SECY-08-0147, the principal pathways for radionuclides to reach the human environment are diffusion of radon through the clay barrier and dissolution of radionuclides in groundwater and from that various other water related pathways, such as ingestion of contaminated food irrigated with contaminated water. However, colloidal transport of radionuclides was not considered. This could be a significant pathway, especially for insoluble forms of uranium and its decay products.

Recommendation 4: Colloidal transport needs to be included in the modeling of DU disposal.

4. The assumption of long-term stability

The model assumes that the disposal site, including the clay cap, will be stable for one million years. Erosion is ignored. It is assumed that the clay liner will not crack for one million years. This is a critical factor in the performance modeling results. Cracks would provide a fast path for radon migration. Assuming that a clay liner will stay intact therefore results in spuriously low radon dose estimates. Of course, considering a thinning of the cap or a complete erosion of the cap prior to dissolution of the waste would result in very large long term doses. For instance, uncovering of the waste by aeolian erosion in a few thousand years would expose intruders to large external gamma doses from radium-226. These doses would be very small if the cap stays intact, which is the assumption in SECY-08-0147. It can be expected that large doses would result from shallow land burial even at the depths at which SECY-08-0147 derives low doses in dry climate if there any significant erosion. This has been demonstrated in straightforward modeling exercises by the Institute for Energy and Environmental Research which were introduced into testimony during the LES licensing proceedings.[20]

Recommendation 5: A realistic modeling of the shallow land burial needs to be done that would include fluvial and aeolian erosion, the effects of compromises of the integrity of the clay cap via the development of cracks, etc.

5. Conclusions regarding modeling in SECY-08-0147

Several of the modeling assumptions that play large roles in the conclusion of SECY-08-0147 that there could exist shallow land disposal sites where doses would be small (less than 25 millirem per year whole body effective dose equivalent) are scientifically unsound. A realistic

[20] Arjun Makhijani and Brice Smith, *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES,* Takoma Park, MD: Institute for Energy and Environmental Research, November 24, 2004. Version for public release redacted on Feb. 1, 2005, on the Web at http://www.ieer.org/reports/du/lesrpt.pdf, p. 24 (Hereafter Makhijani and Smith 2004/2005) and Arjun Makhijani and Brice Smith, "Update to *Costs and Risks of Management and Disposal of Depleted Uranium from the National Enrichment Facility Proposed to be Built in Lea County New Mexico by LES by Arjun Makhijani, PhD. and Brice Smith, Ph.D. based on information obtained since November 2004,*" Takoma Park, MD: Institute for Energy and Environmental Research, July 5, 2005. Version for public release redacted on Aug. 10, 2005, on the Web at http://www.ieer.org/reports/du/LESrptupdate.pdf, p. 16. Hereafter Makhijani and Smith 2005.

analysis that took such factors as climate, clay cap stability, and geochemical considerations into account would lead to three potential conclusions. First, there is no reliable way to estimate long term performance of DU in shallow land disposal facilities. Second, radiation doses from shallow land burial under even modestly realistic assumptions are likely to be well over the performance requirements of Subpart C. Third, the uncertainties in such dose estimates would be so high that they would be reasonably considered unreliable.

It is reasonable to conclude that a scientifically reliable assessment of DU disposal in shallow land disposal facilities cannot be made for the time periods at which peak doses from DU would be expected, or even much shorter time periods of 10,000 or more years.

C. Period of Performance

The Federal Register notice seeks comment on whether the period for which the performance requirements in regard to dose be limited. There is at present no limitation for period of performance in 10 CFR 61. Specifically, Subpart C has no time limitation in it. The Federal Register notice explains the situation as follows:

> NRC continues to consider 10,000 years a sufficient period, with some exceptions, to capture (i) the risk from the short-lived radionuclides, which comprise the bulk of the activity disposed; and (ii) the peak radiological doses from the more mobile long-lived radionuclides, which tend to bound the potential radiological doses at time frames greater than 10,000 years ....As part of a planned rulemaking, NRC is soliciting stakeholder views regarding a time period to evaluate the performance of near-surface disposal of unique waste streams.[21]

Neither condition that normally applies the customary period of 10,000 years for which NRC considers it suitable to estimate performance applies to significant amounts of DU. The first condition obviously does not apply since all three isotopes of uranium in DU (U-234, U-235, and U-238) are very long-lived. The second condition also does not apply. DU from enrichment plants or other similarly pure or nearly pure DU (in any common chemical form) has a specific activity that is far greater than the 100 nanocuries per gram associated with the limit for Class C waste containing transuranic alpha emitters. Under dry climatic conditions, should they persist (as is assumed in some scenarios in SECY-08-0147), the DU would not be expected to be mobile enough for most of it to migrate away from the site. This is indicated by the peak dose analyses in SECY-08-0147.

I have argued in expert testimony before the NRC that DU from enrichment plants is much like (GTCC) waste containing long-lived alpha-emitting transuranic radionuclides at concentrations greater than 100 nanocuries per gram. This conclusion finds support in a National Research Council publication as well.

> If disposal [of depleted uranium oxide] is necessary, it is not likely to be simple. The alpha activity of DU is 200 to 300 nanocuries per gram. Geological disposal is required for transuranic waste with alpha activity above 100 nanocuries per

[21] NRC FR Notice 2009, pp. 30176-30177.

> gram. If uranium were a transuranic element, it would require disposal in the Waste Isolation Pilot Plant (WIPP) based on its radioactivity. The chemical toxicity of this very large amount of material would certainly become a problem as well. One option suggested by the U.S. Nuclear Regulatory Commission (USNRC) is disposal in a mined cavity or former uranium mine. Challenges for this option would include understanding the fundamental differences between uranium ore (see Sidebar 6.1) and the bulk uranium oxide powder.[22]

The peak doses from DU disposal are expected to occur after thousands of years, hundreds of thousands of years, or even a million or more years, depending on the chemical form, disposal site characteristics, etc. Hence, the normal criteria of the NRC limiting performance evaluation to 10,000 years do not apply.

The staff's position in SECY-08-0147 regarding the period of performance is ambiguous:

> Considering the technical aspects of the problem, the performance assessment staff recommends a performance period of *10,000 years* for the analysis of *DU* disposal. However, analyses should be performed to peak impact, and if those impacts are significantly larger than the impacts realized within 10,000 years, then the longer term impacts should be included in the site environmental evaluation.[23]

It is unclear from this whether or not the staff intends for the peak dose to meet Subpart C criteria or not. However, unless Subpart C is sought to be changed, the performance assessment must be carried to the time of peak dose and the dose criteria of 10 CFR 61.41, including organ dose, must be met. But it should be noted in this context that the NRC staff itself does not consider the analysis in SECY-08-147 to be conservative.

Specifically, SECY-08-0147 and its Enclosure 1, states that the staff developed a "screening model" to do a "screening analysis" whose purpose "was to evaluate key variables such as disposal configurations (disposal depth and barriers), performance periods, institutional control periods, waste forms, site conditions, pathways, and scenarios."[24]

During the Bethesda, Maryland, workshop, I asked whether the term "screening" was being used to indicate a conservative analysis – that is, an analysis that would give an upper bound for the dose estimate, so that one could be reasonably assured that a more realistic analysis would yield a lower dose estimate. In other words, such a screening analysis would lead to an assurance that the conclusion that DU could be disposed of in shallow land burial and meet specified performance criteria was robust.

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[22] National Research Council, Board on Radioactive Waste Management, Committee on Improving the Scientific Basis for Managing Nuclear Materials and Spent Nuclear Fuel through the Environmental Management Science Program, *Improving the Scientific Basis for Managing DOE's Excess Nuclear Materials and Spent Nuclear Fuel*, National Academies Press, Washington, DC, 2003. On the Web at http://books.nap.edu/books/0309087228/html/index.html., p. 67 as quoted in Makhijani and Smith 2004/2005, pp. 7-8.

[23] SECY-08-0147 2008, Enclosure 1, p. 21. Emphasis in original.

[24] SECY-08-0147 2008, Enclosure 1, pp. 8-9.

Dr. Esh indicated that the term "screening analysis" was not used in that sense in the paper. He agreed with the suggestion that the screening model in SECY-08-0147 "wasn't conservative."[25]

Conclusion regarding period of performance: The conclusion from the above is that if the NRC wishes to assess performance of disposal of DU in significant amounts according to Subpart C, which contains no time limits, then a limit on the period of performance to 10,000 years is entirely inappropriate. The stated goal of the proposed rulemaking exercise is to limit consideration of changes to 10 CFR 61.55(a). Therefore, a limitation on the period of performance cannot be used for disposal of significant quantities of DU within the context of the present rulemaking. An entirely new rulemaking proceeding would be needed, since restricting performance evaluation to anything short of peak dose in this case would be a de facto change in Subpart C.

One may conclude the following by examining the transcripts of the Bethesda, Maryland, workshop (as well as the Salt Lake City workshop):

- Uncertainties become very large over periods as long as 10,000 to one million or more years,
- Modeling shallow land burial over periods as long as a million years or more quantitatively with some confidence appears infeasible, and
- The main radiological problems in dry areas, other than those that might be associated with uncovering the waste, appear over the long term (thousands of years or more), presuming the areas remain dry.

During the Bethesda, Maryland, workshop, there were several suggestions about restricting the period of performance. One was to use the period now required for mill tailings (1,000 years); another was to use the period required under 40 CFR 191 for deep geologic disposal, for instance at the Waste Isolation Pilot Plant (10,000 years). However, none of these suggestions can be legitimately considered under in the present rulemaking. If the NRC wants to consider limiting the period of performance for significant amounts of DU, then it must start a new proceeding and propose changes in Subpart C, along with the rationale for those changes.

The rationale for limiting the period of performance cannot be simply to protect the industry or provide the industry with a way to get rid of DU from enrichment plants or even that it is difficult to do a modeling exercise to the time of peak dose. Since it is the NRC's mandate to protect public health, and since public health can be much better protected with appropriate deep disposal similar to geologic disposal at WIPP, the NRC must first consider such deep disposal before it considers any relaxation of Subpart C. This would also require a different rulemaking from the one that the NRC is now embarked upon.

In the context of deep geologic disposal, where estimating performance can be done on a better scientific foundation, the NRC might consider adopting the approach taken in the French high-level waste rule. That rule recognizes that the uncertainties increase greatly beyond 10,000

[25] NRC DU meeting transcript, September 2, 2009, p. 83.

years. But instead of changing the dose performance standard, it changes the method by which the modeling is done:

- For up to 10,000 years, the uncertainties in the parameters are specified explicitly and probability distributions are provided. This gives a realistic set of estimates of what the performance would be, assuming the parameters are well characterized.
- Beyond 10,000 years the conservative, fixed values are used for parameters so as to calculate an upper limit of the dose. The same dose reference number is maintained but now we have what would be a bounding value for the long term, presuming the upper bound parameters: climate, geological, and others can be specified in a scientifically defensible way.[26]

D. Some Other Matters

It is important to note that SECY-08-0147 did not analyze performance of above-ground structures, such as those used at the EnergySolutions facility in Utah. Hence, any rule change would not apply to disposal at that site, unless the NRC actually develops modeling approaches for above ground structures for a million years. This would be an even more unrealistic task than the one undertaken in SECY-08-0147 to estimate performance in below ground shallow disposal.

E. Other "Unique" Waste Forms

Like significant amounts of DU, there are several other waste streams that do not clearly fall into the present structure of 10 CFR 61.55(a) as is recognized now by the NRC. These could include significant amounts uranium recovered during reprocessing for instance. Such uranium is typically contaminated with transuranic radionuclides and some fission products.

DU in large amounts is in many ways the best characterized and known of such potential waste streams. There should be no consideration of other waste streams within the present proposed rulemaking to revise 10 CFR 61.55(a)(6) and add a new para 10 CFR 61.55(a)(9).

F. The Rights of Agreement States

States that regulate civilian nuclear licensees under agreement with the NRC ("Agreement States") are required to meet a complex set of "compatibility" requirements to ensure that NRC requirements are being met. The regulation and enforcement is done at the state level in such cases. But the NRC has the responsibility to ensure that there is compliance with applicable federal regulations. The industry and state regulator sentiment is for the NRC to give the

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[26] Règle N° III.2.f (10 juin 1991) *Règles fondamentales de sûreté relatives aux installations nucléaires de base autres que reacteurs Tome III: production, contrôle et traitement des effluents et déchets. Chapitre 2: Déchets solides*, on the Web at http://www.asn.fr/index.php/Les-actions-de-l-ASN/La-reglementation/Reglementation-associee/Regles-fondamentales-de-surete-et-guides-de-l-ASN/RFS-III.2.f-abrogee-par-le-guide-de-surete-relatif-au-stockage-definitif-des-dechets-radioactifs-en-formation-geologique-profonde-du-12.02.08.

maximum possible leeway to state authorities. States can generally set more conservative standards than those at the federal level.

During the Bethesda, Maryland, workshop I expressed concerns as to whether there was adequate oversight regarding the two sites that may, in the near future, dispose of DU from enrichment plants – Utah (EnergySolutions site) and Texas (Waste Control Specialists (WCS) site). Specifically, I raised the issue of whether the NRC was adequately exercising its oversight responsibilities. I had raised the same issue during my testimony as an expert witness for the intervenors in the National Enrichment Facility licensing case.

Specifically, I found that some of the results of the modeling done in a performance assessment that underlies the EnergySolutions license contained physically impossible numbers. For instance, more uranium-238 was proposed to be disposed of per gram of Utah soil than the weight of the Earth. I was asked during the Bethesda, Maryland, workshop whether I was comfortable with the State of Texas agreeing to a DU concentration limit for the WCS site. I said that the last time I looked at the WCS issue, which was four years ago, I was not convinced that WCS was even qualified to receive radioactive waste – since, among other things, their license application at that time proposed to dispose of more U-235 as waste than had ever been mined.[27]

If the NRC and the state of Utah has failed to require a correction of such evident scientific problems, even though it has been formally put on the table, how could one be confident of the process for licensing and enforcing DU disposal regulations? Neither has the NRC responded to my comment regarding WCS during the workshop.

I also pointed out that IEER has done the only independent site specific analysis of DU disposal by shallow land burial for the WCS site and of a site with parameters corresponding to the Utah site. Our analysis had shown that doses would be exceeded at both sites by large margins in well under one million years and in most cases on times scales on the order of 10,000 years. I was told, informally, that NRC staff would look into the record of the LES proceeding. In response, I told them I would supply the IEER LES reports to the staff. IEER has sent the URLs for the reports to the moderator Chip Cameron.[28]

Expectation of IEER: We expect that before any draft rule is promulgated that the NRC will respond specifically to the above problems in regard to WCS and EnergySolutions and also make clear whether it intends to be more vigilant in regard to elementary matters of science when it comes to oversight of agreement states.

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[27] See Makhijani and Smith 2005, for instance at p. 2 and p. 20.

[28] Post-workshop note: IEER sent the URLs to the moderator Chip Cameron on September 21, 2009. These are also cited in footnote 21, above.

G. Conclusions

The present rulemaking is based on the false premise that SECY-08-0147 has demonstrated the feasibility of adequate performance relative to Subpart C of some shallow land disposal facilities. SECY-08-0147 did not actually calculate performance relative to the most important requirement of Subpart C – organ dose. It is also fundamentally flawed in its science and in its assumptions. The suggestions as to limitation of period of performance are, given the NRC's own normal criteria, entirely out of order in this proposed rulemaking.

The Federal Register Notice as well as the NRC instruction to the staff was to consider a very limited change to the low-level waste rule. Specifically, the Commission directed the staff to consider a revision of 10 CFR 61.55(a)(6) and to add a new paragraph 10 CFR 61.55(a)(9) that would specify how a site specific analysis for depleted uranium (and possibly other "unique waste streams") should be done. Associated guidance was also to be developed. The NRC did not state that performance requirements specified in 10 CFR 61 Subpart C would be modified. On the contrary, both the NRC and the NRC staff have represented that the intent is not to modify Subpart C but to assess performance with respect to the requirements of Subpart C.

The analysis of SECY-08-0147 did not assess performance according to all the requirements of Subpart C. Specifically, organ doses were not estimated. There were also explicit suggestions that the period of performance for disposal of significant quantities of DU might be limited in some way. This would also be a material change to Subpart C in the context of disposal of large amounts of DU.

The proposed rulemaking cannot change Subpart C either explicitly or implicitly – for instance by omitting organ dose calculations or limiting the period of performance. The NRC has not provided any estimate of the changes in health damage that may be expected as a result of changes in Subpart C. As a result, the public has been provided with no opportunity to comment specifically on the changes that would be made to their protection of their health aspects as a result of any explicit or implicit changes in Subpart C.

A change to Subpart C, where the core public health provisions of the low-level waste regulations are specified, would be a major change to the regulation. The Atomic Energy Act requires the NRC to have public health protection as one its primary purposes and it empowers the NRC to take action accordingly. A change to Subpart C, which is central to the health protections provided by the low-level waste rule, would therefore be a major federal action. It would violate the Administrative Procedures Act if Subpart C were to be changed in the context of the present proposed rulemaking, where no analysis for changing Subpart C has been provided. .

IEER therefore strongly recommends that:

- The present rulemaking be stopped.
- A new rulemaking that corresponds to Option 3 should be initiated for significant amounts of DU.

- The possibility that DU will fall into the Greater than Class C category of low level waste should be explicitly included.
- The option of deep geologic disposal should be considered – indeed, given the text of the low-level waste rule as it now stands, this would the normal mode of disposal of significant amounts of DU.
- Performance standards as set forth in Subpart C should be maintained.
- There should be no limit on the period of performance.
- A change in the method by which performance is evaluated could be considered along the lines that are specified in the French high-level waste rule cited above.
- The NRC should ensure that sound and defensible scientific assumptions, methods, and analytical tools are used and that input data represent conditions that might reasonably be expected, or that would put an upper limit to dose calculations.
- The NRC should exercise more oversight over agreement states to ensure that the methods, data, conclusions, analyses, computer models, and parameter values meet at least minimal tests of scientific soundness.