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Craver, Patti

From: Smith, Maxwell
Sent: Thursday, April 12, 2012 11:02 AM
To: Uttal, Susan; Woodall, Lauren; Balsam, Briana; Logan, Dennis
Subject: Additional Pilgrim Exhibits
Attachments: DPH PNPSupdate 3-28-12.pdf; Exhibit 1 Scheffer.pdf; Exhibit 2 1999 radwaste waiver.pdf; Final Pilgrim NMFS Letter 4-12-12-1.pdf; PNPS_WDCS.pdf; Thompson Report.pdf; Beyea Report.pdf

Hi Everybody,

(b)(5)

Let me know if you have any questions,

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C/7

Issue/Title: Pilgrim Nuclear Power Station (PNPS): Tritium in Groundwater Monitoring Wells

Topic: PNPS Updates as of March 28, 2012

Previous Plans: Results from groundwater monitoring well samples collected during the weeks of February 21st and March 6th, 2012 were reported by Entergy. Split sample results for the weeks of February 21st, 2012 and March 6th, 2012 have also been reported by MERL.

Current Status:

Table 1[1]: February 21st

Location	Date	MERL[2] pCi/L	GEL[3] pCi/L
MW 201	02/21/2012	514	707
MW 202	02/21/2012	-	-
MW 202 I	02/21/2012	-	-
MW 203	02/21/2012	-	-
MW 204	02/21/2012	-	-
MW 205	02/21/2012	5,406	4,380
MW 206	02/21/2012	2,392	2,180
MW 207	02/21/2012	-	-
MW 208-S	02/21/2012	-	-
MW 208-I	02/21/2012	-	-
MW 209	02/21/2012	1,200	1,200
MW 210	02/21/2012	-	-
MW 211	02/21/2012	1,318	1,380
MW 212	02/21/2012	-	-
MW 213	02/21/2012	-	-
MW 214	02/21/2012	-	-
MW 215 new	02/21/2012	1,465	1,600
MW 217 new	02/21/2012	573	901
MW 3	02/21/2012	-	-
MW 4	02/21/2012	-	-
SW-boat ramp	02/21/2012	-	-
SW-intake	02/21/2012	NDA	NDA

Table 2: March 6th

Location	Date	MERL pCi/L	GEL pCi/L
MW 201	03/06/2012	362	514
MW 202	03/06/2012	884	942
MW 202 I	03/06/2012	376	NDA
MW 203	03/06/2012	NDA	NDA
MW 204	03/06/2012	323	NDA
MW 205	03/06/2012	5,178	5,090
MW 206	03/06/2012	2,660	2,480
MW 207	03/06/2012	522	447
MW 208-S	03/06/2012	NDA	NDA
MW 208-I	03/06/2012	NDA	NDA
MW 209	03/06/2012	1,122	1250
MW 210	03/06/2012	931	1080
MW 211	03/06/2012	1,227	1220
MW 212	03/06/2012	504	534
MW 213	03/06/2012	NDA	NDA
MW 214	03/06/2012	NDA	NDA
MW 215 new	03/06/2012	481	1490
MW 217 new	03/06/2012	523	517
MW 3	03/06/2012	NDA	NDA
MW 4	03/06/2012	417	408
SW-boat ramp	03/06/2012	**	**
SW-intake	03/06/2012	NDA	NDA

* **NDA = not detected at less than activity value listed**
** **results pending**
*** **well inaccessible due to scheduled equipment use**
\- **not analyzed this week**

[1] PNPS screening level for tritium in groundwater monitoring wells is 3,000 pCi/L, which is 1/10th of the NRC-approved Pilgrim Offsite Dose Calculation Manual standard for tritium in non-drinking water sources. The EPA drinking water standard is 20,000 pCi/L. The nearest drinking water wells are approximately 2.5 miles from the plant.

[2] Results from the Massachusetts Environmental Radiation Laboratory (MERL)

[3] GEL Laboratories are a radioanalytical laboratory contracted by PNPS

The latest groundwater monitoring results reported by Entergy show MW205 decreased to a level of 4,380 pCi/L of tritium detected on February 21st and increased to 5,090 pCi/L of tritium detected on March 6th (the previous result on February 7th was 8,400 pCi/L). Results for MW206 decreased to 2,180 pCi/L of tritium detected on February 21st and slightly increased to 2,480 pCi/L of tritium detected on March 6th (2,890 pCi/L of tritium was detected in the previous sample on February 7th). Results for the other priority wells were within their typical ranges between no detectable tritium and approximately 1,800 pCi/L of tritium detected (see table above). Results for the non-priority wells from the week of March 6th were consistent with past results for these wells ranging from no detectable tritium to 1,000 pCi/L of tritium detected (see table above). Entergy has reported that they are having all groundwater monitoring well samples from the week of March 6th analyzed for hard-to-detects. Entergy will report these results to MDPH when they are available. Split sample results from MERL for the weeks of February 21st and March 6th were generally consistent with results reported by Entergy (see table above).

Entergy results for surface water from the intake canal downstream of MW205 indicated no detectable tritium for the weeks of February 21st and March 6th. Split sample results from MERL for the weeks of February 21st and March 6th also indicated no detectable tritium. To date, no tritium has been detected in any of the surface water samples.

The charcoal samplers placed in monitoring wells for the dye testing effort were most recently collected on February 23rd, 2012. Sample collection restarted January 12th, 2012. No dye has been detected in any sample since the dye testing began in January 2011.

MDPH and MEMA have been receiving weekly updates from Entergy on the progress of installing the third new groundwater well, MW216, the original location of which was not technically feasible. All containers that were in the way of MW216 have been moved and all budgetary approvals have been granted. The excavation permit is being processed, and once approved, ground penetrating radar can be scheduled and well excavation can proceed pending ground penetrating radar shows that the sub-surface is clear of interferences.

An in person meeting between Entergy, MDPH, MEMA and MDEP occurred Wednesday March 28, 2012 at MDPH to discuss the tritium in groundwater investigation to date and ways to proceed from here. A detailed document for new investigational activities was discussed at the in person meeting and will be summarized in a report Entergy is preparing. The new activities include addressing several possible sources (e.g., steam heating lines) and adding dye directly to an excavation down to the water table to better characterize groundwater flow specifically related to MW205 and MW206. To date no definitive source has been found despite the addition of new wells along the deep foundation, pipe line inspections, dye testing, soil sampling, and nearly two years of monitoring fluctuating tritium levels in MW205 and MW206.

Looking Forward:

MDPH will continue to closely follow all investigational activities that are currently underway (i.e. well placement).

MDPH and MEMA plan to review Entergy's proposed next steps in the tritium investigation and will provide feedback once a more detailed summary document of the new investigation activities is provided by Entergy.

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April 12, 2012

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Re: **ESA § 7 Consultation with Nuclear Regulatory Commission on Entergy's Pilgrim Nuclear Power Station, Plymouth, Massachusetts**

Dear Mr. Morris,

We are writing on behalf of a network of groups to request that your office consider the following information in connection with its consultation under the Endangered Species Act (ESA), 16 U.S. C. §§ 1531-1544, with the Nuclear Regulatory Commission (NRC) regarding the NRC Staff 2006 Biological Assessment (2006 BA) and 2012 supplemental Biological Assessment (2012 BA) for the relicensing of Entergy Corporation's Pilgrim Nuclear Power Station (PNPS). As you know, Entergy is seeking to extend its operating license an additional 20 years, and to continue to use a once through cooling water intake system (CWIS) for its 715 MWe power station.

We request that NMFS consider the following comments and compilation of resources in making its determination under ESA § 7 as to whether PNPS operations are likely to adversely effect the endangered species documented as being present in Cape Cod Bay "in the vicinity" of PNPS and/or that "may be present" in identified action areas.

These comments relate to all of the species identified in the 2006 BA and the 2012 BA. They address significant data gaps, inconsistencies in the data, new and significant information that should be considered, and erroneous assumptions underlying both biological assessments and the NRC's July 2007 environmental impact statement for PNPS (PNPS EIS).[1] We address the PNPS EIS because NMFS has indicated it will rely

[1] "Generic Environmental Impact Statement for License Renewal of Nuclear Power Plants, Supplement 29, Regarding Pilgrim Nuclear Power Station, Final Report, July 2007," NUREG-1437, and its Appendices. (NUREG-1437). Available on line: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1437/supplement29/index.html; Vol. 1 ML 071990020; Vol. 2 Appendices ML 071990027.

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on it in responding to the NRC's request for ESA § 7 consultation and concurrence on the biological assessments.[2]

General Issues Related to All ESA-Listed Species and Critical Habitat

There are several defects in the biological assessments and the PNPS EIS that cut across all issues relating to the species and habitat that are the subject of the ESA § 7 consultation for PNPS.

First, that the biological assessments fail to identify the "action area" for each ESA-listed species and critical habitat, as required by ESA regulation 50 CFR 402.02. Instead, the assessments and PNPS EIS make inconsistent and vague statements about the "action area." For example, the 2006 BA states, "The project area is defined as the PNPS site, adjacent areas of Cape Cod Bay, and approximately 7.2 miles (mi) of transmission ine right-of-way (ROW)." 2006 BA. In the 2012 BA, there is similarly no defined "action area." Instead the 2012 BA refers to Atlantic sturgeon "in the vicinity of" PNPS, "near Pilgrim" p. 3. We request that NMFS identify the "action area" for each of the 11 ESA-listed species and habitat identified in the BAs.

Second, it is our position that the framework used by the NRC to implement the National Environmental Policy Act, 42 USC 4321 et seq., is not adequate for ESA § 7 consultation purposes. The NRC implements NEPA pursuant to the agency's regulations under 10 CFR 51. In general, under these regulations, the NRC has declared certain issues "generic" to all nuclear power station relicensing proceedings, and classifies them as "Category 1" exempting them from site-specific assessment unless the NRC finds there is "new and significant information." See, e.g. 10 CFR 51.95(c)(2). Other issues are "Category 2" issues requiring a site-specific analysis and are addressed in supplements to the generic EIS. (This process is described in the PNPS EIS Executive Summary). It is our position that certain "Category 1" issues relate to whether ESA-listed species and habitat are likely to be adversely effected and cannot properly be exempt from assessment for ESA purposes. These include the discharge of biocides to Cape Cod Bay, and are discussed below. Therefore, NMFS should do its own individual site-specific assessment of "Category 1" environmental issues that may effect ESA-listed species and habitat. It is simply inadequate for ESA purposes to rely on conclusions in a "generic" EIS where there may be impacts to ESA resources.

Third, we urge NMFS to put the scope of Entergy's CWIS operations in perspective. The facility has operated for 40 years, and seeks to extend for another 20, meaning that if it is relicensed with the current CWIS as proposed, it will operate for 60 years. Statements in the PNPS EIS and by Entergy's own staff indicate that over a 60 year period, Entergy

[2] In the NMFS March 26, 2012 letter to the NRC, NMFS stated that "...we requested information on the effects of the listed species' prey resources and effects of the thermal plume. In response your staff provided references to appropriate sections of the Environmental Impact Statement."

will have used from at least 50% to 100% of the volume of Cape Cod Bay for once-through cooling, depending on whose estimates are used.[3]

Fourth, we urge NMFS to ensure that the NRC 2006 and 2012 biological assessments and the conclusions therein are measured against the broad definitions in the ESA regulations at 50 C.F.R. § 402.02. In order to ensure that the federal action is "not likely to jeopardize" the species or habitat, § 7(a)(2), the biological assessment, which is done to "facilitate compliance with § 7(a)(2)", must accurately portray the "action area", the "cumulative effects" and the "destruction or adverse modification" as those terms are defined in 50 C.F.R. 402.101. § 7(c)(1). The relevant regulatory definitions are:

> *Action area* means all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action.
>
> *Cumulative effects* are those effects of future State or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation.
>
> *Destruction or adverse modification* means a direct or indirect alteration that appreciably diminishes the value of critical habitat for both the survival and recovery of a listed species. Such alterations include, but are not limited to, alterations adversely modifying any of those physical or biological features that were the basis for determining the habitat to be critical.
>
> *Effects of the action* refers to the direct and indirect effects of an action on the species or critical habitat, together with the effects of other activities that are interrelated or interdependent with that action, that will be added to the environmental baseline. The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and

[3] These estimates are calculated as follows. In 2005, Entergy staff Jay Scheffer stated, "Recent studies have shown that Pilgrim Station's cooling water withdrawal rate is 0.05% of the exchange rate for Cape Cod Bay. If Cape Cod Bay were a closed system it would take 70 years to pass the entire volume of the bay through the station's cooling water system." Exhibit 1 hereto, Email Scheffer to Bunn, Amoret, L. Forty of those 70 years have already passed, since PNPS has been operating since 1972, so already over 50% of the water volume of Cape Cod Bay has passed through Entergy's cooling water system. At the end of the relicensing term, in 2032, 60 of those years will have passed. However, Scheffer's figures are contradicted by those in the PNPS EIS, which, if used, would mean ***the entire volume of Cape Cod Bay has been used by Entergy for cooling water in the last 35 years.*** The PNPS EIS states that "...PNPS withdraws a relatively small percentage of the net volumetric flow of water-generally less than 0.1 percent (ENSR and MRI 2005)... PNPS pp. 4-76-77, Section 4.8.1. Using Schaffer's time frame, and the PNPS EIS figure of closer to 0.1 percent (double Scheffer's amount of 0.05%) means that roughly, since it started operating in 1972, PNPS has used the entire volume of all the water in Cape Cod Bay.

> the impact of State or private actions which are contemporaneous with the consultation in process. Indirect effects are those that are caused by the proposed action and are later in time, but still are reasonably certain to occur. Interrelated actions are those that are part of a larger action and depend on the larger action for their justification. Interdependent actions are those that have no independent utility apart from the action under consideration.

As the court stated in Gifford Pinochet Task Force v. U.S. Fish and Wildlife Service, 378 F.3d 1059, 1066 remanded on other grounds, 387 F. 3d 968 (9th Cir. 2004), the type of analysis needed to ensure that the agency action is "not likely to jeopardize" is more than just a "simplistic x number acres = y number of [species] type of equation." But this is exactly the type of oversimplified analysis upon which Entergy and the NRC Staff rely. For examples of the types of information courts have found necessary to meet ESA § 7 obligations, see: Hammond v. Norton, 370 F.Supp. 2d 226 (2006 D.C.); Citizens for Bettei Forestry v. Hanns, 481 F. Supp. 2d 1059 (N.D. Calif. 2007); National Wildlife Federation v. NMFS, 481 F.3d. 1224, (2007), Pacific Coast Federation of Fishermen's Association v. U.S Bureau of Reclamation, 606 F. Supp. 2d 1122 (N.D. Calif. 2001).

Fifth, we incorporate by reference herein comments raised by the documents cited at the end of this letter. We are also conferring with leading experts on the ESA-listed species and habitats that may be effected by PNPS, and plan to submit to NMFS more information from these experts promptly.

Radioactive Releases from Daily Operations

The NRC staff biological assessments and the PNPS EIS fail to adequately address the possible impacts on ESA-listed species and critical habitat from PNPS radiological effluent releases to Cape Cod Bay – both past and future.

Since 1972, PNPS has been releasing radioactive effluent to Cape Cod Bay under a fragmented and inadequate regulatory program overseen by the NRC.[4] Some years of data are available from various sources, but there does not seem to be any comprehensive assessment of how much radioactive material has been released into Cape Cod Bay waters and shoreline sediments. It appears that annual data for the past 40 years of operation is not readily available to the public.

In addition, uncontrolled leaks of liquid radioactive effluents, perhaps from leaking underground pipes, have resulted in contamination of groundwater.[5] According to the Entergy, the groundwater at the site flows toward Cape Cod Bay. PNPS EIS, p. 2-23,

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[4] Radioactive Effluent Reports for PNPS for 2005 to 2010 are available at the NRC website. http://pbadupws.nrc.gov/docs/ML0622/ML062280602.pdf; PNPS Radiological Environmental Monitoring Program (REMP) reports for 2005 to 2010 are available at: http://pbadupws.nrc.gov/docs/ML0614/ML061440629.pdf; Electronic summaries of the data in the liquid radioactive effluent reports for 1998-2007 are available on the NRC website, www.neirs.com/effluent.

[5] See, Mass. Dept. of Public Health testing report, update, March 2011.

Section 2.2.3.2. Prior to 2006, PNPS did not have a groundwater monitoring program so it does not seem that there is data to show how much radioactive effluent leaked into Cape Cod Bay from contaminated groundwater on site.[6]

The haphazard nature of the monitoring of liquid radioactive effluent discharging from PNPS to Cape Cod Bay is typified by 1999 correspondence between Entergy and the U.S. EPA. In 1981, PNPS sought and obtained a waiver for its radwaste system, and the discharge point for the radwastes was not identified as an outfall from 1981 until 1999, nor was sampling required.[7] A "miscellaneous" storm drain similarly escaped the NPDES permit process at least until 1999. This 1999 letter states that the "miscellaneous" storm drain will be addressed in the NPDES permit renewal-which has yet to occur.

The monitoring data for radioactive discharges from PNPS to Cape Cod Bay is limited in part because the NRC's REMP program has allowed licensees like Entergy significant flexibility to make changes to their monitoring program without prior NRC approval. The historical trend has been to reduce the scope of monitoring based on any continued non-detection of radioactivity.[8]

The PNPS EIS essentially relies on only 5 years of data to make conclusions about the environmental impacts of radioactive release. The NRC looked at liquid effluent "Radioactive Effluent and Waste Disposal" (REWD) Reports to develop information for a representative year for capacity factors and operational events that impact the volume and activity of liquid, gaseous, and solid wastes – in other words, to determine what the average year looks like in terms for certain radioactive releases from PNPS. PNPS EIS p. 2-13, Section 2.1.4. *See also*, Section 2.2.7 of the PNPS EIS, 2-98, (NRC staff relied only on 5 years of data, from 2001 through 2005 to make its conclusion that the "radiation and radioactivity in the environmental media monitored around the plant are well within applicable regulatory limits and are not significantly higher than pre-operational levels.") Given the limited sampling frequency, parameters, and locations of this data, it does not meet the standards of the ESA in terms of assessing potential effects on ESA-listed species and/or critical habitat.

The PNPS EIS further relies on the NRC's generic EIS, Section 4.0 and Entergy's conclusion that there is no new and significant information to be considered. The NRC staff concluded that there are "no impacts related to these issues beyond those discussed in the GEIS" and that they are "SMALL" Category 1 impacts. The ESA § 7 does not authorize NMFS to rely on the NRC generic EIS for radiological effects on ESA-listed species and habitats.

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[6] See, July 31, 2006 letter from Entergy to the NRC. http://pbadupws.nrc.gov/docs/ML0622/ML062280602.pdf

[7] June 3, 1999 letter from Boston Edison to U.S. EPA. Exhibit 2 hereto.

[8] "Analysis of Cancer Risks in Populations near Nuclear Facilities, Phase 1 Report, 2012, prepublication copy (Cancer Risks Report). http://www.nap.edu/catalog.php?record_id=13388

The PNPS EIS assessment of cumulative impacts on ESA-listed species, Section 4.8.6, does not address impacts of releases of liquid radioactive effluent, but refers to the 2006 BA, which does not address it either.

Information is needed to assess the bioaccumulation of radioactive materials in Cape Cod Bay from PNPS, including food supplies for ESA-listed species, such as plankton, to determine whether radioactive material is entering the food chain for ESA-listed species and or critical habitats. For example, Cesium-137 was detected in plankton 600 kilometers from Fukushima just 3 months after the disaster, and scientists have stated it is necessary to look at bioaccumulation.[9]

NMFS should carefully examine Entergy's sediment samples from the shoreline, required under the RAMP, even though the sampling location, frequency, and parameters are limited and inadequate to assess harm to marine life, bioaccumulation, food chain impacts, and cumulative impacts of past and future PNPS operations. Table H.1, Cancer Risks. These existing reports may serve as a partial picture of the extent of past and potential future effects of radiological releases on ESA-listed species and habitat, but they are insufficient to form the basis of a biological assessment under the ESA § 7 or a NMFS concurrence on the BAs.

NMFS should also assess whether algae such as Irish Moss in the PNPS vicinity has accumulated the radioactive isotope iodine 131, which may well be found, given the high propensity of a similar species, underwater kelp, to accumulate iodine.[10]
Adult green turns eat seaweed and algae, which could include Irish Moss.[11]

In sum, NMFS should assess whether 40 years of radioactive effluent releases from PNPS to the Bay via multiple routes (point source discharge, groundwater flow, and air deposition from daily radiation emissions) have bio-accumulated in the marine environment, and/or whether they may be adversely effecting the species and habitat themselves. NMFS itself should actually look at the PNPS monitoring reports to get available information on radionuclide releases including the release quantities of specific radionuclides, method of release (i.e. continuous or batch); time of release; and local

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[9] http://enenews.com/yomiuri-cesium-134-detected-plankton-600km-fukushima-3-months-after-meltdowns-scientists-necessary-look-bioaccumulation/comment-page-1; Marine Benchmark Study on the Possible Impact of the Fukushima Radioactive Releases in the Asia-Pacific Region. http://www.iaea.org/newscenter/news/2012/fukushima1yearon.html

[10] http://www.ecofriend.com/scientists-find-traces-radioactive-contaminants-fukushima-california-kelp-beds.html; Over 112 species of algae were identified at PNPS, with Irish Moss being the dominant subtidal macrophyte in Cape Cod Bay and the chief component of the subtidal flora near PNPS. The PNPS thermal discharge is located in the middle of what was once an Irish moss commercial bed. PNPS EIS, Section 2.2.5.3.5.

[11] http://www.whatdoturtleseatinfo.com/what-do-green-sea-turtles-eat/

meteorological conditions at the time of release. NMFS should assess the quality of data in these reports and identify the pre-operational levels of radiation in the action area. We do not believe it is adequate for ESA § 7 purposes for NMFS to rely on the NRC staff review of only 5 years worth of data, summary reports that are not readily available, and the NRC "generic" EIS on radioactive releases to the environment. There should be a site specific assessment of the effect of 40 years and the future discharges of liquid radioactive effluent releases into Cape Cod Bay from PNPS in order to determine whether these discharges are likely to adversely effect ESA-listed species and/or critical habitat.

Impacts on ESA-listed species from severe accidental radiological releases like at Fukushima

PNPS shares design features with the Fukushima reactors, and shares all the design defects of the GE Mark I.[12]

The Fukushima disaster shows that a severe reactor and/or spent fuel accident is significantly more likely than was estimated or assumed in the 2007 PNPS EIS. *Compare*, PNPS EIS, Section 5.0, Environmental Impacts of Postulated Accidents, to challenges filed by Massachusetts Attorney General to PNPS EIS SAMA analysis, available in the NRC Adams reading room. The Thompson Report describes the "occurrence of a large, offsite radiological impact from operation of PNPS that would involve a release to the environment of a substantial amount of radioactive material." Part of the release to the environment would be "an open pathway from the damaged fuel to the plant's environment (atmosphere, ocean, groundwater, etc.)" *Id.*, p. 14.

We request that NMFS consider all of the information in the Thompson Report and the contentions by the Massachusetts Attorney General's office as they relate to the effects on ESA-listed species and critical habitat from a severe accidental radiological release at PNPS.

Thermal Backwashes and Biocides

According to the PNPS EIS, biocide wastes are produced while controlling the pH in the coolant, controlling scale and corrosion, and in cleaning the main condenser. PNPS Section 2.1.5. The PNPS EIS did not assess the cumulative impacts to the environment of 40 years of use of this biocide, or the future cumulative impacts. Instead, it relied on the NRC's generic environmental impact statement on this issue, since discharge of biocides is a "Category I" issue under the NRC NEPA regulations. The NRC staff looked only at April 2005 to March 2006 discharge monitoring reports[13] and then

[12] Institute for Resource and Security Studies, "New and Significant Information from the Fukushima Daiichi Accident in the Context of Future Operation of the Pilgrim Nuclear Power Plant, by Gordon R. Thompson, June 1, 2011, a report for the Office of the Attorney General of the Commonwealth of Massachusetts (Thompson Report) p. 9-10. Available at: http://pbadupws.nrc.gov/docs/ML1115/ML111530339.pdf

[13] These reports are not electronically available to the public; rather to our knowledge they can only be obtained by physically going to EPA Region 1 headquarters and making photocopies.

concluded that there are no "significant impacts of discharge of chlorine or other biocides" during the relicensing period. *Id.* This assessment is entirely inadequate for purposes of determining whether relicensing is likely to adversely effect ESA-listed species and/or critical habitat. The PNPS EIS fails to identify the type of biocide being used, fails to look at the cumulative impacts of 60 years of discharging the biocide to Cape Cod Bay (i.e. 40 years past and 20 years future), fails to provide any information about the environmental toxicity of the biocide, and fails to address bioaccumulation. In addition, it is possible that ESA-species in the vicinity could come in contact with the biocide effluent and be harmed. NMFS should address fully the cumulative impact of biocide use, including toxicity and bioaccumulation.

According to the PNPS EIS, Entergy uses sodium thiosulfate for backwashes. It is "added to the wash water to remove chlorine and protect organism returned to the intake embayment." NMFS should examine the environmental toxicity of the discharges of sodium thiosulfate and the past and future cumulative impacts to determine whether its use can effect ESA-species and/or habitat. Some information on EPA's assessment of sodium thiosulfate is available at 66 Fed. Reg. 65850 (Dec. 21, 2001) however, this information is limited and further investigation is warranted.

Sea Turtles

The NRC staff statements and conclusions about effects on endangered sea turtles are contradictory, unsupported by scientific data, and unlawfully focused narrowly on simply whether or not Entergy has ever reported an impingement of a sea turtle at PNPS. We address several points here. First, Entergy's claims that sea turtles have never been impinged or seen in the vicinity of PNPS are unreliable, for reasons described below. Second, the ESA § 7 process does not allow NMFS to rely solely on Entergy and NRC claims of no impinged turtles to conclude that they are not likely to be adversely impacted. Instead, NMFS must assess all of the *cumulative effects*, the *destruction or adverse modification*, and the *effects of the action* as these are described by ESA regulations. This includes food, effects of climate change, and other factors as described here. Third, the analysis is not just a simplistic assessment of number of turtles that may or may not be impinged. *See, e.g.* Gifford Pinochet Task Force v. U.S. Fish and Wildlife Service, 378 F.3d 1059, 1066 remanded on other grounds, 387 F. 3d 968 (9th Cir. 2004).

Effects on turtles must be assessed in the context of the Cape Cod Bay ecosystem. According to NOAA, the general water flow of Cape Cod Bay "is counter-clockwise, running from the Gulf of Maine south *into the western half of CCB, over to eastern CCB*" (emphasis added) (NOAA 1994).[14] Turtle Journal, an organization devoted to the protection of sea turtles, refers to Cape Cod Bay as a "Marine Stranding Hotspot."[15] Mass

[14] http://www.mwra.state.ma.us/harbor/enquad/pdf/ms-085_04.pdf, Fig 4-1 (with reference) illustrates Cape Cod Bay circulation.

[15] In the Great White North of Cape Cod, the sea turtle stranding season arrives each year as frost begins to form on the pumpkins. Juvenile tropical and semi-tropical sea turtles hunker in Cape Cod Bay as the season turns colder, water temperatures drop and they're cued to head south to warmer climes. Unfortunately, these turtles become trapped in bay waters as the Atlantic Ocean temperature drops more

Audubon has participated in a ***turtle stranding program*** in Cape Cod Bay inconjunction with the New England Aquarium since 1979, and has kept records on the number of turtles stranded in Cape Cod Bay every winter. MassAudubon records show that loggerhead, green, and Kemp's Ridley turtles have been stranded, primarily in Dennis and Brewster at the southern edge of Cape Cod Bay. [16] Nearly two hundred Kemp's Ridleys have been stranded annually in the past two years. We are in the process of obtaining data that ***leatherback turtles*** have been found entangled in fishing gear in the Plymouth area, showing that they are also documented to be present near PNPS. We request the opportunity submit this information to NMFS within the next week.

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quickly to temperatures at which they cannot function. They are faced with a wall of cold ocean water and locked into Cape Cod Bay with no escape. Eventually bay water, too, reaches critical temperature and these turtles become cold-stunned and strand on bayside beaches usually beginning in early November with the lightest massed turtles (Kemp's Ridleys) and proceeding through the season to heavier massed turtles (loggerheads) in December. The hook of Cape Cod, an accident of the Laurentide glacial retreat, has become a huge geological trap and a global stranding hotspot for all marine animals from sea turtles to seals and marine mammals. See also, New England Aquarium website, "The majority of sea turtles that are treated at NEAQ come from annual cold stun stranding events on Cape Cod, Massachusetts, USA. Each fall and winter, juvenile and sub-adult sea turtles strand on Cape Cod beaches after experiencing cold-stunning. Cold stunning, or hypothermia, in sea turtles is thought to occur when the water temperature quickly drops below 50 degrees F (10 degrees C). Sudden cooling of ocean water temperatures leaves the turtles torpid and floating at the surface, unable to swim or dive, and allows them to be tossed by strong sustained storm winds onto the windward shore. Sihce the 1980s, NEAQ has worked with the Massachusetts Audubon Society's Wellfleet Bay Wildlife Sanctuary to save these threatened and endangered species."

[16] http://www.massaudubon.org/PDF/sanctuaries/wellfleet/seaturtles/seaturtlestrandings2010.pdf; See also http://www.neaq.org/conservation_and_research/projects/conservation_medicine/rescue_and_rehabilitation/learn_about_rescue_and_rehabilitation/animal_strandings/sea_turtle_stranding

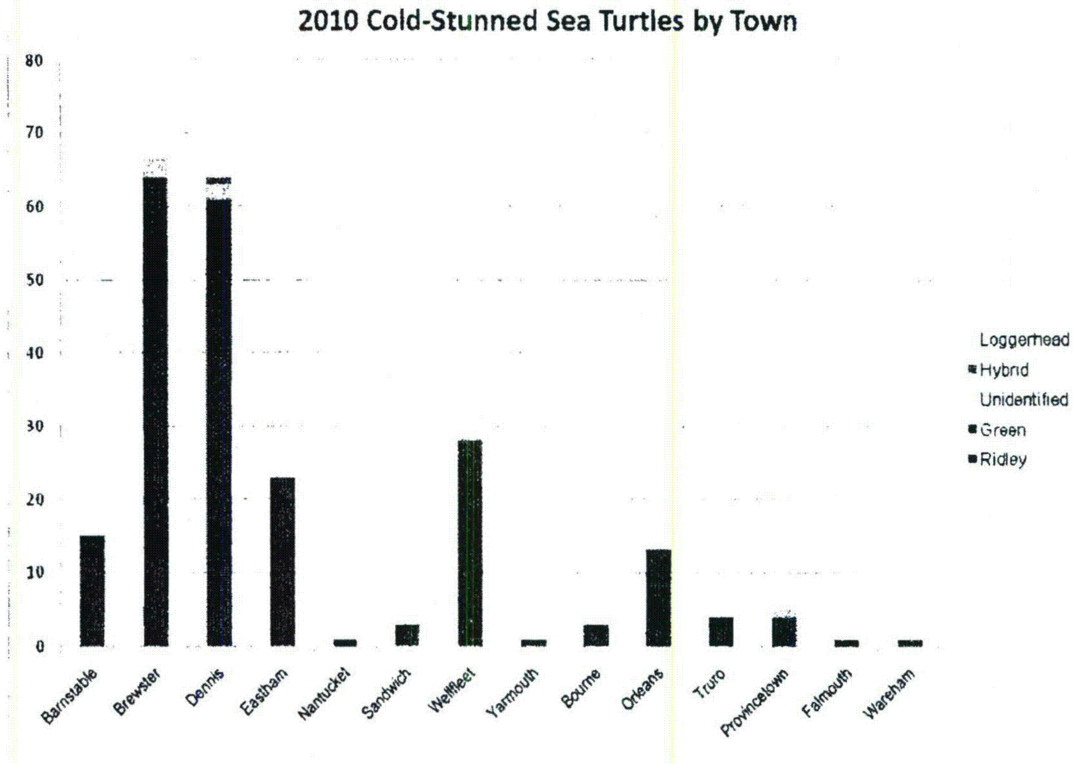

Chart from Mass Audubon

We request that NMFS address the possibility that sea turtles are drifting on currents into the western half of CCB, and encountering the ***thermal plume*** from PNPS, including the periodic thermal backwashes permitted under Entergy's NPDES permit.[17] NMFS should also address whether sea turtles which may encounter the thermal plumes later become cold stunned and strand on beaches to the south of PNPS when they drift out of the plume. The data about sea turtle strandings on Cape Cod should be acknowledged and considered, not merely referred to in passing as is done in the 2006 BA.

Extensive data documents sea turtle impingement and entrainment in CWIS at power stations like Entergy's. Indeed, NMFS' 2005 letter to Entergy states,

> It is the understanding of NMFS that there have been no interactions or impingements of sea turtles at PNPS during the past 30 years of monitoring at PNPS. <u>However, since the entrainment and impingement of sea turtles at several nuclear power plants on the East Coast has been documented, and as sea turtles may be seasonally present in the vicinity of the intakes associated with the PNPS, NMFS recommends that this impact</u>

[17] PNPS's NPDES permit allows a maximum daily discharge of 120 F degrees during thermal backwashes for bio-fouling control, three hours per day, two times a week.

be fully addressed in the application being prepared. (emphasis supplied)

See, PNPS EIS, p. E-6 of Appdx E: March 4, 2005 Letter from NMFS to Steven Bethay, Entergy.

The 1990 book, *Decline of the Sea Turtles: Causes and Prevention* by the National Academy of Sciences, Table 6-2 points out that ***from 5 to 50 Kemp's Ridley and 5 to 50 Loggerheads are fatally entrained in U.S. power plants each year.*** Few data are available for power plants in the Northeast, although sea turtles have been reported killed at the Oyster Creek, NJ and Seabrook, NH nuclear stations. We question whether, since endangered sea turtles are present in the Gulf of Maine north of PNPS at Seabrook, and south at Oyster Creek, there is a reasonable basis, without further investigation, to conclude that PNPS operations are not likely to adversely effect endangered turtles.

In January 2004, the report, *Threatened and Endangered Species Evaluation for Operating Commercial Nuclear Generating Plants,* was prepared for the US. Department of Energy by Pacific Northwest National Laboratory. It addresses the ESA and its significance to licensing by the NRC, and reevaluates 38 of 75 nuclear facilities originally assessed for their impact on endangered species in 1997. The tables in Appendix A to the Report evaluate the presence of endangered species in each of the 38 facilities. ***Endangered sea turtles were either found or indicated to be "probably" present near each of the coastal nuclear facilities reviewed.***

The "NOAA Fisheries Service: Protected Resources Division" website describes a "stranding network" and presents a "sea turtle recovery plan" for each endangered turtle species, jointly administered with USFWS.[18] Although this recovery plan focuses primarily on nesting sites, it acknowledges the Atlantic population of Kemp's Ridley, carried northward by the Gulf Stream, and the impact of power plant entrainment:

> *Industrial Plant Intake and Entrainment*
>
> Kemp's Ridleys have been documented to be taken during power plant operations generally as a result of entrainment in or impingement on the intake structures that transport water to cool plant condensers and auxiliary systems. Intake structures include bar racks, traveling screens, and seawater pump components. Water is drawn from the intake canal through the bar racks, through the traveling screens, and into the pumps. Intake bar racks prevent trash and large debris suspended in the seawater from entering the intake structure. Entrapment in the intake canal can result in direct negative impacts on turtles in a number of ways:

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[18] See, e.g. the *Kemp's Ridley Bi-National Recovery Plan* at **http://www.nero.noaa.gov/prot_res/stranding/stssn.html**; See also, http://www.smithsonianmag.com/science-nature/Saving-the-Worlds-Most-Endangered-Sea-Turtle.html

> drowning in the intake pipes, injury sustained in the pipes and the canal, debilitation of condition due to long entrapment, exposure to predators in the intake canal, injury and stress sustained during capture, and impingement and drowning in barrier nets and on the intake racks.
>
> Under Section 7 of the ESA, NMFS has consulted with the Nuclear Regulatory Commission on the activities of five power plants in the Atlantic Ocean and the possible impacts on sea turtles. St. Lucie Power Plant on Hutchinson Island, Florida, has documented over 6,000 sea turtles entrapped at their intake canal between 1976 through 1999 (NMFS 2001b). Less than 40 of these were Kemp's Ridleys. The majority of turtles entering the canal are in good condition and few die (3.0%) as a result of extensive efforts to capture and safely release entrained turtles on a daily basis. Operations at the Brunswick, North Carolina, power plant resulted in 101 live and 22 lethal sea turtle takes from 1986 through 1996. Of these takes, 5 live and 1 lethal take were Kemp's Ridleys (NMFS 2000). In 1998, the Crystal River Energy Complex, located adjacent to the Cedar Keys, Florida, foraging grounds, documented a total of 40 sea turtles entrapped, of which 37 were Kemp's Ridleys (NMFS 2002b). In ***New Jersey, Oyster Creek Nuclear Generating Station has documented 28 (8 lethal) Kemp's Ridley takes since 2000*** (NMFS 2005b*). BiNational Plan at I-60*

By contrast to those situations where the presence of sea turtles at power stations has been acknowledged and a protection plan prepared, with limited incidental takes allowed, there has been no real assessment of the impacts of PNPS on sea turtles, because there has been ***no acknowledgement of the potential impacts of these endangered species by PNPS*** and no Biological Opinion has been prepared. *See and compare* the 76-page analysis and turtle rescue plan attached to the Biological Opinion prepared by NOAA dated November 21, 2006 for Oyster Creek, NJ nuclear generating station, which used a 50-mile radius from the nuclear power station to assess potential turtle impacts.

Another useful comparison between NMFS actions to date regarding PNPS and other nuclear stations is the Seabrook nuclear station.[19] A 2004 fact sheet on proposed regulations for CWIS prepared by the EPA also acknowledged the impact on sea turtles of once-through cooling systems at power facilities:

> The withdrawal of cooling water from waters of the U.S. harms billions of aquatic organisms each year, including fish, fish larvae and eggs, crustaceans, shellfish, sea turtles, and marine mammals.[20]

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[19] August 5, 2010 letter from NOAA to NRC, Bo Pham, Chief, NRC, Division of License Renewal, NRC, from NMFS, Patricia Kurkel, Regional Administrator.

[20] http://water.epa.gov/lawsregs/lawsguidance/cwa/316b/phase3/ph3-propose

EPA's Clean Water Act Section 316 guidance on Economic Assessments also acknowledges the potential impact on sea turtles and other species from power facilities.[21]

Pollution and climate change are identified as threats to endangered turtles by Oceana. [22] Among the findings in an Ocean report is that evidence is growing that changes in temperature due to climate change shift critical life events in many species, including their breeding, feeding, and migration cycles. [23]

Ocean acidification is predicted to harm the turtles' shells and the supply of crusteans and mollusks which play a large part in the ***loggerhead sea turtle diet***. The Oceana report states that ocean acidification could leave some vital elements in the sea turtle diet more vulnerable to predation by other species, lower rates of population survival, and diminish biodiversity of the ecoystem. Id., p. 7.

A report by Stratus Consulting, "Habitat-Based Replacement Costs: An Ecological Valuation of the Benefits of Minimizing Impingement and Entrainment of the Cooling Water Intake Structure of the Pilgrim Nuclear Power Generating Station in Plymouth, Massachusetts, February 5, 2002, states that ***PNPS destroys 160 billion blue mussels per year, and 460,000 fish comprising 13 species***. P. 4-85.

NMFS should assess the ***diet of sea turtles*** in Cape Cod Bay, and whether they may feed on blue mussels or other species which are destroyed by PNPS. If so, NMFS should

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[21] *See*, Section 316b EPA Chapter 11 for New Facilities CWIS I&E Impacts and Potential Benefits. "The potential for I&E in coastal areas can be quite high, not only because CWIS are located in the productive areas over the continental shelf where many species reproduce, but also because near shore areas within bays, estuaries, wetlands, or coastal rivers provide nursery habitat. In addition, the early life stages of many species are planktonic, and tides and currents can carry these organisms over large areas. The abundance of plankton in temperate regions is seasonal, with greater numbers in spring and summer and fewer numbers in winter.
An additional concern for CWIS in coastal areas pertains to the presence of marine mammals and reptiles, including threatened and endangered species of sea turtles. These species are known to enter submerged offshore CWIS and can drown once inside the intake tunnel..."

[22] http://oceana.org/en/our-work/protect-marine-wildlife/sea-turtles/overview.

[23] "...increasing ocean temperatures, together with the addition of significant amounts of fresh water from melting ice caps and glacier, may disrupt ocean current patterns and break down the marine food web. Sea turtles depend on ocean currents throughout their life. Juvenile sea turtles journey across ocean basins, sometimes swimming with currents, in search of productive feeding grounds. Young adults move through coastal areas, migrating thousands of miles to feed in open-ocean pelagic waters in search of ocean fronts, upwelling zones, and eddies where their food is concentrated....There is growing evidence that climate change will change ocean currents. With any changes in ocean circulation, either through oceans heat content or atmospheric cycles, sea turtles may also have to alter their movements and possibly even shift their range, along with the timing of their nesting." Oceana report, 2007, p. 6, *Climate Change and Commercial Fishing: A One-Two Punch for Sea Turtles*, available at http://oceana.org/sites/default/files/reports/Turtles_and_Climate_final1.pdf (last visited April 10, 2012).

evaluate whether PNPS' destruction of 160 billion blue mussels per year, combined with other factors including climate change, is likely to effect sea turtles and to what degree.

Kemp's ridleys turtles eat species of crabs, shrimp, clams, and sea urchins.[24] Juvenile loggerhead turtles eat mostly bottom dwelling invertebrates.[25] NMFS should assess whether Kemp's ridleys were attracted to the vicinity of PNPS for food, such as mussels, which are being destroyed on an annual basis by PNPS.

Green turtles may be attracted to the vicinity of PNPS to eat Irish Moss.

NMFS should also assess the role that sea turtles play in the ***ecosystem***. For example, sea turtles feed on jellyfish in the Chesapeake Bay; jellyfish in turn feed on fish larvae. Id. p. 7. Leatherback turtles main diet is jellyfish. [26] NMFS should assess whether there is a similar ecosystem role that the turtles play in Cape Cod Bay that would be affected by PNPS.

Entergy has stopped using ***barrier nets*** in the discharge channel. PNPS EIS, p. 4-8 states, "the fish barrier net has been removed from the discharge channel and is currently stored on site."[27] The absence of a barrier net over the discharge channel, where thermally heated effluent – sometimes up to 120F - is discharged, may well pose a risk to sea turtles. Moreover, if a turtle were in the discharge channel during a thermal backwash, any turtle in the discharge canal could be harmed by the superheated water and bio-fouling agents.

The PNPS CWA NPDES permit, nor any other regulatory permit at PNPS mandates ***notifications or reporting of impacts*** to either sea turtles or marine mammals. It is not evident that PNPS personnel have been instructed or trained to identify and report the presence of sea turtles in the intake channel and discharge locations at PNPS. Other power stations have been required to put up posters and conduct training on ESA-listed species as NMFS has required at other power stations. Therefore, Entergy's claims that there have been no "reports" of sea turtles "in the vicinity" of PNPS lack credibility.

The 2006 BA contains contradictory statements. For example, it states that "no Federally endangered or threatened species have ever been observed in Cape Cod Bay near PNPS, or in the intake and discharge areas, during the duration of these studies." The BA does not identify which studies it is relying upon. A small loggerhead turtle was stranded on Priscilla Beach about .63 miles south of PNPS in November 2003, according to the PNPS

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[24] http://wwf.panda.org/what_we_do/endangered_species/marine_turtles/kemps_ridley_turtle/

[25] http://www.nmfs.noaa.gov/pr/pdfs/education/kids_times_turtle_loggerhead.pdf

[26] http://www.vanaqua.org/learn/aquafacts/reptiles/leatherback-turtles

[27] This is contrary to the PNPS NPDES permit, which originally required that the barrier net be maintained at all times. Te permit was later modified to require the barrier net from April to November during fish migration. We have found no authority for Entergy to unilaterally decline to comply with the permit condition requiring a barrier net over the discharge channel on a seasonal basis.

EIS. We request that NMFS investigate this stranding to determine whether this turtle could have been cold stunned after being in the thermal plume at PNPS, and whether a thermal backwash occurred and what the temperatures were. We also request that NMFS provide source data for this stranding report.

NMFS should assess how PNPS' operations may effect the ocean currents that sea turtles use in Cape Cod Bay for the functions of migration and feeding, and determine whether, combined with climate change, this would cause the turtles to shift their range and/or the timing of their nesting.

In sum, the high potential for nuclear generating facilities to harm endangered sea turtles has been well-documented by NOAA and acknowledged by EPA. We respectfully but strongly request that NMFS consider this and other scientific and commercially available data in its ESA § 7 consultation regarding PNPS.

Climate Change

We request that NMFS assess the impacts of climate change on Cape Cod Bay, including changes in salinity, acidification, and temperature as part of its ESA § 7 consultation. NMFS should take into account data predicting the future impacts on ESA-listed species over the 20 year relicense period from climate change and resultant changes in ocean salinity, acidification, and temperature, and the impacts on the local food web, from these changes. A few of the host of current information and resources on this subject are provided:

Science Magazine, 2012 report that ocean acidification is the worst in 300 million years. Hoenisch, B. *et al.*, "The Geological Record of Ocean Acidification," http://academiccommons.columbia.edu/item/ac:145564

Hansen, J. et. all, *Public Perception of Climate Change and the New Climate Dice*, http://arxiv.org/ftp/arxiv/papers/1204/1204.1286.pdf. According to Dr. Hansen, the report shows more frequent weather anomolies, and "Summer anomalies over land are the most important, as discussed in the paper. Averaged over a decade the frequency distribution of seasonal mean temperature anomalies is shifting rapidly toward more extreme hot anomalies, and the distribution is becoming broader (greater extremes). Because the planet is out of energy balance, we can conclude that next decade the distribution will be shifted even further to the right."

U.S. Global Change Research Program, U. *S. National Assessment, New England Regional Assessment, Chapter 6, Climate Impacts on Regional Water.* http://www.globalchange.gov/publications/reports/scientific-assessments/first-national-assessment/606

Fuentes, M. and Hawkes, L., *How Will Sea Turtles Cope with Climate Change*, http://seaturtlestatus.org/sites/swot/files/report/033111_SWOT6_p12-13_Climate%20Change.pdf

Fish as Food Supply for Whales

The food supply for whales that eat schooling fish such as smelt, river herring, and menhaden should be assessed in far greater detail than the ***superficial survey in the PNPS EIS which merely catalogues the numbers of fish that Entergy reported it killed up to 2005***. It does not assess greater food web or ecosystem impacts.

As an example, Entergy's own data reported in its monitoring reports shows the following entrainment impacts from 2000 to 2009:

In 2000, there were 1,700,000 winter flounder eggs and 5,600,000 larvae entrained. During 2001 4,200,000 Atlantic cod larvae were entrained. Winter flounder impingement and entrainment accounted for 27,500 fatalities in 2001, 19,100 deaths in 2002, 3,300 fatalities in 2003, 48,000 mortalities in 2004 and 43,000 deaths in 2005. In 2003 2,000,000 winter flounder eggs and 4,200,000 larvae were entrained. Entrainment in 2007 destroyed 97,000,000 Atlantic mackerel eggs and 6,500,000 larvae, 8,300,000 Atlantic menhaden eggs and 17,500,000 larvae, 6,300,000 Atlantic cod eggs and 1,400,000 larvae, 126,000 winter flounder eggs and 8,600,000 larvae and 341,000 Atlantic herring larvae. In 2008, 1,200,000 winter flounder eggs and 12,000,000 larvae were mortalized. During 2009, 636,000 winter flounder eggs and 11,800,000 larvae were lost.

These are only a few of the 13 species that the Stratus report identifies as being destroyed by PNPS CWIS operations.

We request that you consider the following sources a s well as other broadly available other scientific and commercial data:

JRWA February 6, 2012 letter to NMFS re: facts about PNPS fish kills, including about 300,000 menhaden in 2005, and the listing of river herring as a candidate species under the ESA.

Little Fish Big Impacts, Managing a crucial link in ocean food webs, A report from the Lenfest Forage Fish Task Force, April 2012.
http://www.oceanconservationscience.org/foragefish/files/Little%20Fish,%20Big%20Impact.pdf

Rainbow Smelt (Osemerus mordax) are a NOAA Species of Concern, See Fact Sheet, 3/16/2007 (stating that in the last 15 to 20 years there has been a region wide trend in declining smelt populations in Massachusetts Bay.)

Mass Div. of Marine Fisheries, Technical Report TR-30, Rainbow smelt spawning habitat in the Gulf of Main coast of Massachusetts, Chase, B.C., Mass DMF, Dec. 2006.

Plankton

The PNPS EIS states, "However, based upon the review conducted by the NRC staff, there is no evidence that the operation of the PNPS cooling system has had an impact on phytoplankton or zooplankton communities, or any resultant effects on the aquatic food web, in Cape Cod Bay." The PNPS EIS relies on the NRC's generic EIS for assessing impacts on plankton, and there is no site-specific plankton data referenced in the PNPS EIS, beyond the pre-operational plankton study referred to. PNPS EIS, Section 4.1, p. 4-6. ***The only plankton data we have seen cited this over 40 years old, and this data is not publicly available.***

Plankton are important for many reasons, including because it is the base of food chain and direct food source for baleen whale such as the right whale.[28] NMFS should identify any plankton studies or data that are the basis for the conclusions for its decisions on the 2006 and 2012 BAs. If NMFS is going to rely upon the decades old plankton studies by PNPS, we request that they be made publicly available.

We further note that Entergy itself acknowledges that impacting plankton could effect endangered whales. Entergy official Jacob "Jay" Scheffer opines in his 2005 email, ***"The only way that Pilgrim could possibly impact these [endangered whale species] would be through impacting their food source (plankton) by entrainment***....The impact of the station's cooling system on the Cape Cod Bay ecosystem is insignificant." (emphasis supplied) Exhibit 1 hereto. Thus, even Entergy acknowledges that its operations could impact ESA-listed whales. Since there is no recent plankton data cited in the PNPS EIS or BAs, it is obvious that Scheffer's conclusion is unreliable.

References relied upon for the BA and PNPS EIS are being withheld from the public as CBI

While not necessarily NMFS responsibility, a major flaw with the 2006 and 2012 BAs is that ***references relied upon by the NRC Staff for its findings in the PNPS EIS and consequently the BAs are not publicly available.*** This includes the 2000 ENSR 316 demonstration report cited throughout the PNPS EIS. On March 27, 2012, we requested 4 documents from the NRC Staff that are cited as references in the PNPS EIS. As of the date of this letter, we have not received the documents. These documents are:

1. ENSR Corp. 2000, redacted version, 316 Demonstration Report-PNPS, prepared by Entergy, March 2000.

2. Entergy 2006d "Environmental Reviews and Evaluations" EN-EV-115, May 2, 2006

3. Stone and Webster Engineering Corp., 1975 316 Demonstration, Pilgrim Nuclear Power Station-Units 1 and 2. Prepared for Boston Edison Co., Boston MA

4. Stone and Webster Engineering Corp., 1977 Supplemental Assessment in Support of the 316 Demonstration, Pilgrim Nuclear Power Station-Units 1 and 2, prepared for

[28] See also, July, 2010: Nature News: "Ocean greenery under warming stress,", citing, Boyce, D., Lewis, M. & Worm, B. "Nature" 466, 591-596 (2010) and Behrenfeld, M. et al., Nature 444, 752-755 (2006). http://www.nature.com/news/2010/100728/full/news.2010.379.html

Boston Edison Company, Boston MA

If NMFS intends to rely upon these 4 documents for its ESA § 7 determination, we request that these documents be made publicly available and that they be addressed specifically.

Marine Mammal Protection Act

Although not related to the ESA, we request that NMFS assess the potential impact to marine mammals from PNPS. Species protected by the Marine Mammal Protection Act, 16 U.S.C. §§ 1371-1421h, are present in the vicinity of the PNPS. These include a number of dolphin species, pinnipeds, harbor porpoises and large whales. All of these may be impacted by the thermal discharges as well as by the discharges of biocides, chlorine and radioactive elements. There is a large body of scientific and commercially available data documenting the presence of these species near PNPS.

River Herring

Based on your March 26, 2012 letter, it appears that NMFS plans to ignore its own policy which directs the agency to consider candidate species when making natural resource decisions and in informal consultations and conferences.[29] We urge NMFS to confer with NRC on the river herring, as well as on the proposed expansion of critical habitat for North Atlantic Right Whale in the Gulf of Maine.

Thank you for considering this information. Please contact Meg Sheehan, 508 259 9154, or meg@ecolaw.biz if you have any questions.

Very truly yours,

Signed electronically

Margaret Sheehan, Esq.

Anne Bingham, Esq.

[29] *See* "Endangered Species Consultation Handbook, *Procedures for Conducting Consultation and Conference Activities Under Section 7 of the Endangered Species Act*, U.S. Fish & Wildlife Service, National Marine Fisheries Service (March 1998) available at httt://www.nmfs.nooa.gov/pr/pdfs/laws/esa_section7_handbook.pdf. NMFS Consultation Handbookpp. 31, 3-1, and 6-1.

Enclosures:
Exhibit 1 - Email from Schaffer, 2005
Exhibit 2 – June 3, 1999 Letter from Boston Edison to EPA
Affidavits of: Pine duBois, 3/6/2012, Alex Mansfield (2), dated 3/6/2012 and 3/26/12
Affidavit of Anne Bingham, Esq.
Letter to MassCZM, April 4, 2012 (incorporated by reference herein)
MassDPH Testing Summary, March 2012 (incorporated by reference herein)
Risk 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, May 25, 2006 (incorporated by reference herein)
Report to the Massachusetts Attorney General on the Potential Consequences of A Spent-Fuel Fire At The Pilgrim or Vermont Yankee Nuclear Plant, Jan Beyea, PhD, May 25, 2006. (incorporated by reference herein)

cc:
Massachusetts Office of Coastal Zone Management
Whale and Dolphin Conservation Society
Provincetown Center for Coastal Studies
Mass DEP
U.S. EPA, Region 1
Conservation Law Office
Rep. Edward Markey
New England Aquarium

From: "Eschbach, Tara" <tara.eschbach@pnl.gov>
To: <cxg3@nrc.gov>
Date: 2/18/05 6:29PM
Subject: FW: Endangered and Threatened Species at Pilgrim Nuclear Station

Cristina,

Please docket this email correspondence for the Grand Gulf ESP environmental impact statement.

Thank you,
Tara

-----Original Message-----
From: Scheffer, Jacob [mailto:JScheff@entergy.com]
Sent: Monday, February 07, 2005 11:03 AM
To: Bunn, Amoret L
Cc: ZINKE, GEORGE A
Subject: RE: Endangered and Threatened Species at Pilgrim Nuclear Station

Dr. Bunn:

Pilgrim Nuclear Power Station has not had an impingement of entrainment incident involving the turtle or whale species mentioned in your message.

Pilgrim Station has been conducting impingement monitoring since 1973. An examination of the available impingement records indicates that no sea turtles have been impinged at Pilgrim Station since the start of the monitoring program. Additionally, representatives of the company that performs routine maintenance dives in and around the intake embayment and the end of the discharge canal have said that they have not observed any turtles in the vicinity of the station.

No endangered whale species have been observed in the shallow waters off Pilgrim Station since biological monitoring began in the late 1960s. The only way that Pilgrim could possibly impact these whales would be through impacting their food source (plankton) by entrainment. Recent studies have shown that Pilgrim Station's cooling water withdrawal rate is 0.05% of the exchange rate for Cape Cod Bay. If Cape Cod Bay were a closed system it would take 70 years to pass the entire volume of the bay through the station's cooling water system. The impact of the station's cooling system on the Cape Cod Bay ecosystem is insignificant.

If you have any questions, please feel free to call me at 508-830-8323.

Jay Scheffer

C/7 Encl.

-----Original Message-----
From: Bunn, Amoret L
Sent: Monday, February 07, 2005 8:14 AM
To: 'jscheffer@entergy.com'
Cc: Brandt, Charles A; Eschbach, Tara
Subject: Endangered and Threatened Species at Pilgrim Nuclear Station

Dear Mr. Scheffer,

I am working on the Grand Gulf Early Site Permit DEIS, and Pilgrim Nuclear Station is one of the alternate sites being considered. George Zinke recommended that I contact you about one of our concerns to include further information in the document we are preparing. In correspondence with NOAA Fisheries, they asked NRC to consider the following species: loggerhead turtle (Caretta caretta), Kemp's ridley turtle (Lepidochelys kempii), leatherback turtle (Dermochelys coriacea), North Atlantic right whale (Eubalaena glacialis) and humpback whale (Megaptera novaeangliae). I would like to know if there has ever been an incidence at the Pilgrim Nuclear Station with impingement and/or entrainment of any of these species. If you could please respond, I would like to include your comments in the document. Please feel free to contact me if you have any questions about this request.

Thank you for your assistance,
Amoret

Amoret L. Bunn, Ph.D.
Senior Research Scientist
Pacific Northwest National Laboratory
Ecology Group
(509) 376-6300
FAX (509) 372-3515

CC: <jhw1@nrc.gov>, "Brandt, Charles A" <charles.brandt@pnl.gov>, "Bunn, Amoret L" <Amoret.Bunn@pnl.gov>

Mail Envelope Properties (42167A69.201 : 19 : 16897)

Subject:	FW: Endangered and Threatened Species at Pilgrim Nuclear Station
Creation Date:	2/18/05 6:29PM
From:	"Eschbach, Tara" <tara.eschbach@pnl.gov>
Created By:	tara.eschbach@pnl.gov

Recipients

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CXG3 (Cristina Guerrero)

pnl.gov
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charles.brandt CC (Charles A Brandt)

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Expiration Date:	None
Priority:	Standard
Reply Requested:	No
Return Notification:	None
Concealed Subject:	No
Security:	Standard

Boston Edison
A BEC ENERGY COMPANY

June 3, 1999
BECo Ltr. 5.99.074

Mr. Nicholas Prodany
U.S. EPA, Region I
Mail Code CMA
1 Congress Street
Boston, MA 02114-2023

Dear Mr. Prodany:

The purpose of this letter is to confirm the recent telephone conversation between you and Mr. Robert Anderson of my staff regarding the present status of two discharge points at the Pilgrim Nuclear Power Station (PNPS) not reflected in the current NPDES permit. The first involves the radwaste system discharge, which received a sampling exception from EPA. The second discharge point is a small miscellaneous storm drain. In conjunction with the sale of PNPS to Entergy Nuclear, Entergy Nuclear has concluded that it is important that the status of these discharge points be confirmed.

As a result of Pilgrim's difficulty in obtaining a testing laboratory a radwaste system discharge waiver was requested from EPA on October 1, 1981 (at the time of application for a NPDES permit renewal). EPA concurred with this waiver for the radwaste system in a letter to Boston Edison on March 3, 1982. Although suitable testing laboratories have since become available, subsequent NPDES permit issuances have not identified this discharge point as an outfall or included it as a required sampling point. Effluents from the radwaste system discharge outfall are currently sampled for boron, nitrites, and radioactivity prior to discharge.

A small miscellaneous storm drain noted in the October 25, 1995, NPDES permit renewal application for PNPS is not covered in the existing NPDES permit. The latest permit reissuance has been delayed and as such, PNPS is operating under an extension. During an April 27, 1999, telephone conversation with Mr. Anderson of my staff, you concurred that this miscellaneous storm drain did not have to be monitored at the present time, and that it would be considered, along with the four (4) main storm drains as part of the permit renewal. The four storm drains presently are identified in the permit and sampled.

C/7 Encl.

The above status of the radwaste and miscellaneous storm drain discharges reflects our understanding and documentation of them with regards to the NPDES Permit. To simplify this request rather than have your office respond by letter, your signature below will confirm EPA's concurrence. Please return to us a signed copy of this letter. If you have any questions on the above please contact Robert Anderson or myself at 508-830-8269.

Sincerely,

J. F. Alexander
Nuclear Assessment
Master Process Owner

Nicholas W. Prodany

U.S. EPA

radmisc/usepaltr.doc

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REGION I

J. F. KENNEDY FEDERAL BUILDING, BOSTON, MASSACHUSETTS 02203

RECEIVED
MAR 10 1982
PILGRIM DIVISION

8 MAR 1982

Mr. Richard Machon
Station Manager
Pilgrim Nuclear Power Station
Rocky Hill Road
Plymouth, MA 02360

Re: NPDES Reapplication No. MA00003557

Dear Mr. Machon:

Your reapplication for a National Pollutant Discharge Elimination System (NPDES) permit has been reviewed and appears to be complete. Your request to test only Outfall 001 as representative of Outfalls 002 and 003 is hereby granted. Also, your request to waive the testing for BOD, COD, TOC, TSS and ammonia for Outfall 001 is granted. Testing is also waived for those Part B pollutants for which you have indicated "Believed Present".

Because of the problems you have encountered in locating a testing laboratory to perform the GC/MS testing for Outfall 001A; testing for this discharge point is waived at this time. However, should any problems arise in the future or should suitable labs become available with the capability of testing the Radwaste System Effluent, EPA reserves the right to require testing of this waste stream in the future.

You may be contacted for additional information as the permit is developed, should it be necessary to clarify, modify or supplement any previously submitted information. By copy of this letter, your State Water Pollution Control Agency is being furnished a copy of your complete application for certification pursuant to Section 401(a)(1) of the Clean Water Act, as amended, 33 U.S.C §1341(a)(1).

A draft permit and statement of basis or fact sheet will be prepared by this office and forwarded to you for comment prior to the opening of the public comment period. The draft permit will then be publicly noticed and forwarded for state certification if certification has not previously been received on the application. If it is deemed necessary, a public hearing will be held, in which case, the comment period will be extended until the close of the hearing. After the close of the public comment period, your final permit will be issued providing no new substantial questions are raised. If new questions develop during the comment period, it may be necessary to draft a new permit, revise the statement of basis or fact sheet and/or reopen the public comment period.

The conditions of your present permit will continue in force until your new permit is issued and becomes effective since you have filed a timely and complete application. 40 C.F.R. §122.5, 45 Fed. Reg. 33425 (May 19, 1980).

Should you have any questions concerning the permit issuance process, don't hesitate to contact Victor Alvarez, of my staff. He may be reached at 617/223-5050.

Sincerely yours,

John R. Moebes

John R. Moebes, Chief
Permits Branch

cc: State Water Pollution Control Agency w/encl.

Report To The Massachusetts Attorney General On The Potential Consequences Of A Spent-Fuel-Pool Fire At The Pilgrim Or Vermont Yankee Nuclear Plant.

Jan Beyea, Ph.D.

May 25, 2006

Consulting in the Public Interest
53 Clinton Street
Lambertville, NJ 08530

C17 Encl

35

Personal Background. I am a nuclear physicist who has studied the consequences of both real and hypothetical nuclear accidents, as well as strategies for mitigation. I am a regular member of panels and boards of the National Research Council of the National Academy of Sciences and an advisor to the Division of Engineering and Physical Sciences. After receiving my Ph.D. in nuclear physics from Columbia University, I taught environmental studies at Holy Cross College. Next, I did research at Princeton's Center For Energy and Environmental Studies modeling the consequences of nuclear accidents. I then spent 15 years at the National Audubon Society as Senior Policy Scientist, and ultimately as Chief Scientist and Vice President. Currently, I am senior scientist at Consulting in the Public Interest, providing scientific assistance to not-for-profits, universities, government, and injured plaintiffs.

I am the author of over 100 articles and reports that span a diverse range of topics. I am a regular peer reviewer of articles for scientific journals. One of my specialties is geographic exposure modeling of toxic releases (Beyea and Hatch 1999). My reconstruction of exposures following the TMI accident has been used in radiation epidemiologic studies (Hatch et al. 1990; Hatch et al. 1991). My reconstructions of historical exposures to traffic pollution (Beyea et al.; Beyea et al. 2005) are being used in two ongoing epidemiologic studies of breast cancer (Gammon et al. 2002), (Nie et al. 2005). I am a co-author of studies on risks and consequences of spent-fuel-pool fires (Alvarez et al. 2003a), (Beyea et al. 2004a), (Beyea 1979). I presented a briefing on this work to a committee of the National Research Council that was studying risks of spent fuel.

Introduction I have been asked by the Office of the Attorney General, Commonwealth of Massachusetts, to consider the consequences of releases of radioactivity from spent-fuel-pool fires at the Pilgrim and Vermont Yankee nuclear plants, as part of a relicensing proceeding. In my report I consider important new information on the consequences of releases of radioactivity, in general, and spent-fuel-pool fires, in particular, that was not available to the analysts who prepared earlier documents that are relevant to these proceedings. For example, this new information, which deals with damage costs and radiation risks, was not available prior to the publication of the Environmental Reports for Pilgrim and Vermont Yankee; it was not available prior to the publication of the generic relicensing environmental impact statement (NUREG 1996); and, some of it was not available prior to the filing of Entergy's license renewal application. Consequently, these earlier documents are incomplete from the scientific perspective.

I have addressed the consequences of releases from spent-fuel pools prior to these proceedings (Alvarez et al. 2003a), (Beyea et al. 2004a), (Beyea 1979), in some cases in collaboration with Gordon Thompson, Ph.D., who is filing a separate report in these proceedings. The work we have done has led to a study of the National Research Council[1] and has generated considerable debate and commentary (Alvarez et al. 2003b; Alvarez et al. 2003c; Beyea et al. 2004b)). We have revised our calculations to account for criticisms we thought were valid and easily addressable. In particular, Edwin Lyman, Frank von Hippel and I, in our most recent published work (Beyea et al. 2004a), which forms the backbone of this report on Pilgrim and Vermont Yankee, have specifically responded to criticisms by NRC staff concerning the use of constant population densities around nuclear plants (Alvarez et al. 2003c). In this report, I have addressed additional limitations that raised concerns about our earlier work in some circles. Although critiques of our independent work indicate that there are differences among analysts on the quantity of radioactivity that might be released in a spent-fuel-pool fire and the probability of such releases, there is a consensus among the technical community that this problem needs to be addressed.[2, 3]

For my report, I have considered releases of 10% and 100% of the pool inventory, using methodologies outlined in (Alvarez et al. 2003a) and (Beyea et al. 2004a). I have also provided

1 For a discussion of the relationship between our study and the National Research Council's report (NatRC 2005), see remarks of Kevin Crowley before the Council on Foreign Relations (Crowley 2005).

2 Allan Benjamin, lead author of the original 1979 spent-fuel paper from Sandia Laboratory, was a reviewer of our 2003 paper in SG&S. He provided a public commentary on it, in which he stated, "In summary, the authors are to be commended for identifying a problem that needs to be addressed, and for scoping the boundaries of that problem. However, they fall short of demonstrating that their proposed solution is cost effective or that it is optimal." (Benjamin 2003). Whether or not we "fell short" in demonstrating cost effectiveness or optimality is not the issue at this stage in the relicensing proceedings.

3 It was in 2005, after the relicensing GEIS was completed, that the National Research Council (NatRC) released its study on risks of spent-fuel-pool fires.

> "The committee judges that successful terrorist attacks on spent fuel pools, though difficult, are possible.
>
> ... If an attack leads to a propagating zirconium cladding fire, it could result in the release of large amounts of radioactive material.
> ... Additional analyses are needed to understand more fully the vulnerabilities and consequences of events that could lead to propagating zirconium cladding fires.
> ... it appears to be feasible to reduce the likelihood of a zirconium cladding fire by rearranging spent fuel assemblies in the pool and making provision for water-spray systems that would be able to cool the fuel, even it the pool or overlying building were severely damaged.
> ...Dry cask storage has inherent security advantages over spent fuel pool storage, but it can only be used to store older spent fuel.
>
> The committee judges, however, that further engineering analyses and cost-benefit studies would be needed before decisions on this and other mitigative measures are taken." (NatRC 2005)

I note that such engineering analyses and cost-benefit studies have not been published by the applicants.

additional calculations that a) fill in some gaps left in earlier work, and b) take into account new information that has recently become available. 10% and 100% are the release fractions recommended for consideration by Gordon Thompson in his report. I have read his report and find it consistent with my knowledge of this field. These release fractions match earlier published work by Thompson, myself, and co-authors (Alvarez et al. 2003a), (Beyea et al. 2004a). They also are consistent in order of magnitude with values considered appropriate by the analyst who did the original work on releases from spent-fuel pools.[4] In addition to a 10% and 100% release fraction, I have also considered (briefly) a smaller release. I have presented general formulas that can be used to estimate consequences for a wide range of releases, other than 10% or 100%.

Thompson finds the inventory of Cesium-137 to be somewhat higher at Pilgrim and Vermont Yankee than the default inventory for a generic reactor considered in (Alvarez et al. 2003a). The differences are not major. I have reviewed Thompson's analysis and find his values reasonable for me to use.

Thompson has estimated the heat rate of a spent-fuel-pool fire to be higher at Pilgrim and Vermont Yankee than estimated for a generic spent-fuel pool in (Alvarez et al. 2003a). The difference in resulting plume rise is within one standard deviation for plume rise, using standard formulas, so it has not been necessary for me to modify my calculations with respect to plume rise.

Before submitting a report on consequences of a 10% and 100% release, I have made an independent assessment to assure myself that such releases are probable enough to be more than a mathematical exercise. I have already noted that many analysts have found that the generic, spent-fuel-pool problem needs to be addressed. In addition, I have reviewed the treatment of release probabilities in the companion report of Gordon Thompson, Ph.D. I find his analysis reasonable and conservative. I am certainly comfortable relying on his plant-specific probability numbers for this proceeding. I note that his estimate of the probability of a release caused by a malicious act increases his total probability estimate by only a factor of 6. A factor of 6 increase is modest, given the ingenuity that terrorists have shown in the past. Thompson's plant-specific numbers are consistent with generic probability analyses that were part of a scoping cost-benefit analysis that my colleagues and I made in 2003 (Alvarez et al.

[4] Allan Benjamin, lead author of the original 1979 paper from Sandia Laboratory, was a reviewer of our 2003 paper in SG&S. He provided a public commentary on it, in which he stated,. "Although there is clear evidence that some of the fuel would melt in such a situation, we don't know how much. Since we don't, it is conservative and appropriate to assume that a large fraction of the fission product inventory could become released to the environment. Whether that fraction is 0.20 or 1.00 doesn't change the fact that the release would be unacceptable." (Benjamin 2003)

2003a). Our analysis suggests that even using older probability numbers, and without considering threats of terrorism or new data on radiation risks to be discussed later, moving older fuel to dry cask storage is nearly cost-effective.[5] The Nuclear Regulatory Commission's response to the issues raised by the report of the National Research Council (NatRC 2005) and our paper in *Science and Global Security* (SG&S)(Alvarez et al. 2003a) is discussed in (Dorman 2005). The NRC does not appear to be addressing the scenarios of most concern to me, such as those addressed by Thompson in his report for Pilgrim and Vermont Yankee. The Commission essentially sees the spent-fuel pool problem as a non-issue that is diverting resources from more important areas. However, the basis for the Commission's overall judgment is secret, presenting a challenge in relicensing proceedings to independent scientists like myself, who are not allowed to review the secret analysis. Should I simply accept the Commission's judgment without review and remain silent to avoid any chance of providing useful information to terrorists? The problem with such a stance is that I do not believe the Commission (or any government agency) can best protect the public against terrorism in the absence of vigorous pressure from, and critical analysis by, a range of stakeholders. It would be irresponsible to say nothing, but equally irresponsible to say too much. I hope the balance I have struck in this report is the right one. I certainly conclude from all of the analysis carried out, both by me, Thompson, and others, and the lack of response by the NRC to date, that computing the consequences of large releases of Cesium-137 in regulatory proceedings is responsible and in the public interest.

Another reason that I find it important to make consequence calculations in these proceedings is that the NRC's own Inspector General has observed that the NRC appears to have informally established an unreasonably high burden of requiring absolute proof of a safety problem (IG 2003). Considerable evidence is available that a correspondingly high barrier has been set for alternatives to pool storage at reactors, based on comments by NRC staff on our 2003 paper and by my reading of (Dorman 2005). Thus, independent analysts may be the only vehicle for computing state-of-the-art consequences, if the NRC is reluctant to commission such calculations or require applicants to make them.

Consequences of a release. The first realistic study of the economic and land use consequences of

[5] The approach I took for our 2003 report, when it came to dealing with terrorism, was to think of scenarios that a terrorist group might come up with using the technical means I thought would be reasonably available to them. Since at least one of those generic scenarios I came up with seemed plausible, I considered at the time, and still do, that we need to understand the consequences of spent-fuel-pool fires.

releases of long-lived radioactivity that tried to go beyond bounding calculations was published in 1996 (Chanin and Murfin 1996). This work appeared in the same year of publication of the relicensing GEIS (NUREG 1996), so would not likely have been considered in the GEIS. More recently, in 2003 and 2004, estimates of the long-term health consequences of releases from spent-fuel fires were published by our group of independent analysts, as noted above. Some NRC Commissioners have referred to staff analyses refuting our published results, but such analyses have never been made public, as far as I am aware. If the new staff analysis does exist, it was also prepared after the GEIS and so should be incorporated into the EIS for Pilgrim and Vermont Yankee. The staff analysis that has been published is sobering and only applies specifically to decommissioning (Collins and Hubbard 2001).

For this report, components of damage costs not previously considered at other sites have been included. For instance, new damage cost and latent cancer calculations have been made to extend the work by Beyea, Lyman, and von Hippel to areas contaminated by resuspension. Results from "wedge model" calculations (discussed below) have been used for this purpose. Loss of property value outside remediated areas have also been considered, again with reliance on the wedge model. Approximate correction has been made for wind-rose effects, something that was not done in (Beyea et al. 2004a). In addition, I have made cost and latent cancer estimates, assuming that the latest radiation mortality studies are used in the calculations. As for the standard components of damage calculations, I have scaled, interpolated or extrapolated from values computed for other sites as reported in (Beyea et al. 2004a). Since the MACCS2 model was run in the paper by Beyea, Lyman, and von Hippel, with the parameter values listed there, the results in this report on Pilgrim and Vermont Yankee are based on the MACCS2 model.

The models included in the MACCS2 code are based largely on methodologies originally developed for the 1975 Reactor Safety Study (NUREG 1975), as refined in the CRAC2 code (Kocher et al. 1987; Ritchie et al. 1984). See (Young and Chanin 1996). A simpler approach to consequence analysis (wedge model) was developed by an American Physical Society group that reviewed the Reactor Safety Study (APS 1975). The wedge-model provides quick estimates of consequences that usually gives similar results to more detailed models, such as MACCS2, provided one uses appropriate effective parameters. The wedge model may underestimate acute consequences in situations where changing weather classes dominates health effects, but that is not a major issue for releases of cesium-137, where the risk is from long-term exposure.

Details of the calculations made for this report are given in Appendix I. Tables with quantitative results appear in a subsequent section. Reliance on output from the MACCS2 computer code or the wedge model to estimate consequences from releases of Cesium-137 in this report does not necessarily imply endorsement of the use of these methodologies in other contexts, nor endorsements of the parameter sets that applicants or others may use with them. All models have strengths and weaknesses that must not be forgotten by modelers. MACCS2 does not appear to have undergone extensive field validation (Young and Chanin 1997), but sensitivity studies have been undertaken (Helton et al. 1995; McKay and Beckman 1994), (Neymotin 1994) and a large number of expert elicitations have been carried out that provide uncertainty distribution for input parameters (Goossens et al. 1997; Harper et al. 1993; Little et al. 1997; USNRC 1995). The model has been used in a limited number of peer-reviewed publications. Edwin Lyman, who ran the MACCS2 code for (Beyea et al. 2004a) has probably the greatest number of peer-reviewed papers using MACCS2.

For late health effects, which are of interest in this report, the deposition velocity has been found to be a major parameter affecting MACCS results (Helton et al. 1995). Because the uncertainty distribution for deposition velocity is quite broad (USNRC 1995), the variance in the MACCS2 predictions for cancers (and damage costs) could be large. When possible, I prefer to rely on exposure models that have been tested against field data, such as those I have developed in recent years (Beyea et al.). However, by relying on results from MACCS2 in these proceedings with respect to consequences from releases of Cesium-137, I hope to avoid distracting debate over models.

In the next section, I present results of consequence calculations using standard cancer risk coefficients. In subsequent sections, I discuss major new studies on cancer risks from radiation that suggest the risk coefficients used in most versions of MACCS2 are way too low. I then present consequence calculations using higher cancer coefficients and discuss some of the implications for cost benefit analyses. Finally, I discuss some new developments in dispersion modeling at coastal sites. I suggest that the applicant at Pilgrim should undertake sensitivity studies using appropriate computer codes to see if this new knowledge of meteorology modifies cost-benefit computations.

Quantitative damage estimates for releases from Pilgrim and Vermont Yankee, assuming standard cancer risk coefficients:

This section presents a subset of consequence estimates for hypothetical releases of Cesium-137 from spent-fuel pools at Pilgrim and Vermont Yankee. Estimates are presented for economic costs and latent cancers. Variance in the estimates are not considered for the contention phase. Details of the estimates are given in the Table footnotes and in Appendix I. Political, psychological, and social impacts of hypothetical releases are not considered, although they could obviously be significant. For instance, there appears to exist a "radiation syndrome" that affects a subset of exposed populations, causing debilitating psychiatric symptoms (Vyner 1983). Psychological effects of radiation disasters are expected to be most serious for children (CEH 2003).

Releases of 10% and ~100% of the radiocesium in the spent-fuel pools at both Pilgrim and Vermont Yankee are considered. Results are presented in this section using the standard risk coefficients assumed in (Beyea et al. 2004a). Releases lower than 10% of the Cesium-137 inventory, even releases too low to justify remediation, could have costs associated with loss in property value in the range of 10 to 100 billion dollars.

The damage estimates shown in the Tables are much less than the GDP of the US, which is about 12 trillion per year. However, some of the numbers exceed the annual payment on the national debt, which is about 350 billion dollars per year, indicating that government borrowing to cover the damage payments from a spent-fuel-pool fire could represent a major perturbation on the economy. Thus, significant macroeconomic effects could be expected depending on the state of the economy at the time of any hypothetical release. The regional impacts would be expected to be the most serious. Estimating such effects are beyond the scope of this report.

The Tables include numbers in some cells to 3-significant figures. This does not imply any comparable level of accuracy.

Table 1. Cost estimates for a release of 10% of spent-fuel pool inventory of radioactive Cesium-137 assuming no change in cancer risk coefficient (billions of dollars)

Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	49	39	
Indirect administrative costs[b)]	49	39	
Loss in property values adjacent to treated areas[c)]	7-74	9-87	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings.[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Total	> 105-171	> 87-165	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). Reduction by 1/3rd to account for wind rose effects.
b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset any economies of scale.
c) Assumes 5% loss in property value for an area surrounding the plume that includes 1 to 10 times as many persons as are in the (0.24 radian) plume extending out to 250 miles (see Appendix I). A similar 5% loss in property value is assumed in the plume from 250-1000 miles. $132,000 in property value assumed per capita (Beyea et al. 2004a). Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.
d) We have not attempted an estimate for this category in the contention phase.

Table 2. Cost estimates for a release of ~100% of spent-fuel pool inventory of Cs-137 assuming no increase in cancer risk coefficient (billions of dollars)			
Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	163	173	
Indirect administrative costs[b)]	163	173	
Loss in property values adjacent to treated areas[c)]	16-162	17-172	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings.[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Total	> 342-488	> 364-518	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). Figures reduced by 1/3rd to account for wind rose effects.
b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset the economies of scale.
c) Assumes 5% loss in property value for an area including 1 to 10 times as many persons as are in a 0.24 radian plume extending out to 700 miles (see text). A similar 5% loss in property value is assumed in the plume from 700-1000 miles. $132,000 in property value assumed per capita (Beyea et al. 2004a). Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.
d) We have not attempted an estimate for this category in the contention phase.

Note that the latent cancer estimates in Table 3, below, are lower limits, because they only include the cancers from Cesium-137. This approximation ignores shorter isotopes in the fresh fuel in the pool, especially Cesium-134 (Benjamin 2003).

Table 3. Estimates for latent cancers following releases from the spent-fuel pools at either Pilgrim or Vermont Yankee (assuming no increase in cancer risk number)

Category	10% release	~100% release
Latent cancers in main plume path from residual contamination[a)]	1300	4000
Latent cancers from deposited resuspension[b)]	1300	4000
Total	2,700	8,000

a) Based on typical numbers for plants analyzed in (Beyea et al. 2004a). Figures reduced by 1/3rd to account for wind rose effects. Cancers in the direct plume are reduced by more than a factor of ten from decontamination and deconstruction.
b) Assumes 10% resuspension and redistribution of deposited Cesium-137 resulting from a) wind removal in the first few weeks, and b) remediation/demolition efforts over successive years. It is possible that even the resuspended Cesium would produce concentrations high enough to justify remediation, with a corresponding reduction in projected cancers. However, clean-up costs would be increased.

I have not been able to incorporate new understanding of the flow of air over and around the New England Coastline that has been achieved in recent years. Still, this new knowledge should be taken into account in EISs for coastal facilities. Releases from Pilgrim headed initially out to sea will remain tightly concentrated due to reduced turbulence until winds blow the puffs back over land (Zagar et al.), (Angevine et al. 2006). This can lead to hot spots of radioactivity in unexpected locations (Angevine et al. 2004). Dismissing radioactivity blowing out to sea is inappropriate. Reduction of turbulence on transport from Pilgrim across the water to Boston should also be studied. Although incorporating such meteorological understanding into a PSA or equivalent at Pilgrim would not be likely to make more that a factor of two difference in risk, the change could bring more SAMAs into play and would be significant in an absolute sense, when combined with the increase arising from incorporation of new values of radiation dose conversion coefficients (discussed below). The program

CALPUFF (Scire et al. 2000) has the capability to account for reduced turbulence over ocean water and could be used in sensitivity studies to see how important the phenomenon is at Pilgrim.

New cancer risk coefficients There have been increases in the value of the cancer risk assigned to low doses of radiation that should be taken into account in EISs. These increases have been steady since 1972,[6] which makes the original EISs out of date. In addition, there has been a marked increase in the value of the cancer mortality risk per unit of radiation at low doses (2-to-3 rem average) as a result of recent studies published on a) radiation workers (Cardis et al. 2005) and b) the Techa River cohort (Krestinina et al. 2005). Both studies give similar values for low dose, protracted exposure, namely about 1 cancer death per Sievert (100 rem).

Worker study: The average dose for the workers was 2-rem. The authors of this large, international study of radiation workers included major figures in the field of radiation studies. The authors state, "On the basis of these estimates, 1-2% of deaths from cancer among workers in this cohort may be attributable to radiation." Although it can be misleading to interpret epidemiologic data in this way (Beyea and Greenland 1999), because it implies to non-experts a single-cause model of cancer, there is no doubt that a 1-2% increase in cancer mortality for a worker population is unusually high.

Techa River Cohort: The results for the Techa River cohort are equally striking, showing a strong linear effect down to a few rads. The average dose was 3 rads. The authors, who once again include major figures in the field of radiation studies, state: "It is estimated that about 2.5% of the solid cancer deaths...are associated with the radiation exposure." As in the worker population, an increase in solid cancer deaths of 2.5% from a dose of 3 rads is extraordinarily high compared to past estimates.

Such high risk coefficients imply that background radiation itself must increase cancer mortality by 3-5%.[7] (It has long been known that background radon concentrations may well increase lung cancer rates by 10% or more (Lubin et al. 1995), (Darby et al. 2005).) Critics of studies like those by

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6 For instance, there was a large increase in the risk coefficients estimated between the 1980 BEIR III report and the 1990 BEIR V report. See Table 4-4 of (National Research Council 1990), where the lifetime risk estimates increased by a factor of 4.6-19, depending on the risk model.

7 Assuming 0.1 rem per year background, which ignores the "equivalent" dose to the lung from radon. It is more difficult to compare rates of lung cancer, because the interaction of smoking and radiation has been found to lie between a linear and relative model. Therefore, such interactions must be taken into account, before drawing conclusions about area-wide differences, or lack of differences, in lung cancer rates.

Cardis et al. and by Krestinina et al. argue that such big effects, if they were real, should show up in cancer statistics in places like Colorado, where background radiation is high, when compared to areas of the country where background radiation is lower. However, crude statistical analysis that does not adjust for covariates at an individual level is unlikely to be very reliable (Lubin 1998). Also, there is an issue of the confounding effect of hypoxia (Weinberg et al. 1987). Hypoxia also varies with altitude.

Because the average dose in these two new studies is so low and so close to background radiation dose, there is no way to escape the linear non-threshold model. Even were a hypothetical hormesis effect to lead to a minimum risk at background levels (5 rem lifetime dose), the risk has to rise again after another 2-3 rem dose, based on the studies by Cardis et al. and Krestinina et al.

Could the increased risk numbers be due to a systematic underestimate or underreporting of doses? Random errors in doses would tend, in most cases, to reduce the strength of associations (Carroll et al. 1998), (Thomas et al. 1993). On the other hand, if dose errors were not random, but were proportionately underestimated or proportionately underreported in the worker studies and the Techa River cohort, then the risk coefficients could be inflated. For this to happen in both studies would be a coincidence. And in the radiation worker study, the results for Hanford do not support the missing-dose hypothesis, even though we know the neutron doses were likely underreported at Hanford (CohenAssociates 2005). In fact, the cancer risk numbers at Hanford were lower than average, not higher (Cardis et al. 2005). Finally, should the Techa River cohort dose estimates be too low that would mean that modern dose reconstruction techniques are underestimating doses, suggesting that other modern dose estimation techniques, such as those used in MACCS2 (Chanin and Young 1997), the standard NRC consequence code, could well be too low. In that case, an upward adjustment of doses would be required, if the risk coefficients were kept the same. Certainly, from a public health point of view, the arguments are strong for making use of the new risk coefficients, one way or another, with programs like MACCS2 and other consequence codes.

Recent press reports around the anniversary of the Chernobyl accident seemed to suggest that effects of radiation doses were lower than expected. Not at all. The "new" estimates of 4,000 projected fatalities were merely a re-interpretation of a study from the 1990s. No longer were 5,000 projected cancers outside the most highly contaminated regions counted. Also, another 7,000 cancers projected to occur in Europe were not noted by the press (Cardis et al. 2006). A summary of all of these estimates can be found in (Cardis et al. 2006). Were the new risk coefficients discussed earlier applied to the population dose estimates, the projected numbers of fatalities from the Chernobyl releases would climb much higher.

The confusion over the Chernobyl numbers appears to be traceable to a typo in a highly publicized IAEA report (Forum 2005) that relied on a WHO report for its cancer numbers (WHO 2005). The WHO report stated that the "Expert Group" concluded that there may be up to 4 000 additional cancer deaths among the three *highest* exposed groups over their lifetime (emphasis added). This was translated in the IAEA report to, "The total number of people that could have died or could die in the future due to Chornobyl originated exposure over the lifetime of emergency workers and residents of *most* contaminated areas is estimated to be around 4 000." (Emphasis added.) In fact, in my view, the last clause should have referred to "residents of *the* most contaminated areas..."[8]

<u>Impact of new cancer risks.</u> As a result of these two radiation studies, all probabilistic safety analyses prepared prior to them need to be revisited. These new studies should change the threshold for adoption of severe accident mitigation alternatives (SAMA). For instance, the current Environmental Report for Pilgrim assigns a value of $2,000 per person rem in deciding whether a proposed SAMA is cost effective. According to the results of the study by Cardis et al., $2,000 per rem implies a valuation of $200,000 per cancer death before discounting, which is way to low.[9] The same low valuation of life would arise from use of the risk numbers derived from the Techa River cohort (Krestinina et al. 2005). As a result, the SAMA analyses prepared for the Pilgrim and Vermont Yankee facilities need to be redone, even without inclusion of spent-fuel-pool fires as a risk to be addressed. Presumably, a number of additional SAMAs that were previously rejected by the applicant's methodology will now become cost effective. In addition to affecting the existing SAMA calculations, the new cancer risk coefficients make the consideration in an EIS of mitigation measures for spent-fuel-pool fires especially important.

In addition to providing motivation for a reanalysis of past PSAs and SAMA thresholds, the results of these new epidemiologic studies throw into doubt the entire basis of the NRC culture, which maintains that the linear non-threshold theory (LNT) is conservative, providing a margin of safety. Although it has always been known that the dose-response at doses below the 25-rad average dose of the Atomic Bomb survivors could be supralinear, as opposed to sublinear, the possibility has not been

8 Note that the IAEA stands by its original wording, not accepting it as a typo. Personal Communication, 2006, D. Kinley, IAEA public information, Vienna.

9 $50,000 net present value for a cancer death occurring 20 years from now, based on the 7% per year discount rate assumed in rhe Pilgrim Environmental Report, which leads to a factor of 4 reduction in present value for a cancer induced 20 years from now.

given much attention in the radiation protection community until now.[10] This is not the time for *pro forma* treatment of licensing applications. Whereas it would be unreasonable to require an applicant to redo analysis after every new paper is published in the scientific literature, the increase at low doses is very dramatic in this case. It represents a 5-fold increase over the risk estimated in BEIR VII (NRC 2005). Based on information in (Little 1998), it appears to represent a factor of 10 over the standard value used in the MACCS2 computer code, which is the code on which the applicants' analyses are based. With such a high reported increase, public health considerations have to take precedence over applicant convenience. The paper by Cardis et al., at the very minimum, demands that a thorough analysis be made of mitigation and alternatives to spent-fuel pool storage.

For example, application of the new risk coefficients would drive the risk of spent-fuel-pool accidents during decommissioning (without even considering terrorist threats) above the NRC's safety goal. See Figures ES-1, ES-2 of (Collins and Hubbard 2001).

Quantitative damage estimates for releases from Pilgrim and Vermont Yankee, assuming cancer risk coefficients are increased to accommodate the new epidemiologic studies:

This section presents a subset of consequence estimates for hypothetical releases of Cesium-137 from spent-fuel pools at Pilgrim and Vermont Yankee, assuming a 3-fold increase in cancer risk coefficients to conservatively account for the latest studies on radiation risk at low dose. To account for some weighting of other studies, I have chosen a value lower than the factor of 5-to-10 increase that is suggested by the study of (Cardis et al. 2005).[11]

As with earlier Tables, estimates are presented for economic costs and latent cancers. Variance in the estimates are not considered for the contention phase. See the Table footnotes and Appendix I for details. Political, psychological, and social impacts of hypothetical releases are not considered, although they could obviously be significant. As stated earlier, there appears to exist a "radiation syndrome" that affects a subset of exposed populations, causing debilitating psychiatric symptoms (Vyner 1983). Psychological effects of radiation disasters are expected to be most serious for children (CEH 2003).

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[10] There has been some discussion, however, that the A-Bomb survivor data produces low risk coefficients due to a healthy survivor effect (Stewart and Kneale 1993; Stewart and Kneale 1999). In addition, I have always wondered about the lowest dose data in Pierce, which seems to show a supralinear effect below 5 rem (Pierce et al. 1996), page 9.

11 Part of the factor of 5 comes from the use of a dose and dose rate effectiveness factor, which is commonly used with the MACCS2 code, as in (Beyea et al. 2004a).

Once again, releases lower than 10% of the Cesium-137 inventory, even releases too low to justify remediation, could have costs associated with loss in property value in the range of 10 to 100 billion dollars.

The damage estimates shown in the Tables are much less than the GDP of the US, which is about 12 trillion per year. However, some of the numbers are considerably larger than the annual payment on the national debt, which is about 350 billion dollars per year, indicating that government borrowing to cover the damage payments from a spent-fuel-pool fire could represent a major perturbation on the economy. Thus, once again, significant macroeconomic effects could be expected depending on the state of the economy at the time of any hypothetical release. The regional impacts would be expected to be the most serious. Estimating such effects are beyond the scope of this report.

The Tables include numbers in some cells to 3-significant figures. This does not imply any comparable level of accuracy.

Table 4. Cost estimates for a release of 10% of spent-fuel-pool inventory of Cs-137 assuming 3-fold increase in cancer risk coefficient (billions of dollars)			
Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	89	79	
Indirect administrative costs[b)]	89	79	
Loss in property values adjacent to treated areas[c)]	> 7-74	> 9-87	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings.[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Total	> 186-253	> 167-245	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). An increase in the cancer risk numbers is mathematically equivalent to an increase in release magnitude, which is how the numbers in the Table were computed. Figures reduced by 1/3rd to account for wind rose effects.
b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset the economies of scale.
c) Assumed to be at least as great as the figures calculated in Table 1, where the cancer risk coefficient was left unchanged. Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.
d) We have not attempted an estimate for this category in the contention phase.

Table 5. Cost estimates for a release of ~100% of spent-fuel-pool inventory of Cs-137 assuming a three-fold increase in cancer risk coefficient (billions of dollars)			
Category	Pilgrim	Vermont Yankee	Comment
Direct costs[a)]	283	353	
Indirect administrative costs[b)]	283	353	
Loss in property values adjacent to treated areas[c)]	16-162	17-172	
Costs associated with cleanup or demolition of downtown business and commercial districts, heavy industrial areas, or high-rise apartment buildings[d)]	??	??	Particularly important for Pilgrim, with its proximity to Boston
Costs due to delays in implementing remediation and deconstruction[d)]	??	???	
Total	> 582-728	> 723-878	

a) As estimated from computations with MACCS2 at comparable sites with the parameters given in (Beyea et al. 2004a). An increase in the cancer risk numbers is mathematically equivalent to an increase in release magnitude, which is how the numbers in the Table were computed. Figures reduced by 1/3rd to account for wind rose effects.
b) Based on Chanin and Murfin. "We believe . . . that it might be reasonable to double the cost estimates provided [here] in order to account for indirect costs." (Chanin and Murfin 1996), p. 6-3. The factor might not be as great in the current case, however, because of economies of scale. We assume that litigation costs offset the economies of scale.
c) Assumed to be at least as great as the figures calculated in Table 2, where the cancer risk coefficient was left unchanged. Although not included in this total for the contention phase, loss in property value upon sale by government of remediated property should be included here. MACCS2 assumes no such loss.
d) We have not attempted an estimate for this category in the contention phase.

Note that the latent cancer estimates in Table 6, below, are lower limits, because they only include the cancers from Cesium-137. This approximation ignores shorter isotopes in the fresh fuel in the pool, especially Cesium-134 (Benjamin 2003).

Table 6. Estimates for latent cancers following releases from the spent-fuel pools at either Pilgrim or Vermont Yankee (assuming a 3-fold increase in cancer risk number)		
Category	10% release	~100% release
Latent cancers in main plume path from residual contamination[a)]	4,000	12,000
Latent cancers from deposited resuspension[b)]	4,000	12,000
Total	8,000	24,000

a) Based on typical numbers for plants analyzed in (Beyea et al. 2004a) multiplied by a factor of 3. Figures reduced by 1/3rd to account for wind rose effects. Cancers in the direct plume are reduced by more than a factor of ten from decontamination and deconstruction.
b) Assumes 10% resuspension and redistribution of deposited Cesium-137 resulting from a) wind removal in the first few weeks, and b) remediation/deconstruction efforts over successive years. It is possible that even the resuspended Cesium would produce concentrations high enough to justify remediation, with a corresponding reduction in projected cancers. However, clean-up costs would be increased.

Regulatory implications. The results in Tables 1-6, along with the discussion in the text suggest that: The applicant should withdraw and revise its Environmental Reports for Pilgrim and Vermont Yankee. The NRC should prepare supplements to the August 1979 Generic Environmental Impact Statement on handling and storage of spent fuel (NUREG-0575), and the May 1996 GEIS on license renewal (NUREG-1437). The revised documents should consider the new cancer risk coefficients published by Cardis et al. and Kristinina et al. For both reactor accidents and spent-fuel-pool fires, when relevant, the documents should consider loss of property value outside remediated areas. They should consider wind-driven resuspension, especially from remediation activities, that carries radioactivity to new areas in the immediate weeks and years following the release. Although MACCS2 does not directly account for such refinements, it may be possible to mimic their effects in the program.[12] In their economic calculations, the revised documents should include administrative and litigation costs associated with clean up and demolition. The ER for Pilgrim should consider the reduced turbulence over ocean water, including transport directly over water to the Boston area. The NUREG supplements should consider the impacts of coastal meteorology for reactors on the East and West Coasts. The program CALPUFF can be used to deal with dispersion over coastal waters.

[12] This might be done by adding on extra plume segments to the end of a standard run, with varying delay times, and a total added release equal to the assumed resuspension fraction times the initial release. This will tend to produce the mathematical equivalent of resuspended material being carried in directions different from the main plume.

Appendix I.

Variance in estimates are not considered in this report for the contention phase.

Based on the report of Gordon Thompson, the inventories at Pilgrim and Vermont Yankee are somewhat higher than the 35 MCi considered in (Beyea et al. 2004a). For Pilgrim, Dr. Thompson estimates 44 MCi; for Vermont Yankee, 39 MCi.

Thompson has also estimated a hotter heat rate for releases at Pilgrim and Vermont Yankee than was assumed in the calculations in (Beyea et al. 2004a). 106-128 MW vs 40 MW. Plume rise varies as the 1/3rd power of the heat rate in the standard "Briggs" formula for plume rise (Parks 1997), which implies a 50% greater rise than would have been calculated in the MACCS2 program that was used in the paper by Beyea, Lyman and von Hippel. For the contention phase of these proceedings, this difference has been ignored, since a 50% increase in plume rise is within 1-standard deviation of the value predicted by the formula (Irwin and Hanna 2004).

Rather than make new MACCS2 calculations for the contention phase of these proceedings, the azimuthally-averaged radial population distributions for both Pilgrim and Vermont Yankee have been compared as a function of distance with those for which economic and latent cancer consequences have been calculated in (Beyea et al. 2004a). It is the radial population numbers that drive the economic damage costs and cancer numbers. Figures 1 and 2 show the azimuthally-averaged radial population distributions for Pilgrim and Vermont Yankee for two different maximum distances. The CensusCD computer program (Geolytics 2002) was used to generate these population distributions. The same program was used in (Beyea et al. 2004a) for the five reactors, Catawba, Indian Point, LaSalle, Palo Verde, and TMI.

The effect of variation in wind direction at Pilgrim is to reduce the average damages and latent fatalities. Wind rose data taken from the Pilgrim FSAR shown in Figure 5 for the 300 foot tower suggest a reduction factor of 0.666 for that facility. See caption for Figure 5. I did not find similar data for a high tower in the FSAR for Vermont Yankee, so I have used the 0.666 factor determined for Pilgrim. Wind flows at the surface given in the Vermont Yankee FSAR are not particularly relevant to a hot release during a fire, since the plume will be elevated. The variance with angle appears to be quite large, because the population figures change with release angle, as shown in Figures 3 and 4.

For economic damages from the 10% releases, we are interested in populations out to 250 miles (based on wedge model calculations). For the ~100% releases, the corresponding distance is 700 miles. The Pilgrim population figures best match Catawba out to 250 miles. For Vermont Yankee the population figures best match Lasalle out to 250 miles. Out to 700 miles, both Pilgrim and Vermont Yankee are most similar to Lasalle, although I discount the Lasalle cost figures to account for the lower population values of Pilgrim and Vermont Yankee.

Table 7, shows the relevant costs extracted from Table 3 of (Beyea et al. 2004a) and adjusted as indicated in the Table footnotes. These numbers were then fit to a power law function of release magnitude. The corresponding functions were used to generate costs estimates for the Pilgrim and Vermont Yankee releases estimated by Thompson, which differ somewhat from the releases assumed for a spent-fuel fire in (Beyea et al. 2004a).

Table 7. Assigning damage cost estimates in billions of dollars based on Table 3 of (Beyea et al. 2004a)

Release magnitude	Pilgrim	Vermont Yankee
3.5 MCi	71[a)]	54[b)]
35 MCi	219[c)]	243[d)]

a) Cost figure for Catawba for a 3.5 MCi release.
b) Cost figure for Lasalle for a 3.5 MCi release.
c) Cost figure for Lasalle for a 35 MCi release reduced by 20%
d) Cost figure for Lasalle for a 35 MCi release reduced by 10%

Extrapolated and interpolated direct damage costs for Pilgrim and Vermont Yankee were computed from the following formulas:

Pilgrim: Damages = $0.66 * 35 * (\text{release in Mci})^{0.5}$

Vermont Yankee: Damages = $0.66 * 24 * (\text{release in MCi})^{0.65}$

The factor of 0.66 comes from wind-rose effects.

Administrative costs are taken equal to direct costs, following the suggestion of (Chanin and Murfin 1996). Property loss estimates are discussed below.

Estimates of losses in property value. It is assumed that an area exists around the "main portion" of the plume, where potential property buyers would be concerned about residual risk. (The main portion of the plume is defined as the area where remediation or demolition takes place.) Outside the main plume, contamination would still be measurable. Lack of trust in statements by government would translate into loss in property values. All things being equal, persons would wish to live as far away from contaminated areas as possible.

Note that radioactive deposition would extend into these non-remediated areas, both from the immediate release and from resuspension in the weeks and years after the release and from subsequent demolition and remediation efforts. People would be accumulating long-term radiation doses, which government sources would say are too trivial to worry about. Expert opinion would differ on the seriousness of the long-term exposures. Confidence in government would likely drop over time based on revelations of government failings. If past patterns are followed, government leaders would early on feel compelled to downplay the true situation to prevent panic. Although it is hard to see how they could act otherwise, it is also hard to see how citizens enthusiasm for purchasing property in the vicinity of the main plume would not be weakened.

How much would property values decline? Based on expert reports filed in litigation concerning the Rocky Flats nuclear weapons facility, and the jury decision favorable to plaintiffs in that litigation (2006), I assume a 5% loss in property value for property lying within measurable contours of contamination. This is quite conservative, since the jury accepted Plaintiffs' expert assessment that residential values dropped by 7%,[13] vacant land by 30%, and commercial land by 53%. For the calculations in this report, I define the main, remediated plume as a 0.24 wedge extending out to 250 miles for the 10% release and 700 miles for the ~100% release.

Areas where property damage loss is assumed to take place extends outward from the plume to 1000 miles, which is where the damage calculations stop in (Beyea et al. 2004a). In addition, property in areas to the side of the plume are also expected to suffer a 5% loss in value. Because I have no firm basis for determining the distance to which property loss would extend, I have picked a ten-fold range. At the low end, as many people outside the main plume are assume to be affected as live in the main plume. At the high end, I pick ten times as many persons.

13 The "residential" figure appears to be some sort of compromise. It's within a range reported by expert Radke's year-by-year multiple regressions for 1988-95, but it's less than the 10% that expert Hunsperger ultimately estimated. Personal commuication, 2006, Peter Nordberg, Berger and Montague.

MACCS2 accounts for inhalation of resuspended material at the location where radioactivity is deposited (Chanin et al. 2004), Section 2, page 6-14. However, MACCS2 does not allow for redistribution of resuspended material to new locations. Yet, 10% of radioactivity deposited on vegetation may be blown off in the first few weeks,[14] with additional resuspension over decades,[15] increased dramatically by anthropogenic activity during clean up and remediation (Schershakov 1997). I adopt a net resuspension factor for Cesium-137 of 10% over the long term, which should be a conservative choice in this context.[16] To account for the latent cancers that would be caused by this redistribution of radioactivity, I have made the approximation that no such re-deposited material would be high enough to generate remediation. (If this assumption is violated, the number of latent cancers from redistributed radioactivity would go down, but it would then be necessary to increase clean-up costs.)

Based on wedge model calculations, I know that remediation reduces latent cancers by a factor of 10 or more. Thus, the contribution from redistributed radiation to total cancers, under the assumptions I have made, should be more than the direct contribution from the remediated plume (10% X 10 = 100%). A more precise calculation could be obtained by running MACCS2 in a special way, even though MACCS2 does not directly handle redistributed radioactivity. (MACCS2 only allows straight-line plume segments and does not allow wind trajectories (Chanin et al. 2004), Section 5, page 1-4.) However, MACCS2 does allow multiple straight-line segments with different starting times (Chanin et al. 2004), Section 2, page 6-14. If MACCS2 was run with extra plume segments added on to the end of a standard release sequence, with varying delay times, and a total added release equal to

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[14] (NUREG 1975), Appendix VI. Radioiodine after weapons fallout shows very rapid decline over periods of days, some of which must be due to wind action (NCI 1997), Table 4.8. The half-life for small particles is longer, about 14 days (Prohl et al. 1995). Resuspension *factors* in the early days after the Chernobyl accident have shown very high values, including 2.4 E-04 m^{-1} at one day after deposition (Schershakov 1997). Such a high rate could not be maintained without completely exhausting the surface concentration in a very short time. The resuspension factor has been estimated to drop as an inverse power of time in days, with an exponent of 0.5-to-1.67 (Schershakov 1997). At issue is the size of the resuspended material, because some radioactivity might deposit on relatively large particles on vegetation that are easily removed by wind.

[15] Resuspension *rates* measured for Chernobyl radiocesium are also high (1E-08 s^{-1}) (Schershakov 1997). When such a high uplift rate is totaled for periods of years, a 10% net loss is quite reasonable, although resuspension rates were measured to decrease by an order of magnitude over time (Schershakov 1997). Studies by my colleagues and I have indicated that underground material is brought to the surface by animal burrowing (Morrison et al. 1997; Smallwood et al. 1998), where it is subject to wind resuspension. Thus, movement into the soil of radiocesium does not keep it away from the surface forever. Smallwood has estimated from his measurements in California and Colorado that about 0.5 % of underground radioactivity should be brought to the surface each year by animal burrowing, including ant burrowing (Smallwood, personal communication, 1998). How relevant this number is to the East Coast is not known.

[16] Because of lack of data on particle sizes, analysts may differ as to how much resuspended material would be in particle sizes large enough to travel outside the main plume before remediation. However, most land area would not be remediated. In any case, it will be important for the field of contamination consequence analysis to have debates on this subject.

the assumed resuspension fraction times the initial release, then MACCS2 will produce as output the mathematical equivalent of resuspended material being carried in directions different from the main plume.

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Figure 1.

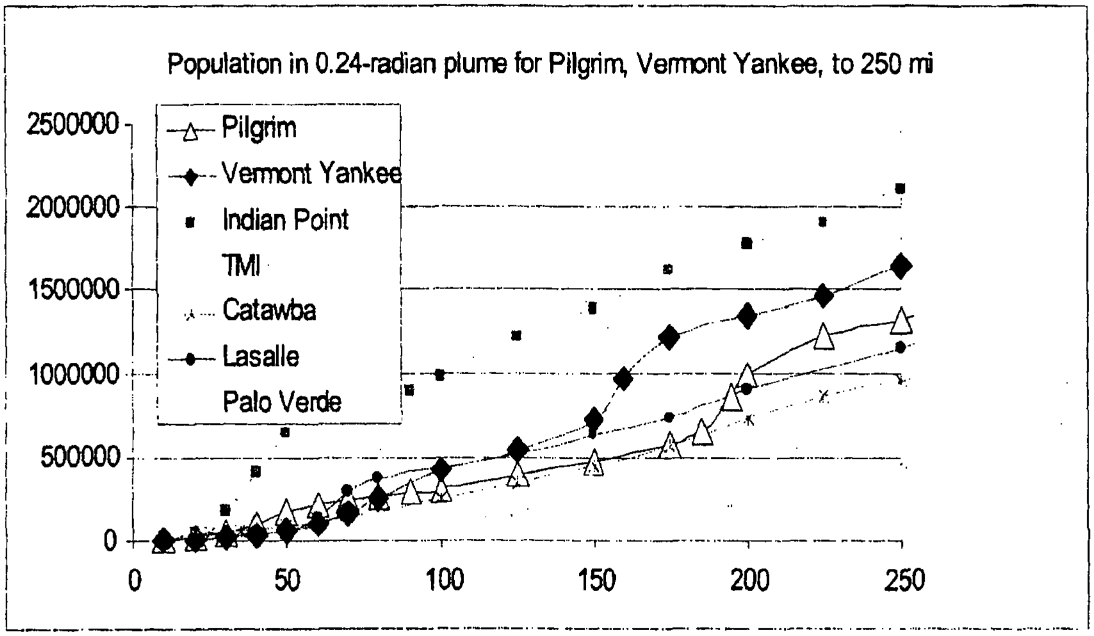
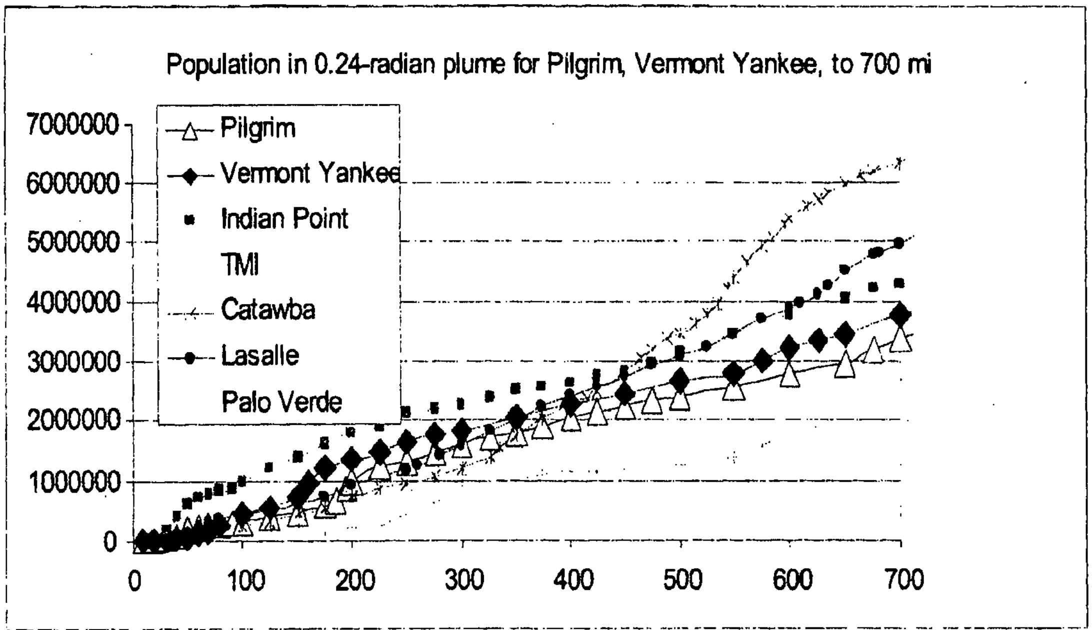

Population in 0.24-radian plume for Pilgrim, Vermont Yankee, to 250 mi
2500000
2000000
1500000
1000000
500000
0
0
50
100
150
200
250
Pilgrim
Vermont Yankee
Indian Point
TMI
Catawba
Lasalle
Palo Verde

Figure 2.



Population in 0.24-radian plume for Pilgrim, Vermont Yankee, to 700 mi
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
0
100
200
300
400
500
600
700
Pilgrim
Vermont Yankee
Indian Point
TMI
Catawba
Lasalle
Palo Verde

Figure 3. Calculated with the SECPOP 2000 computer code (Bixler et al. 2003).

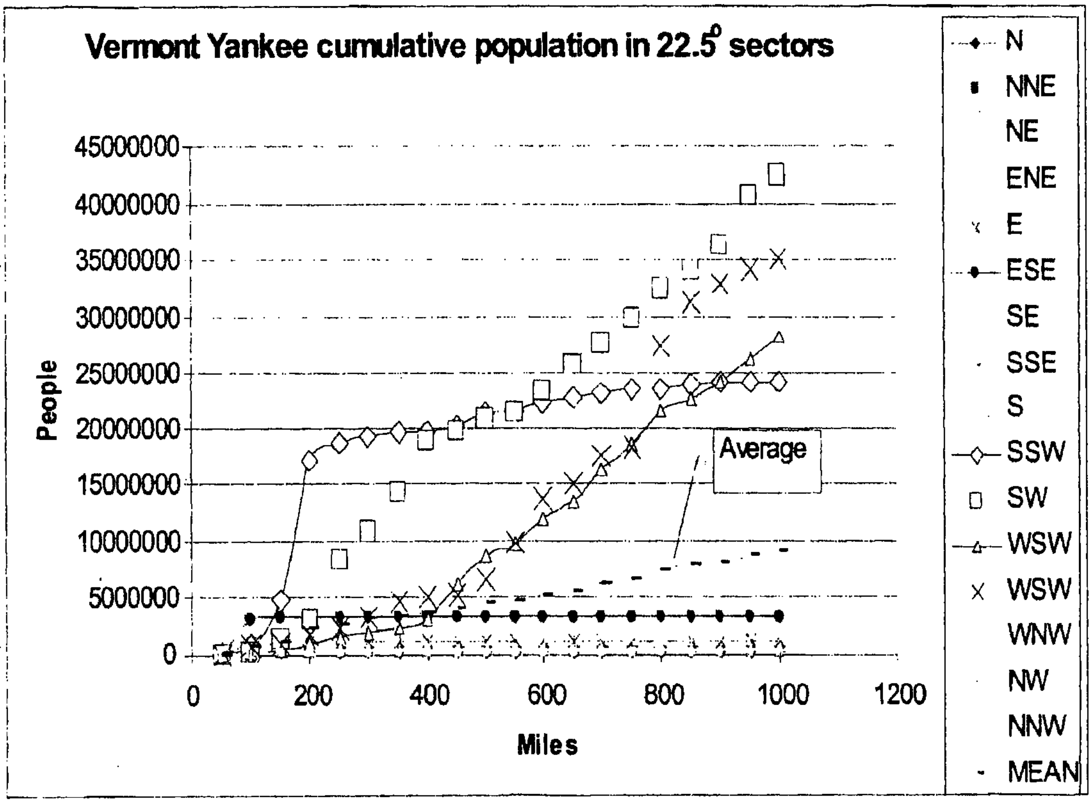


Figure 4. Calculated with the SECPOP 2000 computer code (Bixler et al. 2003).

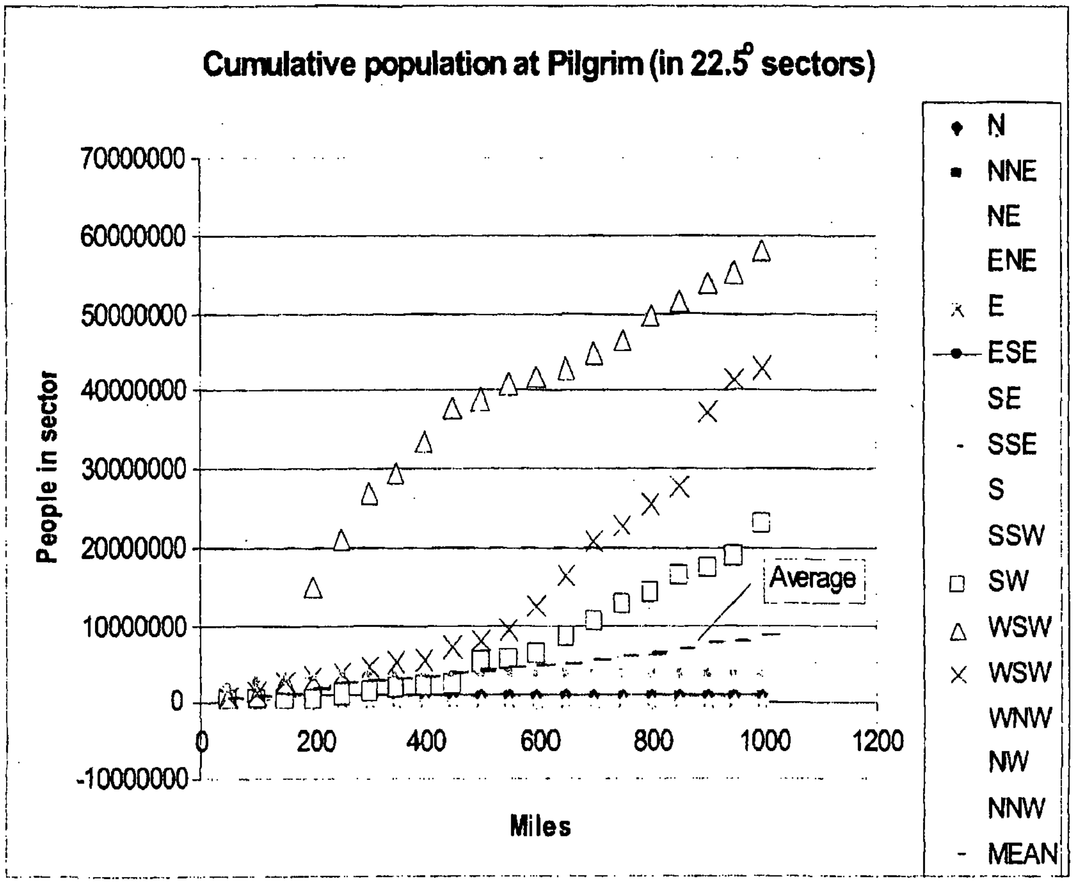


Figure 5: In the wind rose below for Pilgrim, an excess frequency beyond the 4% circle is shown for winds coming from the Southwest, which would blow out over the ocean. Ignoring return flows, such excess flows would not contribute to damage. The excess beyond the 4% circles is about 33% of the total year. Removing this excess leaves a roughly axially-symmetric flow, which matches the assumptions used in the paper by Beyea, Lyman, and von Hippel.

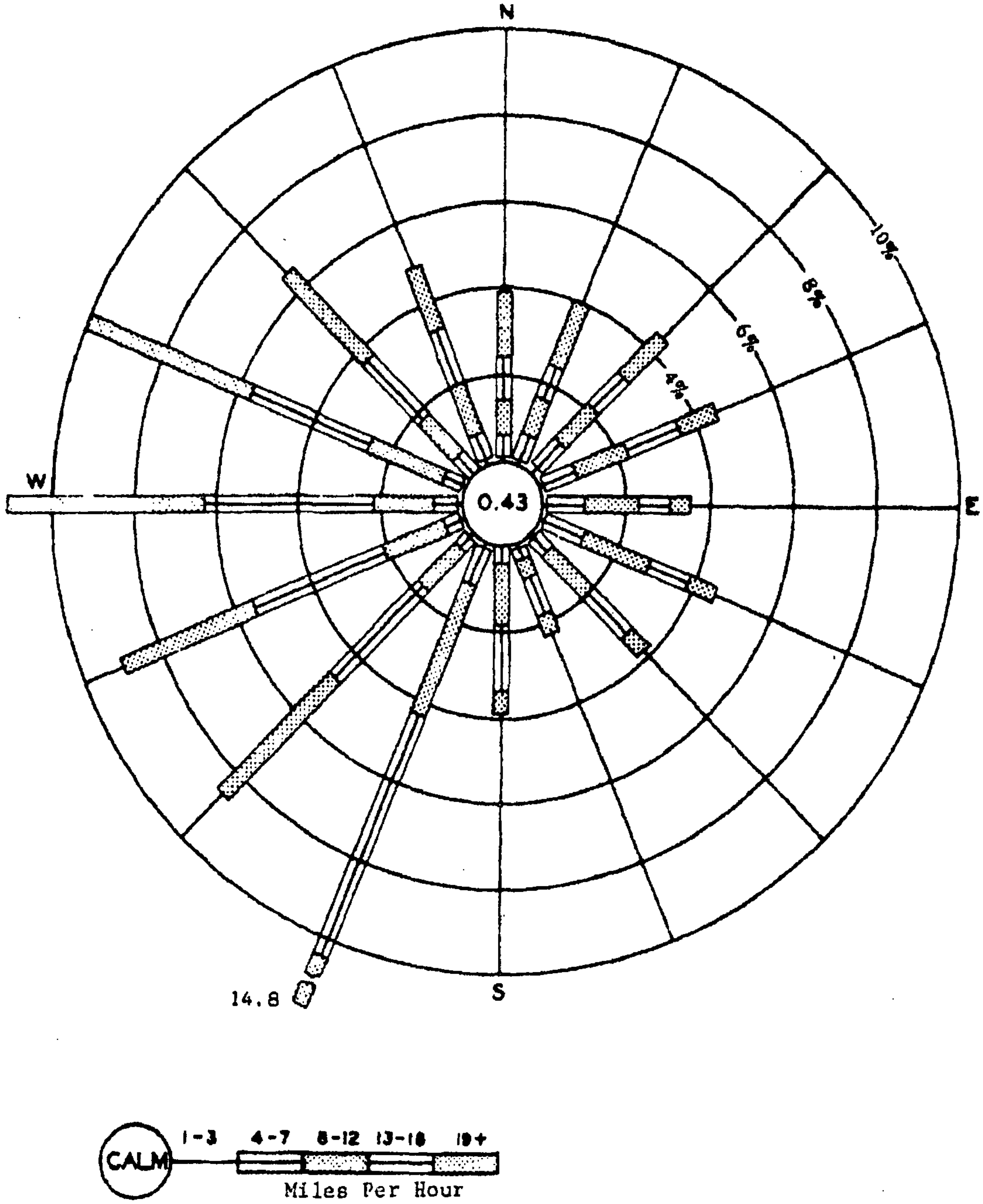


FIGURE 2.3-6
ELEVATION 300 FT. MSL
WIND ROSE ANNUAL
PILGRIM SITE
PILGRIM NUCLEAR POWER STATION
FINAL SAFETY ANALYSIS REPORT

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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.

C|7 Encl

50 pages

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.

Contents

(See next page)

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

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

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[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]

[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.

[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.

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[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

[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]

[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]

[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

[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

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[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

[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.

[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.
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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.