UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of | Docket # 50-293-LR

Entergy Corporation

Pilgrim Nuclear Power Station

License Renewal Application | January 3, 2011

PILGRIM WATCH SAMA REMAND PRE-FILED TESTIMONY

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PILGRIM WATCH SAMA REMAND PRE-FILED TESTIMONY

I. INTRODUCTION

On September 23, 2010, the Board Ordered (Order Confirming Matters Addressed at September 15, 2010, (Telephone Conference), hereinafter "September Order") that the hearing now scheduled for March 2010 will be bifurcated to consider two issues.

According to the September Order (pp. 1, 2),

> [T]he primary and threshold issue [is] "*whether the meteorological modeling in the Pilgrim SAMA analysis is adequate and reasonable to satisfy NEPA, and whether accounting for the meteorological patterns/issues of concern to Pilgrim Watch could, on its own, credibly alter the Pilgrim SAMA analysis conclusions on which SAMAs are cost-beneficial to implement* (hereinafter referred to as "the meteorological modeling issues").

Then, and only "if the Board decides in favor of of Interventors on the primary and threshold issue..., the hearing will proceed to consideration of whether, and the extent to which, additional issues as set forth below will be heard."

The Board also said that "the Board will, if it finds that they were timely raised, consider whether Pilgrim Watch's concerns about the NRC's practice of using mean consequence values in SAMA analyses, resulting in an averaging of potential consequences (hereinafter referred to as 'averaging practice concerns') could bring into question the reasonableness of this NRC practice and affect the Board's findings and conclusions of the the meteorological issues." (September Order)

On November 23, a majority of the Board found "that the mean consequences values issue was not timely raised and therefore the issue will not be entertained by the Board during the evidentiary hearing on Contention 3." (November 23 Order, pp. 1-2).

In view of these Orders, on December 2, 2010, Pilgrim Watch ("PW") submitted to the Board *Pilgrim Watch Memorandum Regarding SAMA Remand Hearing*. As there said, Pilgrim Watch will not present any new evidence at the upcoming SAMA Remand Hearing and will rely solely on what has previously been presented.

The evidence already of record shows, as discussed below, that use of a site-appropriate variable plume model, rather than a straight line Gaussian plume model, could result in significant changes in the areas that would be affected by a serious accident at PNPS.

It is also clear, however, that simply a change in area, "on its own" would not alter the Pilgrim SAMA Analysis. The majority Orders of September 23, 2010 and November 23, 2010 have so limited the scope of the remand hearing (in PW's view improperly) that it would be a "fool's-errand" for PW to expend its limited resources to prepare and submit to the Board additional meteorological evidence for the limited initial phase of the remand hearing, or additional cost evidence for the limited second phase, should a second phase occur.[1]

II. Meteorological Patterns/Issues

The September and November Orders preordain that a majority of this Board will find that "*accounting for the meteorological patterns/issues of concern to Pilgrim Watch could **[not]**, <u>on its own</u>, credibly alter the Pilgrim SAMA analysis conclusions on which SAMAs are cost-beneficial"* (September Order).

It is not possible for either Pilgrim Watch, or anyone else, to show that meteorology, *in and of itself*, would result in a significantly different SAMA analysis. But that is all Pilgrim

[1] As said in PW's memorandum, we of course do not waive, and reserve, all of our appeal rights.

Watch has been left to argue. Further, at least a majority of the Board has effectively again rewritten Contention 3 to require Pilgrim Watch not only to show that "further analysis is required" (as Contention 3 states), but to require that Pilgrim Watch itself conduct the "further analysis" listed in the Appendix to the Order – something that neither it nor any other intervenor could possible do without spending hundreds of thousands of dollars, or should be required to do.

As for whether meteorology "could, on its own, credibly alter the Pilgrim SAMA analysis," the evidence already before the Board shows (as discussed below) that the Gaussian Plume model used by Entergy in its SAMA analysis is non-conservative and deficient, and that if a proper, e.g. a variable plume, model were to be used, the geographical area affected by a "serious" accident, and the deposition within that area, would be different.

But "on its own" using a variable plume model would not alter Entergy's SAMA analysis. That analysis would continue to use the MACCS2 in the same flawed way in which Entergy has used it; in particular Entergy's choice of "source," ill-chosen average (mean) and "probability" would reduce any consequences that resulted from different meteorological inputs to such a low level that they could have no effect on the SAMA cost-benefit analysis.

Moreover, the effect a variable plume would have on even a proper SAMA analysis cannot be determined without running a site-appropriate variable plume model to determine exactly where and how large the affected area might be, and, more importantly, how a major radiological accident could affect that area and what, using an updated computer modeling code with proper inputs, the true resulting costs and damage might be.

Simply stated, Pilgrim Watch has shown (as discussed below) that the meteorological model used by Entergy is deficient. But neither Pilgrim Watch nor anyone else, regardless of how much time and money they might spend, can prove that "meteorological patterns/issues ... could, on its own, credibly alter the Pilgrim SAMA analysis/issues of concern." Contention 3 as admitted should not require Pilgrim Watch to do so.

A Straight-Line Gaussian Plume Model Used by Entergy is Deficient

1. Introduction

PW has submitted significant evidence to the Board and Commission that the straight-line Gaussian plume model does not subsume all reasonably possible meteorologic patterns, and "is not appropriate for the PNPS coastal location." [Egan Dec. at 13[2]] and did not predict site-specific atmospheric dispersion. The MACCS2 code used by Entergy could not model many *site-specific* conditions and did not determine economic costs for Pilgrim's affected area that includes within its 50-mile radius densely populated areas of Boston, Providence, smaller cities and Cape Cod and Islands in summer, located across the bay.

The Gaussian plume model assumes that a released radioactive plume travels in a steady-state straight-line [Egan, 9], i.e., the plume functions much like a beam from a flashlight. The MACCS2 code used by Entergy was based upon this straight-line, steady-state model; it also assumed meterological conditions that are steady in time and uniform spatially across the study region [Egan, 9]. However, PW presented evidence that, "the assumption of a steady-state, straight-line plume are inappropriate when complex inhomogeneous wind flow patterns happen

[2] Dr. Bruce Egan's Declaration: Pilgrim Watch's Answer Opposing Entergy's Motion for Summary Disposition of Pilgrim Watch Contention 3, June 29, 2007, pg., 132. Adams ML071840568, Exhibit 1

to be prevailing in the affected region." [Rothstein[3], 2] The meteorological inputs that Entergy's Gaussian plume model ignored include the variability of winds, sea breeze effects, the behavior of plumes over water, and re-suspension of contaminants.

PW evidence shows another significant defect in Entergy's model - its meterological inputs (e.g., wind speed, wind direction, atmospheric stability and mixing heights) into the MACCS2 are based on data collected by Applicant at a single, on-site anemometer, plus precipitation data from Plymouth airport, some 5 or so miles inland [Application ER, E.1.5.2.6], and that the data is from only one year.

The record before the Board shows that the use of a variable trajectory model could materially affect whether additional SAMAs may be cost-beneficial. Using its straight-line Gaussian plume model, Entergy projected costs could well be as low as $567,000 or even $0.00**.** PW's evidence shows that, using a variable trajectory model, the projected costs could run from $31 to >$100 Billion dollars. [4]

2. PW Evidence Showed Deficiencies of Entergy's Use of a Straight-Line Gaussian Plume Model to Characterize Consequences in Pilgrim's SAMA analysis

Entergy's straight-line, steady-state Gaussian plume model does not allow consideration for the fact that the winds for a given time period may be spatially varying, and it ignores the presence of sea breeze circulations which dramatically alter air flow patterns. Because of these

[3] Richard Rothstein's Declaration: Pilgrim Watch's Answer Opposing Entergy's Motion for Summary Disposition of Pilgrim Watch Contention 3, June 29, 2007, pg., 168. Adams ML071840568, Exhibit 5

[4] Dr. Jan Beyea's Declaration: Pilgrim Watch's Answer Opposing Entergy's Motion for Summary Disposition of Pilgrim Watch Contention 3, June 29, 2007, pgs., 97, 112; Summary Comparison- Population Multiplied by Sensitivity Case, pg., 88-9. Adams ML071840568, Exhibit 2

failings the straight-line Gaussian plume model "is not appropriate for the PNPS coastal location." [Egan 9, 13]

The nearby presence of the ocean greatly affects atmospheric dispersion processes and is of great importance to estimating the consequences in terms of human lives and health effects of any radioactive releases from the facility [Egan, 9], and that the transport, diffusion, and deposition of airborne species emitted along a shoreline can be influenced by mesoscale atmospheric motions. These cannot be adequately simulated using a Gaussian plume model. [Feasibility of Exposure Assessment for The Pilgrim Nuclear Power Plant, Dr. J.D. Spengler and Dr. G.J. Keeler, May 12, 1988, 9]

a. Sea breeze effect

The sea breeze effect, ignored by Entergy's model, is a critical feature to consider at Pilgrim's coastal location. Egan explained, at 10,

> The sea breeze circulation is well documented (Slade, 1968, Houghton, 1985, Watts, 1994, Simpson, 1994)…. [T]he presence of a sea breeze circulation changes the wind directions, wind speeds and turbulence intensities both spatially and temporally through out its entire area of influence. The classic reference *Meteorology and Atomic Energy*, (Section 2-3.5) (Slade, 1968) succinctly comments on the importance of sea breeze circulations as "The sea breeze is important to diffusion studies at seaside locations because of the associated changes in atmospheric stability, turbulence and transport patterns. Moreover its almost daily occurrence at many seaside locations during the warmer seasons results in significant differences in diffusion climatology over rather short distances."

Spengler and Keeler[5], 1988 showed that the sea breeze at Pilgrim's coastal location increases doses on communities inland to an approximate 15 Km (9.3 miles). [Spengler; see also Egan, 12], and that the topography of a coastal environment plays an important role in the sea breeze circulation, and can alter the typical flow pattern expected from a typical sea breeze along a flat

[5] Final Project Report, Feasibility of Exposure Assessment For the Pilgrim Nuclear Power Plant, Prepared for the Massachusetts Department of Public Health, Dr. J.D. Spengler and Dr. G.J. Keeler, May 12, 1988. Exhibit 11

coastline. [Spengler, 40] But as PW showed, "[t]The atmospheric model included in the [MACCS2] code does not model the impact of terrain effects on atmospheric dispersion." 1997 User Guide for MACCS2.

PW's expert specifically contradicted Entergy's expert Kevin O'Kula statements about the sea breeze effect at Pilgrim Station. [Egan, 13, replying to O'Kula's declaration, item 10]

1) [Mr. O'Kula's] statement that the meteorological data collected at the PNPS site would reflect the occurrence of the sea breeze in terms of wind speeds and direction is not necessarily true.
2) A measurement at a single station tower, 220 feet, will not provide sufficient information to allow one to project how an accidental release of a hazardous material would travel.[6] Measurement data from one station will definitely not suffice to define the sea breeze.
3) [Mr. O'Kula's] contention that the seabreeze is 'generally beneficial in dispersing the plume and in decreasing doses' is incorrect. In fact, the development of seabreeze flow that would transfer a release inland is the greatest danger. Contrary to the implications of this declaration, the development of a sea breeze flow is the common meteorological condition that must be most closely monitored at the PNPS.
4) [Mr. O'Kula's] statement reflects a misconception that the sea breeze is "generally a highly beneficial phenomena that disperses and dilutes the plume concentration and thereby lowers the projected doses downwind from the release point." If the same meteorological conditions (strong solar insolation, low synoptic-scale winds) that are conducive to the formation of sea breezes at a coastal site occurred at a non coastal location, the resulting vertical thermals developing over a pollution source would carry

[6] License Application 2.10 Meteorology and Air Quality at 2-31; and at Attachment E, E.1.5.2.6 at E.1-63]

contaminants aloft. In contrast, at a coastal site, the sea breeze would draw contaminants across the land and inland subjecting the population to potentially larger doses.

b. Behavior of Plumes Over Water

Entergy's Gaussian plume model assumed that plumes blowing out to sea would have no impact. PW showed that a plume over water, rather than being rapidly dispersed, will remain tightly concentrated due to the lack of turbulence. The marine atmospheric boundary layer provides for efficient transport. Because of the relatively cold water, offshore transport occurs in stable layers. Wayne Angevine's (NOAA) research of the transport of poluttants on New England's coast concluded that major pollution episodes along the coast are caused by efficient transport of pollutants from distant sources. "The transport is efficient because the stable marine boundary layer allows the polluted air masses or plumes to travel long distances with little dilution or chemical modification. The sea-breeze or diurnal modulation of the wind, and thermally driven convergence along the coast, modify the transport trajectories." Therefore a plume will remain concentrated until winds blow it onto land. [Zager et al.; Angevine et al. 2006[7]]. This can lead to hot spots of radioactivity in places along the coast, certainly to Boston. [Beyea, 11] The compacted plume also could be blown ashore to Cape Cod, directly across the Bay from Pilgrim and heavily populated in summer. [Rep. Patrick, 2] An alternative model that Entergy did not use, CALPUFF, could provide the ability to account for reduced turbulence over water and could be used for sensitivity studies. [Beyea, 11-12].

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[7] Angevine, Wayne; Tjernström, Michael; Žagar, Mark, Modeling of the Coastal Boundary Layer and Pollutant Transport in New England, Journal of Applied Meteorology and Climatology 2006; 45: 137-154, Exhibit 6

c. Storms

"The storm cycle consists generally of northeasters in the winter and spring (and) [h]Hurricanes sometimes occur in the late summer and fall." [Applicant's LA Apprendix E, 2-31]. The accompanying strong and variable winds would carry a plume to a considerable distance.

d. Geographical Variations, Terrain Effects, and Distance

PW showed that topography of a coastal environment plays an important role in the sea breeze circulation, and can alter the typical flow pattern expected from a typical sea breeze along a flat coastline. [Spengler, 40] But "[t]The atmospheric model included in the [MACCS2] code does not model the impact of terrain effects on atmospheric dispersion." [1997 User Guide for MACCS2.]

The Gaussian plume model also does not take terrain effects, which PW showed can have a highly complex impact on wind field patterns and plume dispersion, into account. Wind blowing inland will experience the frictional effects of the surface which decrease speed and direction. [PW Motion to Intervene, May 25, 2006 citing Lyman, *Chernobyl on the Hudson*, 27; Rothstein, Appendix A].

EPA has recognized that "geographical variations can generate local winds and circulations, and modify the prevailing ambient winds and circulations" and that "a*ssumptions of steady-state straight-line transport both in time and space are inappropriate.*" [EPA Guidelines on Air Quality Models (Federal Register Nov. 9, 2005, Section 7.2.8, Inhomogeneous Local Winds, italics added EPA's November 9, 2005 modeling Guideline (Appendix A to Appendix W) lists EPA's "preferred model;" the Gaussian plume model used by Entergy (ATMOS) is not on the list. EPA recommends that CALPUFF, a non-straight-line model, be used for dispersion beyond 50 Km.[8]

The essential difference between the models that EPA recommends for dispersion studies and the two-generation-old Gaussian plume model (ATMOS) used by Entergy and the NRC is more than determining where a plume will likely to go. Major improvements in the simulation of vertical dispersion rates have been made in the EPA models by recognizing the importance of surface conditions on turbulence rates as a function of height above the ground (or ocean) surfaces. We know that turbulence rates and wind speeds vary greatly as a function of height above a surface depending upon whether the surface is rough or smooth (trees vs over water transport) (Roughness), how effectively the surface reflects or absorbs incoming solar radiation (Albedo) and the degree that the surface converts latent energy in moisture into thermal energy (Bowen ratio). These parameters are included in the AERMOD and CALPUFF models and determine the structure of the temperature, wind speed and turbulent mixing rate profiles as a function of height above the ground. Entergy's ATMOS model does not include these parameters. This is an especially important deficiency when modeling facilities located along coastlines, such as Pilgrim.

3. PW Evidence Showed That Entergy's Inputs to the MACCS2 Code Were Deficient and Did Not Account for Site-Specific Conditions

a. Meteorological Inputs

One fundamental defect in Entergy's use of the MACCS2 code is that its meterological inputs to that code are all based on the straight-line Gaussian plume model. PW showed that this model does not allow consideration of the fact that the winds for a given time period may be

[8] Appendix A to Appendix W to 40 CFR Part 51, EPA Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule, November 9, 2005. http://www.epa.gov/ scram001/guidance/guide/appw_05.pdf.

spatially varying. [Egan, 9] The 1997 User Guide for MACCS2, SAND 97-0594[9] makes a related point: "The atmospheric model included in the code does not model the impact of terrain effects on atmospheric dispersion."

Indeed, the MACCS2 Guidance Report, June 2004,[10] is even clearer that Entergy's inputs to the code do not account for variations resulting from *site-specific* conditions such as those present at PNPS. (1)The "code does not model dispersion close to the source (less than 100 meters from the source)." Thereby ignoring resuspension of contamination blowing offsite. (2) The code "should be applied with caution at distances greater than ten to fifteen miles, especially if meteorological conditions are likely to be different from those at the source of release." There are large potentially affected population concentrations more than 10-15 miles from Pilgrim - for example: Boston, Providence, Brockton, New Bedford, Fall River, Quincy, Cape Cod. (3) "Gaussian models are inherently flat-earth models, and perform best over regions where there is minimal variation in terrain." Entergy description of the PNPS site says that the, "[t]opography consists of rolling forested hills interspersed with urban areas." [Lic.A, Appendix E, 2-1]

A second defect in the Applicant's inputs into the MACCS2 code lies in the data itself. Entergy input meteorological data for only a single year [O'Kula Dec. at 21; WMSM at 22], and except for precipitation all of the data was collected from a *single, on-site* weather station. [Application ER, E.1.5.2.6]

PW showed that one year of data would have been insufficient even if more than one station had been used; "Seasonal wind distributions can vary greatly from one year to the next." [Spengler and Keeler Report, Page 22]. "*The NRC staff considers 5 years of hourly*

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9 Chanin, D.I., and M.L. Young, Code Manual for MACCS2:Volume 1, User's Guide, SAND97-0594 Sandia National Laboratories, Albuquerque, NM, (1997)

10 MACCS2 Guidance Report June 2004 Final Report page 3-8:3.2 Phenomenological Regimes of Applicability, Exhibit 21

observations to be representative of long-term trends at most sites," although "with sufficient justification [not presented by Entergy here] of its representativeness, the minimum meteorological data set is one complete year (including all four seasons) of hourly observations." (NRC Regulatory Guide 1.194, 2003)

The simple fact is that measurements from a single 220' high anemometer will not provide sufficient information to project how an accidental release of a hazardous material would travel. [Egan, 13] For cases when the sea breeze was just developing and for cases when the onshore component winds do not reach entirely from the ground to the anemometer height. The occurrence of a sea breeze would not be identified. The anemometer would likley indicate an offshore wind indication. Furthur PW demonstrated that basing wind direction on the single on-site meteorological tower data ignores "shifting wind patterns away from the the Pilgrim Plant including temporary stagnations, re-circulations, and wind flow reversals that produce a different plume trajectory." [Rothstein, Town of Plymouth Nuclear Matters Committee Recommendation to Selectmen, Appendix A Meteorology, 13, Exhibit 5, Exhibits 3,4]

"Since the 1970s, the USNRC has historically documented all the advanced modeling technique concepts and potential need for multiple meteorological towers especially in coastal regions." [Rothstein, June 24, 2006 letter, 2] NRC Regulatory Guide 123 (Safety Guide 23) On Site Meteorological Programs 1972, states that, "at some sites, due to complex flow patterns in non-uniform terrain, additional wind and temperature instrumentation and more comprehensive programs may be necessary."[Ibid., cited in Appendix 1]; and an EPA 2000 report, Meteorological Monitoring Guidance for Regulatory Model Applications, EPA-454/R-99-005, February 2000, Sec 3.4 points to the *need for multiple inland meteorological monitoring sites.* See also Raynor, G.S.P. Michael, and S. SethuRaman, 1979, Recommendations for

Meteorological Measurement Programs and Atmospheric Diffusion Prediction Methods for Use at Coastal Nuclear Reactor Sites. NUREG/CR-0936.

Entergy should have taken data from more locations over a longer period; and modified the MACCS2 code to account for the inability of the code that Entergy used to account for site-specific conditions. "The user has total control over the results that will be produced." [1997 User Guide, Section 6.10].

Finally, PW presented evidence that statements made in the O'Kula declarations that were relied on by Entergy to support its contention that the inputs into the MACCS2 code were sufficient are incorrect or misleading. As Egan, at 13, established,

1) MACCS2 is not a state-of-the-art computer model. It does not rely upon or utilize current understandings of boundary layer meteorological parameterizations such as those adopted by the EPA in the models AERMOD OR CALPUFF (EPA, 2001).
2) The Gaussian plume model employed in the PNPS MACCS2 model may be the standard for NRC but it is not the basis for advanced modeling used by other US regulatory agencies.
3) Computational time should not be a major factor in the choice of a dispersion model used for non-real time applications. Contrary to Entergy, these applications are not "simply impracticable"
4) The idea that randomly chosen meteorological conditions would give the same results as inputting meteorological conditions as a function of time is erroneous. To accommodate the real role of persistence in dispersion modeling EPA requires sequential modeling for all averaging times from 3 hour averages to annual averages.

5) The fact that a model may seem to be conservative in particular applications or in limited data comparisons does not mean that the model is better or should be recommended. Models can be conservative but have incorrect simulations of the underlying physics. Sensitivity studies do not add useful information if the primary model is flawed.

b. The Affected Area

The evidence presented by PW also established important disputes of material fact with respect to Entergy's *site specific* meteorology-related economic inputs into its MACCS2 code analyses. Pilgrim Watch evidence showed that Entergy choices of inputs consistently and significantly underestimated the economic consequences of a radioactive release from PNPS.[11]

Entergy's choice of a straight-line Gaussian plume rather than a variable trajectory model drastically reduced, to a wedge, the size of the area that might potentially be impacted by a release. Entergy's analyses also assumed a "small" accident that had no real impact beyond 10 miles. Entergy did not consider the potential of the by far largest, and perhaps also the most likely, potential radiological release – from the spent fuel pool. In addition, Entergy chose to use the MACCS2 Code that, *absent site specific modifications that Entergy chose not to make*, cannot provide credible cost estimates.

The use of a variable trajectory model, rather than the straight-line Gaussian plume, would have significantly increased the area potentially affected by a released readioactive plume, and thus would also greatly increase the size of the affected population and property, and the economic effect, beyond 10 miles.

[11] Beyond its statements that PW's challenges were "immaterial," the Board majority opinion gives no indication of what PW evidence the majority actually considered. In dissent, Judge Young said that "my colleagues apply a standard that overlooks or ignores genuine issues of material fact that Intervenors present through reputable experts, as well as considerations of practical reality and fundamental fairness." [LBP-06-848, 02-LR, at 40]

Entergy admits that its MACCS2 analysis does not assume an evacuation zone of greater than 10 miles because "to do so would not be realistic" [Sowden, 4-5]. Entergy's KLD Time Estimates assume that the only area to be evacuated will be an area 2-miles around the reactor and the area within the "key-hole" from 2-5 miles, or perhaps extended within the key-hole, 5-10 miles. [Sowden, 3; KLD 1998 Report, 9-1.; and KLD 2004 Report, 2-2]. A variable plume analysis would increase the "potentially affected area" to far more than 2 miles around the plant and a few miles within the key-hole, resulting in potentially far greater risk and damage and also increasing evacuation time estimates. Despite orders to the contrary, more people inside and outside the EPZ will self evacuate. [Martecchini, 3; Zeigler,1-2]

PW showed that the consequences from a severe accident would not be restricted to a key-hole shaped wedge within a 10 mile radius, or to the entire populated area within 10 miles, but rather could encompass a much wider area including the densely populated metropolitan areas of Boston (38 miles NNW), Providence (44 miles SW), smaller cities of Quincy, Brockton, New Bedford and Fall River, and the summer population of Cape Cod and the Islands. The majority of the Cape's population is within 10-20 miles; the summer population approximates 600,000, the year round about 210,000. [Rep. Patrick, 2]

A second major defect in the MACCS2 inputs is that Entergy apparently assumed that the only source of radiation in the event of an accident would be from the reactor within the containment. The potentially far greater source of leaked radiation, the spent fuel pool, contains far more radioactive material and is located outside the containment. It was ignored. [Beyea Decl.]

Absent modifications to permit inputs that address the MACCS2 code limitations discussed above, the MACCS2 code used by Entergy is incapable of providing an accurate estimate of economic consequence, here. David Chanin author of the code said, "If you want to discuss economic costs … the 'cost model' of MACCS2 is not worth anyone's time. My sincere advice is to not waste anyone's time (and money) in trying to make any sense of it." (and) "I have spent many many hours pondering how MACCS2 could be used to calculate economic costs and concluded it was impossible." [Chanin Decl.]

c. NEPA's Rule of Reason

(1) Meteorological plume model: CLI-10-22, pg., 9 emphasized, as they had done earlier, that NEPA requirements are "tempered by a practical rule of reason" and an environmental impact statement is not intended to be a "research document." If relevant or necessary meteorological data or modeling methodology prove to be unavailable, unreliable, inapplicable, or simply not adaptable for evaluating the SAMA analysis cost-benfit conclusions, there may be no way to assess, through mathmatical or precise model-to model comparisons, how alternative meteorological models would change the SAMA analysis results."

The plume modeling that PW presented as appropriate for Pilgrim's SAMA analysis, instead of Entergy's decision to use the straight line Gaussian model, are not techniques that require research. They are, in fact, established methods that are publically available, routinely used, and appropriate for quantifying atmospheric dispersion of contaminants. (Appendix 2 lists examples from government and independent sources) Although an effort may be required to adapt these methods for SAMA analyses, this would be very straightforward and research would not be required.

Appropriate meteorological data or modeling methodology is available. There is no shortage of appropriate meteorological data for a licensing model application. Alternative modeling methods that would use more extensive meteorological data are also available.

The applicant chose to use only one year of onsite data collected at the Pilgrim's site. Meteorological data is also available from nearby airports and, importantly, processed data on a gridded basis can be obtained from NOAA to augment the onsite meteorological data relied upon for the SAMA analyses that have been provided by Entergy. PW demonstrated this by disclosing, for example, the Jennifer Thorpe[12] site-specific meteorological study and Spengler and Keeler study (both Dr. Egan and Hanna attended the studies sea breeze workshop, Chapter 8 of Spengler's study) and Dr. Egan's "Development of a Dispersion Modeling Capability for Sea Breeze Circulations and other Air Flow Patterns over Southeastern Massachusetts, Upper Cape Cod Modeling Study," that used available meteorological data. Also there are several publically available meteorological modeling methods that can simulate variable trajectory transport and dispersion phenomena. MM5 is one which is routinely used nationally and internationally. There are other options as well. The present state of art of an appropriate meteorological model would use multi station meteorological measurement data as input to the meteorological model. The numerical computations, based upon numerical weather prediction techniques, would compute wind fields appropriate for modeling dispersion over a much larger geographic area than the a single measurement site would be appropriate for.

A second reasonableness criterion is that the modeling method must be reliable. The outputs from such meteorological models that are used to produce inputs for the dispersion

[12] Thorp, Jennifer E., Eastern Massachusetts Sea Breeze Study, Thesis Submitted to Plymouth State University in Partial Fulfillment of the Requirements for the Degree of Master of Scince in Applied Meteorology, May 2009. Exhibit 10

models are well accepted and form the basis for the weather predictions provided by the national weather service as well as analyses of air pollution impacts of concern to regulatory agencies . These techniques have been proven to be reliable and acceptable for air quality permitting and policy applications in complex terrain and over large distances for the US EPA , the US Park Service as well as internationally. PW argued with sufficient particularity that for complex meteorological situations such as for the Pilgrim, these techniques would be *more* reliable than using the straight line Gaussian model.

The third reasonableness criterion is that the modeling methods be applicable to SAMA analyses. The methods PW recommended are applicable because with straightforward modifications to incorporate nuclear radiation decay rates, they can produce the fields of concentration values and deposition rates needed for dosage calculations.

The fourth reasonableness criterion is that the modeling methodology be adaptable for evaluating SAMA analysis cost benefit conclusions. There is nothing inherent in variable trajectory models that would prohibit the output concentration and deposition fields from being applied to SAMA analyses.

None of the criteria cited would make the use of alternative models unreasonable to apply to the Pilgrim's SAMA analyses.

Further there is no basis to the argument that there may be no way to assess through mathematical or precise model to model comparisons, how alternative meteorological models would change the SAMA analysis results. Some assessments may necessarily be qualitative, based simply upon expert opinion. But this argument seems to undercut the very value of mathematical simulation models in general as a method to assess the impacts of nuclear reactor emissions.

Last, the rationale offered that the use of advanced models would be computationally too expensive and/or burdensome to use are not justified by the actual run time shown in our review of MACCS2 output files. With modern computers, the use in inappropriate models on the basis of differences of computational costs is indefensible.

Invoking the "practical rule of reason" to the present disagreement about the most appropriate modeling methodology for application to the Pilgrim SAMA analyses is blatantly dismissive of the concept that the present methods are inappropriate and outdated and that there are indeed alternative modeling available.

(2) MACCS2 risk consequence code: The Applicant's SAMA analysis uses MELCOR Accident Consequence Code System (MACCS2) computer program. PW stated the plain fact that there is no NRC regulation *requiring* the use of that code, or any other particular code. It was Entergy's choice. There are other consequence computer codes in use for nuclear accidents around the world. Research is not necessary. Alternatively modifying the code with updated assumptions and inputs is clearly reasonable for a site-specific, Category 2 analysis.

B. The Board Majority's Specific Questions (Board Order, Appendix A, Sept., 23, 2010)

Appendix A to the September 23, 2010 Board order asked parties to address specific issues concerning meteorological patterns raised by Pilgrim Watch, limited to only the sea-breeze effect and the hot spot effect.

Pilgrim Watch has attempted to do so below. It appears, however, that the questions avoid significant meteorological issues brought forward by PW in these proceedings that are pertinent to understanding how Entergy underestimated the likely area impacted in a severe accident and deposition in that area; pertinent to answering the specific questions; and that should not be ignored. At the risk of being repetitive, these include:

ASLB's Questions Avoid Significant Meteorological Issues Brought Forward

1. Data Source:

PW demonstrated (PW Response to CLI pages 8-9) that basing wind direction on the single on-site meteorological tower data ignores "shifting wind patterns away from the Pilgrim Plant including temporary stagnations, re-circulations, and wind flow reversals that produce a different plume trajectory." [Motion to Intervene, Pg., 36; Rothstein, Town of Plymouth Nuclear Matters Committee Recommendation to Selectmen, Appendix A Meteorology, 13]

"Since the 1970s, the USNRC has historically documented all the advanced modeling technique concepts and potential need for multiple meteorological towers especially in coastal regions." [Rothstein, June 24, 2006 letter, 2] NRC Regulatory Guide 123 (Safety Guide 23) On Site Meteorological Programs 1972, states that, "at some sites, due to complex flow patterns in non-uniform terrain, additional wind and temperature instrumentation and more comprehensive programs may be necessary."[Ibid., cited in Appendix 1]; and an EPA 2000 report, Meteorological Monitoring Guidance for Regulatory Model Applications, EPA-454/R-99-005, February 2000, Sec 3.4 points to the *need for multiple inland meteorological monitoring sites.* See also Raynor, G.S.P. Michael, and S. SethuRaman, 1979, Recommendations for Meteorological Measurement Programs and Atmospheric Diffusion Prediction Methods for Use at Coastal Nuclear Reactor Sites. NUREG/CR-0936.

Entergy should have taken data from more locations over a longer period; and modified the MACCS2 code to account for the inability of the code that Entergy used to account for site-specific conditions. "The user has total control over the results that will be produced." [1997

User Guide, Section 6.10]. There are many other data sources available for coastal Massachusetts and SE Massachusetts, in general.

2. Single-Year data: (CLI , Pg.,8)

PW showed that one year of data would have been insufficient even if more than one station had been used; "Seasonal wind distributions can vary greatly from one year to the next." [Spengler and Keeler Report[13], Page 22]. "*The NRC staff considers 5 years of hourly observations to be representative of long-term trends at most sites,"* although "with sufficient justification [not presented by Entergy here] of its representativeness, the minimum meteorological data set is one complete year (including all four seasons) of hourly observations." (NRC Regulatory Guide 1.194, 2003)

3. Precipitation, Moisture, Fog[14].

Entergy failed to properly account for another site specific characteristic in Pilgrim's coastal location - precipitation, moisture, fog – that affects dispersion (concentration) and hence the cost-benefit analysis. Dispersion (concentration) is affected by precipitation that, like wind flow, is highly complex. Fog varies along the coast and also in the interior, affected by bogs and ponds. Fog with low inversion layer and constant easterly winds could result in less dispersion of the plume. Because fog patches and precipitation can be highly localized, precipitation data from one location at Plymouth Airport 5 or so miles inland is inadequate. [PW Motion to Intervene, 3.3.3.1.c]

> "…worst case scenario of exposure from a release at the Pilgrim Plant may (be)… drizzly, foggy day with a low inversion layer and constant easterly winds (because they) could potentially have less dispersion." (Spengler, Decl., pg., 35)

[13] Feasibility of Exposure Assessment For The Pilgrim Nuclear Power Plant- prepared for the Massachusetts Department of Public Health, Dr. J.D. Spengler and Dr. G.J. Keeler, May 12, 1988; Egan Decl., at 12 "I support (Spengler's and Keeler's) analysis of the sea breeze effects and their general recommendations."

[14] http://www.mass.gov/czm//oceanmanagement/waves_of_change/pdf/troceancc.pdf

4. Storms:

"The storm cycle consists generally of northeasters in the winter and spring (and) [h]Hurricanes sometimes occur in the late summer and fall." [Applicant's LA Appendix E, 2-31]. The accompanying strong and variable winds would carry a plume to a considerable distance. (CLI-09) Coastal storms are an intricate combination of events that impact a coastal area. A coastal storm can occur any time of the year and at varying levels of severity; common to coastal storms are high winds, erosion, heavy surf and unsafe tidal conditions, and fog.[15] Massachusetts is susceptible to high wind from several types of weather events, including, hurricanes and tropical storms, tornados, and nor'easters.

PW brought forward these issues forward throughout these proceedings beginning in PW's Request for Hearing May 25, 2006 at 37-38. There PW said that,

> However with onshore winds the tower measurements do not reflect the effects of the overland conditions. The wind is likely to be slightly stable as it approaches land and Pilgrim's meteorological tower. As air flows over a heated surface thermally generated turbulence is induced. Under sea breeze conditions the turbulence structure of the atmosphere will not be accurately determined by the meteorological sensors at the coastal site. Dispersion is also affected by precipitation. Like wind flow, precipitation is highly complex - for example, fog patches vary along coastal locations and also in the interior affected by ponds and bogs. On a drizzly, foggy day with a low inversion layer and constant easterly winds there would potentially be less dispersion than a clear day with strong winds and a sea breeze. Fog patches and precipitation can be highly localized therefore precipitation data from one location at Plymouth Airport located *5* or so miles inland are inadequate. To obtain an accurate analysis it is necessary to install continuous recording meteorological instruments along the coast and at additional inland sites in the communities likely to be impacted by Pilgrim, for example the 7 towns identified by Spengler and Keeler (see Exhibit C). The parameters measured should include wind speed and direction, temperature, dew point, and solar insulation. This would allow an analysis which could more adequately analyze the penetration of the sea breeze front and better

[15] Commonwealth of Massachusetts -State Hazard Mitigation Plan,2007http://www.mass.gov/Eeops/docs/mema/disaster_recovery/state_plan_2007_rvn4.pdf at 1.2 Natural hazards

characterize the spatial variation of the wind flow. The NRC has acknowledged that more meteorological data may be required. In Regulatory Guide 1. 194, this subject is discussed as follows: "The NRC staff considers *5*years of hourly observations to be representative of long-term trends at most sites. With sufficient justification of its representativeness, the minimum meteorological data set is one complete year (including all four seasons) of hourly observations" (NRC, 2003). Despite the fact that several site specific reports (see Exhibit C) have been prepared for Pilgrim that show one year of observations gathered from one site will not satisfy this "representativeness" requirement, the Applicant has used only one year's worth of observations, gathered from only one location. The inputs into the MACCS2 Code are inadequate. In Exhibit E Petitioners describe an improved scheme for meteorological monitoring. This improved monitoring will not just provide better inputs for this kind of Severe Accident Modeling, but it is also a necessary tool for Emergency Planning.

APPENDIX A, SEPTEMBER 23, 2010 – QUESTIONS

Q.1. Regarding the meteorological phenomena at issue in this remand hearing, describe in depth each of the following, with supporting data also provided, to the extent available:

Q.1.a. The <u>annual frequency</u> of occurrence of the "sea breeze" effect and the "hot spot" effect, and the respective duration of each such occurrence

1. The annual frequency of the sea breeze effect and the "hot spot" effect cannot be known without reviewing data from multiple weather stations and over at least a 5-year period. This is the "further analysis" that is properly the responsibility of the Applicant, not the Petitioner. Data is available. For example, NOAA lists multiple weather stations in SE Massachusetts. Included, for example, are Logan Airport, Cape Cod Canal, Scituate Harbor, Plymouth Airport, Taunton, Chatham, and Hyannis.

PW's expert, Dr. Egan, was clear that data from Pilgrim's single 220' high anemometer will not provide sufficient information to determine the frequency of sea breeze and the hot spot effects. [See Egan, 13, replying to O'Kula declaration, item 10] A measurement at a single station tower, 220 feet, will not provide sufficient information to allow one to project how an accidental release of a hazardous material would travel.[16] For cases when the sea breeze was just developing and for cases when the onshore component winds do not reach entirely from the ground to the anemometer height, the occurrence of a sea breeze would not be identified. The anemometer would likely indicate an offshore wind indication. (CLI, Pg., 8) This was also explained in PW Motion to Intervene, May 25, 2006 at 36-38.

2. <u>A sea-breeze</u> (or onshore breeze) is a wind from the sea that develops over land near coasts. It is formed by increasing temperature differences between the land and water which create a pressure minimum over the land due to its relative warmth and forces higher pressure, cooler air from the sea to move inland. Therefore in Plymouth's climate, "while the sea breeze can occur throughout the year, it occurs *most frequently* during the spring and summer months when the land warms up relative to the ocean. On average, Pilgrim experiences about 45 sea breeze days during these two seasons. Typically the onshore component commences round 10 AM and can persist to about 4 PM." (Spengler and Keeler, page 1) Late afternoon, the land cools off quicker than the ocean due to differences in their specific heat values, which forces the dying of the daytime sea breeze. If the land cools below that of the adjacent sea surface temperature, the pressure over the water will be lower than that of the land, setting up a land breeze as long as the environmental surface wind pattern is not strong enough to oppose it. The breeze, and plume, will swing back out to sea. Seasonal wind distributions can vary greatly from one year to the next" (Ibid, p., 22)

3. The "hot spot" effect can occur in combination with the sea breeze or when winds headed intially offshore are blown back towards shore due to wind shifts. The prevailing wind direction

[16] License Application 2.10 Meteorology and Air Quality at 2-31; and at Attachment E, E.1.5.2.6 at E.1-63]

at Plymouth is from the south west,[17] heading generally towards the Outer-Cape Cod or Provincetown. Although, seasonal wind distributions can vary greatly from one year to the next" (Spengler, p., 22)

MTC Community Wind Collaborative – Town of Plymouth *August 2008*

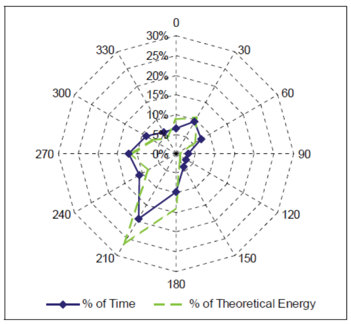

Figure 6 - Measured Wind Rose from May 2007 to April 2008

In comparison, Figure 7 is the measured wind rose from the Plymouth Municipal Airport weather station from July 1996 to March 2008; it also indicates a primary southwest wind direction, in both frequency of time and energy.

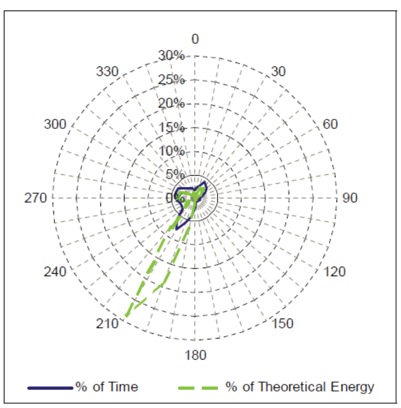

Figure 7 - Measured Wind Rose from Plymouth Municipal Airport

4. The annual frequency of occurrence and duration of the "sea breeze" effect and the "hot spot" effect was made irrelevant by the Board's October 16, 2006 and November 23, 2010 Orders, that respectively took Entergy's use of probabilities and averaging off the table. Although both the sea breeze and hot spot effects increase the area likely to be impacted (areas

[17] Town of Plymouth Wind Energy Feasibility Study, DNV Global Energy Concepts, Inc., August 2008' Pg., 3-5: online at: http://www.masstech.org/Project%20Deliverables/Comm_Wind/Plymouth/PlymouthWWTPFinalFeasibilityStudy.pdf

of greater population density) and the deposition in that area, both are trivialized by Entergy's choice to use an extremely low likelihood of an accident and the mean as an average instead of the 95th percentile. Entergy used hourly meteorological data from 2001 (WSMS, p., 6) yielding 8760 observations. There are, on average, 45 sea breeze days a year; i.e., 12 percent of the 365 days in a year. This impact would not be reflected by Entergy's use of a mean average; its impact would be reflected if Entergy had used the 95% percentile.

Q.1.b. The <u>spatial and time-dependent pattern of wind and other meteorological phenomenological parameters associated with each such occurrence</u>, or, if such data are not available, expert professional opinion for such parameters, and scientific literature references supporting those opinions

1. The Gaussian plume model assumes that a released radioactive plume travels in a steady-state straight-line [Egan, 9], i.e., the plume functions much like a beam from a flashlight. The MACCS2 code used by Applicant is based upon this straight-line, steady-state model; it also assumes meteorological conditions that are steady in time and uniform spatially across the study region [Egan, 9]. Entergy's expert, Kevin O'Kula acknowledges that the "MACCS2 does not model spatial variation in weather conditions." (WSMS Report, pg., 13)

2. PW presented evidence to the Board and Commission that, "the assumption of a steady-state, straight-line plume are inappropriate when complex inhomogeneous wind flow patterns happen to be prevailing in the affected region." (Rothstein, p., 2)

<u>Sea Breeze</u>

3. PW's expert, Dr. Bruce Egan's declaration responded to the Board's question.

> The MAACS2 code is based upon a straight line, steady state Gaussian plume equation that assumes that meteorological conditions are steady in time and uniform

spatially across the study region for each time period of simulation. It does not allow consideration for the fact that the winds for a given time period may be spatially varying. For example, the wind speeds and directions over the ocean and over the land near the Pilgrim Nuclear Power Station (PNPS) are assumed to be the same. Thus the presences of sea breeze circulations which dramatically alter air flow patterns are ignored by the model. As discussed later, the nearby presence of the ocean greatly affect atmospheric dispersion processes and is of great importance to estimating the consequences in terms of human lives and health effects of any radioactive releases from the facility (Egan Decl., item 8)

And

The sea breeze circulation is well documented (Slade, 1968, Houghton, 1985, Watts, 1994, Simpson, 1994).The pressure differences that result in the development of a sea breeze essentially start over the land area well after sunrise. Along a coast, the sun heats the land surfaces faster than water surfaces. The warmer air above the land is more buoyant and initially rises vertically. The resulting lower pressure over the land draws air horizontally in from surrounding areas. Near a coast, the air over the water is cooler and denser and is drawn in to replace the rising air. This horizontal flow represents the advent of the sea breeze. The air starting to flow over the land is cooler than the air aloft and like any dense gas tends to resist upward vertical motions and prefers to pass around a terrain obstacle rather than up and over it. The density difference also suppresses turbulence that would mix the air vertically. As this air flows over the rougher and warmer land, an internal boundary layer is created which grows in height within the land bound sea breeze flow. Further inland the flow slows and warms and creates a return flow aloft which flows much more gently back out over the ocean to complete the overall circulations. Thus, the presence of a sea breeze circulation changes the wind directions, wind speeds and turbulence intensities both spatially and temporally through out its entire area of influence. The classic reference *Meteorology and Atomic Energy*, (Section 2-3.5) (Slade, 1968) succinctly comments on the importance of sea breeze circulations as "The sea breeze is important to diffusion studies at seaside locations because of the associated changes in atmospheric stability, turbulence and transport patterns. Moreover its almost daily occurrence at many seaside locations during the warmer seasons results in significant differences in diffusion climatology over rather short distances."

Regarding the model's ability to take into account meteorological conditions as a function of time, Dr, Egan explained that,

> [Entergy's expert, O'Kula's] declaration seems to state that randomly chosen meteorological conditions would give the same results as inputting meteorological conditions as a function of time. This is an erroneous concept with real meteorology which does not generally behave in a random manner. In order to take into account meteorological conditions 'as a function of time' a model must process the meteorological data sequentially with time. A common phenomena in weather data analysis is the role of persistence of combinations of meteorological events over periods of hours to many days. The probability that the next hour's meteorology will be similar to the previous hour's or that tomorrows weather will be like today's is fairly high and certainly not random or independent of what happened in the previous time period . It also matters from an air quality point of view if winds are very low and dispersion very small for several hours in a row. To accommodate the real role of persistence in dispersion modeling EPA requires sequential modeling for all averaging times from 3 hour averages to annual averages. (Egan Decl., item 12 Comments on O'Kula's declarations, item 16)

PW further explained in its Motion to Intervene:

> 3.3.3.1. a Wind speed: Accurately characterizing wind speed is critical to estimating concentration sea breeze will decrease wind speed as they move over land.
> 3.3.3.1. b Wind Direction Wind direction will change with height above the ground and will be influenced by terrain features. The coriolis effect will cause a clockwise turning of the wind direction as the sea breeze develops over the course of the day. This effect is reflected in the coastal wind sensor, but the effect of surface friction and surface features are not. As a result wind blowing inland will experience the frictional effects of the surface which decreases speed and changes direction.

3. Entergy's expert's declaration (O'Kula WSMS Report, pg., 21) agreed that sea breezes are sometimes recognized to be able to penetrate long distances inland. Simpson (1994) shows evidence of sea breeze penetrations up to 300 km inland over a period of 15 hrs in Australia. Although not all coastal locations will experience such a large inland penetration, Simpson (1994) noted that penetrations on the south coast of England up to 100 km inland. Buckley and Kurzeja (1997) found evidence of sea breeze penetration over 100 km on the South Carolina coast. Penetration on Massachusetts southern coast have not been fully documented; yet data

gathered to date do not indicate deep penetration. However the important point is that as O'Kula acknowledges "meteorological data collected on towers at the Pilgrim site do not reflect the occurrence of sea breeze conditions in both the wind speed and direction." (O'Kula report, pg., 21)

4. Wind direction will change with height above the ground and will be influenced by terrain features. The coriolis effect will cause a clockwise turning of wind direction as the sea breeze develops during course of the day and eventually heads back to sea. [Spengler and Keeler, Pg., 39]

5. The topography of the coastal environment also plays an important role in the sea breeze circulation. When cool, dense, stable marine air encounters a hill or mountain, the heavy air tends to flow around them rather than over them. This can alter the flow pattern expected from a typical sea breeze along a flat coastline. [Spengler and Keeler, Pg., 6] Hence, a larger area becomes impacted.

6. Note that there can be larger (synoptic) scale weather patterns that are interacting with seabreeze conditions and vice-versa that can affect the wind flow and degree of seabreeze penetration inland.

Hot Spot Effect[18]:

PW's response to the Commission (CLI-09-11 at 5) explained, "Entergy's Gaussian plume model assumed that plumes blowing out to sea would have no impact. This is important because about 60% of the land mass around Pilgrim NPS is water. PW showed that a plume over water, rather than being rapidly dispersed, will remain tightly concentrated due to the lack of turbulence, and will remain concentrated until winds blow it onto land [Zager et al.; Angevine et al. 2006]. At 153, Angevine concluded that,

> major pollution episodes along the northern New England coast are caused by efficient transport of pollutants from distant sources. The transport is efficient because the stable marine boundary layer allows the polluted air masses or plumes to travel long distances with little dilution or chemical modification. The sea-breeze or diurnal modulation of the wind, and thermally driven convergence along the coast, modify the transport trajectories.

Although Angevine did not specifically study the transport of radionuclides, there is no reason to believe that the basic principles do not hold.

This effect can lead to hot spots of radioactivity in places along the coast, certainly to Boston. [Beyea, 11] The compacted plume also could be blown ashore to Cape Cod, directly across the Bay from Pilgrim and heavily populated in summer. [Rep. Patrick, 2] An alternative

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[18] Listing of references: *Angevine*, Wayne*; Senff,* Cristoph; *White,Allen; Williams, Eric; Koermer,James; Miller,Samuel T.K.; Talbot,Robert, Johnston,Paul; McKeen,Stuart,* Coastal Boundary Layer Influence on Pollutant Transport in New England, http://journals.ametsoc.org/doi/full/10.1175/JAM2148.1;Angevine WM, Tjernstrom M, Zagar M., "Modeling of Coastal Boundary Layer and Pollutant Transport in New England," J. of Applied Meterorology & Climatology, 45:137-154, 2006;Beyea, Jan, PhD.,"Report to The Massachusetts Attorney General On The Potential Consequences Of A Spent Fuel Pool Fire At The Pilgrim Or Vermont Yankee Nuclear Plant," May 25, 2006, The Massachusetts Attorney General's Request for a Hearing and Petition for Leave to Intervene With respect to Entergy Nuclear Operations Inc.'s Application for Renewal of the Pilgrim Nuclear Power Plants Operating License and Petition for Backfit Order Requiring New Design features to Protect Against Spent Fuel Pool Accidents, Docket No. 50-293, May 26, 2006; Miller, Samule T.K.; Keim, Barry; Synoptic-Scale Controls on the Sea Breeze of the Central New England Coast**, AMS Journal Online,** Volume 18, Issue 2 (April 2003); Thorp, Jennifer E., Eastern Massachusetts Sea Breeze Study, Thesis Submitted to Plymouth State University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Applied Meteorology, May 2009.

model that Entergy did not use, CALPUFF, could provide the ability to account for reduced turbulence over water and could be used for sensitivity studies. [Beyea, 11-12].

Q.*1.c. The <u>radioactive deposition distribution</u> you would expect to occur from each such occurrence, assuming a normalized source term. If such depositions are not readily discernable or determinable, a computer model, such as those contained in ATMOS (excluding the straight line Gaussian plume portion) or another model selected by the relevant expert may be utilized to provide such information*

Both the sea breeze and behavior of plumes over water (the so-called hot spot effect) will change the area of impact and concentration within that area. DOE explained that, "straight-line Gaussian models could not only underestimate the consequences of a release, but also can *incorrectly identify locations where higher concentrations can occur*."[19] [Emhasis added]

<u>Sea Breeze</u>

1. Entergy's cost-benefit analysis is based on its contention that the sea breeze is "generally beneficial in dispersing the plume and in decreasing doses." This fundamental underlying assumption is incorrect. Dr. Egan explained that, "at a coastal site, the sea breeze would draw contaminants across the land and inland subjecting the population to potentially larger doses." [Egan, 13].

> [Mr. O'Kula's] contention that the seabreeze is 'generally beneficial in dispersing the plume and in decreasing doses' is incorrect. In fact, the development of seabreeze flow that would transfer a release inland is the greatest danger. Contrary to the implications of this declaration, the development of a sea breeze flow is the common meteorological condition that must be most closely monitored at the PNPS.
> [Mr. O'Kula's] statement reflects a misconception that the sea breeze is "generally a highly beneficial phenomena that disperses and dilutes the plume concentration and

[19] DOE/EH-0173T CHAPTER 4 (REVISED 2004), February 11, 2005, Pg., 4-6, Exhibit 13

> thereby lowers the projected doses downwind from the release point." If the same meteorological conditions (strong solar insolation, low synoptic-scale winds) that are conducive to the formation of sea breezes at a coastal site occurred at a non coastal location, the resulting vertical thermals developing over a pollution source would carry contaminants aloft. In contrast, at a coastal site, the sea breeze would draw contaminants across the land and inland subjecting the population to potentially larger doses. (Egan Decl., Item 13 Comment on O'Kula's declarations, Item 20)

Spengler confirmed that "[t]hese flow reversals and stagnations documented here at our coast result in an increased area impacted, increased concentration of the plume and ultimate cost. (Spengler, 3).

2. Closely related, Entergy' model failed to take into account that wind direction changes and terrain features could not only change plume direction (resulting in a larger affected area), but could also reduce diffusion of the plume (increasing the amount of radiation received within the area). PW explained that a variable plume model could take account not only of the sea breeze, but also of wind direction changes that occur with height above the ground and terrain changes. [PW Motion to Intervene, citing Lyman at 27; Rothstein, Appendix A; MACCS2 Guidance Report, June 2004, Entergy LA, Appendix E, 2-1]

3. Dose can be defined as a product of concentration and episode duration. The duration is a function of the relative sea breeze strength. Thus it is necessary to gather information on the affected receptor location(s), vector speed and strength, wind speeds, mixing heights, and spread statistics." (Spengler at 35) Entergy's reliance simply on meteorological data from the onsite met tower necessarily means that they do not have sufficient data. This "further analysis" is the responsibility of the Applicant, not the Petitioner.

4 The coriolis effect will cause a clockwise turning of wind direction and decrease in speed as the sea breeze develops during course of the day. [Spengler and Keeler, Pg., 39] This will result in a larger area of impact than modeled by a straight line model and the the decrease in

speed will result in increased exposure. Sea breeze and gradient winds would advect (convey horizontally) emissions over populated areas [Spengler at 2]

5. The direction of the sea breeze is not constant but rotates in a clockwise direction during the day. The winds start off normal to the shore and eventually blow parallel to the shore…this may preferentially expose populations to the west and north. [Spengler and Keeler, Pg., 2]

6. Air pollution effects of sea breezes have been studied for a long time. One of the generally occurring effects of the onshore flow of marine air is fumigation of pollutants, in this case radiation, downwind of the shoreline. Effluent in a severe accident at Pilgrim's shore location blown inland by onshore winds may be confined to a plume in the stably stratified marine air. However, as this plume intersects the convective boundary layer inland, pollutants can be mixed down to the surface resulting in fumigation (Lyons and Cole, 1973). Another commonly occurring effect in coastal areas is plume trapping. Stably stratified marine air moving onshore can have a mean mixing depth that is 10% of that existing away from the influence of the water (Lyons and Cole, 1973). Thus, effluent that is ejected into this layer is effectively trapped and high concentrations of pollutants can subsequently reach the surface. Fumigation and plume trapping commonly occur in association with sea or lake breezes. However, lake and land breezes can introduce unique problems. The first is the ability of sea/lake and land breezes to transport pollutants in three dimensions. Lake and land breezes are quasi-closed circulations and pollutants emitted into them can be recirculated several times over the near-shore area (Lyons, 1972). That is, pollutants emitted into the inflow layer get lofted in the frontal regions and disperse into the return flow aloft. A fraction of these pollutants are forced into the inflow layer again by the descending branch of the circulation. Remaining pollutants reside in an elevated layer aloft. Lyons and Olsson (1973) observed a helical trajectory within a sea/lake

breeze circulation and suggested that the motion of pollutants might include an along-coast component in addition to the cross-coast components. Lyons et al. (1995) have successfully simulated this three-dimensional behaviour using a numerical model. Also, during periods of stagnant synoptic conditions, lake and land breezes can occur nearly continuously, effectively confining pollutants to coastal regions and causing the accumulation of pollutants over periods of several days (Simpson, 1994; Lu and Turco, 1995). Despite apparently adequate ventilation with onshore winds, rapidly deteriorating air quality can result.

Hot Spots or the Behavior of Plumes Over Water [20]

7. Entergy's Gaussian plume model assumed that plumes blowing out to sea would have no impact. PW showed that a plume over water, rather than being rapidly dispersed, will remain tightly concentrated due to the lack of turbulence, and will remain concentrated until winds blow it onto land [Zager et al.; Angevine et al. 2006]. This can lead to hot spots of radioactivity in places along the coast, certainly to Metropolitan Boston and its densely populated suburbs. [Beyea, 11] The compacted plume also could be blown ashore to Cape Cod, directly across the Bay from Pilgrim and heavily populated in summer. [Rep. Patrick, 2] An alternative model that

[20] Listing of references: *Angevine*, Wayne*; Senff,* Cristoph; *White,Allen; Williams, Eric; Koermer,James; Miller,Samuel T.K.; Talbot,Robert, Johnston,Paul; McKeen,Stuart,* Coastal Boundary Layer Influence on Pollutant Transport in New England, http://journals.ametsoc.org/doi/full/10.1175/JAM2148.1;Angevine WM, Tjernstrom M, Zagar M., "Modeling of Coastal Boundary Layer and Pollutant Transport in New England," J. of Applied Meterorology & Climatology, 45:137-154, 2006; Beyea, Jan, PhD.,"Report to The Massachusetts Attorney General On The Potential Consequences Of A Spent Fuel Pool Fire At The Pilgrim Or Vermont Yankee Nuclear Plant," May 25, 2006, The Massachusetts Attorney General's Request for a Hearing and Petition for Leave to Intervene With respect to Entergy Nuclear Operations Inc.'s Application for Renewal of the Pilgrim Nuclear Power Plants Operating License and Petition for Backfit Order Requiring New Design features to Protect Against Spent Fuel Pool Accidents, Docket No. 50-293, May 26, 2006; Miller, Samule T.K.; Keim, Barry; Synoptic-Scale Controls on the Sea Breeze of the Central New England Coast**, AMS Journal Online,** Volume 18, Issue 2 (April 2003); Thorp, Jennifer E., Eastern Massachusetts Sea Breeze Study, Thesis Submitted to Plymouth State University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Applied Meteorology, May 2009.

Entergy did not use, CALPUFF, could provide the ability to account for reduced turbulence over water and could be used. [Beyea, 11-12].

8. Wayne Angevine (NOAA) has performed extensive research on pollutant transport along New England's coast, the behaviour of plumes over these waters.[21] Experiments showed that polluted air becomes stably stratified, and vertical mixing is limited. Although, he studied ozone, and not radionuclide transport, there is no reason to believe that the results would be different. He showed (Exhibit 6) that:

> Pollutant transport is most efficient over the ocean. The coastline makes transport processes complex because it makes the structure of the atmospheric boundary layer complex. During pollution episodes, the air over land in daytime is warmer than the sea surface, so air transported from land over water becomes statically stable and the formerly well-mixed boundary layer separates into possibly several layers, each transported in a different direction. His 2006 study examined several of the atmospheric boundary layer processes involved in pollutant transport. The basic conclusion is: major pollution episodes along the northern New England coast are caused by efficient transport of pollutants from distant sources. The transport is efficient because the stable marine boundary layer allows the polluted air masses or plumes to travel long distances with little dilution or chemical modification. The sea-breeze or diurnal modulation of the wind, and thermally driven convergence along the coast, modify the transport trajectories.
>
> To summarize, the coastal boundary layer influences pollutant transport in northern New England by allowing for stable layers over water that carry pollutants, relatively undiluted and with minimal deposition, to distant (20–200 km) areas on other parts of the coast. The sea breeze modifies the large-scale flow to select the particular sites that receive polluted air. Elevated layers transport polluted air very long distances (200–2000 km).

[21] *Angevine*, Wayne*; Senff,* Cristoph; *White,Allen; Williams, Eric; Koermer,James; Miller,Samuel T.K.; Talbot,Robert, Johnston,Paul; McKeen,Stuart,* Coastal Boundary Layer Influence on Pollutant Transport in New England, http://journals.ametsoc.org/doi/full/10.1175/JAM2148.1;Angevine WM, Tjernstrom M, Zagar M., "Modeling of Coastal Boundary Layer and Pollutant Transport in New England," J. of Applied Meterorology & Climatology, 45:137-154, 2006

In another study, Coastal Boundary Layer Influence on Pollutant Transport in New England Angevine et al[22] they found that:

> the coastal boundary layer influences pollutant transport in northern New England by allowing for stable layers over water that carry pollutants, relatively undiluted and with minimal deposition, to distant (20–200 km) areas on other parts of the coast. The sea breeze modifies the large-scale flow to select the particular sites that receive polluted air. Elevated layers transport polluted air very long distances (200–2000 km). Air pollution episodes in northern New England often are caused by transport of pollutants over water. Two such episodes in the summer of 2002 ware examined (22–23 July and 11–14 August). In both cases, the pollutants that affected the study areas, coastal New Hampshire and coastal southwest Maine, were transported over coastal waters in stable layers at the surface. These layers were at least intermittently turbulent but retained their chemical constituents. The lack of deposition or deep vertical mixing on the overwater trajectories allowed pollutant concentrations to remain strong.

Why is overwater transport important; and different than transport over land?

> In northern New England, air transported from land encounters a cooler, smoother surface; convective mixing, therefore, decreases. A persistent pool of cold water exists offshore in the northern and eastern Gulf of Maine and the Bay of Fundy, with warmer water inshore Strong layering of the atmosphere caused by the cold water offshore overwater transport more efficient than transport over land. Because the overwater trajectory segments are always stable in these episodes, the pollutants in the surface layer are not diluted by deep vertical mixing. The surface layer is, however, turbulent, as evidenced by its cooling, and, therefore, pollutants could be lost to surface deposition. However, ozone and most of its precursors are deposited much more slowly to water surfaces than to vegetation, and so the polluted layers over water retain most of their ozone and precursors.
>
> To summarize, the coastal boundary layer influences pollutant transport in northern New England by allowing for stable layers over water that carry pollutants, relatively undiluted and with minimal deposition, to distant (20–200 km) areas on other parts of the coast. The sea breeze modifies the large-scale flow to select the particular sites

[22] Coastal Boundary Layer Influence on Pollutant Transport in New England,Wayne M. Angevine, Christoph J. Senff, Allen B. White, Eric J. Williams, James Koermer, Samuel T. K. Miller, Robert Talbot, Paul E. Johnston, Stuart A. McKeen, and Tom Downs, Journal of Applied Meteorology 2004; 43: 1425-1437, http://journals.ametsoc.org/doi/full/10.1175/JAM2148.1

> that receive polluted air. Elevated layers transport polluted air very long distances (200–2000 km).

Although the study focsued on waters north of Boston, the water temperature also is cold in Cape Cod and Massachusetts Bays. The Gulf stream, warmer waters, are kicked offshore by Cape Cod.

Q.1.d. How that deposition would differ from that expected using a straight-line Gaussian plume model

The straight-line Gaussian plume model decreases the potential area of impact and concentration within that area. Entergy's model reflects only the initial direction of the wind, as indicated by their onsite meteorological tower. It further underestimates potential radiological damage and costs because it cannot reflect that offsite surface friction and surface features can decrease plume speed thereby increasing dose and change plume direction affecting larger areas. [PW Motion to Intervene, citing Lyman at 27; Rothstein, Appendix A; MACCS2 Guidance Report, June 2004, Entergy LA, Appendix E, 2-1]

Q.1.e. <u>The cost differential</u> caused by the differences indicated in subsection d above (to be provided quantitatively if practicable, or if not, supported qualitative estimates may be provided).

1. This question makes little sense, for a number of reasons.

a. It is premature. On September 23, 2010, the Board ordered (Order Confirming Matters Addressed at September 15, 2010, Telephone Conference) that the hearing on Contention 3 "will be bifurcated." In phase one, the parties were instructed to first look at *meteorological patterns/issues of concern to Pilgrim Watch*. The second phase of the hearing will not proceed unless the Board finds that "*meteorological patterns/issues of concern to*

Pilgrim Watch could, on its own, credibly alter the Pilgrim SAMA analysis conclusion," and even if the Board did so find, it would, consider at most, very limited economic costs issues and would not address real costs..

b. Second the question incorrectly assumes that the cost differential caused by the differences in the model could be determined while holding all variables in Entergy's SAMA analysis, except the plume model, constant. The only way to compare consequence would be to run both Entergy's flawed model and a proper model, and to account for all consequences in a severe, not fantasy, accident (including: health costs, based on up-to-date dose response research; economic costs, including cleanup costs and excluding a discount factor; using the 95% percentile, instead of the mean; and not multiplying probability by the consequences.) The methodology to determine costs would then be modeled on the Estimation of Attributable Costs from Plutonium-Dispersal Accidents, SAND96-0957, David Chanin, Walt Murfin, UC-502, (May 1996) and studies commissioned by the US Department of Homeland Security,[23] discussed in this brief's section "What Pilgrim Watch would have proved but for prior Board and Commission orders."

c. Third, it is not reasonable to expect Pilgrim Watch to answer this question. As Administrative Judge Ann Marshall Young explained, at 38, in her Dissenting Opinion in the Memorandum and Order (Ruling on Motion to Dismiss Petitioners contention 3 Regarding Severe Accident Mitigation Alternatives), October 30, 2007,

> In this proceeding, Intervenors …provide the reasoned statements of several well-qualified experts. They do not, it is true, provide any results of calculations proving

[23] Economic Consequences of a Rad/Nuc attack: Cleanup Standards Significantly Affect Cost Barbara Reichmuth, Steve Short, Tom Wood, Fred Rutz, Debbie Swartz, Pacific Northwest National laboratory, 2005 (Attachment 6, Exhibit 8); Survey of Costs Arising From Potential Radionuclide Scattering Events, Robert Luna, Sandia National laboratories, WM2008 Conference, February 24-28, 2008, Phoenix AZ (Attachment 7, Exhibit 9)

> the negative of Entergy's sensitivity analysis. But such a requirement — or anything approaching its essential equivalent — is unreasonable, given the extremely complex, expensive, and time-consuming nature of the computer calculations that would be necessary to do this, which even the Applicant, with its relatively greater resources, has called "impractical." *See* Entergy's Motion for Summary Disposition of Pilgrim Watch Contention 3 at 13 (May 17, 2007).

Also the accepted contention called for "further analysis" –i.e., further analysis by the Applicant not the Petitioner.

2. Nonetheless, PW in Pilgrim Watch's Answer Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, June 29, 2007, provided rough "ball park" estimates using Entergy's population and trivialized economic data; the Massachusetts Attorney General's analysis by Jan Beyea, reference to Sandia's CRAC 11 study, and Chernobyl.

<u>Economic Consequences using a spatial distribution:</u> The total population was estimated by Entergy for the year 2032 for each spatial element by combining total population projections with transient population data obtained from Massachusetts and Rhode Island.

E. 1.5.2.1 Projected Total Population by Spatial Element, 2032 (PNPS Applicant's Environmental Report Operating License Renewal Stage, Attachment E, E.1-61)

Table E.1-13
Estimated Population Distribution within a 50-mile Radius

Sector	0-10 Miles	10-20 Miles	20-30 Miles	30-40 Miles	40-50 Miles	50-Mile Total
N	0	0	0	0	80474	80474
NNE	3	0	0	0	0	3
NE	3	0	0	0	0	3
ENE	3	0	33121	0	0	33124
E	5	0	33121	23185	0	56311
ESE	23	0	49682	92740	0	142445
SE	950	9936	115925	23185	0	149996
SSE	13289	69555	82803	0	0	165647
S	23695	99364	132485	84383	43397	383324
SSW	23695	49762	23696	23185	21699	142037
SW	23695	71088	277374	349491	114546	836194
WSW	23695	71088	277374	349491	183037	904685
W	22818	71088	277374	388324	286370	1045974
WNW	16494	71088	118481	303450	390150	899663
NW	11269	71088	195075	1529212	405561	2212205
NNW	5599	35544	43350	31295	321894	437682
Total	165236	619601	1659861	3197941	1847128	7489767

The table below illustrates potential costs if a variable trajectory plume dispersion model is used so that variable wind conditions are modeled and releases are not minimized to simply a "minor release."

For illustration purposes, if all or most of the 10-20 mile area is impacted; some of the 20-30; and a portion of the 30-50 then you have a very different situation than simply assuming impact in the two miles around and a pie-shaped wedge from 2 to 5 miles. PW explained in our Response to Entergy's Motion for Summary Disposition and Brief in Response to CLI-09-11 that Entergy's cost figures are unrealistically low and it is necessary to consider both the initial deposition and subsequent resuspension in Pilgrim's coastal area characterized by variable winds.

Table: Population Per Mile Multiplied By Sensitivity Case I&2 Costs

Sector Miles	**Total Population**	**Pop x $135,187.77/per person 1st sensitivity**	**Pop x $189,041/person 2nd sensitivity**
0-10	165,236	$22,337,886,364	$31,236,378,676
10-20	619,601	$83,762,477,480	$117,129,992,641
20-30	1,659,661	$224,365,869,546	$313,743,975,101
30-40	3,197,941	$432,322,512,382	$604,541,964,581
40-50	1,847,128	$249,709,115,225	$ 349,182,924,248
50 total	7,489,767	$1,012,524,898,550	$ 1,415,873,043,447

In contrast, the table below illustrates potential costs if a straight-line plume distribution is used. For illustration when looking at the table assume only a minimal, not moderately severe accident, so that only a portion of any 0-10 sector is assumed impacted. It is not hard to understand how using an inappropriate plume model and minimizing a severe accident to a "hiccup" can reduce projected costs.

Table: Population Per Geographic Sector Multiplied By Sensitivity Case I&2 Costs

Sector	Total Population 0-10 miles	Pop x $135,187.77/per person - 1st sensitivity	Pop x $189,041/person -2nd sensitivity
N	0	0	0
NNE	3	$405,563.31	$567,123.00
NE	3	$405,563.31	$567,123.00
ENE	3	$405,563	$567,123
E	5	$675,939	$945,2050
ESE	23	$3,109,319	$4,347,943
SE	950	$128,428,381	$179,588,950
SSE	13,289	$17,883,854,906	$2,512,165,849
S	23,695	$3,203,274,210	$4,479,326,495
SSW	23,695	$3,203,274,210	$4,479,326,495
SW	23,695	$3,203,274,210	$4,479,326,495
WSW	23,695	$3,203,274,210	$4,479,326,495
W	22,818	$3,084,714,536	$4,313,537,538
WNW	19,494	$2,635,350,388	$3,685,165,254
NW	11,269	$1,523,430,980	$2,130,303,029
NNW	5,599	$756,916,324	$1,058,440,559

In the above table, imagine if Entergy assumes a severe accident is really one with small off-site release. For example if their straight line plume model, once averaged, predicts winds blowing to the NNE, perhaps one person will be affected costing at most $189,041 in damages

Summary: In contrast if a variable trajectory plume distribution model is used, winds shifting carrying the plume over many geographic areas; and a "severe accident" is assumed to be more than a small offsite release, then more SAMAs are likely to come into play – as the table below illustrates.

Summary Comparison- Population Multiplied by Sensitivity Case

Population within area	**1st sensitivity** $135,187.77/person	**2nd sensitivity-** $189,041/person
	Straight-line Gaussian Plume Model	
Population SE Sector, 950 (0-10 miles)	$128,428,382 > 128 Million	$179,588,950
Population SSW Sector, 23695 (0-10 miles)	$3,203,274,210 > 3 Billion	$4,479,326,495 >4 billion
	Variable Plume Model	
Population within 10 miles, 165236	$22,337,886,364 > 22 Billion	$31,236,378,676 >31 Billion
Population within 20 miles 619601	$83,762,477,480 > 83 Billion	$117,129,992,641 >117 Billion
Population within 50 miles	$1,012,524,898,550 (1 Trillion +)	$ 1,415,873,043,447 > 1 Trillion
Previous Projections		
Core Melt, Pilgrim (1982) CRAC-2, Sandia National Laboratory,1982[24]	$81.8 Billion	
Release C-137 from Core -Beyea	$105-488 Billion [MA AGO, Dr. Beyea] [Based upon Massachusetts Attorney General's Office Analysis, Dr. Jan Beyea[25]]	

In reviewing the above table, it is sobering to consider the impact of the 1996 Chernobyl accident, 1986, to help understand the potential impact from an accident as Pilgrim. Sheep remain contaminated in Scotland and reindeer are still contaminated in Lapland, from an accident 20 years ago. Chernobyl was bad, no doubt, but certainly not worst case. The 1986 Chernobyl accident released 2,403,000 curies of C-137; whereas Pilgrim's core during license

[24] Calculation of Reactor Accident Consequences U.S. Nuclear Power Plants (CRAC-2), Sandia National Laboratory, 1982

[25] The Massachusetts Attorney General's Request for a Hearing and Petition for Leave to Intervene With respect to Entergy Nuclear Operations Inc.'s Application for Renewal of the Pilgrim Nuclear Power Plants Operating License and Petition for Backfit Order Requiring New Design features to Protect Against Spent Fuel Pool Accidents, Docket No. 50-293, May 26, 2006 includes a 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, PhD., May 25, 2006. Exhibit 2

extension will have 5,130,000 curies of C-137 [Beyea Decl, Chernobyl; and LR, Pilgrim CS-137 figures].

Q.2 . Regarding <u>the radioactive contamination</u> to be computed from the dispersion and deposition caused by the meteorological patterns at issue, describe in sufficient detail for scientific understanding the following:

Q.2.a. ***How the <u>source term</u> to be used for each computation of radioactivity dispersion and deposition is determined***

Entergy knows how the source terms it used were determined. PW understands that Entergy used the MAAP code, a proprietary industry code, to estimate the consequences of severe accidents (radionuclide release fractions generated by the Modular Accident Analysis Progression, MAAP[26]). The code has not been validated by NRC. The release fractions are consistently smaller for key radionuclides than the release fractions specified in NUREG-1465 and its recent revision for high-burnup fuel. The source term used results in lower consequences than would be obtained from NUREG-1465 release fractions and release durations. This has been observed by NRC in studies such as NUREG-1150. A Brookhaven National Laboratory study that independently analyzed the costs and benefits of one SAMA in the license renewal application for the Catawba and McGuire plants noted that the collective dose results reported by the applicant for early failures

> …seemed less by a factor between 3 and 4 than those found for NUREG-1150 early failures for comparable scenarios. The difference in health risk was then traced to differences between [the applicant's definitions of the early failure release classes] and the release classes from NUREG-1150 for comparable

[26] See, for example, ER. E. 1,2,1; and the limitations of the code are examined in Appendix 4, A Critique Of The Radiological Consequence Assessment Conducted In Support Of The Indian Point Severe Accident Mitigation Alternatives Analysis, Dr. Edwin S. Lyman. Dr Lyman would have performed a similar reprot for Piglrim Watch had the issue not been removed from consideration in these proceedings. Exhibit 12

> scenarios … the NUREG-1150 release fractions for the important radionuclides are about a factor of 4 higher than the ones used in the Duke PRA. The Duke results were obtained using the Modular Accident Analysis Package (MAAP) code, while the NUREG-1150 results were obtained with the Source Term Code Package [NRC's state-of-the-art methodology for source term analysis at the time of NUREG-1150] and MELCOR. Apparently the differences in the release fractions … are primarily attributable to the use of the different codes in the two analyses.[27]

Thus, Entergy's use of source terms generated by MAAP appears to lead to anomalously low consequences when compared to source terms generated by NRC staff. In fact, NRC has been aware of this discrepancy for at least two decades. In the draft "Reactor Risk Reference Document" (NUREG-1150, Vol. 1), NRC noted that for the Zion plant (a four-loop PWR), that "comparisons made between the Source Term Code Package results and MAAP results indicated that the MAAP estimates for environmental release fractions were significantly smaller. It is very difficult to determine the precise source of the differences observed, however, without performing controlled comparisons for identical boundary conditions and input data."[28] We are unaware of NRC having performed such comparisons.

The NUREG-1465 source term was also reviewed by an expert panel in 2002, which concluded that it was "generally applicable for high-burnup fuel."[29] This and other insights by the panel on the NUREG-1465 source term are being used by the NRC in "radiological consequence assessments for the ongoing analysis of nuclear power plant vulnerabilities."[30]

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[27] J. Lehner et al., "Benefit Cost Analysis of Enhancing Combustible Gas Control Availability at Ice Condenser and Mark III Containment Plants," Final Letter Report, Brookhaven National Laboratory, Upton, NY, December 23, 2002, p. 17. ADAMS Accession Number ML031700011.

[28] U.S. NRC, "Reactor Risk Reference Document: Main Report, Draft for Comment," NUREG-1150, Volume 1, February 1987, p. 5-14.

[29] J. Schaperow, U.S. NRC, memorandum to F. Eltawila, "Radiological Source Terms for High-Burnup and MOX Fuels," December 13, 2002.

[30] J. Schaperow (2002), op cit.

Q.2.b. ***The degree of <u>conservatism</u> imbedded in that methodology, its sources, and the rationale for each source of conservatism***

1. There are two conventional meanings of conservative. One definition is "old-fashioned" or "old-school." In this sense of the term, the methodology used by Entergy was indeed old-school, and that is a major problem with their analysis. The straight-line Gaussian plume model is a simplistic out-of-date model as illustrated in Appendix 2, Meteorological Modeling: Government and Independent Studies. Dr Egan explained:

> The field of dispersion modeling has developed rapidly since models were first routinely used in regulatory applications in the 1960 s and early 1970s. The Clean Air Act Amendments of 1977 created further reliance on atmospheric dispersion models for the establishment of emission limits for new industrial sources seeking licenses and permits under the Clean Air Act. The US EPA and other groups initiated research program to improve the science of dispersion models and the US EPA began to establish performance measures for models and to provide guidance and recommendations for the testing and adoption of improved models in permit applications. The result was further advancement in modeling methods that have persisted to the current decade. Specifically, very significant improvements have been made in the parameterization of the atmospheric boundary layer wind profiles, temperature profiles and variations of turbulent mixing rates with height above the ground surface. As a result of the Clean Air Amendments of 1977, The US EPA has been instrumental in encouraging and supporting the development of improved models including those defined as guideline models AERMOD and CALPUFF (EPA, 2005). AERMOD includes highly sophisticated algorithms for including spatial variations of the ground surface parameters of roughness lengths, surface albedo and the Bowen ratio into the parameterizations of wind and turbulence levels as a function of height. CALPUFF has the added features of allowing spatially variable wind fields. These models are now routinely used for regulatory applications and for risk assessments. (Egan Decl., at 7)

Additionally, the assumptions regarding dose-response are outdated and likewise the entire MACCS2 computer code.

2. The second definition of conservatism is “cautious.” PW’s response to the Commission (CLI-09-11 at 15) explained that the Gaussian Plume Model/ MACCS2 Applied in Entergy’s and the Board’s Cost-Benefit Analysis was not conservative.

a. Lewellen and Mollenkamp: Entergy’s experts cite two reports (Lewellen and Mollenkamp[31]) claiming that they showed the straight-line Gaussian model was conservative. [Entergy, Motion for Summary Disposition, 12] The fundamental flaw in Entergy’s contention is that a comparison made in the high desert land in Idaho, Kansas or Oklahoma tells little or nothing about what a comparison made in Plymouth, Massachusetts would show. PNPS’ site is characterized by its coastal location, varying terrain, “forested hills interspersed with urban areas” (Appendix E, 2.1). In contrast, the Lewellen and Mollenkamp studies were performed in areas that are not in the least comparable to the PNPS site. As a predictor of what might happen at PNPS, Entergy’s reports are not “conservative;” they are simply meaningless. Whether the Gaussian plume model is “conservative” relative to the Pilgrim site cannot be determined without running both ATMOS (the Gaussian plume) and an alternative model (e.g. MM5 and CALPUFF) with PNPS site specific data.

NRC itself has said that the Mollenkamp study site in central Oklahoma and Kansas did not have “topography that would interact with the large-scale flow producing local modification of wind speed and direction” and that it did not have “changes in surface properties that could affect local flow, such as a coastal site with a land-sea breeze” [NUREG/CR 6853, 3]. The Mollenkamp sites are “ relatively smooth and (have) has minimal effect on the wind field and the

[31] WSMS refers to the results from a test that released a tracer conducted in 1981 at the Idaho National lab (INL is located in high desert land, eastern Idaho), Lewellen, 1985, NUREG/CR-4159; Mollenkamp et al (2004) compared several codes for recorded data in the Midwest, NUREG/CR-6853] Exhibit 16

surface is fairly uniform and therefore produces relatively little thermal forcing." The NUREG says that it "would have preferred a site with greater topological and diurnal homogeneity" (NUREG/CR-6853, Oct. 2004, at xi and 2); and readily admitted that "it would be best if MACCS2 and RASCAL/RATCHET results could be compared with measurements over the long distances and types of terrain of interest to the NRC." The only reason that "the less desirable comparison with a state-of-the art code was chosen to provide input into the decision on the adequacy of MACCS2 ATD was that such measurements do not exist." (Ibid at 2)

b. Entergy's Sensitivity Studies: Entergy's two supplemental sensitivity studies, by Enercon and WSMS, similarly were not conservative. PW's initial brief also pointed to evidence (at 16) that no matter how many "scenarios" WSMS may have studied using a "downwind in a straight line" assumption, they cannot provide a valid comparison to variable trajectory "scenarios" that WSMS never studied. The same holds true for Enercon. PW evidence showed that both the code used by Entergy and the meterological and economic information it used were inadequate. Dr. Egan summed it up: "sensitivity studies do not add useful information if the primary model is flawed." Egan Decl. ¶ 13.

c. Whether the Gaussian plume model is "conservative" relative to the Pilgrim site cannot be determined without running both ATMOS (the Gaussian plume) and an alternative model (e.g. MM5 and CA NRC Staff's own expert, Dr. Bixler, (Exhibit 7) generally agreed with Dr. Egan and admitted that the Gaussian plume model results are "conservative" is correct only if the word "conservative" is defined narrowly:

> 8. (NEB) Material fact number 12 states that the MACCS2 Gaussian plume model results are in good agreement with, and generally more conservative than those obtained by more sophisticated models. *If the word conservative implies* that calculated plumes with the MACCS2 code are generally more focused and more concentrated than would be the case if the calculations had been performed with more sophisticated models, then the statement is accurate. However, a more focused,

more concentrated plume does not always correspond to a smaller number of person-rem, *depending on the trajectory of the plume* compared with population centers. (Emphasis added)

Therefore NRC Staff's expert is in full accordance with PW's argument that whether a Gaussian model is conservative depends entirely on "*the trajectory of the plume compared with population centers;"* and PW submitted significant evidence that the straight-line Gaussian plume could not, and did not, predict site-specific atmospheric dispersion for Pilgrim's coastal region, or accurately predict what population centers the likely variable plume would affect. [PW CLI-09-11 Br., 4-10, 14,17]

For example, while Entergy assumed that a plume blowing out to sea would have no impact on any population centers, PW showed that a plume over water, rather than being rapidly dispersed, will remain tightly concentrated due to the lack of turbulence, and will remain concentrated until winds change the plume's trajectory and blow it ashore. This can lead to hot spots of concentrated radioactivity in places along the coast, certainly including densely populated Metropolitan Boston; or to Cape Cod directly across the Bay with a summer population of 600,000. [PW Br., 5, 17, Rep. Patrick Decl., 2]

Further, Dr. Bixler (Exhibit 7) said very plainly that Entergy's claim, that its study was conservative because it used conditions at the beginning of a plume release, was "erroneous."

> 9. (NEB) Material Fact number 16 states that Sensitivity Case 2 estimated the effects of changing wind direction trajectory and was conservative because it used conditions at the beginning of a plume release, when the release has larger dose quantity and less decay has occurred. The MACCS2 value modified in Sensitivity Case 2 appears to have been REFTIM (Representative Time Point for Dispersion and Radioactive Decay). *REFTIM* affects the way in which dispersion, deposition, and radioactive decay are calculated. It *does not affect the manner in which "wind direction trajectory" is calculated.* This statement appears to be *erroneous*…"

Again, the Staff's expert is in full accordance with PW's expert, leaving Entergy and NRC Staff at odds.

Although the sea breeze effect is a critical feature at Pilgrim's coastal site, here again Dr. Bixler agrees with PW and Dr Egan, [Egan Decl.,13, Item 20] and says that "*the effect of sea breeze is not taken into account"* in Entergy's studies.

> 10. (NEB) Material Fact number 19 states that the effect of sea breeze is taken into account in the Pilgrim site meteorological data. *Although the wind speed and direction of a sea breeze may be included in the actual PNPS meteorological data, the effect of sea breeze is not taken into account.* The effect that is not taken into account is that the *complex flow pattern under sea breeze conditions differs substantially from the straight-line pattern used in the MACCS2 analyses*. The sea breeze occurrences are typically diurnal events, occurring during daylight hours and during warmer seasons. (Emphasis added, Exhibit 7)

Entergy claims that the Gaussian model concentrates and maximizes the plume in a narrow wedge close to the reactor maximizing health effects; whereas a variable model will produce a more diffuse plume and thereby have less impact on population dose. However, Entergy has presented no data to justify its claim; so far as PW knows, Entergy has never run a variable plume model, much less one that properly used the MACCS2 code.

And most important, one cannot be conservative both close to the reactor and far afield. Arguably, the severe health effects close in may be greater with a Gaussian model; but the latent health effects, economic damage and cleanup costs will be greater due with a variable model due to its larger area of impact.

Q.2.c. ***The extent to which those conservatisms cause the resultant deposition to be conservative; be as quantitative as is practicable, but qualitative discussions are acceptable where quantitative analysis is not practicable***

PW's response to Q.2.b answers this question. The short answer is that the straight-line Gaussian plume is not conservative or cautious, the resultant deposition is underestimated and consequences minimized.

Once again, it is not reasonable to expect Pilgrim Watch to answer this question because, as explained in *The Dissenting Opinion of Administrative Judge Ann Marshall Young*, at 38, in the Memorandum and Order (Ruling on Motion to Dismiss Petitioners contention 3 Regarding Severe Accident Mitigation Alternatives), October 30, 2007:

> In this proceeding, Intervenors …provide the reasoned statements of several well-qualified experts. They do not, it is true, provide any results of calculations proving the negative of Entergy's sensitivity analysis. But such a requirement — or anything approaching its essential equivalent — is unreasonable, given the extremely complex, expensive, and time-consuming nature of the computer calculations that would be necessary to do this, which even the Applicant, with its relatively greater resources, has called "impractical." *See* Entergy's Motion for Summary Disposition of Pilgrim Watch Contention 3 at 13 (May 17, 2007).

The accepted contention called for "further analysis" – i.e., further analysis by the Applicant not the Petitioner.

III. Beyond Meteorology

Even if a majority of the Board should find that "meteorological concerns/issues ... could, on its own, credibly alter the Pilgrim SAMA analysis conclusions," the economic issues that "might be open for adjudication" have, once again, been so drastically limited that the result is preordained.

Evidence showed that the most significant economic costs – clean/up, decontamination, and health - have been forced off the table. All that Pilgrim Watch even "might" be permitted to show about costs has been *limited to business and tourism in Plymouth County*.

No matter what weather, or what loss of business and tourism in Plymouth County, might be input into the MACCS2 code, a downstream portion of the code (the MACCS2's so-called "output file") would reduce consequences to such a low level that there would be no change in the SAMA conclusion. The MACCS2 "output file" uses Entergy's chosen ill-chosen "mean" average rather than the 95th or higher percentile permitted by the code, averages the consequences produced by EARLY and CHRONC (using a discount figure when prices increase over time) and then applies a ridiculously small "probability," again selected by Entergy. The result, as intended by Entergy, is that no significant SAMAs will be required.[32]

The prior orders of this Board have precluded Pilgrim Watch from proving real costs. At the beginning of these proceedings the Board rewrote Contention 3 in ways that, at least in the view of the majority, eliminated any discussion of probability, and any discussion of the code other than a few particular "inputs;" the majority's Summary Disposition Order and its Order of November 23, 2010 took Entergy's misuse of the code off the table. These decisions were wrong, and subject to appeal, but they unfortunately (for both Pilgrim Watch and the public) have made this remand hearing meaningless.

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[32] Consequences necessarily depend on the size of an accident, the "source" input into the code. This critical input, chosen by Energy, has also been taken off the table.

IV. The Board's Prior Orders

In attached Appendix I, Pilgrim Watch has outlined prior decisions of this Board to show how they have removed from consideration any real chance that this proceeding will meet the NRC's stated goal of "ensur[ing[adequate protection of the public health and safety and the environment." (See NRC Strategic Plan, Fiscal Years 2008-2010, At-A-Glance). The NRC says that its "MISSION" is to "[l]icense and regulate the Nation's civilian use of byproduct, source, and special nuclear materials to ensure adequate protection of public health and safety ... and protect the environment," and that its desired "Strategic Outcomes" include (Id.):

- Prevent the occurrence of any nuclear reactor accidents.
- Prevent the occurrence of any inadvertent criticality events.
- Prevent the occurrence of any acute radiation exposures resulting in facilities.
- Prevent the occurrence of any releases of radioactive materials that result in significant radiation exposure.
- Prevent the occurrence of any releases of radioactive materials that cause significant environmental impacts.

This Board's own brochure says that "Congress made it possible for the public to get a full and fair hearing on nuclear matters."

Pilgrim Watch respectfully submits that, in the aggregate, the prior decisions of this Board have created a situation that is inconsistent with the NRC's fundamental goals, and that that has failed to "provide for ... a full and fair hearing."

Pilgrim Watch's Contention 3 squarely raised important issues that are consistent with "ensur[ing] adequate protection of public health and safety ... and protect[ion of] the environment." Originally filed Contention 3 (*Request For Hearing and Petition To Intervene By Pilgrim Watch*, May 25, 2006 ("Hearing Request), p 26) was:

> **Contention 3**: The Environmental Report is inadequate because it ignores the true off-site radiological and economic consequences of a severe accident at Pilgrim in its Severe Accident Mitigation Alternatives (SAMA) analysis
>
> **3.0 Contention** The Environmental Report inadequately accounts for off-site and economic costs in the SAMA analysis of severe accidents. By *using probabilistic modeling* and *incorrectly inputting certain parameters* into the modeling software, Entergy has downplayed the consequences of a severe accident at Pilgrim and this has caused it to draw incorrect conclusions about the costs versus benefits of possible mitigation alternatives. (Italics added)

Pilgrim Watch's Hearing Request explained numerous ways in which Entergy misused the MACCS2 code,and in which its Environmental Report inadequately accounts for off-site health exposure and economic costs in its SAMA analysis of severe accidents.

As shown in Appendix I, prior decisions of this Board have (improperly in PW's view) taken essentially everything important to protecting the public and the environment "off the table." The result has been effectively to ensure that this proceeding will not fulfill the NRC's stated Mission or accomplish the NRC's stated Strategic Objectives. The Board should review its prior orders, and particularly its October 16, 2006 Order that threw out the heart of Pilgrim Watch's original contention, portions of the Majority's Summary Disposition Order that further limited rewritten Contention 3, and its Order of Novembr 23, 2010.

In her dissent from the majority's order granting summary disposition, Judge Young recognized the importance of insuring the public understand that "fairness and justice had been done":

> Even if in the end Entergy were, in such a hypothetical situation, to prevail on all points, the hearing process, appropriately and flexibly handled so as to assure reasonable and meaningful efficiencies, would (as it should always) ultimately allow for differences between the testimony of the parties' various experts on relevant issues to be addressed with all interested parties in one room, without the need for the filing of perhaps so much paper, and with the ability to address much more directly and concisely relevant questions to clarify matters in dispute. Consequently, even if Intervenors lost on these matters, *they might well walk away with greater understanding of the issues and a greater sense that fairness and justice had been done.* While the resulting increase in public confidence and trust in the NRC adjudication process may not be measurable, I would expect that this would benefit as well from allowing a hearing on the matters of public concern at issue in Contention 3 (at 43, italics added)[33]

One unfortunate, and perhaps unforseen, result of the Board's prior orders is that licensee applicants have been citing the orders to create the impression that the Board decided issues against PilgrimWatch on their merits, rather than only as a matter of pleading

Pilgrim Watch moves that this Board revisit its prior orders and ensure that their effect is consistent with the NRC's stated goals, Mission, and Strategic Outcomes, and provides the "full and fair" hearing promised by the Board's own brochure.

[33] See also fn 47, p 39: "[I]n my view my colleagues apply a standard that overlooks or ignores gejuine issues of material fact the Intervenors present throug reputable experts, as well as considerations of practical reality and fundamental fairness.

V. What Pilgrim Watch Would Have Proved But for the Prior Orders

If Pilgrim Watch had been allowed to argue issues that were properly brought forward in its initial Motion to Intervene, May 25, 2006, and it would have offered evidence to prove that:

(i) Entergy's use of probabilistic modeling,

(ii) Entergy's assumption of a small sized accident, instead of what is commonly understood as a severe accident,

(iii) Entergy's use of the MACCS2 code,

(iv) Entergy's use of the mean consequence values, and

(v) The Board's and Commission's elimination of the significant economic costs, especially cleanup and health costs,

both individually and collectively improperly watered- down consequences and permitted Entergy to avoid having to take mitigation steps that would have been required by a proper SAMA analysis.

A. Probabilistic Modeling

If PW had been allowed to dispute Entergy's use of probabilistic modeling in its SAMA analysis, we would have introduced evidence to show the following:

1. The probability/likelihood of a severe accident used by Entergy in its SAMA analysis was far too low and was intentionally chosen to insure that Entergy would not have to make any significant mitigation steps.
2. By using probabilistic modeling and incorrect parameters in its SAMA analysis Entergy arrives at a result that downplays the likely consequences of a severe accident at PNPS, and thus incorrectly discounts possible mitigation alternatives. This could have enormous implications for public health and safety because a

potentially cost effective mitigation alternative might not be considered that could prevent or reduce the impacts of that accident. Petitioners allege the Environmental Report's SAMA analysis is deficient and the deficiency could significantly impact health and safety.

3. Entergy's SAMA analysis multiplied mean consequences by a weighted too-low probability to improperly insure that, no matter how large real economic consequences might be, the consequences supposedly balanced against costs in the SAMA analysis would be trivialized.
4. Permitting an Applicant to simply multiply all consequences of an accident by extremely low probability and thus reject all possible mitigation as too costly, is inconsistent with the NRC's supposedly required Severe Accident Mitigation Analysis.
5. It is widely recognized that probabilistic modeling can underestimate the deaths, injuries, and economic impact likely from a severe accident. By multiplying high consequence values with low probability numbers, the consequence figures appear far less startling. For example a release that would cause 100,000 cancer fatalities would only appear to cause 1 cancer fatality per year if the associated probability of the release were 1/100,000 per year.
6. NRC in the GEIS recognized what happens when probability weighted consequences are used by the Applicant. It said that,

> The *probability weighted consequences* of atmospheric releases, fallout onto open bodies of water, releases to ground water, and societal and economic impacts from severe accidents are small for all plants. However, alternatives to mitigate severe accidents must be considered for all plants that have not considered such alternatives. *See* § 51.53(c)(3)(ii)(L). (10 C.F.R. Part 51, Subpart A, Appendix B, Table B-1, Issue 76.) (Emphasis added)

7. This statement was misinterpreted by Entergy, NRC Staff, the Board, and Commission. Properly understood, the GEIS does not say that accident consequences __ small; rather it simply says that "probability weighted consequences" insures that they will appear to be small.
8. The GEIS supports PW's contention that Entergy's choice to multiply the "mean" by the "weighted probability" in the MACCS2 Output File resulted in minimizing the true consequences in Pilgrim's SAMA analysis.
9. Probability may be taken into consideration, but it must be taken with caution, particularly as it relates to Pilgrim's SAMA analysis. Kamiar Jamali's (DOE Project Manager for Code Manual for MACCS2) *Use of Risk Measures in Design and Licensing Future Reactors,*[34] explains that "PRA" uncertainties are so large and so unknowable that it is a huge mistake to use a single number coming from them for any decision regarding adequate protection. "Examples of these uncertainties include probabilistic quantification of single and common-cause hardware or software failures, occurrence of certain physical phenomena, human errors of omission and commission, magnitudes of source terms, radionuclide release and transport, atmospheric dispersion, biological effects of radiation, dose calculations, and many others." (Jamali, Pg., 935) (Emphasis added)
10. Probability analysis has other pitfalls. Human error is not considered in PRAs. PRAs project into the future and come up with some very small number that an accident scenario only is likely to occur in so many hundreds-to-thousands of years. But no reactor has operated 45 or more years so actual experience is absent to base predictions. Uncertainty must be respected by making certain that appropriate and up-to-date methods and assumptions are used in the analysis. Entergy failed to do so.

[34] Appendix 3, Exhibit 14

B. Amount of Radioactive Release – Size of Accident

If PW had been permitted to do so, it would have presented evidence that

1. Entergy limited its SAMA analysis to avoid having to take proper mitigation steps by assuming, and inputting into the MACCS2 code.[35]
2. A proper source input would have shown that more SAMAs would be justified.
3. Entergy severely and improperly minimized the likely amount of radiation that could be released in a severe accident by (i) assuming, for example, a relatively small release of CsI from the core; (ii) ignoring any release from the spent fuel pool; (iii) and using a source code that underestimated consequence.
4. The source terms used by Entergy to estimate the consequences of severe accidents (radionuclide release fractions generated by the Modular Accident Analysis Progression, MAAP[36]) code, have not been validated by NRC. They are consistently smaller for key radionuclides than the release fractions specified in NUREG-1465 and its recent revision for high-burnup fuel. The source term used results in lower consequences than would be obtained from NUREG-1465 release fractions and release durations.
5. MAAP generates lower release fractions than those derived and used by NRC in studies such as NUREG-1150. A Brookhaven National Laboratory study that independently analyzed the costs and benefits of one SAMA in the license renewal application for the Catawba and McGuire plants noted that the collective dose results

[35] Expert Reference: Dr. Edwin Lyman would conduct for PW a similar analysis as provided to Riverkeeper in Riverkeeper, Inc's Request for Hearing and Petition to Intervene in the License Renewal Proceedings of Indian Point Nuclear Plant, November 30, 2007, pgs., 68-9. Dr. Lyman's expert testimony is attached, Appendix 4, Exhibit 12. Because Entergy also used MAAP at Pilgrim, comments made by Dr. Lyman in that declaration are applicable.

[36] See, for example, ER. E.1.2.1

reported by the applicant for early failures …seemed less by a factor between 3 and 4 than those found for NUREG-1150 early failures for comparable scenarios. The difference in health risk was then traced to differences between [the applicant's definitions of the early failure release classes] and the release classes from NUREG-1150 for comparable scenarios.

6. The NUREG-1150 release fractions for the important radionuclides are about a factor of 4 higher than the ones used in the Duke PRA. The Duke results were obtained using the Modular Accident Analysis Package (MAAP) code, while the NUREG-1150 results were obtained with the Source Term Code Package [NRC's state-of-the-art methodology for source term analysis at the time of NUREG-1150] and MELCOR.
7. The differences in the release fractions are primarily attributable to the use of the different codes in the two analyses.[37]
8. The use of source terms generated by MAAP, a proprietary industry code that has not been independently validated by NRC, leads to anomalously low consequences when compared to source terms generated by NRC staff.
9. The NRC has been aware of this discrepancy for at least two decades. In the draft "Reactor Risk Reference Document" (NUREG-1150, Vol. 1), NRC noted that for the Zion plant (a four-loop PWR), that "comparisons made between the Source Term Code Package results and MAAP results indicated that the MAAP estimates for environmental release fractions were significantly smaller. It is very difficult to determine the precise source of the differences observed, however, without

[37] See J. Lehner et al., "Benefit Cost Analysis of Enhancing Combustible Gas Control Availability at Ice Condenser and Mark III Containment Plants," Final Letter Report, Brookhaven National Laboratory, Upton, NY, December 23, 2002, p. 17. ADAMS Accession Number ML031700011.

performing controlled comparisons for identical boundary conditions and input data."[38] We are unaware of NRC having performed such comparisons.

10. The NUREG-1465 source term was also reviewed by an expert panel in 2002, which concluded that it was "generally applicable for high-burnup fuel."[39] This and other insights by the panel on the NUREG-1465 source term are being used by the NRC in "radiological consequence assessments for the ongoing analysis of nuclear power plant vulnerabilities."[40]

11. Entergy should not have used a MAAP-generated source terms in its SAMA analysis.

<u>Core Release</u>

If permitted to do so, PW would have presented evidence that Entergy ignored the consequences of a severe accident,[41] for example, that

1. Pilgrim has the potential to release <u>more than twice</u> the amount of Cs-137 than was released at Chernobyl. The amount of Cs-137 released during Chernobyl in 1986 was 2,403,000 curies; the amount of Cs-137 in Pilgrim's <u>Core</u> during license extension will be 190,000 TBq or 190,000 X 27 Ci = 5,130,000 curies.

2. Entergy's MACCS2 model apparently estimated costs based on a release (i) of noble gases in the core inventory and (ii) a <u>small fraction</u> of the core inventory of CsI. [PNPS Radionuclide Release Category Summary, Figure E.1.1].

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[38] U.S. NRC, "Reactor Risk Reference Document: Main Report, Draft for Comment," NUREG-1150, Volume 1, February 1987, p. 5-14.
[39] J. Schaperow, U.S. NRC, memorandum to F. Eltawila, "Radiological Source Terms for High-Burnup and MOX Fuels," December 13, 2002.
[40] J. Schaperow (2002), op cit.
[41] See for example, Pilgrim Watch's Brief In Response To CLI-09-11 (Requesting Additional Briefing), June 25, 2009, Pg.,20-21; and Pilgrim Watch's Answer Opposing Entergy's Motion for Summary Disposition of Pilgrim Watch Contention 3, June 29, 2007,Pgs 89-90; Declaration Jan Beyea and 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, Pg, 94 -

Magnitude of Release: Source term results from previous risk studies suggest that categorization of release magnitude based on cesium iodide (CsI) release fractions are appropriate [Reference E.1-5]. The CsI release fraction indicates the fraction of in-vessel radionuclides escaping to the environment. (Noble gas release levels are non-informative since release of the total core inventory is essentially complete given containment failure.) The source terms were grouped into four distinct radionuclide release categories or bins according to release magnitude as follows: (1) High (HI) – A radionuclide release of sufficient magnitude to have the potential to cause early fatalities. This implies a total integrated release of ›10% of the initial core inventory of CsI [Reference E.1-5]. (1) High (HI) - A radionuclide release of sufficient magnitude to have the potential to cause early fatalities. This implies a total integrated release of $>10\%$ of the initial core inventory of CsI [Reference E.1-5].(2) Medium (MED) - A radionuclide release of sufficient magnitude to cause near term health effects. This implies a total integrated release of between 1 and 10% of the initial core inventory of CsI [Reference E.1-5]. (3) Low (LO) - A radionuclide release with the potential for latent health effects. This implies a total integrated release of between 0.001% and 1% of the initial core inventory of CsI. (4) Negligible (NCF) - A radionuclide release that is less than or equal to the containment design base leakage. This implies total integrated release of $<0.001\%$ of the initial core inventory of CsI.

Spent Fuel Pool Release

If permitted to do so, PW would have presented evidence that:

1. A spent fuel pool fire could release more than 44,010,000 curies of Cs-137, an amount that is 8 times more than a core release. Further a spent fuel pool fire would result in releases going higher into the air and thereby significantly impacting locations at greater distance with denser populations.
2. Accidents are severe by reason of their consequence, not because of where originate [NUREG-1437, GEIS, Section 5]. If the costs of an accident resulting from a pool fire were considered, the value of SAMAs would rise significantly. Dr. Beyea estimated the cost of a 10% release from a spent pool fire to be $105-175 billion dollars; and that a 100% release of C-137 would cost between $342-$488 billion. (Beyea, 10). In contrast, Entergy modeled only the release of a relatively small amount of C-137 from the reactor core.
3. A severe accident from the spent fuel pool at Pilgrim resulting from either human error, mechanical failure or an act of malice is reasonably foreseeable. The offsite cost risk of a pool fire is substantially higher than the offsite cost of a release from a core-damage accident.
4. SAMAs designed to avoid or mitigate conventional accidents may be different than SAMAs designed to avoid or mitigate spent fuel accidents. Moreover, the radiological consequences of a spent-fuel-pool fire are significantly different from the consequences of a core-damage accident.
5. There are significant potential interactions between the pool and the reactor in the context of severe accidents at Pilgrim. The spent-fuel pool is located in the attic of the

main reactor building, outside containment. It shares essential support systems with the reactor. There could be at least three types of interactions between the pool and reactor.[42] First, a pool fire and a core-damage accident could occur together, with a common cause. For example, a severe earthquake could cause leakage of water from the pool, while also damaging the reactor and its supporting systems to such an extent that a core-damage accident occurs. Second, the high radiation field produced by a pool fire could initiate or exacerbate an accident at the reactor by precluding the presence and functioning of operating personnel. Third, the high radiation field produced by a core-damage accident could initiate or exacerbate a pool fire, again by precluding the presence and functioning of operating personnel. Many core-damage sequences would involve the interruption of cooling to the pool, which would call for the presence of personnel to provide makeup water or spray cooling of exposed fuel. The third type of interaction was considered in a license-amendment proceeding in regard to expansion of spent-fuel-pool capacity at the Harris nuclear power plant. Such accidents are conceivable and would result in a very high magnitude of release.

6. 10 C.F.R. § 51.53(c)(3)(ii)(L), does not provide a definition of severe accidents.
7. GEIS[43] which provides the factual background for the SAMA requirement in the regulations, *does* define a "severe accident."

> The term "accident" refers to any unintentional event outside the normal plant operational envelope that results in a release or the potential for release of radioactive materials into the environment. Generally, the U.S.

[42] Dr. Gordon Thompson, Risks of Pool Storage of Spent Fuel at Pilgrim Nuclear Power Station and Vermont Yankee, A Report for the Massachusetts Attorney General by IRSS, May 2006, Pgs., 12, 16. NRC Electronic Library, Adams Accession Number ML061630088"

[43] See NUREG-1437, Generic Environmental Impact Statement for License Renewal of Nuclear Plants (May 1960) [hereinafter GEIS]; Final Rule, "Environmental Review for Renewal of Nuclear Power Plant Operating Licenses," 61 Fed. Reg. 28, 467 (June 5, 1960, amended by 61 Fed. Reg. 66, 537 (Dec. 18, 1996); 10 C.F.R. Pt. 51, Subpart A, Appendix B n.1)

> Nuclear Regulatory Commission (NRC) categorizes accidents as "design basis" (i.e., the plant is designed specifically to accommodate these) or "severe" (i.e., those involving multiple failures of equipment or function and, therefore, whose likelihood is generally lower than design-basis accidents but where consequences may be higher), for which plants are analyzed to determine their response. *The predominant focus in environmental assessments is on events that can lead to releases substantially in excess of permissible limits for normal operation. Normal release limits are specified in the NRC's regulations* (10 C.F.R. Part 20 and 10 C.F.R. Part 50, Appendix A). GEIS, 5.2.1. Italics added

8. According to Section 5.2.1 of NUREG 1437 "General Characteristics of Accidents," the "term '***accident***' refers to any unintentional event outside the normal plant operational envelope that results in a release or the potential for release of radioactive materials into the environment" and '**severe' …** [includes] those involving multiple failures of equipment or function and, therefore, whose likelihood is generally lower than design basis accidents but where consequences may be higher . . ." (emphasis added). This section recognizes the potential for a severe accident in which there are "releases substantially in excess of permissible limits for normal operation.

9. Section 5 focuses on potential *consequences* to determine whether or not a potential accident is severe – and thus within the scope of a Severe Accident Mitigation Analysis.

10. Section 6 of the GEIS with Section 5. Section 6 deals with *normal operations* (see, for example, section 6.1: "Accidental releases … could conceivable result in releases that would cause moderate or large radiological impacts. *Such conditions are beyond the scope of regulations controlling normal operations*…." (Emphasis added).

11. Section 5, <u>not</u> Section 6, deals with severe accidents. The question is not whether the source of the Severe Accident is the first or second largest inventory of radioactive

materials. Nothing in Section 5 excludes severe accidents involving what at Pilgrim Station is the largest inventory of radioactive materials – the spent fuel pool.

Use of the MACCS2 Code

If permitted to do so, PW would have presented evidence that Entergy improperly used the MACCS2 code to reduce the supposed consequences of an improperly assumed accident and, thus, mitigation steps that Entergy properly should be required to take. More particularly, PW would have presented evidence showing:

1. No NRC regulation *requires* the use of the MACCS2 code, or any other particular code, and there other codes available.
2. The code is not Quality Assured.[44] The MACCS & MACCS2 codes were developed for research purposes not licensing purposes –for that reason they were not held to the QA requirements of NQA-a (American Society of Mechanical Engineering, QA Program Requirements for Nuclear Facilities, 1994). Rather they were developed using following the less rigorous QA guidelines of ANSI/ANS 10.4. [American Nuclear Standards Institute and American Nuclear Society, *Guidelines for the Verification and Validation of Scientific and Engineering Codes for the Nuclear Industry*, ANSI/ANS 10.4, La Grange Park, IL (1987).
3. In addition to the meteorological inputs discussed above, important code input parameters include source, average (cumulative distribution function), probability, and a discount rate applied in CHRONC.

[44] Chanin, D.I. (2005), "The Development of MACCS2: Lessons Learned," [written for:] *EFCOG Safety Analysis Annual Workshop Proceedings*, Santa Fe, NM, April 29–May 5, 2005. Full text: the development of maccs2.pdf (154 KB), revised 12/17/2009. http://chaninconsulting.com/index.php?resume. (Attachment 5, Exhibit 4)

4. Source is chosen by Entergy and input to ATMOS. ATMOS outputs, based on Entergy's chosen source, are input into both EARLY and CHRONC which determine consequences of an accident from Entergy's chosen source. Entergy chose an unrealistically low source input for the purpose of avoiding having to take mitigation steps that would have to be taken if a realistic source input was used.
5. A discount rate is chosen by Entergy and input to CHRONC, which in determining consequences applies the discount rate to property that must be condemned. A discount makes little sense. Properties appreciate over 20 years, not depreciate.
6. The type of average and probability of an accident are also chosen by Entergy. The Output file "averages" consequences from EARLY and CHRONC and permits the user to "average" using any one of several percentiles, including "mean," 90^{th} percentile, and 95^{th} percentile. Entergy chose mean for the purpose of avoiding having to take mitigation steps that would have to be taken if a higher, i.e., 90^{th} or 95^{th} percentile had been chosen.
7. Entergy failed to consider the uncertainties in its consequence calculation resulting from meteorological variations by only using mean values (LRA, Appendix E.1.5.3) for population dose and offsite economic cost estimates. If PW had been allowed to show the impact from using different statistical analyses, more SAMAs would have come into play.
8. In the License Renewal GEIS refers repeatedly to the 95^{th} percentile of the risk uncertainty distribution as an appropriate "upper confidence bound" in order not to "underestimate potential future environmental impacts."[45]

[45] U.S. NRC, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," NUREG-1437, Vol. 1, May 1996, Section 5.3.3.2.1.

9. The consequence calculation, as carried out by the MACCS2 code, generates a series of results based on random sampling of a year's worth of weather data. The code provides a statistical distribution of the results. Based on calculations done at other reactors such as Indian Point, the ratio of the 95th percentile to the mean of this distribution is typically a factor of 3 to 4 for outcomes such as early fatalities, latent cancer fatalities and off-site economic consequences. [46]

10. The Output file also multiplies the consequences resulting from Entergy's chosen consequence percentile by an assumed probability of an accident, which is also chosen by Entergy. Entergy improperly assumed, and chose, an extremely low probability for the purpose of avoiding having to take mitigation steps that would have to be taken if a probability that was realistic and would provide protection to the public had been chosen.

Cleanup/Decontamination, Health and Other Costs

If permitted to do so, Pilgrim Watch would have presented evidence that Entergy, severely minimized decontamination and clean-up costs[47], health costs[48] (that includes inaccurately

[46] Dr. Edwin S. Lyman, Senior Staff Scientist, Union of Concerned Scientists report commissioned by Riverkeeper, Inc., November 2007, A Critique of the Radiological Consequence Assessment Conducted in Support of the Indian Point Severe Accident Mitigation Alternatives Analysis; available at NRC Electronic Library, Adams Accession Number ML073410093, Exhibit 12

[47] Decontamination/Cleanup, see for example: Pilgrim Watch's Answer Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, June 29, 2007, Pg., 90-; And Accompanying Declaration Of David L. Chanin In Support Of Pilgrim Watch's Response Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, (*Maccs2 Support Forum,* August 23, 2006 & January 23, 2007) June 5, 2007; and Pilgrim Watch's Brief in Response to CLI-09-11 (Requesting Additional Briefing) June 25, 2009, Pgs., 12-13

[48] Health Costs, see for example: Pilgrim Watch's Answer Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, June 29, 2007,Pg.,7,8,18,23,32-37,46-48,66, 81-86; and Declaration Dr. Jan Beyea (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), Pgs., 6,7,13,15; and Pilgrim Watch's Brief in Response to CLI-09-11 (Requesting Additional Briefing) June 25, 2009, Pgs.,12, 19. Evacuation time estimates incorrect resulting in increased health costs as fewer people evacuate in a timely manner: see : Pilgrim

modeling evacuation time estimates), and minimized and ignored a myriad of other economic costs,[49] both within and outside of Plymouth County, that belong in a SAMA analysis.

For example, with respect to the area potentially affected by a severe accident at PNPS, Pilgrim Watch would have presented evidence that:

1. The costs of a radiological accident at PNPS would not be limited to Plymouth County, but would affect the Commonwealth of Massachusetts," Southeastern Massachusetts, and three other counties.
2. Both Providence and Boston are within 45 miles PNPS and could be sustain significant radiological damage if a severe accident should occur at PNPS.

With respect to cleanup, Pilgrim Watch would have presented evidence showing that:

1. Cleanup costs are the "Elephant in the Room" that NRC and Entergy want to avoid. Proper clean-up would result in major offsite costs requiring the addition of a large number of mitigations.
2. The MACCS2 Decontamination Plan is described in part in the Code Manual for MACCS2: Volume I, User's Guide (NUREG/CR-6613, Vol. 1) Prepared by D. Chanin and M.I. Young, May 1998. Section 7.5 Decontamination Plan describes some of the assumptions. It says at 7-10 that,

> Many decontamination processes (e.g., plowing, fire hosing) reduce groundshine and resuspension doses by washing surface contamination down into the ground. Since these processes may not move contamination out of the root zone, the WASH-1400 based economic cost model of

Watch's Answer Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, June 29, 2007,Pg.,58-71 and Pilgrim Watch's Answer Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, June 29, 2007, Pg., 11,19-20.

[49] Other Economic Costs, see for example: Pilgrim Watch's Answer Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, June 29, 2007, Pg.,72-91; Pilgrim Watch's Answer Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, June 29, 2007, Pg.,10-12, 22.

> MACCS2 assumes that farmland decontamination reduces direct exposure doses to farmers without reducing uptake of radioactivity by root systems. Thus decontamination of farmland does not reduce the ingestion doses produced by the consumption of crops that are contaminated by root uptake.

3. The MACCS2 cleanup assumptions used by Entergy are directly based on WASH-1400; WASH-1400, in turn, was based on clean up after a nuclear explosion.
4. Cleanup after a nuclear bomb explosion is not comparable to clean up after a nuclear reactor accident; Entergy's apparent assumption that the two are comparabile severely underestimated cleanup costs. Nuclear explosions result in larger-sized radionuclide particles; reactor accidents release small sized particles. Decontamination is far less effective, or even possible, for small particle sizes. Nuclear reactor releases range in size from a fraction of a micron to a couple of microns; whereas nuclear bomb explosions fallout is much larger- particles that are ten to hundreds of microns. These small nuclear reactor releases can get wedged into small cracks and crevices of buildings.
5. WASH-1400's nuclear weapon clean up experiments involved cleaning up fallout involving large mass loading where the there was a small amount of radioactive material in a large mass of dirt and demolished material. Only the bottom layer will be in contact with the soil and the massive amount of debris can be swept up with brooms or vacuums resulting in a relatively effective, quick and cheap cleanup that would not be the case with a nuclear reactors fine particulate. (CLI-10-11, Pg., 29-30)
6. A weapon explosion results in non-penetrating radiation so that workers only require basic respiration and skin protection. This allows for cleaning up soon after the event. In contrast a reactor release involves gamma radiation and there is no gear to protect

workers from gamma radiation. Therefore cleanup cannot be expedited and decontamination is less effective with the passage of time.

7. Entergy's cost model ignored radioactive waste disposal. In a weapon's event, the waste could be shipped to Utah or to the Nevada Test Site. The Greater- than- Class C waste expected in a reactor accident would not have a repository likely available to receive such a large quantity of material in the foreseeable future. Also, the costs incurred for safeguarding the wastes and preventing their being re-suspended are not accounted for in the model. Even optimistically assuming a repository becoming available, (Utah' site is approximately one-square mile) it seems unlikely that there would be a sufficient quantity of transport containers and communities not objecting to the hazardous materials going over their roads and through their communities.

8. The User's Guide describes decontamination processes as "plowing" and "fire hosing." CERLA, EPA and local authorities would not allow use of those methods. Fire hosing and plowing do not decontaminate, it simply moves the contamination from one place to another – only to reappear again later in groundwater, resuspended into the air, or in food. Therefore cleanup will take far longer and be more expensive than assumed by Entergy; and its success (defined as returning to pre-accident status) unlikely.

9. Also apparently missing from consideration is that forests, wetlands and shorelines cannot realistically be cleanup and decontaminated. The area within 50-miles of Pilgrim Station consists of miles of beaches, rivers, lakes, ponds, bogs, wetlands, forests and park land Additionally, urban areas will be considerably more expensive and time consuming to decontaminate and clean than rural areas.

10. The US Department of Homeland Security has commissioned studies for the economic consequences of a Rad/Nuc attack. Much more deposition would occur in reactor accident, magnifying consequences and costs, but there are important lessons to be learned from these studies. Barbara Reichmuth's study, Economic Consequences of a Rad/Nuc attack: Cleanup Standards Significantly Affect Cost, 2005,[50] Table 1 Summary Unit Costs for D &D (Decontamination and Decommissioning) Building Replacement and Evacuation Costs provides estimates for different types of areas from farm or range land to high density urban areas. Reichmuth's study also points out that the economic consequences of a Rad/Nuc event are highly dependent on cleanup standards: "Cleanup costs generally increase dramatically for standards more stringent than 500 mrem/yr."

11. Currently the NRC and EPA have not agreed on a cleanup standard.[51] The potential standard appears to range from 15 mrem/yr to 5 rem/yr. The General Accounting Office (GAO) reports that the current EPA and NRC cleanup standards differ and these differences have implications for both the pace and ultimate cost of cleanup.[52] Entergy should have used the EPA (15 mrem/yr) standard in determining clean-up costs; it did not.

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[50] Economic Consequences of a Rad/Nuc attack: Cleanup Standards Significantly Affect Cost Barbara Reichmuth, Steve Short, Tom Wood, Fred Rutz, Debbie Swartz, Pacific Northwest National laboratory, 2005 (Attachment 6, Exhibit 8)

[51] See Pilgrim Watch's Request For Hearing On New Contention; the information upon which this contention is available from a trade publication INSIDE EPA; please see report and supporting documents at http://environmentalnewsstand.com/Environmental-NewsStand-General/Public-Content/agencies-struggle-to-craft-offsite-cleanup-plan-for-nuclear-power-accidents/menu-id-608.html

[52] GAO, "Radiation Standards Scientific Basis Inconclusive, and EPA and NRC Disagreement Continues," June 2004

12. A similar study was done by Robert Luna, *Survey of Costs Arising from Potential Radionuclide Scattering Events,*.[53] concluded that,

> …the expenditures needed to recover from a successful attack using an RDD type device …are likely to be significant from the standpoint of resources available to local or state governments Even a device that contaminates an area of a few hundred acres (a square kilometer) to a level that requires modest remediation is likely to produce costs ranging from $10M to $300M or more depending on the intensity of commercialization, population density, and details of land use in the area." (Luna, Pg., 6)

13. A severe accident at Pilgrim will result in huge costs, not accounted for by Entergy, largely because the type and magnitude of radionuclides released in a reactor accident are very different than those released by a RDD type device as explained directly above, 3-5.

14. In place of the outdated decontamination costs figure in the MACCS2 code, the SAMA analysis for Entergy should have incorporated the analytical framework contained in the 1996 Sandia National laboratories report concerning site restoration costs[54] as well as Luna's and Reichmuth's methodology and studies examining Chernobyl.

15. The Sandia Site restoration study analyzed the expected financial costs for cleaning up and decontaminating a mixed-use urban land and Midwest farm and range land. The study was commissioned by DOE to estimate activities

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[53] Survey of Costs Arising From Potential Radionuclide Scattering Events, Robert Luna, Sandia National laboratories, WM2008 Conference, February 24-28, 2008, Phoenix AZ (Attachment 7, Exhibit 9)

[54] Site Restoration: Estimation of Attributable Costs from Plutonium-Dispersal Accidents, SAND96-0957, David Chanin, Walt Murfin, UC-502, (May 1996)

likely to be involved in the decontamination of an accident involving the dispersal of plutonium. Although there would be many differences in a nuclear reactor accident, the methodology and conclusions to estimate costs are directly useful.

16. The Sandia Site study recognized that earlier estimates (those incorporated in WASH-1400 and incorporated in MACCS2) of decontamination costs are incorrect because they examined fallout from nuclear explosion of nuclear weapons that produce large particle sizes and high mass loadings.
17. For an extended decontamination and remediation operation in a mixed-use urban area with an average population density, Site restoration (1996) predicted a cleanup cost of $311,000,000 per square km using offsite disposal and $309,000,000 per square km using on-site disposal. (Site restoration, Pg., 6-5)
18. The costs would be much higher today with inflation and for example for the metropolitan areas of Boston and Providence considering that they are tourist, educational, transportation, and financial centers. The economic losses stemming from the stigma effects of a severe accident would be staggering. The Sandia Site restoration study further says,

> In comparing the numbers of cancer health effects that could result from a plutonium-dispersal accident to those that could result from a severe accident at a commercial nuclear power plant, it is readily apparent that the health consequences and costs of a severe reactor accident could greatly exceed the consequences of even a "worst- case" plutonium-dispersal accident because the quantities of radioactive material in nuclear weapons are a small fraction of the quantities present in an operating nuclear power plant. (Site restoration, Pg., 2-3, 2-4)

19. Under decontamination costs, Entergy lists the costs of farm and non-farm decontamination and the value of farm and nonfarm wealth. However nowhere is there a discussion of the loss of, and costs to remediate the economic infrastructure that make business, tourism and other economic activity possible.

20. Economic infrastructure is the basic physical and organizational structures needed for the operation of a society or enterprise, or the services and facilities necessary for an economy to function. The term typically, and as used by PW, refers to the technical structures that support a society, such as roads, water supply, sewers, power grids telecommunications, and so forth. Viewed functionally, infrastructure *facilitates* the production of goods and services; for example, roads enable the transport of raw materials to a factory, and also for the distribution of finished products to markets. Also, the term may also include basic social services such as schools and hospitals.

21. Entergy appears to ignore the indirect economic effects or the "multiplier effects." For example, depending on the business done inside the building contaminated, the regional and national economy could be negatively impacted. A resulting decrease in the area's real estate prices, tourism, and commercial transactions could have long-term negative effects on the region's economy.

22. Entergy should have been required to take all of these real cleanup costs into account; but the Board and Commission's decisions resulted in their not being required to do so and as a result the public will not get the safety enhancements that we deserve.

23. The following illustrates the significant effect of Entergy's failure properly to consider the costs of cleanup:

1987 Radiological Accident in Goiania, Brazil[55]

In September 1987, a hospital in Goiania, Brazil, moved to a new location and left its radiation cancer therapy unit behind. Found by scrap metal hunters, it was dismantled and the cesium chloride source containing 1,400 Ci of cesium-137 was removed. Pieces were distributed to family and friends, and several who were intrigued by the glow spread it across their skin. Eleven days later, alert hospital staff recognized symptoms of acute radiation syndrome in a number of victims.

The ensuing panic caused more than 112,000 people – 10% of the population – to request radiation surveys to determine whether they had been exposed. At a makeshift facility in the city's Olympic Stadium, 250 people were found to be contaminated. 28 had sustained radiation-induced skin injuries (burns), while 50 had ingested cesium, so for them the internal deposition translated to an increased risk of cancer over their lifetime. Tragically, 2 men, 1 woman, and 1 child died from acute radiation exposure to the very high levels of gamma radiation from the breached source.

In addition to the human toll, contamination had been tracked over roughly 40 city blocks. Of the 85 homes found to be significantly contaminated, 41 were evacuated and 7 were demolished. It was also discovered that through routine travels, within that short time people had cross-contaminated houses nearly 100 miles away. Cleanup generated 3,500 m3 radioactive waste at a cost of $20 million.

The impacts of this incident continued beyond the health and physical damage to profound psychological effects including fear and depression for a large fraction of the city's inhabitants.

Further, frightened by the specter of radioactive contamination, neighboring provinces isolated Goiania and boycotted its products. The price of their manufactured goods dropped 40% and stayed low for more than a month. Tourism, a

[55] Revisiting Goiania: Toward a final repository for radioactive waste, IAEA Bulletin 1993,Rad waste 3,500 cubic meters,1270 to 1340 curies in waste,http://www.ead.anl.gov/pub/doc/rdd.pdf Exhibit 15

primary industry, collapsed and recent population gains were reversed by business regression. Total economic losses were estimated at hundreds of millions of dollars.

Health Costs

With respect to health costs, Pilgrim Watch would have presented evidence showing that Entergy's "life lost" value is much too low.

1. EPA values a life lost at $6.1 million (U.S.E.P.A., 1997, The Benefits and Costs of the Clean Air Act, 1970 to 1990, Report to US Congress (October), pages 44-45). Pilgrim's ER assigns a value of $2000 per person rem.

2. The population dose conversion factor of $2000/person-rem used by Entergy to estimate the cost of the health effects generated by radiation exposure is based on a deeply flawed analysis and seriously underestimates the cost of the health consequences of severe accidents.

3. Entergy underestimates the population-dose related costs of a severe accident by relying inappropriately on a $2000/person-rem conversion factor. Entergy's use of the conversion factor is inappropriate because it (a) does not take into account the significant loss of life associated with early fatalities from acute radiation exposure that could result from some severe accident scenarios; and (b) underestimates the generation of stochastic health effects by failing to take into account the fact that some members of the public exposed to radiation after a severe accident will receive doses above the threshold level for application of a dose- and dose-rate reduction effectiveness factor (DDREF).

4. Entergy's $2000/person-rem conversion factor is apparently intended to represent the cost associated with the harm caused by radiation exposure with respect to the causation

of "stochastic health effects," that is, fatal cancers, nonfatal cancers, and hereditary effects.[56] The value was derived by NRC staff by dividing the Staff's estimate for the value of a statistical life, $3 million (presumably in 1995 dollars, the year the analysis was published) by a risk coefficient for stochastic health effects from low-level radiation of $7x10^{-4}$/person-rem, as recommended in Publication No. 60 of the International Commission on Radiological Protection (ICRP). (This risk coefficient includes nonfatal stochastic health effects in addition to fatal cancers.) But the use of this conversion factor in Pilgrim's SAMA analysis is inappropriate in two key respects. As a result Entergy underestimated the health-related costs associated with severe accidents.

5. First, the $2000/person-rem conversion factor is specifically intended to represent only stochastic health effects (e.g. cancer), and not deterministic health effects "including early fatalities which could result from very high doses to particular individuals."[57] However, for some of the severe accident scenarios evaluated, large numbers of early fatalities could occur representing a significant fraction of the total number of projected fatalities, both early and latent. This is consistent with the findings of the Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437).[58] Therefore, it is inappropriate to use a conversion factor that does not include deterministic effects. According to NRC's guidance, "the NRC believes that regulatory issues involving deterministic effects and/or early fatalities would be very rare, and can be addressed on a case-specific basis, as the need arises."[59] Based on our estimate of the

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[56] U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy," NUREG-1530, 1995, p. 12.
[57] U.S. NRC (1995), op cit., p. 1.
[58] U.S. NRC, Generic Environmental Impact Statement for License Renewal of Nuclear Plants, NUREG-1437, Vol. 1, May 1996, Table 5.5.
[59] U.S. NRC, "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy (1995), op cit., p. 13.

potential number of early fatalities resulting from a severe accident at Pilgrim, this is certainly a case where this need exists.

6. Second, the $2000/person-rem factor, as derived by NRC, also underestimates the total cost of the latent cancer fatalities that would result from a given population dose because it assumes that all exposed persons receive dose commitments below the threshold at which the dose and dose-rate reduction factor (DDREF) (typically a factor of 2) should be applied. However, for certain severe accident scenarios at Pilgrim evaluated by Entergy, we estimate that considerable numbers of people would receive doses high enough so that the DDREF should not be applied.[60] This means, essentially, that for those individuals, a one-rem dose would be worth "more" because it would be more effective at cancer induction than for individuals receiving doses below the threshold. To illustrate, if a group of 1000 people receive doses of 30 rem each over a short period of time (population dose 30,000 person-rem), 30 latent cancer fatalities would be expected, associated with a cost of $90 million, using NRC's estimate of $3 million per statistical life and a cancer risk coefficient of $1x10^{-3}$/person-rem. If a group of 100,000 people received doses of 0.3 rem each (also a population dose of 30,000 person- rem), a DDREF of 2 would be applied, and only 15 latent cancer fatalities would be expected, at a cost of $45 million. Thus a single cost conversion factor, based on a DDREF of 2, is not appropriate when some members of an exposed population receive doses for which a DDREF would not be applied.

7. A better way to evaluate the cost equivalent of the health consequences resulting from a severe accident is simply to sum the total number of early fatalities and latent cancer

[60] The default value of the DDREF threshold is 20 rem in the MACCS2 code input

fatalities, as computed by the MACCS2 code, and multiply by the $3 million figure. It is not reasonable to distinguish between the loss of a "statistical" life and the loss of a "deterministic" life when calculating the cost of health effects.

8. That Entergy's estimates of how many lives might be lost are too low is also shown by the 1982 Sandia National Laboratory report. Using 1970 census data, that report estimated the number of cancer deaths at Pilgrim as a consequence of a severe reactor accident[61] in a severe accident to be 3,000 early fatalities within the first year and 30,000 peak early injuries within the first year.7,000 and early injuries 27,000. Peak fatalities were estimated by CRAC to occur within 20 miles of Pilgrim; and peak injuries to occur with 65 miles of Pilgrim from a core melt. (CRAC 2, Sandia, 1982[62])

9. The population of the affected area, no matter what model is used, has greatly increased during the intervening almost 40 years; SAMAs project forward to 2050 based on projected demographics. Entergy estimated the population within 50-miles (2032) to total 7489767. (LRA, Appendix E.1.5.2.1, Table E.1-13) Further CRAC was based on old, and now outdated, dose response models.

10. In Entergy's SAMA analysis, cancer incidence was not considered; neither were the many other potential health effects from exposure in a severe radiological event (National Academy of Sciences, BEIR VII Report, 2005).

11. Entergy's cost-benefit analysis ignored a marked increase in the value of cancer mortality risk per unit of radiation at low doses (2-3 rem average), as shown by recent studies

[61] Sandia National Laboratory study for U.S. Nuclear Regulatory Commission, Calculation of Reactor Accident Consequences for U.S. Nuclear Power Plants (CRAC 2), 1981.

[62] Calculation of Reactor Accident Consequences, U.S. Nuclear Power Plants (CRAC-2), Sandia National Laboratory, 1982.

published on radiation workers (Cardis et al. 2005[63]) and by the Techa River cohort (Krestina et al (2005[64]). Both studies give similar values for low dose, protracted exposure, namely (1) cancer death per Sievert (100 rem). According to the results of the study by Cardis et al. and use of the risk numbers derived from the Techa River cohort the SAMA analyses prepared for Pilgrim needs to be redone. If done so properly a number of additional SAMAs that were previously rejected by the applicant's methodology would become cost effective.

12. Cancer incidence and the other many health effects from exposure to radiation in a severe radiological event (National Academy of Sciences, BEIR VII Report, 2005) should have been considered; they were not. Neither did Entergy consider indirect costs. Medical expenditures are only one component of the total economic burden of cancer. The indirect costs include losses in time and economic productivity and liability resulting from radiation health related illness and death.

13. Applicant's data into the code were unrealistically low. If correct evacuation times and assumptions regarding evacuation had been used, the analysis would show far fewer will evacuate in a timely manner, increasing health-related costs.

<u>Evacuation Time Estimates → Health Costs</u>

If Pilgrim Watch had been permitted to do so, it also would have presented evidence showing:

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[63] Elizabeth Cardis, "Risk of cancer risk after low doses of ionising radiation: retrospective cohort study in 15 countries." *British Medical Journal* (2005) 331:77. Referenced Beyea, Exhibit 2

[64] Krestinina LY, Preston DL, Ostroumova EV, Degteva MO, Ron E, Vyushkova OV, et al. 2005.Protracted radiation exposure and cancer mortality in the Techa River cohort. Radiation Research 164(5):602-611.Exh 2

14. The KLD time estimates relied upon did not take into consideration in the analysis variables that would slow evacuation: shadow evacuation; evacuation time estimates during inclement weather coinciding with high traffic periods such as commuter traffic, traffic during peak commute times, holidays, summer beach/holiday traffic; notification delay delays because notification is largely based on sirens that cannot be heard in doors above normal ambient noise with windows closed or air conditioning systems operating.

15. The Applicant performed a sensitivity analysis that assumed no evacuation of the population in a severe accident and found only a small increase to the overall total accident dose risk and no change in economic risk. However, Entergy's sensitivity studies did not provide useful information since the model on which they were based was flawed.

Myriad of Other Economic Costs

16. Entergy did not appear to include in their economic cost estimates the business value of property and the incurred costs such as costs required from job retraining, unemployment payments, and inevitable litigation. Entergy used an assumed value of non-farm wealth that appeared not justified by review of Banker and Tradesmen sales figures. Entergy underestimated Farm Value, for example, by not considering the value of the farm property for development purposes as opposed to agricultural; and farm land assessments are intentionally very low to encourage farming and open space.

If the Board Majority and Commission had not removed from consideration all the important factors initially brought forward by Pilgrim Watch, PW could have proved that Entergy significantly minimized the consequences from a severe accident at Pilgrim to such a degree as to require substantial mitigation.

The magnitude of Entergy's minimization of costs makes obvious that many SAMAs would be cost effective if the described defects in the analysis were addressed. In *Duke Energy Corp.*, at 13, the board said that "[w]hile NEPA does not require agencies to select particular options, it is intended to 'foster both informed decision-making and informed public participation, and thus to ensure the agency does not act upon incomplete information, only to regret its decision after it is too late to correct' (*citing Louisiana Energy Services* (Claiborne Enrichment Center), CLI-98-3, 47 NRC 77, 88 (1998))." It then said "if 'further analysis' is called for, that in itself is a valid and meaningful remedy under NEPA."

In its Contention 3, PilgrimWatch pointed to a material deficiency in the Application - Entergy has drastically under counted the costs of a severe accident that could have led to erroneously rejecting mitigation alternatives and the admitted contention's statement that "further analysis is required" is correct, and could produce a very different outcome of this proceeding.

Respectfully Submitted,

[Signed electronically]

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Appendices

APPENDIX 1

A Review of Prior Board and Commission Decisions (2006-2010)

A. Request for Hearing.

Pilgrim Watch filed its *Request For Hearing and Petition To Intervene By Pilgrim Watch* on May 25, 2006 ("Hearing Request"). That Hearing Request set forth four Contentions. Contentions 1, 2 and 4 have been rejected by the Board and Commission, and remain only for appeal.

Pilgrim Watch's Contention 3 squarely raised important issues that are consistent with "ensur[ing] adequate protection of public health and safety ... and protect[ion of] the environment. Originally filed Contention was (Hearing Request p 26):

> **Contention 3:** The Environmental Report is inadequate because it ignores the true off-site radiological and economic consequences of a severe accident at Pilgrim in its Severe Accident Mitigation Alternatives (SAMA) analysis
>
> **3.0 Contention** The Environmental Report inadequately accounts for off-site and economic costs in the SAMA analysis of severe accidents. By *using probabilistic modeling* and *incorrectly inputting certain parameters* into the modeling software, Entergy has downplayed the consequences of a severe accident at Pilgrim and this has caused it to draw incorrect conclusions about the costs versus benefits of possible mitigation alternatives. (Italics added)

The complete inputs to the MACCS2 actually used by Entergy were not publicly available, and were not included in Entergy's Environmental Report. Without knowing what parameters (e.g., probabilities, source term, consequences percentile) and other specific inputs chosen by Entergy, "it [was] not possible [for PW] to fully evaluate the correctness of the conclusions about Severe Accident Mitigation Alternatives. However, from what is included in the ER, Petitioners have been able to piece together some possible reasons that Entergy's described consequences of a severe accident at Pilgrim look so small." (Hearing Request 34).

Based on the information available to it, Pilgrim Watch's Hearing Request pointed out a number of ways in which Entergy improperly used the MACCS2 code, and in which its Environmental Report inadequately accounted for off-site health exposure and economic costs in its SAMA analysis of severe accidents.

For example, the Hearing Request said at the outset that:

> By using probabilistic modeling and incorrectly inputting certain parameters into the modeling software, Entergy has downplayed the consequences of a severe accident *at Pilgrim* and this has caused it to draw incorrect conclusions about the costs versus benefits of possible mitigation alternatives. [Emphasis added]" (Hearing Request, 28)

Pilgrim Watch then said, not that probabiltic modeling was *per se* improper, but that Entergy had misused it to improperly minimize SAMAs:

- [T]he likely impacts of a servere accident have been dramatically minimized by using probabilistic modeling which makes the costs of all severe accidents appear negligible. ... [A]ny time an applicant multiplies an accident consequence by an extremely low probability number, the consequences will appear minute. (Hearing Request 29)

- It would make no sense for the NRC to require Severe Accident Mitigation Analysis if an applicant could simply multiply all consequences of an accident by extremely low probability and thus reject all possible mitigation as too costly. (Hearing Request 30).

As for the manner in which consequences were calculated, before being reduced to nothingness by Entergy's choice of "probability" used in the code's Output File, the Hearing Request said, as quoted above, that "Entergy has downplayed the consequences of a severe accident" by incorrrectly inputting certain parameters into the modeling software." (Hearing Request 28). The Request went on to say:

> In addition, Entergy has used incorrect input parameters, including meteorological, emerency response, and economic data, into a software model of limited scope. (Hearing Request 29).

Because of the limited public information available showing what Entergy had actually done, Pilgrim Watch's use of "including" was not, could not be, and was not intended to be, inclusive. Entergy's choice of a "low probability number" was clearly encompassed by the Hearing Request (see Hearing Request 28, 29).

What Pilgrim Watch now knows, is that there many important "inputs" and "parameters," chosen by Entergy, that drastically effect consequences. These "include" not only "meteorological, emergency response, and economic data" and the "probability number," but also the chosen source (Entergy chose a small source) and averaging method

(Entergy chose "mean" rather than one of larger percentiles, e.g., 95th, that the code presents as options).

On the basis of what it then knew from public knowledge, Pilgrim Watch's Hearing Request was able to, and did, say that: Neither the MACCS2 model used to analyze consequence nor the input data provided by the applicant provide an accurate assessment of the off-site dose and economic consequences of a severe accident.... [T]here are limitations inherent in the software ... which by design omit the majority of economic costs. (Hearing Request 34)

In short, Pilgrim Watch's original contention made at least three points, <u>specific to</u> Pilgrim's SAMA:

1) The way in which Entergy used probabilistic modeling was inadequate.
2) As used by Entergy to analyze consequences, the MACCS2 model did not provide an accurate assessment of the off-site dose and economic consequences of a severe accident
3) Entergy's choice of parameters it put into the modeling software had the intended result of downplaying the consequences of a severe accident.

There can be no question that each of these points, as applied to Pilgrim's SAMA analysis, could be proved. There also can be no question that the Hearing Request pointed to each as specific deficiencies in Pilgrim's SAMA analysis, and that Pilgrim Watch's original Contentiion was not "generic."[65]

B. The Orders Narrowing Contention 3

Nonetheless, at the outset of this proceeding, in its October 16, 2006 Memorandum And Order (Ruling on Standing and Contentions of Petitioners Massachusetts Attorney General and Pilgrim Watch), the Board, in Pilgrim Watch's view improperly, rewrote Contention 3 to say only that:

> Applicant's SAMA analysis for the Pilgrim plant is deficient in that the input data concerning (1) evacuation times, (2) economic consequences, and (3) meteorological patterns are incorrect, resulting in incorrect conclusions about the costs versus benefits of possible mitigation alternatives, such that further analysis is called for.

In doing so, the Board entirely deleted "by using probabilistic modeling" from PW's original contention, saying that probabilistic techniques that evaluate risk could not be challenged on "a generic basis,"[66] and that "the use of probabilistic risk assessment and modeling is obviously accepted and standard practice in SAMA analyses." (Id at 100).

[65] Under NRC Regulations, SAMAs are a Category 2 (site specific), and not a Category 1 (generic), issue. Table 9.1 of NUREG 1437 lists both Category 1 and Category 2 issues, and identifies SAMAs as Category 2. Entergy seems to agree that SAMAs are Category 2.

[66] The Board majority seemed not to appreciate that PW's original Contention 3 did not generically challenge probabilistic modeling, the MACCS2 code, or averaging. Pilgrim Watch's challenges were specific both to the site and to the ways in which Entergy chose to misuse probabilities, the MACCS2 code, and averaging: "Applicant's SAMA *analysis for the Pilgrim plant* is deficient..."

The Board then went on to limit what remained of the original contention - *incorrectly inputting certain parameters* into the modeling software - to the specific "in addition" inputs that Pilgrim Watch had been able to identify from public information at the time its Hearing Request was filed. To complete its exclusion of "probabilistic modeling" from the rewritten contention and scope of this proceeding, the "low probability number" (Hearing Request 29) and "extremely low probability" (Hearing Request 30) inputs were never mentioned.

At that time in history, Pilgrim Watch, a small public interest group, did not fully appreciate what the Board's re-writing of Contention 3 had done. And PW certainly did not appreciate, and then could not have appreciated, that the majority's later Summary Disposition decision would go even farther, and hold that its rewriting of Contention 3 eliminated all challenges, not simply to "probabilistic modeling," but also to the "adequacy" of the MACCS2 code (Order Granting Summary Disposition, pg.,2, italics added):

> *Not at issue here*, as discussed below in more depth, because these matters were raised and *eliminated at the contention admissibility stage*, are issues related to: (1) the adequacy *of the computer code* (MACCS2) used to perform the SAMA computations; (2) the *use* for SAMA analyses *of probabilistic* (as opposed to deterministic) *methodologies;* and (3) the health effects of low doses of radiation.

Judge Young certainly did not understand the October 2006 order to be that draconian (Dissenting Opinion of Administrative Judge Ann Marshall Young, 35, italics Judge Young's):

> By stating that we found "inadmissible" any part of the contention that could be construed as "challenging on a generic basis the use of probabilistic techniques that evaluate risk," we did *not* exclude *specific* challenges that might bring into question specific aspects of the SAMA analysis regarding the three types of input we admitted.

Judge Young also recognized that what the Board majority really did was to "exclude any meaningful challenge to what is put into the code," and to render Contention 3 "meaningless" (Id. at 35-36, italics added):

> The upshot of this is that, although we admitted the issue of whether the input data regarding meteorological patterns were correct, by now *excluding consideration of anything relating to the adequacy of the MACCS2 code as specifically applied with regard to the Pilgrim plant's SAMA analysis*, the majority in effect e*xcludes any meaningful challenge to what is put into the code* relating to meteorological patterns, because such input is effectively predetermined by the current state of the MACCS2 code. *Our admission of Contention 3 is thus rendered meaningless* with regard to meteorological issues.

The majority's efforts to render Contention 3 meaningless continued in its order of November 23, 2010. Without mentioning any of the portions of Pilgrim Watch's Hearing Request quoted above, the majority held that Pilgrim Watch's Hearing Request failed not only to raise any issues "about the NRC's practice of using mean consequence values in SAMA analyses, resulting in an averaging of potential consequences," but also to raise anything that "could bring into question the reasonableness of this NRC practice and affect the Board's findings and conclusions on the meteorological modeling issues." (November Order).

Once again, and in PW's view correctly, Judge Young disagreed (Order of September 23, 2010:

> First, in consulting the User's Guide for the MACCS2 code, I find various references to "mean consequence values," "mean consequence results," and averaging, some of which appear in discussions of plumes and deposition processes in the ATMOS part of the code. This would seem to support straightaway a conclusion that these usages of the terms are implicitly encompassed within Pilgrim Watch's challenge in Contention 3 to the Gaussian plume model and the modeling processes associated with that – which would lead to a conclusion that the subject at issue was timely raised, at least as to these usages (Sept. Order, at 3)
>
> Entergy's arguments and assertions were challenged by Pilgrim Watch in response to Entergy's summary disposition motion. Intervenor also challenged Entergy's arguments and assertions relating to the use of mean consequence values and averaging. And again, these "mean consequence values/averaging" issues would also seem to fall under, and be material to, the broad, "bottom-line" issue the Commission has remanded – namely, "whether the Pilgrim SAMA analysis resulted in erroneous conclusions on the SAMAs found cost-beneficial to implement." It seems at a minimum arguable that, much as it raises the conservatisms and sensitivity studies, Entergy has raised these averaging/mean consequence values issues in the manner of raising "defenses" to Pilgrim Watch's "charges" in Contention 3, with respect to the effect such averaging has on whether any additional SAMAs might be cost-beneficial to implement.(Sept. Order, at 10)

C. The Bases of the Majority Decisions and What They "Overlooked"

A. Probabilities and the MACCS2 Code

In its October 16, 2006 Order rewriting Contention 3, the Board majority said (emphasis added):

> With respect to Entergy's characterization of PW's contention as being that "risk is to be ignored [in a SAMA analysis]," to the extent that anypart of the contentions or basis may be construed as challenging on a generic basis the use of probabilistic techniques that evaluate risk, we find any such portion(s) to be inadmissible. *The use of probabilistic risk assessment and modling is obviously accepted and standard practice* in SAMA analyses.

The majority's Order granting Summary Disposition, went even further. Over Judge Young's dissent, the majority construed the October Order as having "eliminated ... issues related to: (1) the adequacy of the computer code (MACCS2) used to perform the SAMA computations; [and] (2) the use for SAMA analyses of probabilistic (as opposed to deterministic) methodologies."

The majority's justification for removing all aspects of the MACCS2 code from consideration was again NRC practice: "it is necessary for the Staff to take a uniform approach to its review of such analyses by license applicants and for performance of its own analyses, and it would be imprudent for the Staff to do otherwise without sound technical justification."

In relying on "practice," the majority overlooked at least two important things.

First, it failed to appreciate that NRC "practice" is not NRC "regulation"- neither probabilistic modeling nor the use of the MACCS2 code are required. Regardless of what the Staff's "practice" may be, no NRC regulation requires probabilistic modeling or use of the MACCS2 code. In CLI-10-11, the Commission agreed "that the Staff used a 'customarily' used code, 'widely used and accepted as an appropriate tool' for conducting SAMA analyses, and that the Gaussian plume model is a 'fundamental part' of the MACCS2 Code. But the Commission was equally clear that "those reasons are not a sufficient ground to exclude the code's integral dispersion model from all challenge if adequate support is presented for a contention." (CLI010-11, 17). Indeed, for the Commission to have concluded that they were not sufficient would have been to endorse the view that a desire for"uniformity" could somehow have made it proper for Entergy (and apparently the NRC Staff) to have designed and used an approach that insured that no significant SAMAs will ever be required.

Second, the majority overlooked that Pilgrim Watch's contention did not challenge anything "on a generic basis." Pilgrim Watch's challenge was directed to probability and the MACCS2 Code *as they were specifically used by Entergy* in its SAMA analyses.

B. Health and Cleanup Costs

The majority's Summary Disposition decision also said that health consequences caused by low doses of radiation had been rejected at the contention admissibility stage because "the only economic impact computations it [apparently Pilgrim Watch's Hearing Request] intended to challenge were those relating specifically to loss of economic activity, loss of economic infrastructure and loss of tourism income (and not the economic costs relating to the effects of low levels of radiation upon human health). However, the majority overlooked PW's Hearing Request explicitly included health costs: "The Environmental Report inadequately accounts for off-site health exposure and economic costs in its SAMA analysis of severe accidents." (Hearing Request, 2)

As for costs of clean-up and decontamination, Pilgrim Watch's Hearing Request did say that the "MACCS2 model analysis of economic costs include the cost of decontamination, [and] the cost of condemnation of property that cannot be decontaminated to a specified level" (Hearing Request, 43) But the October Order overlooked that Pilgrim Watch never said that Entergy's use of the MACCS2 code properly determined any of these. The October Order simply paraphrased what Pilgrim Watch said (October Order 83), and never mentioned the subject cleanup or decontamination again.

In its October 26 Order, the Board found "that Pigrim Watch has provided sufficient alleged facts ... to demonstrate a genuine dispute with the Applicant on the material factual issues of whether in its SAMA analysis the Applicant had adequately taken into account relevant and realistic data with respect to evacuation times....[and] economic consequences of a severe accident in the area" (October Order, 103). It went on to say that it thus admitted "that part of Contention 23 having to do with the input data for evacuation [and] economic ... information (id.).

The majority's decision granting Summary Disposition seemed to echo that the "admitted arguments of Pilgrim Watch were that the estimates of economic cost impact failed to preperly account for 'loss of economic activity,' or for loss of economic infrastructure and tourism" (SD 13); but it soon became clear that the majority's view of what "economic conseqences," "economic activiety" and "loss of economic infrastructure" were included was very limited. Judge Young recognized the contrary (SD 34):

> The term "economic consequences" is a broad one, which may fairly be said to encompass some of the various tyupes of costs that Intervenors now wish to litigate. Before deciding these issues, I would at least allow oral arugment on, among other things, issues relating to the scope of the contentions and the types of economic costs that are normally included in SAMA analyses.[67]

Yet the majority of the Board has since made plain that the only a few economic costs will be considered, e.g., "the cost differential caused by the differences" between the radiological deposition caused by the "sea breeze" or "hot spot" effects "from that expected using a straight-line Gausssian plume model," (September 23 Order, Appendix A) and even then apparently only to the extent they might effect the loss of tourism and other business in Plymouth County.[68]

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[67] All members of the Board seem to agree that clean-up and decontamination costs are "normally included in SAMA analyses.

[68] Pilgrim Watch's Hearing Request said that the MACCS2 model used by Entergy did not account for the loss of economic activity in Plymouth County (Hearing Request 44) But Pilgrim Watch never said that the costs of a radiological accident at PNPS woule be limited to Plymouth County. Indeed, the very next paragraph of the Hearing Request specifically referred to "the Commonwealth of Massachusetts," Southeastern Massachusetts, and three other counties. The Hearing Request also said that both Providence and Boston are within 45 miles of a severe PNPS accident should one occur (Hearing Request 50)

Despite the Board's finding that there were "material factual issues of whether ... the Applicant had adequately taken into account relevant and realistic data with respect to ... economic consequences of a severe accident in the area" (October Order, 103), the majority has consistently overlooked the largest "economic consequence[] of a severe accident, " the cost of cleaning up contaminated infrastructure to its pre-accident condition." Yet there can be, and apparently is, no disagreement that one of "the types of economic costs that are normally included in SAMA analyses" is cleanup/ decontamination costs.

As for "input data concerning (1) evacuation times," majority dismissed this part of rewritten contention 3 ever more curtly: "Applicant's MACCS2 Sensitivity Case 6 .... convincely demonstrates that the evacuation time assumptions ... cannot make any difference...." (SD 11-12) Overlooked was the fact that "Sensitivity Case 6" in fact proves nothing, because is based on the same faulty practices and inputs as Entergy used in the rest of its SAMA analyses.

C. Inputs

In addition to excluding the two perhaps most important inputs – source and likelihood of an accident – at the outset, the majority's Summary Disposition Decision said that the "adequacy of the computer code" was "eliminated at the contention admissibility stage; and on November 23, 2010 the majority held that contention 3 did not include any consideration whatever of what the MACCS2 Code as used by Entergy actually did. Apparently adopting some unknown definition of "inputs," the majority, in what is effectively a one paragraph order, said that the

“the mean consequene values issue was not timely raised and ... will not be entertained by the Board....”

The majority reached this decision only after having ordered the experts for both parties to explain to it, “in detail sufficient for understanding of the computer code’s process order and mechanics... at what point in the process of SAMA computations perfomred using the MACCS2 code the ‘mean consequences’ ... are done. In particular, the majority of the Board asked what was done by each of three specific modules – ATOMOS, EARLY and CHRONC. For some reason the majority never mentioned the code’s OUTPUT FILE in which it now appears that the averaging and probability that so drastically reduce consequences are actually accomplished.

If, even at this late date, a majority of the Board, including the Judges with technical backgrounds, in found it necessary to ask about ATOMOS, EARLY and CHRONC, but not to ask about the OUTPUT FILE, it hardly was fair for the same majority to use Pilgrim Watch’s failure, in May of 2006, to understand exactly what was an input and exactly what was done within the code, as a basis for rejecting Pilgrim Watch’s challenge to how Entergy used the code.

Further, both the Commission and Judge Young have recognized that the outcome of this proceeding should not depend on a hypertechnical definition of what is or is not an input. What is important is not what technically is an “input,” but what the Code does with the information put into it to reach the final estimated “consequences” on which SAMA determinations are based. In plain language, what the code finally put out.

Judge Young recognized that "the plume model, while not "input" *per se* in the technical sense, is implicitly part of what is "put in" to the MACCS2 code to produce results about meteorologial patterns. (SD Dissent 34). And in CLI 10-11, the Commission was equally clear that the

> "Board decision admitting the contention ... did not make a distinction between specific *input* date that is entered into the MACCS2 code and the specific *models* embedded in the code.... Therefore, there easily may be an overlap between arguments challenging the sufficiency of 'input data" used and challenging the model used...." (CLI 10-11, 14-15)

Pilgrim Watch suggests that the Board majority has consistently "overlooked" the overlap, and drawn distinctions that the Board decision admitting the rewritten Contention 3 did not make, and that the Board majority should not have made thereafter.

As said before, these decisions have denied Pilgrim Watch the opportunity to deal with substance. Equally important, and again as said before, the Board's brochure says that "Congress made it possible for the public to get a full and fair hearing on nuclear matters." Given the cumulative effect of the Board's prior decisions, the Board should consider whether this was possible for Pilgrim Watch.

APPENDIX 2

Meteorological Modeling: Government and Independent Studies

Government and Independent Studies support Petitioners claim that a straight line Gaussian plume model cannot account for the effects of complex terrain on the dispersion of pollutants from a source. Therefore its use is inappropriate for use for Pilgrim's SAMA analysis to determine the potential area of impact and deposition in a severe accident. For example:

NRC

Since the 1970s, the USNRC has historically documented advanced modeling technique concepts and potential need for multiple meteorological towers appropriately located in offsite communities, especially in coastal site regions. But ignored implementing its' own advice.

In 2009, the NRC made a presentation to the National Radiological Emergency Planning Conference;[69] and although it was focused on emergency planning, the content is equally relevant to meteorological modeling for consequence analysis. The presentation concluded that the straight-line Gaussian plume models cannot accurately predict dispersion in a complex terrain and are therefore scientifically defective for that purpose [full presentation is available at ML091050226, ML091050257, and ML091050269 (page references used here refer to the portion attached, Part 2, ML091050257). Exhibit 19

Most reactors, if not all, are located in complex terrains, including Pilgrim. In the presentation, NRC said that the "most limiting aspect" of the basic Gaussian Model, is its "inability to evaluate spatial and temporal differences in model inputs" [Slide 28]. Spatial refers to the ability to represent impacts on the plume after releases from the site e.g., plume bending to follow a

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[69] What's in the Black Box Known as Emergency Dose Assessment (ML091050226), 2. Dispersion (ML091050257), 3. Dose Calculation (ML091050269), 2009 National Radiological Emergency Planning Conference, Stephen F. LaVie

river valley or sea breeze circulation. Temporal refers to the ability of the model to reflect data changes over time, e.g., change in release rate and meteorology [Slide 4].

Because the basic Gaussian model is non-spatial, it cannot account for the effect of terrain on the trajectory of the plume – that is, the plume is assumed to travel in a straight line regardless of the surrounding terrain. Therefore, it cannot, for example, "'curve' a plume around mountains or follow a river valley." NRC 2009 Presentation, Slide 33. Entergy acknowledges that within 50-miles from Pilgrim there are hills and river valleys. Further it cannot account for transport and diffusion in coastal sites subject to the sea breeze. Sea breeze also applies to any other large bodies of water. The sea breeze causes the plume to change direction caused by differences in temperature of the air above the water versus that above the land after sunrise. If the regional wind flow is light, a circulation will be established between the two air masses. At night, the land cools faster, and a reverse circulation (weak) may occur [Slide 43]. Turbulence causes the plume to be drawn to ground level [Slide 44].

The presentation goes on to say that, "Additional meteorological towers may be necessary to adequately model sea breeze sites" [Slide 40].

Significantly, the NRC 2009 Presentation then discussed the methods of more advanced models that *can* address terrain impact on plume transport, including models in which emissions from a source are released as a series of puffs, each of which can be carried separately by the wind, (NRC 2009 Presentation Slides 35, 36). This modeling method is similar to CALPUFF. Licensees are not required, however, to use these models in order to more accurately predict where the plume will travel to base either consequence analyses or protective action recommendations.

The NRC recognized as early as 1977 that complex terrain presented special problems that a model must address if the air dispersion analysis is to be accurate.[70] For example: NRC, Regulatory Guide 1.111, *Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors* (July 1977) (Draft for

[70] Ibid

Comment) says that, "Geographic features such as hills, valleys, and large bodies of water *greatly* influence dispersion and airflow patterns. Surface roughness, including vegetative cover, affects the degree of turbulent mixing." (Emphasis added).

This is not new information; knowledge of the inappropriateness of straight-line Gaussian plume in at complex sites goes back a long way within NRC. For example:

1972: NRC Regulatory Guide 123 (Safety Guide 23) On Site Meteorological Programs 1972, states that, "at some sites, due to complex flow patterns in non-uniform terrain, additional wind and temperature instrumentation and more comprehensive programs may be necessary."

1977: NRC began to question the feasibility of using straight line Gaussian plume models for complex terrain. *See* U.S.NRC, 1977, Draft for Comment Reg. Guide 1.111 at 1c (pages 1.111-9 to 1.111-10)

1983: In January 1983, NRC Guidance [**NUREG-0737,** Supplement 1 "Clarification of TMI Action Plan Requirements," January 1983 Regulatory Guide 1.97- Application to Emergency Response Facilities; 6.1 Requirements], suggested that changes in on-site meteorological monitoring systems would be warranted if they have not provided a reliable indication of monitoring conditions that are representative within the 10-mile plume exposure EPZ.

1996: The NRC acknowledged the inadequacy of simple straight-line Gaussian plume models to predict air transport and dispersion of a pollutant released from a source in a complex terrain when it issued RTM-96, *Response Technical Manual,* which contains simple methods for estimating possible consequences of various radiological accidents. In the glossary of that document, the NRC's definition of "Gaussian plume dispersion model" states that such models have important limitations, including the inability to "deal well with complex terrain." NUREG/BR-0150, Vol.1 Rev.4, Section Q; ADAMS Accession Number ML062560259,

2004: A NRC research paper, *Comparison of Average Transport and Dispersion Among a Gaussian, A Two- Dimensional and a Three-Dimensional Model*, Lawrence Livermore National Laboratory, October, 2004 at 2. ("Livermore Report") had an important caveat added to the Report's summary about the scientific reliability of the use of a straight-line Gaussian model in complex terrains:

> . . . [T]his study was performed in an area with smooth or favorable terrain and persistent winds although with structure in the form of low-level nocturnal jets and severe storms. In regions with *complex terrain*, particularly if the surface wind direction changes with height, *caution should be used.*

Livermore Report at 72 (Emphasis added) Exhibit 16

2005: In December, 2005, as part of a cooperative program between the governments of the United States and Russia to improve the safety of nuclear power plants designed and built by the former Soviet Union, the NRC issued a Procedures Guide for a Probabilistic Risk, related to a Russian Nuclear Power Station. The Guide, prepared by the Brookhaven National Laboratory and NRC staff, explained that atmospheric transport of released material is carried out assuming Gaussian plume dispersion, which is "generally valid for flat terrain." However, the Guide the caveat that in "specific cases of plant location, such as, for example, a mountainous area or a valley, more detailed dispersion models may have to be considered." *Kalinin VVER-1000 Nuclear power Station Unit 1 PRA, Procedures Guide for a Probabilistic Risk Assessment,* NUREG/CR- 6572, Rev. 1 at 3-114; excerpt attached as Exhibit 8, full report available at http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6572. Exhibit 20

2007: NRC revised their Regulatory Guide 1.23, Meteorological Monitoring Programs for Nuclear Power Plants. On page 11, the section entitled *Special Considerations for Complex Terrain Sites* says that, "At some sites, because of complex flow patterns in nonuniform terrain, additional wind and temperature instrumentation and more comprehensive programs may be necessary. For example, the representation of circulation for a hill-valley complex or a site near a large body of water may need additional measuring points to determine airflow patterns and spatial variations of atmospheric stability. Occasionally, the unique diffusion characteristics of a particular site may also warrant the use of special meteorological instrumentation and/or studies. The plant's operational meteorological monitoring program should provide an adequate basis for atmospheric transport and diffusion estimates within the plume exposure emergency planning zone [i.e., within approximately 16 kilometers" (10 miles)].[71]

These excerpts from Regulatory Guide 1.23 demonstrate that the NRC recognizes there are certain sites, such as those located in coastal areas, like Pilgrim, that multiple meteorological data input sources are needed for appropriate air dispersion modeling. Not simply one or two meteorological towers onsite. Since the straight-line Gaussian plume model is incapable of handling complex flow patterns and meteorological data input from multiple locations, Regulatory Guide 1.23 demonstrates NRC's recognition that it should not be used at any site with complex terrain.

EPA

Likewise, EPA recognized the need for complex models. For example: EPA's 2005 Guideline on Air Quality Models says in Section 7.2.8 *Inhomogenous Local Winds* that,

> In very rugged hilly or mountainous terrain, along coastlines, or near large land use variations, the characterization of the winds is a balance of various forces, such that the assumptions of steady-state straight line transport both in time and space are inappropriate. (Fed. Reg., 11/09/05).

[71] For example, if the comparison of the primary and supplemental meteorological systems indicates convergence in a lake breeze setting, then a "keyhole" protective action recommendation (e.g., evacuating a 2-mile radius)

EPA goes on to say that, "In special cases described, refined trajectory air quality models can be applied in a case-by-case basis for air quality estimates for such complex non-steady-state meteorological conditions." This EPA Guideline also references an EPA 2000 report, *Meteorological Monitoring Guidance for Regulatory Model Applications,* EPA-454/R-99-005, February 2000. Section 3.4 of this Guidance for coastal Locations, discusses the need for multiple inland meteorological monitoring sites, with the monitored parameters dictated by the data input needs of particular air quality models.

EPA concludes that a report prepared for NRC [72] provides a detailed discussion of considerations for conducting meteorological measurement programs at coastal sites, reactors on large bodies of water. Most important, EPA's November 2005 Modeling Guideline (Appendix A to Appendix W) lists EPA's "preferred models" and the use of straight line Gaussian plume model, called ATMOS, is not listed. Sections 6.1 and 6.2.3 discuss that the Gaussian model is not capable of modeling beyond 50 km (32 miles) and the basis for EPA to recommend CALPUFF, a non - straight line model.[73]

DOE

DOE, too, recognizes the limitations of the straight-line Gaussian plume model. They say for example that Gaussian models are inherently flat-earth models, and perform best over regions of transport where there is minimal variation in terrain. Because of this, there is inherent

[72] Raynor, G.S.P. Michael, and S. SethuRaman, 1979, *Recommendations for Meteorological Measurement Programs and Atmospheric Diffusion Prediction Methods for Use at Coastal Nuclear Reactor Sites.* NUREG/CR-0936, U.S. Nuclear Regulatory Commission, Washington, DC

[73] http://www.epa.gov/scram001/guidance/guide/appw_05.pdf

conservatism (and simplicity) if the environs have a significant nearby buildings, tall vegetation, or grade variations not taken into account in the dispersion parameterization.[74]

National Research Council

Tracking and Predicting The Atmospheric Dispersion of Hazardous Material Releases Implications for Homeland Security, Committee on the Atmospheric Dispersion of Hazardous Material Releases Board on Atmospheric Sciences and Climate Division on Earth and Life Studies, National Research Council of the National Academies, 2003. The report discusses how the analytical Gaussian models were used in the 1960s and tested against limited field experiments in flat terrain areas performed in earlier decades.

In the 1970s the US passed the Clean Air Act which required the use of dispersion models to estimate the air quality impacts of emissions sources for comparison to regulatory limits. This resulted in the development and testing of advanced models for applications in complex terrain settings such as in mountainous or coastal areas. In the 1980s, further advances were made with Lagrangian puff models and with Eulerian grid models. Gaussian models moved beyond the simple use of sets of dispersion coefficients to incorporate Monin-Obukhov and other boundary layer similarity measures which are the basis of contemporary EPA models used for both short range and long range transport applications. Helped enormously by advances in computer technologies, in the 1990s, significant advances were made in numerical weather prediction models and also further improve dispersion models through the incorporation of field experiment results and improved boundary layer parameterization. The decade starting with the year 2000 has seen improved resolution of meteorological models such as MM5 and the routine linkage of meteorological models with transport and dispersion models as exemplified by the

[74] the MACCS2 Guidance Report June 2004 Final Report, page 3-8:3.2 Phenomenological Regimes of Applicability

real time forecasts of detailed fine grid weather conditions available to the public at Olympic events. Computational Fluid Dynamics (CFD) models which involve very fine grid numerical simulations of turbulence and fluid flow began to see applications in atmospheric dispersion studies. The next decade will see routine application of CFD techniques to complex flows associated with emergency response needs.

The nuclear industry does not show evidence of keeping up with these technological advances. For use in modeling air quality concentrations, the NRC uses straight-line Gaussian dispersion algorithms that date back to the 1960s. Complex flow situations such as those associated with flow around high terrain features or that would incorporate sea breeze circulations are not simulated. For emergency response applications, the NRC does not seem to require any advanced modeling to be installed at nuclear power plants.

Atmospheric Scientists & Meteorologists

For over three decades atmospheric scientists and meteorologists have been identifying problems in the use of models similar to ATMOS for such settings. Example: Steven R. Hanna, Gary A. Briggs, Rayford P. Hosker, Jr., National Oceanic and Atmospheric Administration, Atmospheric Turbulence and Diffusion Laboratory, *Handbook on Atmospheric Diffusion* (1982)).

The inability of a simple Gaussian plume model to accurately predict air transport and dispersion in complex terrains is such a basic flaw that it is discussed in a textbook for a college-level introductory course in environmental science and engineering (Steven R. Hanna, Gary A. Briggs, Rayford P. Hosker, Jr., National Oceanic and Atmospheric Administration, Atmospheric Turbulence and Diffusion Laboratory, *Handbook on Atmospheric Diffusion* (1982)). (Chapter 13 authored by William J. Moroz). In listing the assumptions that are made to develop a simple straight line Gaussian plume model, the textbook warns that:

> The equation is to be used over relatively flat, homogeneous terrain. It should not be used routinely in coastal or mountainous areas, in any area where building profiles are highly irregular, or where the plume travels over warm bare soil and then over colder snow or ice covered surfaces

APPENDIX 3

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Use of risk measures in design and licensing of future reactors

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ABSTRACT

Use of information and insights from probabilistic risk assessments (PRAs) in nuclear reactor safety applications has been increasing by the nuclear industry and the regulators, both domestically and internationally. This is a desirable trend, as PRAs have demonstrated capability to improve safety and operational flexibility beyond that provided through deterministic approaches alone. But there can be potential pitfalls. The limitations of risk assessment technology can be lost through approaches that rely heavily on quantitative PRA results (referred to as risk measures in this paper), because of the unambiguous but potentially misleading message that can be delivered by risk-based numbers. This is particularly true for future reactors, where PRAs are used during the design and licensing processes. For these applications, it is important to ensure that the actual, de facto, or even perceived use of risk measures in the context of either regulatory or design acceptance criteria is avoided. While the issues discussed here can have a significant influence on design certification or combined license applications for future reactors, they can also have secondary impacts on currently operating reactors.

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1. Introduction

Probabilistic risk assessment (PRA) results and insights have helped to improve nuclear power plant safety and operational flexibility for more than 30 years. This success has led to increased use of PRAs by the nuclear industry and regulatory authorities worldwide. While this trend is largely positive, there can be potential negative consequences that have not been widely discussed in related literature, with some exceptions (e.g., [1]).

It was because of this positive contribution to safety that the US Nuclear Regulatory Commission (NRC) gradually refined their original deterministic-based nuclear safety regulations by incorporating the use of risk information and insights within a risk-informed framework. Risk-informed regulations for the current fleet of operating light-water reactors (LWRs) are defined through a combination of rule-making and publication of lower-tier documents, such as regulatory guides or NRC's endorsement of certain nuclear industry documents. Thus, in a risk-informed framework, risk information and insights supplement the traditional deterministic approaches and form a part of the overall safety case (which is sometimes referred to as the safety basis) for a nuclear plant. The Commission has also called for increased use of PRA technology in all regulatory matters in a manner that complements NRC's predominantly deterministic approaches within the confines of a risk-informed as opposed to a risk-based regulatory construct. Some of the distinguishing features between the two are also discussed in this paper.

The nuclear industry also has used PRA techniques extensively with beneficial results, including in the design of advanced or evolutionary nuclear reactors. These benefits are, in part, related to the fact that these same users can also control and limit the influence of the incomplete safety information that is provided through the results of the PRA alone. Factors that are usually not fully accounted for in a PRA model but are germane to the consideration of adequacy of safety features for a specific issue or accident scenario may include: magnitudes of relevant safety margins, incorporation of defense in depth, potential for corrective or compensatory actions, degree of conservatism in analysis, and many others. The very same PRA information, however, when used to comply with well-intentioned regulatory policies and approaches can lead to some undesirable consequences. Some of the undesirable consequences in applications involving future reactors are also discussed below.

PRAs provide both qualitative and quantitative information. Recent trends in the development of new risk-related approaches, whether they are performed by the regulatory staff, nuclear industry, or other domestic or international bodies, are towards heavier emphasis in use of quantitative PRA results (interchangeably referred to as "risk measures" in this paper). It is well-known that quantitative results of PRAs, in particular, are subject to various types of uncertainties. Examples of these uncertainties include probabilistic quantification of single and common-cause hardware or software failures, occurrence of certain physical phenomena, human errors of omission and commission,

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magnitudes of source terms, radionuclide release and transport, atmospheric dispersion, biological effects of radiation, dose calculations, and many others. Unlike deterministic uncertainties related to physical phenomena (e.g., neutronics, thermal-hydraulics), PRA uncertainties are not readily reducible in most instances. Uncertainties associated with physical phenomena can often be reduced by tests, experiments, operating experience on actual or prototype designs, or improvements in analytical models or computational capabilities. Despite this well-known limitation, if quantitative PRA results are used in the context of risk acceptance criteria (i.e., when they are compared against a set of threshold values established by either the industry or the regulator), it would be difficult to counter the unambiguous but potentially misleading or incorrect message that is delivered by such a number-based process; i.e., implying that a design is unacceptable or unsafe because it did not meet a particular risk-based numerical threshold (labeled as a risk acceptance criterion).

An important issue that is outside of the scope of this paper, but is worthy of detailed discussions of its own, is that the introduction and impact of PRAs in the design and licensing stages for a future reactor is by and large different from the way that risk-informed regulations have been applied to existing reactors. Currently operating reactors had a deterministically established licensing basis (which included the plant's safety basis) before plant-specific or generic risk information and insights were made available through PRAs. The PRAs generally confirmed that the original deterministic approach to design and licensing was conservative (e.g., plants could respond to some accident scenarios in manners that were not credited in the deterministic analyses) and further identified changes that could improve plant design or operational safety. Meeting the deterministic requirements meant that implementation of their attendant provisions embodied within the concepts of defense in depth, safety margins, conservative assumptions and analyses, quality assurance, and numerous other factors (many of which are not readily measurable within a PRA model) created a safety cushion or margin that protected these plants from uncertainties, including those from "unknown unknowns" (for which a euphemism can be "emerging safety issues" as discussed in Section 2). On the other hand, PRA models have to rely on realistic inputs to ensure that risk significant insights are not obscured by artificially biased results derived from the application of uneven conservatisms. Therefore, great care must be exercised in bringing PRAs into the design process to ensure that the fundamental pillars of deterministic safety assurance process mentioned above are not unduly compromised. Thus, for future reactors, use of risk information can have a far more significant impact on the safety basis of the plant, including the potential to drive some key design decisions. The intent of risk-informed regulations is to ensure their influence is positive in safety tradeoff decisions.

2. NRC's approach to safety goals and risk acceptance criteria

NRC published the Safety Goals Policy Statement on August 8, 1986 [2]. While the text of this Policy Statement does use the phrase "acceptable risk," the title and the rest of the discussions were careful to avoid the use of the Quantitative Health Objectives (QHOs) of prompt fatalities (PFs) and latent cancer fatalities (LCFs) as regulatory risk-acceptance criteria. In other words, the selection of the terminology of "safety goals" was very deliberate. An important attribute of the calculation of plant-specific PFs and LCFs for comparison with the dual QHOs is that both are by necessity "integral" quantities that are derived from the contributions of all accident scenarios that are considered in the plant-specific PRA model.

The Commission's 1995 PRA Policy Statement on use of PRA methods in nuclear regulatory activities [3], which was issued in the aftermath of the completion of PRAs for all operating nuclear plants in accordance with the Individual Plant Examinations Generic Letter [4] states, in part:

> The use of PRA technology should be increased in all regulatory matters to the extent supported by the state-of-the-art in PRA methods and data and in a manner that complements the NRC's deterministic approach and supports the NRC's traditional defense-in-depth philosophy.
>
> The Commission's safety goals for nuclear power plants and subsidiary numerical objectives are to be used with appropriate consideration of uncertainties in making regulatory judgments on the need for proposing and back-fitting new generic requirements on nuclear power plant licensees.

The Commission approved the staff's White Paper on Risk-Informed and Performance-Based Regulation in March 1999 [5], which provided definitions of risk-informed and risk-based regulations. It reiterates that the Commission does not endorse an approach that is risk-based, wherein decision-making is solely based on the numerical results of a risk assessment.

Regulatory Guide 1.174 [6] established the framework for risk-informed regulations in applications regarding making plant-specific changes to the licensing basis. Its approach ensures that numerical PRA results would not form the sole basis for making nuclear safety decisions by listing five key principles (i.e., meeting current regulations [which are primarily deterministic], meeting defense-in-depth principles, maintaining sufficient safety margin, keeping increases in risk small, and performance monitored) that have to be met for a risk-informed approach. Clearly, current regulations are by and large based on deterministic requirements. A key portion of the section on scope (Section 1.4) states:

> … The NRC has chosen a more restrictive policy that would permit only small increases in risk, and then only when it is reasonably assured, among other things, that sufficient defense in depth and sufficient margins are maintained. This policy is adopted because of uncertainties and to account for the fact that safety issues continue to emerge regarding design, construction, and operational matters notwithstanding the maturity of the nuclear power industry. These factors suggest that nuclear power reactors should operate routinely only at a prudent margin above adequate protection. The safety goal subsidiary objectives are used as an example of such a prudent margin.

The clause about continual emergence of safety issues for plants with many years of operating experience is an alternative way to state the concern regarding uncertainties about the "unknown unknowns" that are a more significant concern for future reactor designs.

One reason that Regulatory Guide 1.174 has worked well in application is that it was intended for operating plants with a primarily deterministic licensing basis already in place, which means that the plants were already determined to be safe before applying the results of plant-specific PRAs.

Finally, Note 2 of Chapter 19 of the Standard Review Plan (SRP) [7] states that the QHO-surrogates of Core Damage Frequency (CDF) and Large Release Frequency (LRF) are goals and not regulatory requirements.

The key conclusion from the above is that the NRC Commissioners have not endorsed a "risk-based" approach to regulation because of the uncertainties in quantitative results of

PRAs. These uncertainties are large for currently operating nuclear plants, particularly in the so-called Level 2 and Level 3 PRAs. The fact that the large uncertainties in the estimates of probabilities for hardware failures and human errors, and understanding and probabilistic quantification of occurrence of some physical phenomena in PRAs of currently operating reactors seem less so because of repeated reuse should not be overlooked. Treatment of uncertainties in severe accident progression and delineation has always been limited in risk assessments performed to date, even in the studies that went the furthest in such analyses, such as NUREG-1150 [8].

Another important consideration, also related to the general category of uncertainties, is the issue of state-of-the-art in PRA methods and data. This is an issue for risk modeling of all reactor designs as alluded to above, and it is especially so for designs that primarily rely on passive safety functions performed by safety-related Systems, Structures, and Components (SSCs) and digital systems (e.g., in instrumentation and control—I&C). The current state-of-the-art does not permit a high quality modeling for reliability evaluations for these systems. In particular, there is considerable uncertainty with respect to the contribution of software common-cause failures (CCF) to digital system reliability. For the potentially safer and more passive advanced reactor designs, it is possible that digital systems and human errors of commission (due in part to longer time constants—see, e.g., [13]) might have a higher relative risk contribution, a contribution that may be difficult to assess with any significant level of confidence. These issues offer additional reasons to apply quantitative PRA results judiciously for future nuclear plants.

The Commission also offered another goal of 1E−6/yr within the Safety Goals Policy Statement for frequency of large releases to the environment for further staff examination. A definition for large release was not offered in that document [2]. In [9] the staff considered several options and finally recommended that a large release be defined as a release that has the potential for causing an offsite early fatality. Several other SECY papers (denotes papers submitted to the Commissioners by the NRC staff), Staff Requirements Memoranda (SRMs), and Advisory Committee on Reactor Safeguards (ACRS) letters to the Commission (e.g., [10]) were devoted to this subject. The Commission directed the staff to ensure that their evaluation of large release magnitude be consistent with ACRS proposed guidelines linking the hierarchical levels of the safety goal objectives, where the large release guideline was considered the third level objective (the qualitative and quantitative health objectives were the level one and two objectives). According to these guidelines, each subordinate level of the safety goal objectives should:

- be consistent with the level above,
- not be so conservative as to create a de facto new policy,
- represent a simplification of the previous level,
- provide a basis for assuring that the Safety Goal Policy Objectives are being met,
- be defined to have broad generic applicability,
- be stated in terms that are understandable to the public, and
- generally comply with current PRA usage and practice.

In the end, the staff reached the overall conclusion that development of a large release definition and magnitude, beyond a simple qualitative statement related to the frequency of 1E−6/yr is neither practical nor required for design or regulatory purposes. In addition, based upon the work done evaluating large releases in NUREG-1150 [8] and other related activities, the staff noted that the general performance guideline of 1E−6/yr and the CDF subsidiary objective of 1E−4/yr are not consistent with the original QHOs [11] (i.e., they are more conservative, and the degree of conservatism depends on the specific plant).

In addition, the Commission rejected the use of 1E−5/yr of reactor operation as a CDF goal for advanced designs in SECY-90-016 [12] and its SRM. This rejection should be examined together with a series of Commission Policy Statements on regulation of advanced reactors. The last in the series published in October of 2008 [13] states:

> The Commission expects, as a minimum, at least the same degree of protection of the environment and public health and safety and the common defense and security that is required for current generation light-water reactors. Furthermore, the Commission expects that advanced reactors will provide enhanced margins of safety and/or use simplified, inherent, passive, or other innovative means to accomplish their safety and security functions. The incorporation of enhanced safety margins may help offset the effects of added uncertainties in the PRA model and/or in accident analyses arising from the novelty of advanced reactor designs. [Elsewhere other attributes of advanced designs are described as: reliable and less complex shutdown heat removal systems; longer time constants and sufficient instrumentation; simplified safety systems; minimize potential for severe accidents by incorporating redundancy, diversity, safety system independence; incorporate defense-in-depth; etc.].

The important aspects of this Policy Statement are: (a) it contains only qualitative but well-proven principles for enhanced safety of nuclear reactor designs, and (b) it specifically lacks any risk-based numerical criteria. Because of large uncertainties of risk-based numerical results, risk analysts typically do not consider variations of less than factors of 10 or so in such numbers as meaningful increments. Risk experts may convert the above policy statement into a corresponding numerical criterion by providing an order of magnitude as the smallest discriminator for deciding how much safer advanced reactors should be from current reactors. This, however, is a non-sequitur and a problem inherent to risk-based calculations. An order of magnitude is a very large increment in the real world, and current nuclear reactors are already much safer than any other comparable industrial facilities and hazardous human activities. Ultra-conservatism in design has a price, both economically and operationally. As discussed in Section 3, the proposed new surrogate numerical risk-based criteria can be far more restrictive than the QHOs. They are also quantitatively unpredictable in "real risk space" and not comparable with QHOs as they are non-integral measures of risk. They are more restrictive in the sense that a reactor that in a hypothetical case may fail to meet some of the new criteria (described in Section 3) can still meet the QHOs by orders of magnitude.

In spite of the above discussions and the broad policy guidance by the NRC Commissioners, this paper's observation is that throughout many publications of the national and international regulatory agencies and commercial entities, there is an increasing trend toward more prevalent use of risk-based regulatory concepts in general, and the use of some form of numerical risk thresholds as acceptance criteria vis-a-vis safety goals, in particular. For example, a number of NRC staff documents (e.g., [14,15]), as well as industry and international publications (e.g., [16–23]), have employed various types of risk-acceptance criteria (consistent with the terminology employed within the documents) which involve some form of a frequency versus consequence (FC) curve, or FC anchor points or regions. It can be shown that these approaches generally establish much more restrictive numerical thresholds than the QHOs, and are applied as non-integral quantities. While the intentions behind this trend are noble and motivated in part from a desire to continuously improve nuclear reactor safety, and in part from the Commission Policy Statements on regulation of advanced reactors [13], their actual implementation can lead to a number of undesirable consequences, as discussed in Section 3.

3. Critique of frequency-consequence curve from NUREG-1860

This section presents a brief review of a specific section (i.e., the discussion on FC curve as a potential risk threshold for Licensing Basis Events) of the representative and probably the most high-profile, document among the international references mentioned above, namely NUREG-1860 [15], and describes some issues that can arise in using similar approaches with regard to numerical risk assessment results. NUREG-1860 does address deterministic requirements and defense in depth guidelines, but a discussion of these topics is beyond the scope of this paper.

An important part of the reason for the prominence of NUREG-1860 in these discussions is SECY-07-0101 and it's Staff Requirements Memorandum [24], in which the Commission directed the NRC staff to test the concept of this framework on an actual future reactor design.

The most likely candidate for the application of this "Risk-Informed and Performance-Based Regulatory Structure for Future Plant Licensing" is the Next Generation Nuclear Plant (NGNP) [25]. The ramifications of this action can go beyond the NGNP license application, and potentially have a significant impact on all future reactors, particularly advanced reactors that would largely constitute the group that is currently referred to as the Small Modular Reactors (SMRs). Moreover, they can create an environment for raising and/or revisiting questions on whether currently operating reactors are indeed safe enough, even though this question had been emphatically put to rest with a positive response in the past.

The issue that this section examines is whether the use of numerical results of PRAs (i.e., risk measures) to be compared against pre-established risk thresholds (i.e., risk-acceptance criteria), as employed in NUREG-1860 and the similar approaches in the other referenced documents listed above, is akin to modifying NRC's long-established risk-informed regulation paradigm towards one of being risk-based; and whether these approaches could lead to other, unintended consequences.

Discussions in Sections 2.5.1, 3.2.2, 6.2.2, and 6.3 of NUREG-1860 state:

- The FC curve is used in the following ways:
  1. For the selection of Licensing Basis Events (LBEs) (discussion and definition provided in [15]), including frequent, infrequent, and rare events.
     - This paper notes that the retention of accident scenarios other than severe accidents in the PRA beyond the initial screening stage creates an entirely new type of PRA that is, among other things, much larger than the current PRAs. Current PRAs do not retain for further analysis accident scenarios that terminate in states other than one of any pre-defined consequence categories, often referred to as plant damage states. For current plants these generally involve core damage, based on predefined thresholds (e.g., peak cladding temperature above 2200°F). The NUREG-1860 PRA method would additionally include all intermediate accident scenarios from simple initiating events to those intermediate scenarios that are terminated successfully before reaching any plant damage state, as well as the traditional PRAs' plant damage state scenarios. This type of PRA can become significantly larger than the traditional PRAs, depending on the specifics of the methodology chosen by the analysis team. A significant increase in the level and complexity of the PRA can lead to problems of cost, configuration control, difficulty for analysis of results and review, and issues regarding quality assurance of the product.
  2. Possibly as a surrogate risk metric to the QHOs, because the CDF metric for LWRs is not fully applicable to all advanced reactors (such as the high-temperature gas cooled reactor—HTGR); and
  3. As a guide to designers, i.e., it relates the frequency of potential accidents to "acceptable" [emphasis added] radiation doses at the site boundary from these accidents.

Fig. 6.2 of NUREG-1860, reproduced here as Fig. 1, is an example of a worldwide and industry-wide trend (documented in Refs. [14–23]). The ACRS expressed a number of concerns with earlier versions of this curve [26].

NUREG-1860 indicates that doses in Fig. 1 are total effective dose equivalents (TEDEs, which includes the 50-year committed dose) calculated at the site boundary on a per scenario basis. Additional discussion related to this figure, and those in a number of other references, e.g., [14,18,27] also reiterate a questionable relationship between an accident frequency of 1E−4/yr, a dose of 25 rem, and design basis accidents (DBAs). First, it is important to note that many traditional DBA frequencies are demonstrably below this frequency, when initiating event frequencies are combined with the partial failure probabilities of safety systems imposed by the requirements of single failure criterion. For example, in the last paragraph of page, 6–7 of NUREG-1860 it is stated that:

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> ... doses in the range 100–300 rem are assigned a frequency of 1E−6 per year, 300–500 rem a frequency of 5E−7 per year, and the curve is capped beyond doses greater than 500 rem at 1E−7 per year.

This paper proposes that using Fig. 1 in regulatory or even design applications as suggested in NUREG-1860 can lead to a number of unintended consequences for two principal reasons: (1) the use of the labels of "acceptable" and "unacceptable," and (2) comparison of the embedded criteria against the attributes of individual accident scenarios (as opposed to integral measures of risk, such as CDF or LCFs). Specifically:

- The Commission has long avoided establishing any kind of risk-based acceptance criteria by endorsing the QHOs as "safety goals." As stated earlier, the significant roles played by both the uncertainties and state-of-the-art (both of which are exacerbated for future/advanced reactors with little or no operating experience) associated with the PRA model of a plant are the main drivers for this decision. In accounting for uncertainties, the PRA model can only provide some treatment of the "known" uncertainties through propagation of parameter uncertainties and performing sensitivity studies (to address some modeling uncertainties), and is generally incapable of handling uncertainties associated with (lack of) completeness inherent to the continuously improve nuclear reactor safety, and in part from the Commission Policy Statements on regulation of advanced reactors [13], their actual implementation can lead to a number of undesirable consequences, as discussed in Section 3.

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- The Commission has long avoided establishing any kind of risk-based acceptance criteria by endorsing the QHOs as "safety goals." As stated earlier, the significant roles played by both the uncertainties and state-of-the-art (both of which are exacerbated for future/advanced reactors with little or no operating experience) associated with the PRA model of a plant are the main drivers for this decision. In accounting for uncertainties, the PRA model can only provide some treatment of the "known" uncertainties through propagation of parameter uncertainties and performing sensitivity studies (to address some modeling uncertainties), and is generally incapable of handling uncertainties associated with (lack of) completeness inherent to the

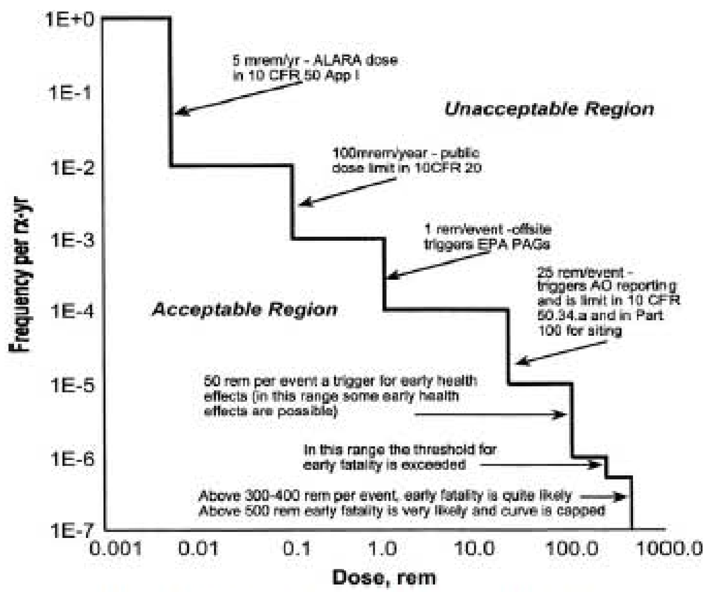

Fig. 1. Frequency versus consequence curve (Fig. 6.2) of NUREG-1860.

analytical models and many other factors (e.g., impact of safety margins). Even then, the use of representative parameters (such as the mean) associated with the frequencies and consequences of individual or integrated accident scenarios has limitations of its own, as the types and widths of the underlying distributions of the input random variables are generally assigned by subjective judgment. It is clear that these issues become more dominant in analyses of future/advanced reactor designs with less knowledge about several key aspects of the safety of the design, such as the fidelity of analyses in thermal-fluids, neutronics, fission product transport, material properties at high temperatures, component reliabilities, and the "unknown unknowns."

- The QHOs have a logical relationship with the risk that the members of the public are otherwise exposed to as articulated in the qualitative health objectives. They establish the risks of nuclear power plant operations at a small fraction of the risks that the members of the public, not the general public at large, but those living in the vicinity of the plant are already exposed to. A reduction in these risks for future reactors proposed by any stakeholder (which would be consistent with the stated qualitative goal of the Commission), should be within reason and not so drastic as to deprive the same population from the benefits that they may otherwise realize from operation of these reactors.
- Plant-specific PFs and LCFs are calculated for comparison against the QHOs. Both of these, as well as the more widely used surrogate metrics to QHOs, such as CDF and LRF for LWR applications, are integral quantities that are derived from the contributions of all accident scenarios that are considered in the plant-specific risk model. Integral risk measures incorporate at least three important properties:
  1. Definition or characterization of individual accident scenarios is dependent on both the specific PRA model (e.g., large fault tree/small event tree versus small fault tree/large event tree) and the specific plant design (e.g., complex with more active safety systems versus less complex with more passive safety systems). Integrated risk measures are not subject to such dependencies on the calculation model or plant design.
     - It will be a challenge to establish criteria to ensure that individual accident scenarios are defined or characterized at the same level of "resolution" across different plant designs and associated PRA models for use with this type of FC curve construct. The system would be inherently unstable and dependent on subjective interpretations by all sides in a dispute.
  2. Relative uncertainties decrease when the associated random variables are summed, and they increase when the random variables are multiplied. Therefore, the effects of uncertainties are minimized when integrated risk measures are used as opposed to when intermediate and product quantities, such as frequencies and consequences of individual accident scenarios are used.
  3. Comparison of any partial level of plant risk, such as those that are based on individual accident scenarios, against some quantitative criteria can misinform or even mislead. The potential for misinformation is large because it would not be known as to what fraction (is it 0.001% or 10%) of the overall integral risk (even within the same category, such as internal events) is being compared against the criteria.
     - Thus, the risk of an individual scenario would/should not necessarily be unacceptable if it falls in the "unacceptable" region of an FC curve, because the QHOs (as safety goals) might still be met with large margin.
     - A converse corollary is that the risk of individual scenarios should not necessarily be viewed as "acceptable" in the other region either, as a prudent approach to safety assurance always seeks to incorporate reasonable additional controls where ever a proper qualitative engineering judgment or a quantitative analysis so dictates. Falling within the acceptable region could deny the designers and others from thorough engineering thinking in the safety design process.
- If it is assumed that a future design of an HTGR or an SMR meets the FC curve, then the NRC will be on record for

certifying that the level of risk-based safety of this design is "acceptable," and in contrast, any design that does not meet this level of safety, even for a single accident scenario with all the attendant uncertainty, is unsafe. The same problem is encountered even if the governing document is from the industry, whether or not it is explicitly endorsed by the NRC, such as an ASME or ANS standard as in [18]. How could the regulator accept a design with one or more accident scenarios in the "unacceptable" region when the governing industry standard itself has labeled it as such?

- Some current LWRs will likely not meet this FC curve. A misunderstanding of the intent of this curve and the role that NUREG reports play at NRC could lead some to incorrect conclusions concerning the adequacy of safety of current plants, because the NRC and/or the nuclear industry themselves (as, e.g., in [15,18]) have labeled plants that do not meet this curve as "unacceptable."
- The FC curve is, in fact, introducing new and more restrictive acceptance criteria than the QHO safety goals as evident by inspection and as mentioned in [15], in contradiction to the ACRS guidance mentioned above.
- The combined effect of using risk metrics as acceptance criteria and applying them on the level of individual accident scenarios can lead to other undesirable outcomes. Future reactor designs offering lower total (integrated) risk than current operating reactors may be erroneously labeled as "unsafe" and not be pursued, or be burdened with costly and unnecessary design modifications.
  - An example of the above (involving a potentially safer future reactor design) is a reactor coolant line break for a high-temperature gas-cooled reactor (HTGR). In a hypothetical case, it can be assumed that an applicant calculates the frequency and the consequences of the scenario in a way that allows them to show that it is "acceptable." Anyone inclined to question the validity of the calculations can: (a) point to the degree of uncertainty in the pipe break frequency because of very limited number of years of operating experience with these reactors; (b) point to conditions such as high operating temperatures as additional reasons for much higher failure frequency potential than in the LWR experience; and (c) challenge the assumed radionuclide airborne fractions produced by uncertainties in source terms (e.g., long-term diffusion of radionuclides through coated fuel particles, resuspension caused by vibration effects, higher temperatures, lower plateout, etc.). These challenges can lead to a conclusion that the scenario falls in the "unacceptable" region instead.
- Simple and/or passive reactor designs would have fewer numbers of accident scenarios than complex and active designs at the same level of accident scenario definition (e.g., system level) and within the same PRA model. The difference in the number of accident scenarios could be in multiples of 10 rather than in algebraic fractions. As a hypothetical example, two reactors may have the same risk profile, but the first has 10 sequences with 30 rem at 2E−6/yr, and the second has one sequence with a consequence of 30 rem at 2E−5/yr. Under the FC curve construct, one is deemed acceptable and the other is not, which does not make sense in "real risk space."
  - Thus, the use of risk-based acceptance criteria on the level of individual accident scenarios (as opposed to integral quantities) may be viewed as penalizing simple and passive designs in favor of active and complex designs, in violation of the Commission Policy Statement on Advanced Reactors [13].
- Again, because integral measures of risk are not obtained in this model, applications of these scenario-level and risk-based acceptance criteria will be variable for each design, specific PRA model, and reactor site. The variability can be substantial in some cases.

It is important that the NRC staff be cognizant of the above issues in complying with the Commission direction in testing the concepts embodied in NUREG-1860 in an actual licensing approval process for a future plant. The staff should ensure that their review will not deviate from the long-standing Commission precedents in establishing the many elements of a risk-informed approach. While this paper has touched upon only a few topics, future papers can discuss the use of PRA, including the introduction of a proposed technology-neutral generic risk measure that will allow for cross-comparison of the level of safety for different plant designs independent of site-specific characteristics; approach to defense-in-depth; selection of the so-called licensing-basis events; and selection of safety SSCs in a risk-informed and performance-based framework.

It should be added that alternative and complementary risk metrics to QHOs can be useful to a potential applicant for a design certification or combined license, for example to assist in determination of having reached a sufficient mix of preventive and mitigative features in a new design (i.e., safety design trade-off decisions) or to compare relative safety of different designs. The technology-neutral generic risk measure mentioned above will satisfy the latter need for future reactor designs for which the CDF and LRF metrics may not be fully applicable. An example of an alternative FC curve that can be effectively used for safety design trade-off decisions is discussed in Section 6.

4. Use of risk measures by industry

The impact of the aforementioned issues may not be as great in practice when the FC curve of NUREG-1860 or a similar construct is used only by the designer as opposed to the regulator. The designer can use such constructs or concepts as complementary information in an iterative manner throughout the design process. A problem that may be encountered in that process is that a proper interpretation of some risk-based concepts may not be as intuitive for the designer, especially for those who are not PRA experts, as it may appear at first. In addition, manuals of practice, such as standards or guides that are developed by the industry may be endorsed or referenced by the regulators and be used in ways that produce the unintended results (e.g., leading to rejection of safer designs). For this reason, it is suggested that the use of quantitative PRA results in the context of design or regulatory risk-acceptance criteria be avoided by all. Instead, Section 6 provides an alternative construct that may be used by the industry that will accomplish the intended purpose (design safety trade-off decisions) without the negative connotations that are associated with NUREG-1860s version of an FC curve.

5. Interpretation of the 25 Rem criterion used in 10 CFR 100/50.34

The 25 rem criterion used in 10 CFR 100 and 10 CFR 50.34 is often used as a de facto dose acceptance criterion for DBAs by the NRC staff. This usage is, however, contradictory to actual Commission policy and guidance as described explicitly in NRC regulations, as discussed in this section. Since a nuclear plant is designed to adequately respond to the occurrence of Design Basis Events (DBEs—includes Anticipated Operational Occurrences and Design Basis Accidents), the expectation is that the associated offsite consequences will be small (e.g., fractions of 25 rem TEDE).

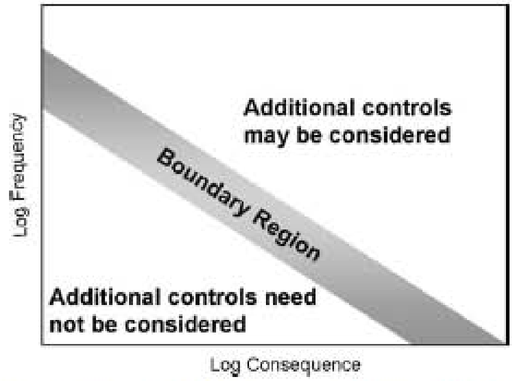

Fig. 2. A conceptual accident sequence-level frequency versus consequence curve that can be used by applicant during design process.

whether additional controls should be considered for the specific scenario.

(v) The two regions are separated by a band of perhaps an order of magnitude variation with diffused boundaries (such as in Regulatory Guide 1.174) on frequency and consequence, rather than firm boundaries. This is because any single parameter of scenario frequency or consequence (the mean is typically used for all) is itself subject to uncertainty and ensuing challenges, as the ranges of variability and the underlying distributions are generally assigned subjectively.

(vi) The consequence scale may be related to appropriate public health measures and/or cost-benefit for the inclusion of the additional control under consideration.

(vii) Since this curve is used as a design aid for the applicant, regulatory staff would have no position about the acceptability or the lack thereof associated with any part of its construct, including the anchor points. The regulator must use the totality of the safety information delivered by the design and the proposed operational plan that includes the traditional deterministic requirements along with the supplemental PRA information in concluding that the proposed plant is safe.

Note that the boundary region of essentially constant risk is only conceptual. The designer may decide that in certain sub-regions and because of specific considerations, such as events with particularly high or low frequencies and/or consequences, and in those areas governed by existing regulations, deviations from the boundary region are warranted.

7. Summary and conclusions

Risk-informed regulation is built around the concept of using traditional deterministic techniques of safety assurance supplemented by PRA information and insights. Traditional deterministic techniques include concepts such as incorporation of redundancy and diversity, incorporation of safety margins, application of defense in depth, application of quality assurance, etc. PRA results should play a limited and supportive role in making decisions about adequacy of safety in a risk-informed regulatory framework.

However, recent trends in the development of new risk-related approaches, whether they are performed by the industry, NRC staff or other domestic or international bodies, are towards heavier emphasis in use of quantitative PRA results. These risk measures are sometimes compared to risk threshold values that have attained an actual, or even a de facto, regulatory stature of "risk acceptance criteria" in certain instances. Such applications of risk measures for a nuclear reactor design or a specific plant are not always in keeping with the tenets of risk-informed regulations, which call for comparing (integral) measures of the calculated risk (e.g., PFs and LCFs or their suitable surrogates such as the CDF or the LRF) against QHOs (or their surrogate targets, e.g., 1E−4/yr for CDF) only as "safety goals."

In addition, using numerical PRA results, particularly those that are not integral quantities, in a risk-acceptance context, even by the nuclear industry (as opposed to the regulators) can have numerous undesirable consequences. Examples of these among many discussed in the text include: the tendency to penalize simple, passive safety system designs in favor of complex, active designs; and future reactor designs offering lower integrated risk than those of the current and highly safe operating reactors may be erroneously labeled as unsafe and not be pursued, or be burdened with costly but unnecessary design modifications. These issues can lead to serious unintended consequences in licensing of future reactors or creating new challenges regarding the safety adequacy of existing plants.

The paper also offered an alternative use for a frequency versus consequence curve as a design or operational safety optimization tool for use by the reactor designer or plant operator.

Disclaimer

The work related to the development of this paper was conducted at the request of the Director of the Advanced Reactor Programs at the Office of New Reactors (now retired) in the last quarter of 2008 at the US NRC, while the author was on loan from the US Department of Energy.

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APPENDIX 4

A CRITIQUE OF THE RADIOLOGICAL CONSEQUENCE ASSESSMENT CONDUCTED IN SUPPORT OF THE INDIAN POINT SEVERE ACCIDENT MITIGATION ALTERNATIVES ANALYSIS

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November 2007
In Memoriam: John Gofman

Introduction

In order to conduct the Severe Accident Mitigation Alternatives (SAMA) analysis for the Environmental Report submitted as part of its application for renewal of the licenses for the Indian Point 2 and 3 reactors, Entergy Nuclear was required to conduct a quantitative assessment of the radiological consequences of severe accidents at the Indian Point nuclear plant. This analysis is needed to calculate the value of the radiological consequences that would be averted if the SAMAs considered by Entergy were implemented. When combined with calculated core damage frequencies from the Indian Point Probabilistic Risk Assessment (PRA), the annual radiological risk to the public from severe accidents can be computed, and the value of the averted risk associated with each SAMA can be compared to the SAMA's cost to evaluate which options, if any, are cost-beneficial.

The calculation of radiological risk to the public is a highly uncertain exercise. The uncertainties are associated both with the values of the severe accident frequencies and the quantitative results of consequence calculations. This report will focus on the consequence assessment.

We find that in three significant respects, Entergy's consequence calculations are seriously flawed and do not lead to an assessment of risk to the public that is sufficiently conservative to serve as a reasonable basis for its SAMA analysis:

First, the source term used by Entergy to estimate the **consequences of the most severe accidents with early containment failure is based on radionuclide release fractions generated by the MAAP code** (a proprietary industry code that has not been validated by NRC), which are smaller for key radionuclides than the release fractions specified in NRC guidance such as NUREG-1465 and its recent reevaluation for high-burnup fuel.[75] The source term used by Entergy results in lower consequences than would be obtained from NUREG-1465 release fractions and release durations.

[75] L. Soffer, et al. U.S. Nuclear Regulatory Commission, "Accident Source Terms for Light-Water Nuclear Power Plants: Final Report," NUREG-1465, February 1995; Energy Research, Inc., "Accident Source Terms for Light-Water Nuclear Power Plants: High-Burnup and MOX Fuels: Final Report," ERI/NRC 02-202, November 2002.

Second, Entergy **fails to consider the uncertainties in its consequence calculation resulting from meteorological variations by using only mean values for population dose and offsite economic cost estimates.**

Third, **the population dose conversion factor of** $2000/person-rem used by Entergy to estimate the cost of the health effects generated by radiation exposure underestimates the cost of the health consequences of severe accidents by failing to address the value of lives lost as a result of acute radiation syndrome, in addition to cancer.

As a result of these deficiencies in Entergy's analysis, Entergy rejected most SAMAs on the basis that they were not cost-beneficial. In contrast, an analysis based on the more severe consequences that we have calculated would likely conclude that many of these SAMAs in fact would be cost-effective.

We have used the MACCS2 code to conduct an independent evaluation of severe accident consequences for Indian Point Unit 2 for the highest-impact severe accident scenario. Our results indicate that Entergy's baseline consequence analysis significantly underestimates (by more than a factor of three) mean population doses and other off-site costs resulting from such an accident. This is partly due to the particular source term used by Entergy, which was derived from calculations using the industry-developed MAAP code, as opposed to our study, which used a source term derived from NRC studies and regulatory guidance. In addition, we find that taking into account reasonable uncertainties associated with meteorological variations (in particular, by considering the 95th percentile consequences over the course of a year rather than the mean consequences) can increase the consequences by at least another factor of three relative to the mean consequences.

In summary, we calculate for the highest-impact severe accident scenario that the 95th percentile equivalent cost of off-site health impacts is more than ten times greater than Entergy's estimate of the equivalent cost of off-site health impacts. We also find that the 95th percentile off-site economic impacts for this scenario is over 70 times greater than Entergy's estimate of off-site economic impacts for the same scenario, and is over 12 times greater than Entergy's estimate of the <u>total</u> cost (off- and on-site) for <u>all</u> severe accident scenarios, the value it used to determine the cost-effectiveness of candidate SAMAs.

We have not carried out a similar analysis of Entergy's consequence assessment for IP3, but we would expect to find similar results in that case as well.

Major Flaws in the Entergy SAMA Analysis

<u>1. The source terms used by Entergy to estimate the consequences of severe accidents Radionuclide release fractions generated by the MAAP code, which has not been validated by NRC, are consistently smaller for key radionuclides than the release fractions specified in NUREG-1465 and its recent revision for high-burnup fuel. The source term used by Entergy results in lower consequences than would be obtained from NUREG-1465 release fractions and release durations.</u>

For example, the IP2 cesium release fraction for the early containment failure, high release ("early high") category used by Entergy is 0.229, compared to a total of 0.75 for NUREG-1465. It has been previously observed that MAAP generates lower release fractions than those derived and used by NRC in studies such as NUREG-1150. A Brookhaven National Laboratory study that independently analyzed the costs and benefits of one SAMA in the license renewal application for the Catawba and McGuire plants noted that the collective dose results reported by the applicant for early failures

> "…seemed less by a factor between 3 and 4 than those found for NUREG-1150 early failures for comparable scenarios. The difference in health risk was then traced to differences between [the applicant's definitions of the early failure release classes] and the release classes from NUREG-1150 for comparable scenarios … the NUREG-1150 release fractions for the important radionuclides are about a factor of 4 higher than the ones used in the Duke PRA. The Duke results were obtained using the Modular Accident Analysis Package (MAAP) code, while the NUREG-1150 results were obtained with the Source Term Code Package [NRC's state-of-the-art methodology for source term analysis at the time of NUREG-1150] and MELCOR. Apparently the differences in the release fractions … are primarily attributable to the use of the different codes in the two analyses."[76]

Thus the use of source terms generated by MAAP, a proprietary industry code that has not been independently validated by NRC, appears to lead to anomalously low consequences when compared to source terms generated by NRC staff. In fact, NRC has been aware of this discrepancy for at least two decades. In the draft "Reactor Risk Reference Document" (NUREG-1150, Vol. 1), NRC noted that for the Zion plant (a four-loop PWR quite similar to the Indian Point reactors), that "comparisons made between the Source Term Code Package results and MAAP results indicated that the MAAP estimates for environmental release fractions were significantly smaller. It is very difficult to determine the precise source of the differences observed, however, without performing controlled comparisons for identical boundary conditions and input data."[77] We are unaware of NRC having performed such comparisons.

In light of this, it is clear that Entergy should not rely on MAAP-generated source terms in its SAMA analysis unless it can provide a technically credible justification for the differences between them and those developed by NRC.

In contrast, we have based our analysis on the more conservative NUREG-1465 source term, which has undergone extensive review by the public, and which is being voluntarily implemented by licensees in other regulatory applications.[78] The NUREG-1465 source term was

[76] J. Lehner et al., "Benefit Cost Analysis of Enhancing Combustible Gas Control Availability at Ice Condenser and Mark III Containment Plants," Final Letter Report, Brookhaven National Laboratory, Upton, NY, December 23, 2002, p. 17. ADAMS Accession Number ML031700011.

[77] U.S. NRC, "Reactor Risk Reference Document: Main Report, Draft for Comment," NUREG-1150, Volume 1, February 1987, p. 5-14.

[78] In adapting NUREG-1465 for this purpose, we have assumed that all radionuclides released to containment are released to the environment in early containment failure scenarios, as explained in this author's attached report, "Chernobyl-on-the-Hudson?"

also reviewed by an expert panel in 2002, which concluded that it was "generally applicable for high-burnup fuel."[79] This and other insights by the panel on the NUREG-1465 source term are being used by the NRC in "radiological consequence assessments for the ongoing analysis of nuclear power plant vulnerabilities."[80]

2. Entergy fails to consider the uncertainties in its consequence calculation resulting from meteorological variations by only using mean values for population dose and offsite economic cost estimates.

Entergy applies an inconsistent approach to its consideration of the uncertainties in its risk calculations. Entergy conducted an uncertainty analysis for its estimate of the internal events core damage frequency (CDF). As a measure of the uncertainty inherent in the internal events CDF as determined by the PRA, Entergy provides the ratio of the CDF at the 95th percentile confidence level to the mean CDF, which it calculates to be 2.1 for IP2 and 1.4 for IP3 (ER at 4-51). It then bases its SAMA cost-benefit evaluation on the 95th percentile CDF (ER at E.1-31), rather than the mean CDF. However, Entergy omits consideration of the uncertainties associated with other aspects of its risk calculation. In particular, it does not consider the impact of the uncertainties associated with meteorological variations, which we find to be even greater than the CDF uncertainties reported by Entergy.

The consequence calculation, as carried out by the MACCS2 code, generates a series of results based on random sampling of a year's worth of weather data. The code provides a statistical distribution of the results. We find, based on our own MACCS2 calculations, that the ratio of the 95th percentile to the mean of this distribution is typically a factor of 3 to 4 for outcomes such as early fatalities, latent cancer fatalities and off-site economic consequences. Because these ratios are greater than the ones considered in Entergy's CDF uncertainty analysis, it is illogical to ignore these uncertainties, as Entergy has done. For consistency, the "baseline benefit with uncertainty" that Entergy uses in the SAMA cost-benefit evaluation should be based on the 95th percentile of the meteorological distribution in addition to the 95th percentile of the CDF distribution. This would also be consistent with the approach taken in the License Renewal GEIS, which refers repeatedly to the 95th percentile of the risk uncertainty distribution as an appropriate "upper confidence bound" in order not to "underestimate potential future environmental impacts."[81]

3. The population dose conversion factor of $2000/person-rem used by Entergy to estimate the cost of the health effects generated by radiation exposure is based on a deeply flawed analysis and seriously underestimates the cost of the health consequences of severe accidents.

Entergy underestimates the population-dose related costs of a severe accident by relying inappropriately on a $2000/person-rem conversion factor. Entergy's use of the conversion factor

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[79] J. Schaperow, U.S. NRC, memorandum to F. Eltawila, "Radiological Source Terms for High-Burnup and MOX Fuels," December 13, 2002.
[80] J. Schaperow (2002), op cit.
[81] U.S. NRC, "Generic Environmental Impact Statement for License Renewal of Nuclear Plants," NUREG-1437, Vol. 1, May 1996, Section 5.3.3.2.1.

is inappropriate because it (a) does not take into account the significant loss of life associated with early fatalities from acute radiation exposure that could result from some of the severe accident scenarios included in Entergy's risk analysis; and (b) underestimates the generation of stochastic health effects by failing to take into account the fact that some members of the public exposed to radiation after a severe accident will receive doses above the threshold level for application of a dose- and dose-rate reduction effectiveness factor (DDREF).

The $2000/person-rem conversion factor is intended to represent the cost associated with the harm caused by radiation exposure with respect to the causation of "stochastic health effects," that is, fatal cancers, nonfatal cancers, and hereditary effects.[82] The value was derived by NRC staff by dividing the Staff's estimate for the value of a statistical life, $3 million (presumably in 1995 dollars, the year the analysis was published) by a risk coefficient for stochastic health effects from low-level radiation of 7×10^{-4}/person-rem, as recommended in Publication No. 60 of the International Commission on Radiological Protection (ICRP). (This risk coefficient includes nonfatal stochastic health effects in addition to fatal cancers.) But the use of this conversion factor in Entergy's SAMA analysis is inappropriate in two key respects. As a result Entergy underestimates the health-related costs associated with severe accidents.

First, the $2000/person-rem conversion factor is specifically intended to represent only stochastic health effects (e.g. cancer), and not deterministic health effects "including early fatalities which could result from very high doses to particular individuals."[83] However, for some of the severe accident scenarios evaluated by Entergy at IP, we find that large numbers of early fatalities (hundreds to thousands) could occur, representing a significant fraction of the total number of projected fatalities, both early and latent. This is consistent with the findings of the Generic Environmental Impact Statement for License Renewal of Nuclear Plants (NUREG-1437).[84] Therefore, it is inappropriate to use a conversion factor that does not include deterministic effects. According to NRC's guidance, "the NRC believes that regulatory issues involving deterministic effects and/or early fatalities would be very rare, and can be addressed on a case-specific basis, as the need arises."[85] Based on our estimate of the potential number of early fatalities resulting from a severe accident at Indian Point, this is certainly a case where this need exists.

Second, the $2000/person-rem factor, as derived by NRC, also underestimates the total cost of the latent cancer fatalities that would result from a given population dose because it assumes that all exposed persons receive dose commitments below the threshold at which the dose and dose-rate reduction factor (DDREF) (typically a factor of 2) should be applied. However, for certain severe accident scenarios at IP evaluated by Entergy, we calculate that considerable numbers of people would receive doses high enough so that the DDREF should not be applied.[86] This means, essentially, that for those individuals, a one-rem dose would be worth "more" because it would be more effective at cancer induction than for individuals receiving doses below the threshold. To illustrate, if a group of 1000 people receive doses of 30 rem each over a short

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[82] U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy," NUREG-1530, 1995, p. 12.
[83] U.S. NRC (1995), op cit., p. 1.
[84] U.S. NRC, Generic Environmental Impact Statement for License Renewal of Nuclear Plants, NUREG-1437, Vol. 1, May 1996, Table 5.5.
[85] U.S. NRC, "Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy (1995), op cit., p. 13.
[86] The default value of the DDREF threshold is 20 rem in the MACCS2 code input.

period of time (population dose 30,000 person-rem), 30 latent cancer fatalities would be expected, associated with a cost of $90 million, using NRC's estimate of $3 million per statistical life and a cancer risk coefficient of $1x10^{-3}$/person-rem. If a group of 100,000 people received doses of 0.3 rem each (also a population dose of 30,000 person-rem), a DDREF of 2 would be applied, and only 15 latent cancer fatalities would be expected, at a cost of $45 million. Thus a single cost conversion factor, based on a DDREF of 2, is not appropriate when some members of an exposed population receive doses for which a DDREF would not be applied.

A better way to evaluate the cost equivalent of the health consequences resulting from a severe accident is simply to sum the total number of early fatalities and latent cancer fatalities, as computed by the MACCS2 code, and multiply by the $3 million figure. Again, we do not believe it is reasonable to distinguish between the loss of a "statistical" life and the loss of a "deterministic" life when calculating the cost of health effects.

Results of IP2 Consequence Assessment

We have performed our own calculation of the consequences of a severe accident at IP2, using the MACCS2 code. The model is largely based on the one used in this author's 2004 study "Chernobyl-on-the-Hudson? (copy attached)," to which the reader is referred for all details. The model was revised, based on Entergy's ER, to incorporate (1) the core inventory specified in Table E.1-13, and (2) the expected population in 2034. To calculate the latter, we scaled the output of the SECPOP2000 code by a factor of 1.145. This normalized the total population within 50 miles to 19.2 million, to correspond to Entergy's projection of the total population within 50 miles of the IP site in 2034.[87] We use a finer site data input grid than Entergy does, with 21 intervals between 0 and 50 miles, compared to the five intervals used by Entergy. This allows for more accurate modeling of the dose and economic consequences.

The model we use is different compared to the one used by Entergy in a number of notable respects. First, we use a source term derived from NUREG-1465, as discussed previously, with regard to both the magnitude and timing of radionuclide releases. We use a two-plume model based on the approach of NUREG/CR-6295[88] that more realistically models the releases that would occur in an early containment failure scenario.[89] We also assume that the entire population of the 10-mile EPZ evacuates as determined by the evacuation time estimates provided by KLD Associates in 2004 (ER reference E.1-21), whereas Entergy assumes no

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[87] We have adjusted the SECPOP2000 input and output files to correct the errors disclosed in the August 2007 memo to SECPOP2000 users from Sandia National Laboratories and verified that the county data file is being read correctly. However, according to a personal communication from Nathan Bixler of Sandia National Laboratories, there is another potential problem with SECPOP2000 that was not mentioned in the August 2007 memo. When this problem is rectified, we will amend our calculations accordingly.

[88] R. Davis, A. Hanson, V. Mubayi and H. Nourbakhsh, *Reassessment of Selected Factors Affecting Siting of Nuclear Power Plants*, NUREG/CR-6295, US Nuclear Regulatory Commission, 1997, p. 3-30.

[89] Entergy's model assumes a single plume with a duration of over 22 hours, which is longer than for any other early containment failure source term we have encountered. We note that when we ran the MACCS2 code using Entergy's source term for the "early, high" scenario, the MACCS2 output file contained the following warning: "The total release duration exceeds 20 hours. This may cause erroneous results to be produced." Thus it is unclear to us that Entergy's results for this case are even valid.

evacuation at all. (It is not clear whether Entergy assumes sheltering or normal activity for the inhabitants of the EPZ.) We use the evacuation scenario because we have found that for the source term that we utilize, the all-sheltering scenario actually results in a smaller number of latent cancer fatalities than in an evacuation scenario, in part because more individuals succumb to acute radiation syndrome in the former scenario (and thus do not get cancer).[90]

In our model, we utilize the option in MACCS2 to calculate consequences for an entire year's worth of weather conditions, starting on each hour of the year. Each of these 8760 results is a weighted sum of results evaluated for each of the 16 compass directions, with the weighting determined by the Indian Point site wind rose. The accident is assumed to occur randomly at any time during the year. (Entergy does not make clear in the ER whether it calculated as large a number of outcomes or used the random sampling function of MACCS2, which selects only a few hundred hours during the year for evaluation.) We use the meteorological data file originally compiled for the Indian Point site for the CRAC2 study, which is publicly available.

Our results for off-site health consequences within a 50-mile radius of IP for the "early high" release category with full evacuation, compared to Entergy's, are presented in Table I. The values for latent cancer fatalities as a result of "early" exposures (e.g. during the 1-week emergency phase) are reported separately from those resulting from "chronic" exposures (those resulting from the intermediate and long-term phases, as defined by MACCS2). The results for "chronic" exposures depend in on the parameters for long-term protective actions and have greater uncertainties than the results for "early exposures. We assume, for purposes of comparison, that Entergy's result for total population dose is the sum of both early and chronic exposures.

TABLE I
Health Impacts of "Early, High" Release

	This study	Environmental Report (Table E.1-14)
Mean early fatalities	860	Not reported
Mean latent cancer fatalities from early exposure	37,600	Not reported
Mean latent cancer fatalities from chronic exposure	950	Not reported
Mean latent cancer fatalities (total)	38,500	Not reported
Mean population dose (person-Sv)	4.97 $x10^5$	1.58 $x10^5$
95^{th} percentile early fatalities	4,440	Not reported
95^{th} percentile latent cancer	129,000	Not reported

[90] We find for our source term that the evacuation scenario actually results in a slightly greater number of combined early and latent fatalities. This appears to be an artifact of the particular population data file used rather than a reflection of a general principle.

fatalities from early exposure		
95th percentile latent cancer fatalities from chronic exposure	3,450	Not reported
95th percentile latent cancer fatalities (total)	130,000	Not reported
95th percentile population dose from early and chronic exposures (person-Sv)	1.64×10^6	Not reported

Our mean population dose result is over three times greater than that calculated by Entergy. To try to understand the reason for this difference, we reran the calculation with Entergy's MAAP-derived source term. For the no-evacuation (all-sheltering) scenario, we found a 45% reduction in population dose to 276,000 person-rem, which is still nearly twice Entergy's result of 158,000 person-rem. Without access to all the MACCS2 input files used by Entergy in its calculation, we cannot identify the other factors that may account for the remainder of the difference. But it is clear that the choice of source terms alone can have a significant (at least two-fold) impact on the population dose results.

We can also see from Table I that the 95th percentile population dose is over three times the mean population dose, and the 95th percentile number of early fatalities is over five times the mean value. This demonstrates that Entergy's focus on the mean consequences significantly underestimates the potential consequences of accidents occurring during less frequent but not uncommon meteorological conditions.
As discussed above, we maintain that the mean population dose is not an accurate representation of the total cost detriment associated with lives lost, because it does not include the costs of early fatalities, which as one can see from Table I, are substantial. In addition, as shown above, use of population dose as a surrogate for latent cancer fatalities is not appropriate because the total population dose does not account for the non-linear relationship between population dose and total number of latent cancer fatalities when the range of individual doses include both doses above and below the DDREF threshold. To remedy these problems, the total number of early fatalities and latent fatalities should be summed and the total multiplied by the monetary equivalent of lives lost, which is $3 million in NRC guidance.

From this data, we obtain an equivalent cost, at $3 million per life lost, of $118 billion for the mean case. For the 95th percentile case, the equivalent cost of the latent cancer fatalities alone would be $390 billion.[91] This should be compared to the result if only the equivalent cost of the population dose, using the $2000/person-rem conversion factor, were considered: $99.8 billion and $328 billion for the mean and 95th percentile, respectively.

However, in either case these results are far greater than Entergy's calculated equivalent cost of $31.6 billion. From the results presented in Table II, we see that our result for the cost detriment associated with loss of life from the "early, high" release is approximately 3.7 times greater than Entergy's result for the mean case, and over 12 times greater for the 95th percentile case.

[91] The MACCS2 code does not have an option for calculating the sum of early and latent cancer fatalities, and therefore does not report the 95th percentile value of this sum.

According to Entergy's calculations, this scenario is the largest single contributor (47%) to the overall population dose risk.

TABLE II
Equivalent Cost of Off-Site Health Impacts of "Early, High" Release

	This study	Environmental Report
Mean off-site health impacts equivalent cost (early and latent cancer fatalities)	$118 billion	$31.6 billion
95^{th} percentile health impacts equivalent cost (latent fatalities only)	$390 billion	Not reported

We have also obtained results for the off-site economic costs from the "early, high" release. We generally follow the methodology of Beyea, Lyman and von Hippel for our calculation of economic impacts.[92] The model utilizes the results of a 1996 Sandia National Laboratories report that estimates radiological decontamination costs for mixed-use urban areas.[93] We refer interested readers to these two references for information on the limitations and assumptions of the model.

Our results, as calculated by SECPOP2000 and the MACCS2 code, are also considerably higher than Entergy's results. In Table II, the MACCS2 results, which were obtained from 1996 and 1997 data, were converted to 2005 dollars by multiplying by an inflation factor of 1.2.

TABLE III
Off-Site Economic Impacts of "Early, High" Release

	This study	Environmental Report
Mean off-site economic impacts	$816 billion	$34.2 billion
95^{th} percentile off-site economic impacts	$2.48 trillion	Not reported

By using the standard discount factor applied by Entergy (e.g. see page 4-53 of the ER), Entergy's frequency result, and neglecting the risk contributions of all other scenarios, we find a mean monetary equivalent present dollar value for the "early, high" release of $825,514, and a 95^{th} percentile present dollar value (for latent cancers alone) of $2.73 million.

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[92] J. Beyea, E. Lyman and F. von Hippel, "Damages from a Major Release of 137Cs into the Atmosphere of he United States," *Science and Global Security* 12 (2004) 1-12.

[93] D. Chanin and W. Murfin, *Site Restoration: Estimates of Attributable Costs From Plutonium Dispersal Accidents*, SND96-0057, Sandia National Laboratories, 1996.

Again using the same discount factor, we find a mean present dollar value of the off-site economic consequences of the "early, high" release of $5.71 million, and a 95th percentile present dollar value of $17.3 million.

Adding the equivalent cost of off-site health impacts to the off-site economic cost, we find for the "early, high" release alone the mean total cost equivalent present dollar value is $6.54 million. (We have not made our own estimates of on-site dose and on-site economic costs.) This is nearly seven times greater than Entergy's estimate of the sum of these two costs for all release categories.

For the 95th percentile, the present dollar value off-site economic cost for the "early, high" release alone is over 72 times Entergy's mean estimate for the same release and over 12 times Entergy's mean estimate for all costs (off- and on-site) and all release categories of $1.34 million.

These results are summarized in Table IV.

TABLE IV
Present Dollar Value Equivalent of "Early, High" Release Consequences

	This study	Environmental Report
Mean present dollar value of total off-site costs	$6.54 million	$460,334
95th percentile present dollar value equivalent of off-site fatalities (latent cancers only)	$2.73 million	Not reported
95th percentile present dollar value of off-site economic impacts	$17.3 million	Not reported

We have not carried out a review of Entergy's calculations for the other release categories that contribute to the Indian Point 2 severe accident risk. However, we would expect similar findings to those we have obtained in our review of the "early, high" release. In our judgment, many SAMA candidates would become cost-effective based on the difference in mean consequences alone, and many more rejected SAMA candidates would become cost-effective when the 95th percentile case is considered. If we were to extrapolate our result for the 95th percentile off-site costs of the "early,high" release to all release categories, leading to a nearly twenty-fold increase in total economic cost compared to Entergy's estimate, even the most costly SAMAs, such as the Phase II SAMA #015, "Strengthen Containment," could well become cost-effective.

We note that this conclusion would be further strengthened if we incorporated the increased frequency of the "early, high" release category estimated by Dr. Gordon Thompson in his

November 2007 report *Risk-Related Impacts from Continued Operation of the Indian Point Nuclear Power Plant.*

Based on these findings, we believe that Entergy has grossly underestimated the off-site costs of severe accidents at Indian Point, and should revise its estimates using more credible and conservative source terms. It should also consider the 95^{th} percentile consequence values of the distribution with respect to weather variations and use these values as the upper confidence bound in carrying out the SAMA cost-benefit evaluation for Indian Point. Entergy should use a methodology for calculating the cost equivalent of off-site health impacts that properly accounts for individuals who receive acute radiation doses above the threshold for early fatalities, and for those who receive chronic doses above the threshold for application of a DDREF.

Analysis

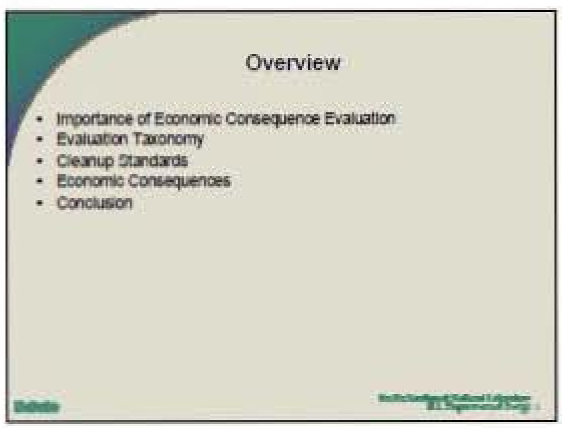
Our estimate of the mean off-site economic consequences of the "early, high" release is approximately 20 times Entergy's estimate. We have identified some of the reasons for the difference, but not all of them. The difference in source terms does not appear to be as great a factor as for the calculation of health impacts. The differences in the choices of economic and other parameters between Entergy's model and ours also plays a role. For instance, we use decontamination cost estimates obtained from a 1996 Sandia study that are significantly higher than those used by Entergy, which uses values based on the default parameters in the MACCS2 code. However, even after running the code with Entergy's source term and economic parameters, we still find economic consequences at least an order of magnitude greater than Entergy's. The results are also dependent on factors such as the dose criteria for triggering interdiction and condemnation actions. We use a more restrictive model than the default MACCS2 model in order to more closely approximate the EPA Protective Action Guides.[94] In

[94] U.S. Environmental Protection Agency, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," Washington, DC, 1991.

any event, it is clear that reasonable differences in parameter choices can lead to order-of-magnitude differences in consequences in the MACCS2 long-term economic consequences model, and that Entergy has not done due diligence in exploring the sensitivity of their results to parameter variations.

APPENDIX 5


Economic Consequences of a Rad/Nuc Attack:
Cleanup Standards Significantly Affect Cost
Barbara Reichmuth
Steve Short
Tom Wood
Pacific Northwest National Laboratory
Working Together: Research & Development (R&D)
Partnerships in Homeland Security Conference
April 28, 2005, Boston, MA


Overview
• Importance of Economic Consequence Evaluation
• Evaluation Taxonomy
• Cleanup Standards
• Economic Consequences
• Conclusion

Why Evaluate Economic Consequences?

- Loss of life, property destruction, and loss of economic activity have significant consequences
- Loss of use of productive assets can extend for long periods and generate considerable economic loss
- Economic impacts need to be addressed in sequential order:
  - Detonation,
  - Atmospheric dispersion and deposition,
  - Fallout from the weapon.
- Weapon characteristics provide the boundary conditions for the response:
  - How large is the affected area?
  - What actions need to be taken to protect the population?

Economic Evaluation Taxonomy

The decision to invest in countermeasures can be viewed as a tradeoff between investment cost and the economic consequences of an event.

Economic Consequence Calculation Methodology

- Literature review yields numerous methodologies for economic evaluation. Data used in this analysis:
  - Federal Reserve Bank of New York Study[1]
  - Sandia National Lab RadTran V Economic Model
- Focus on five broad categories of cost ($2005):
  - Loss of productivity from earnings forgone
  - Indirect economic effects or multiplier
  - Loss and damage to building structures
  - Decontamination and decommissioning (D&D) cost (including disposal)
  - Evacuation Cost
- Analysis does not cover the universe of all possible economic impacts
- Diversity of meteorological conditions not evaluated
  - Same physical consequence plume evaluated for different locations
- Focus on sensitivity analysis of cleanup standards

1. [illegible] "Measuring the Effects of the September 11 Attack on New York City", FRBNY Economic Policy Review, November 2002

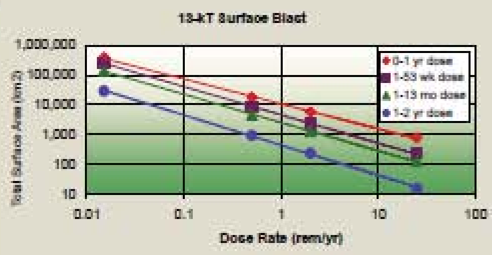
Economic Consequence Criteria

- Selected five locations from isolated rural to high density urban areas:
  - Lukeville, AZ
  - Charleston, SC
  - Detroit, MI
  - San Ysidro, CA
  - New York City, NY
- Evaluated consequences for 4 weapon types:
  - 0.7kT nuclear weapon
  - 13kT nuclear weapon
  - 100kT nuclear weapon
  - 10kCi Cs-137 RDD
- Evaluated five potential cleanup levels

Potential Range of Cleanup Guidance for a Rad/Nuc Event – Which One Do We Use?

15 mrem/yr	EPA, "Establishment of Cleanup Levels for CERCLA Sites With Radioactive Contamination" (e.g., Hanford Site)
25 mrem/yr	NRC, Final Rule on Radiological Criteria for License Termination (10 CFR Part 20 Subpart E)
100 mrem/yr	Health Physics Society Position Statement, "Guidance for Protective Actions Following a Radiological Terrorist Event"
500 mrem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, ... "doses in any single year after the first will not exceed 0.5 rem."
2 rem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, ... "doses in first year will not exceed 2 rem."
5 rem/yr	NRC, "Standards for Protection Against Radiation," recommendation and established dose limit for workers of 5 rem/yr (10 CFR 20 Subpart C)

Radioactivity Decays Over Time



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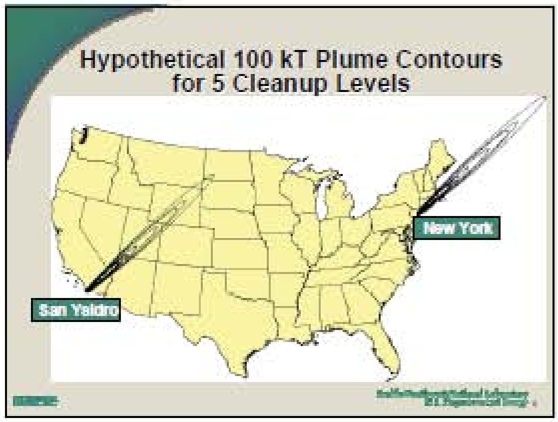
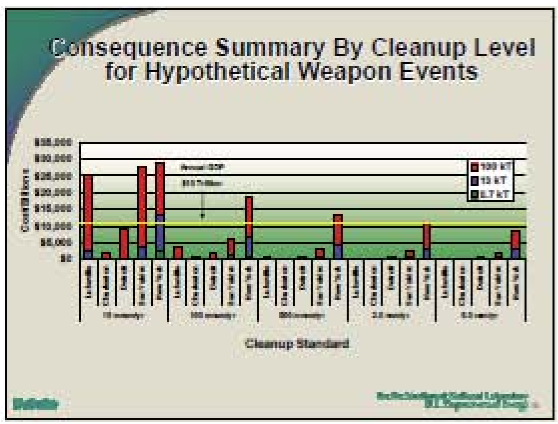
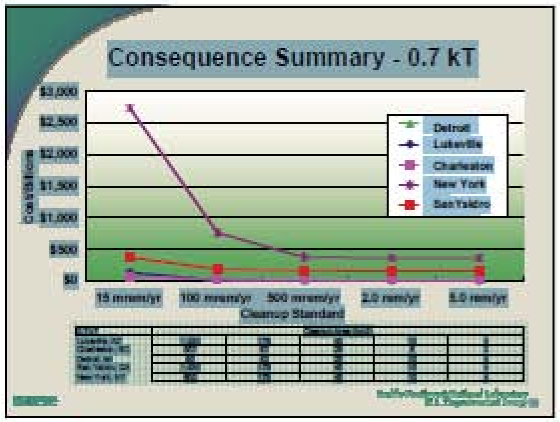
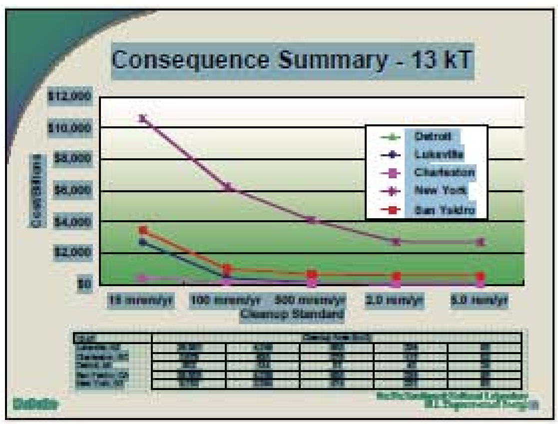
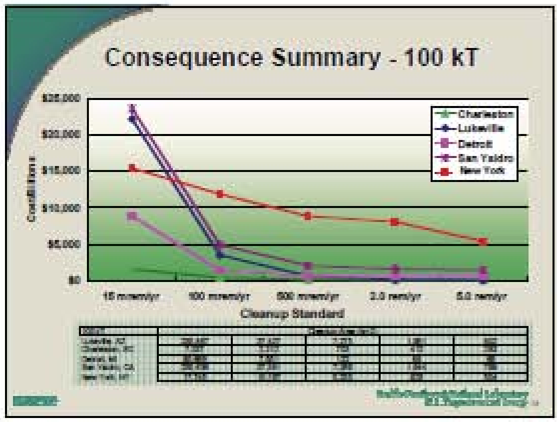
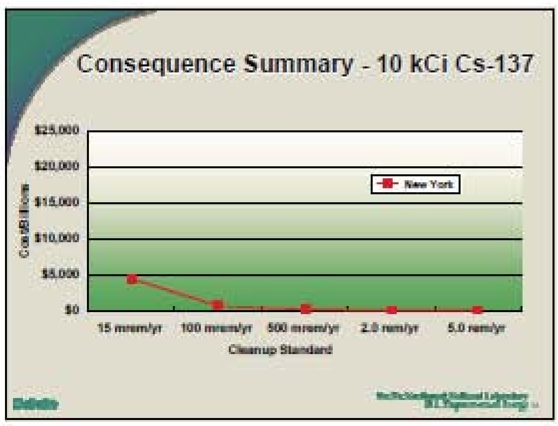

Hypothetical 100 kT Plume Contours
for 5 Cleanup Levels
New York
San Ysidro


Consequence Summary By Cleanup Level
for Hypothetical Weapon Events
$35,000
$30,000
$25,000
$20,000
$15,000
$10,000
$5,000
$0
100 kT
15 kT
Cleanup Standard


Consequence Summary - 0.7 kT
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Cost/Billions
Detroit
Lukeville
Charleston
New York
San Ysidro
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
Cleanup Standard

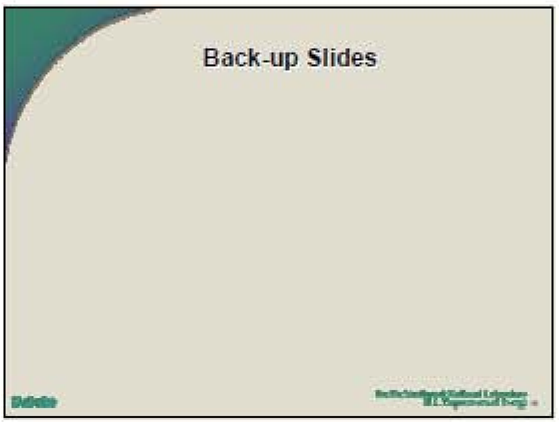

Consequence Summary - 13 kT
$12,000
$10,000
$8,000
$6,000
$4,000
$2,000
$0
Cost/Billions
Detroit
Lukeville
Charleston
New York
San Ysidro
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
Cleanup Standard

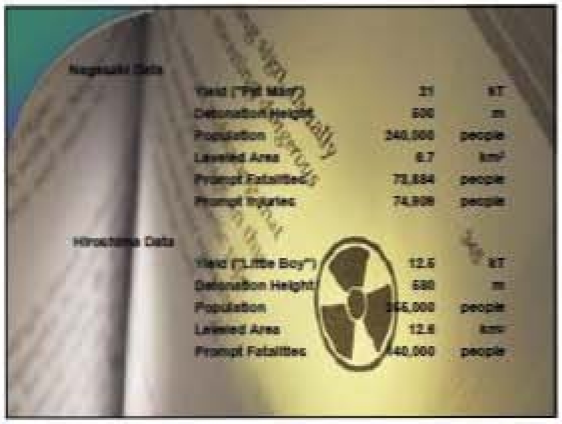

Consequence Summary - 100 kT
Cost Billions
$25,000
$20,000
$15,000
$10,000
$5,000
$0
Charleston
Lukeville
Detroit
San Ysidro
New York
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
Cleanup Standard

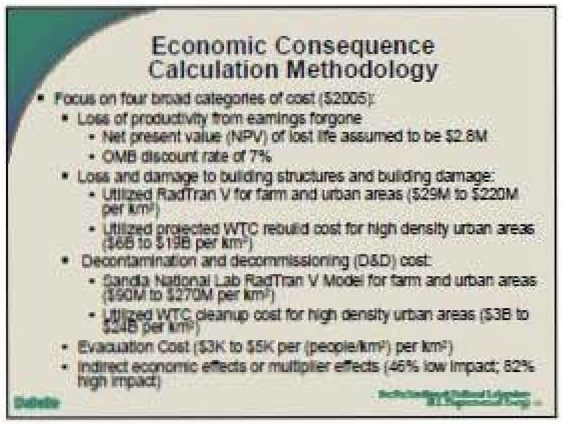

Consequence Summary - 10 kCi Cs-137
Cost Billions
$25,000
$20,000
$15,000
$10,000
$5,000
$0
New York
15 mrem/yr
100 mrem/yr
500 mrem/yr
2.0 rem/yr
5.0 rem/yr
Cleanup Standard

7


Conclusions
Economic consequences of a Rad/Nuc event are highly dependent on cleanup standards
Cleanup costs generally increase dramatically for standards more stringent than 500 mrem/yr
Cleanup to the most conservative current standards (no matter what the class of target or weapon event) magnifies the consequences of the event
Because such an event could potentially spread contamination very widely, even an event in a "remote" location could have huge economic consequences
A risk-based approach to the development and application of cleanup standards is needed
Policy implications of such a cleanup need to be fully evaluated
Cleanup after a weapon event will be vastly different from cleanup of a contaminated industrial facility or former weapons production facility


Back-up Slides


Nagasaki Data
Yield ("Fat Man") 21 kT
Detonation Height 500 m
Population 240,000 people
Leveled Area 6.7 km²
Prompt Fatalities 73,884 people
Prompt Injuries 74,909 people
Hiroshima Data
Yield ("Little Boy") 12.5 kT
Detonation Height 580 m
Population 55,000 people
Leveled Area 12.6 km²
Prompt Fatalities 40,000 people


Economic Consequence
Calculation Methodology
Focus on four broad categories of cost ($2005):
Loss of productivity from earnings forgone
Net present value (NPV) of lost life assumed to be $2.8M
OMB discount rate of 7%
Loss and damage to building structures and building damage:
Utilized RadTran V for farm and urban areas ($29M to $220M per km²)
Utilized projected WTC rebuild cost for high density urban areas ($6B to $19B per km²)
Decontamination and decommissioning (D&D) cost:
Sandia National Lab RadTran V Model for farm and urban areas ($90M to $270M per km²)
Utilized WTC cleanup cost for high density urban areas ($3B to $24B per km²)
Evacuation Cost ($3K to $5K per (people/km²) per km²)
Indirect economic effects or multiplier effects (46% low impact; 82% high impact)
Battelle

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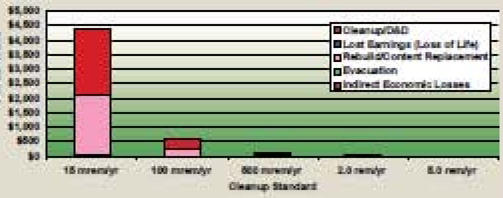
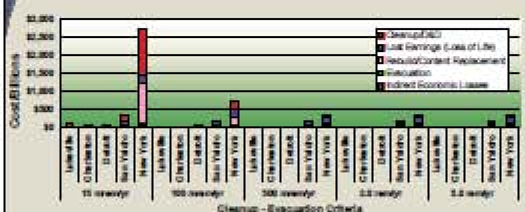
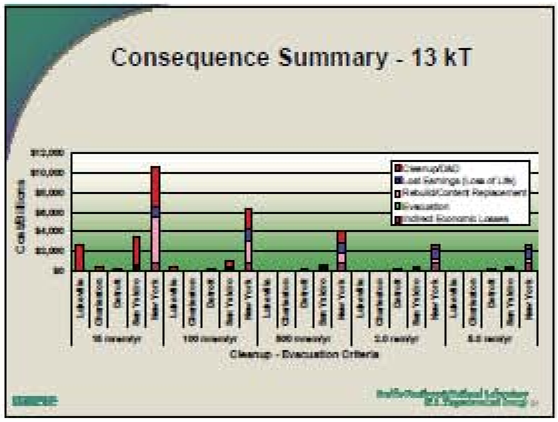
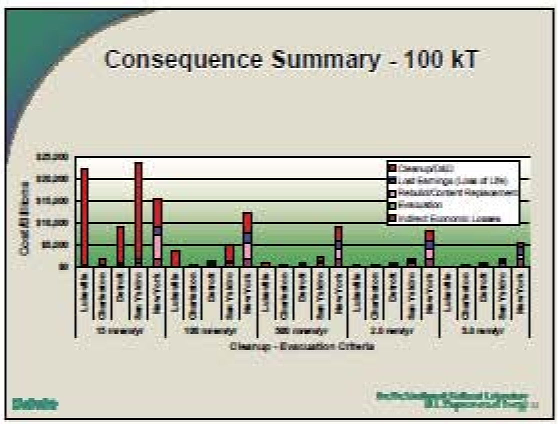
RDD Yield - 10 kCi Cs-137



Consequence Summary - 0.7 kT




Consequence Summary - 13 kT
Cleanup - Evacuation Criteria


Consequence Summary - 100 kT
Cleanup - Evacuation Criteria

PNNL-SA-45256

ECONOMIC CONSEQUENCES OF A RAD/NUC ATTACK: CLEANUP STANDARDS SIGNIFICANTLY AFFECT COST

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ABSTRACT

Property destruction, loss of life, and injuries sustained from a nuclear or radiological attack have significant economic consequences. The loss of productive assets can extend for long periods and generate significant economic loss. Economic impacts caused by an event need to be addressed in sequential order beginning with the detonation, atmospheric dispersion, and deposition of the fallout from the weapon. Weapon characteristics provide the boundary conditions for the response, including defining how large the response area is and what specific actions need to be taken to protect the population in the target area. These economic consequences are highly dependent on the magnitude of the weapon event and do not scale in a linear fashion.

The cost to clean up or remediate the affected area will depend on the cleanup standard applied to the event and is highly sensitive to this standard. Currently, there are no cleanup standards specifically designed for Rad/Nuc terrorist events, but it is likely that the existing Environmental Protection Agency (EPA) and Nuclear Regulatory Commission (NRC) standards would apply defacto. The Department of Energy (DOE) has spent billions of dollars on superfund cleanup, under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) guidance, at former weapons production sites, and the cleanup is expected to continue through 2035. This paper offers an economic perspective on the magnitude of the consequences for a selected class of targets in the United States, with an emphasis on cost sensitivity as the cleanup standard changes.

INTRODUCTION

The prospect of a nuclear attack on the United States was long thought to be restricted to the domain of state actors. Following the terrorist events of September 11, 2001, and other more recent terrorist activities around the world, concerns about all types of terror attacks, including potential radiological and nuclear attacks, have been magnified. The spotlight has shifted to countermeasures that will either reduce the likelihood or reduce the consequences of a radiological or nuclear (Rad/Nuc) terrorist attack.

The decision to invest in Rad/Nuc countermeasures can be viewed as a tradeoff between investment cost of the countermeasure and the consequences of the event. There are both physical consequences and economic consequences that would result from a Rad/Nuc event. Economic impacts caused by an event, and the subsequent response to the event, need to be addressed in sequential order and begin with the physical impacts of the detonation, atmospheric

[1] The Pacific Northwest National Laboratory is operated by Battelle for the U.S. Department of Energy.

dispersion, and deposition of the fallout from the weapon. Physical consequences dictate the response function including the long-term cleanup and site restoration actions taken. One of the recurring themes regarding event response is that there are currently no federal standards that cover the long-term site restoration and cleanup following a radiological or improvised nuclear device (IND) terrorist attack.

The cost to clean up or remediate the affected area is highly sensitive to the cleanup standard applied to the event. There are currently no cleanup standards specifically designed for Rad/Nuc terrorist events, but it is likely that the existing EPA and NRC standards would apply defacto [1].

The General Accounting Office (GAO) reports that the current EPA and NRC cleanup standards differ and these differences have implications for both the pace and ultimate cost of cleanup [2].

The Department of Energy (DOE) has spent billions of dollars on superfund cleanup at former weapons production sites and the cleanup is expected to continue through 2035 [3]. In 2003 recognizing the importance of this issue, the Department of Homeland Security (DHS) tasked an interagency working group to address the issue of Protective Action Guidelines (PAGs) for radiological dispersal devices (RDDs) and improvised nuclear device (IND) incidents. DHS anticipates a draft of that guidance to be issued in the *Federal Register* in June of 2005.

This paper offers an economic perspective on the magnitude of the consequences for selected targets with an emphasis on cost sensitivity as the cleanup standard changes. The work described provides a framework within which the physical consequences of a Rad/Nuc attack can be translated into the economic consequences in U.S. dollars. These effects need to be understood in order to prescribe appropriate countermeasures and policy remedies.

A METHODOLOGY FOR ECONOMIC CONSEQUENCE CALCULATIONS

For this study, "Rad/Nuc" spans a range of possible nuclear weapons and one large radiological dispersion device:

- 0.7 kT nuclear weapon
- 13 kT nuclear weapon
- 100 kT nuclear weapon
- 10 kCi Cs-137 RDD

Five potential targets were selected ranging from an isolated rural area to very high density urban areas. All of the following targets are located on U.S. Borders and/or Ports of Entry into the United States:

- Lukeville, AZ
- Charleston, SC
- Detroit, MI
- San Ysidro, CA
- New York City, NY

The taxonomy of location, weapon yield, and contamination contours was parameterized and fed into the National Atmospheric Release Advisory Center (NARAC) Model to generate the physical consequences. Consequences vary based upon assumptions about where the population is at the time of the attack (home vs. work, indoors vs. outdoors), on what meteorological conditions are assumed, and on the prompt versus fallout effects of the weapon. Those assumptions are classified and not discussed in this paper.

Our focus here was primarily on the economic consequences of a nuclear weapon attack; the impacts of an RDD are still under investigation and will merit further research.

Weapon characteristics, including the type of weapon, the quantity of material, and how the dispersion is achieved, provide the boundary conditions for the response including how much area is impacted and what actions need to be taken to protect human health and the environment. The physical consequences derived from weapon characteristics were then used to calculate economic consequences in five broad categories of cost:

1. Loss of productivity from earnings forgone
2. Indirect economic effects or "multiplier"
3. Loss and damage to building structures and building contents
4. Decontamination and decommissioning referred to as cleanup cost
5. Evacuation cost

These economic consequences, including the cost and time to clean up from the event, are highly dependent on the magnitude of the weapon event and do not scale in a linear fashion.

The consequences of a nuclear weapon detonation are estimated to have both significant loss of human life and substantial cleanup and reconstruction costs. A high degree of outright destruction of property (buildings, public infrastructure, and productive capital equipment of all sorts) will occur due to the detonation. In general, the economic cost of this type of loss is just the lost productivity of the capital (including human capital) destroyed. In a market economy, it is a reasonable approximation to use market values as a surrogate for the value of this production.

The economic and psychosocial effects of an RDD attack are expected to be more significant than the potential loss of human life and building destruction [4]. In the event of a radiological dispersion event, there is a set of economic consequences generated as a result of the event and a set of economic consequences that is independent of the magnitude of a radiological event because of public perception about the dangers associated with RDDs.

In order to derive consequence estimates, an economic evaluation taxonomy was established to determine what potential targets and cleanup levels should be evaluated for the five broad categories of economic consequences.

The responses to nuclear weapon events can be thought of as phases: 1) the initial emergency response and evacuation, 2) the intermediate response where most emergencies have been handled and the focus shifts to cleanup, and 3) the cleanup phase where recovery and cleanup actions are designed to reduce radiation levels in order for land/buildings to be re-used or re-inhabited.

Our primary focus is on phase 3. The cleanup cost for an area is highly dependent on the cleanup standard used, the cleanup technology employed, and the radiological (and other safety) conditions under which cleanup is conducted. Decontamination efforts will include cleaning or sandblasting the exterior or completely demolishing affected buildings, safely disposing of generated radioactive waste, decontaminating the emergency vehicles used in the response and recovery process, and many other activities. These efforts alone could cost billions of dollars and take decades to accomplish, depending on the magnitude of the radiological event and the cleanup level employed.

Because of our interest in the impacts of cleanup levels on the cost, we considered a range of potential cleanup levels from existing standards and protective action guidelines that might ultimately apply to a terrorist attack (Figure 1). This taxonomy was applied to all five potential targets for the purpose of providing a consequence valuation methodology. On a scale of most conservative to least conservative, the Environmental Protection Agency (EPA) standard governing cleanup at sites with radioactive contamination represents the most conservative level that we evaluated. The intent of this paper was to assess the sensitivity, not to determine which cleanup standard is best.

15 mrem/yr	EPA, "Establishment of Cleanup Levels for CERCLA Sites With Radioactive Contamination" (e.g., Hanford Site)
25 mrem/yr	NRC, Final Rule on Radiological Criteria for License Termination (10 CFR Part 20 Subpart E)
100 mrem/yr	Health Physics Society Position Statement, "Guidance for Protective Actions Following a Radiological Terrorist Event"
500 mrem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, ... "doses in any single year after the first will not exceed 0.5 rem."
2 rem/yr	EPA, "Manual of Protective Action Guides and Protective Actions for Nuclear Incidents," 400-R-92-001, ... "doses in first year will not exceed 2 rem."
5 rem/yr	NRC, "Standards for Protection Against Radiation," recommendation and established dose limit for workers of 5 rem/yr (10 CFR 20 Subpart C)

Figure 1. Cleanup Levels Evaluated for Economic Consequences

There are a large number of economic variables that could potentially be included in the calculation of impacts. These include psychological impacts and long-term societal impacts of living under enduring heightened security conditions. Our intent was to quantify those elements we believed were most representative of this type of terrorist attack. A discussion of those five variables follows.

Loss of Productivity from Earnings Forgone

To calculate the loss of human capital due to death from a weapon event, we used a "lifetime-earnings loss" method outlined in a study by the Federal Reserve Bank of New York [5]. This method estimates individual economic losses by estimating a worker's annual earnings over his or her remaining working lifetime. The estimated earnings are then discounted to the current time period (net present value) using a discount factor of 7%, which is the OMB rate to discount lifetime earnings lost and includes a "social factor" to account for the other societal losses that result from premature death. Ex ante, the number of affected workers is tied to the geographic size of the event.

Indirect Economic Effects or "Multiplier"

There will be "indirect" economic impacts associated with the consequences of a nuclear or radiological attack. For example, during the decontamination process, buildings in the affected area would not be functional. Residents would have to be relocated. Businesses would have to do the same or simply halt their activities until completion of the decontamination. Depending on the nature of business conducted inside those buildings, the regional and national economy could be negatively impacted. A resulting decrease in the area's real estate prices, tourism, and commercial transactions could have long-term negative effects on the area's economy.

There are several economic methods whereby "multipliers" are applied to the estimated direct costs (lost income) to estimate the indirect economic impacts. These values may be estimated on the basis of information about the nature of the affected businesses in the response area. The indirect impacts will be larger if the markets for directly affected sectors are beyond the local economic area. In essence, these sectors are "export" driven. If these sectors are no longer allowed to operate, then the impacts will be severe because supporting businesses in the local area will be forced to scale back. We derived multipliers from the FRBNY 9/11 study [5] as follows:

- Low impact scenario (10 kCi Cs-137 RDD, and 0.7 kT nuclear weapon) – 46% of lost earnings
- High impact scenario (13 kT and 100 kT nuclear weapon) – 82% of lost earnings

Decontamination and Decommissioning or Cleanup Cost

Cleanup and restoration of buildings and land after a Rad/Nuc event will be complicated by the need to decontaminate and, potentially, demolish radiologically contaminated buildings and land. The cost of this cleanup will be highly dependent on the areal extent of cleanup, which, in turn, is highly dependent on the level of cleanup required. The cost of cleanup of any given area will be dependent on the relative level of economic development or financial investment that has been made in the area of concern. The approach taken in this study was to develop unit cost factors ($\$/km^2$) for the cleanup of areas having different levels of population density; population density being used as a surrogate for economic activity. Cleanup cost data primarily came from two sources:

- The economic model provided as a companion to the RADTRAN 5 computer program developed for analysis of the consequences and risks of radioactive material transportation (see http://ttd.sandia.gov/risk/radtran.htm). [6] This economic model was initially developed to estimate the economic consequences of plutonium-dispersal accidents.
- The FRBNY study of the economic effects of the 9/11 terrorist attack on New York City, "*Measuring the Effects of the September 11 Attack on New York City*" [5].

RADTRAN 5's companion economic model includes estimated unit costs ($\$/km^2$) for: emergency actions (e.g., applying fixatives) following the event; access control (e.g., guards) to prevent unauthorized access to the contaminated areas; radiological characterization; decontamination/demolition operations; and disposal of radiologically contaminated waste. These elements were summed together to obtain the total cost of cleanup and site restoration.

RADTRAN 5 varies these costs depending on whether the area is an urban area that is lightly contaminated, moderately contaminated, or heavily contaminated or whether the area is farm or range land. The unit costs from the economic model, assuming offsite disposal of radioactive waste, are summarized in Table 1.

Table 1. Summary of Unit Costs for D&D, Building Replacement, and Evacuation Valuation

Area Description	D&D Unit Cost Per km^2 (2005$)	Replacement Unit Cost Per km^2 (2005$)	Evacuation Cost Per Person	Comments
Farm or Range Land	$93 million	$1.2 million	$4,500	Applied to contaminated areas having a population density of less than 50 people/km^2.
Lightly Contaminated Urban	$130 million	$29 million	$2,600	Applied to urban areas having a population density greater than 50 people/km^2 and less than 3,000 people/km^2 and requiring a decontamination factor (DF) of 1-2 to remediate to the required cleanup standard.
Moderately Contaminated Urban	$182 million	$45 million	$3,300	Applied to urban areas having a population density greater than 50 people/km^2 and less than 3,000 people/km^2 and requiring a DF of 2-10 to remediate to the required cleanup standard.
Heavily Contaminated Urban	$275 million	$220 million	$4,500	Applied to urban areas having a population density greater than 50 people/km^2 and less than 3,000 people/km^2 and requiring a DF greater than 10 to remediate to the required cleanup standard. This level of decontamination is difficult to achieve and cost may exceed the property value. **RADTRAN 5 assumes that heavily contaminated buildings and structures are demolished rather than decontaminated.**
High Density Urban	$2.7 billion	$6.6 billion	$4,500	Applied to urban areas having a population density greater than 3,000 people/km^2 but less than 10,000 people/km^2 and requiring a DF greater than 10 to remediate to the required cleanup standard.
Very High Density Urban	$24 billion	$19 billion	$4,500	Applied to urban areas having a population density greater than 10,000 people/km^2 and requiring a DF greater than 10 to remediate to the required cleanup standard.

The urban area upon which the RADTRAN 5 economic model derives its unit cleanup costs is assumed to have an average population density of 1,344 people/km^2. This is significantly lower than high density metropolitan areas such as New York City, which has an average population density of over 20,000 people/km^2. For this reason, the unit costs derived from RADTRAN 5 were not considered to be a good estimate for the cleanup of higher density population areas.

To estimate the impacts on New York City, a proxy for high density urban areas was derived from the FRBNY study, [5] which reported a value of $1.5 billion to clean up and restore the 16-acre World Trade Center site after the terrorist attack. This equates to $24 billion/$km^2$ in 2005 dollars. This is almost two orders of magnitude greater than the RADTRAN 5 economic model unit cost for cleanup of a heavily contaminated urban area. Furthermore, the cost of cleanup of the WTC site would undoubtedly have been much higher had it been destroyed by a Rad/Nuc event. On the other hand, the WTC site is not representative of New York City in general or any other major population center in the United States because of the unique and very high value buildings that stood on this site. Taking these important points into consideration, this FRBNY data was used to derive the unit cleanup costs for the high and very high density urban areas reported in Table 1.

Loss and Damage to Building Structures

The costs to replace and/or rebuild property damaged or destroyed as the result of a Rad/Nuc event, or to compensate owners for the loss of use of this property (including business income loss), were also calculated using unit costs derived from the RADTRAN 5 companion economic model and the FRBNY 9/11 study. As with site cleanup and restoration, these costs are highly dependent on the areal extent and level of contamination. These unit costs are also presented in Table 1.

The unit costs for lightly, moderately, and heavily contaminated urban areas and for farm and range land were derived from the RADTRAN 5 economic model. Again, for the reasons presented previously, the unit costs derived from the RADTRAN 5 economic model were not considered to be a good estimate of the cost to rebuild high population density areas after a Rad/Nuc event. The unit costs for these areas were derived from the FRBNY 9/11 study.

The FRBNY 9/11 study reported a value of $11.9 billion to replace the buildings and contents of the WTC complex, equating to $193 billion/km^2 in 2005 dollars (and which does not include business income loss). This is almost three orders of magnitude greater than the RADTRAN 5 economic model unit cost for replacement of destroyed property in a heavily contaminated urban area having an average population density of 1,344 people/km^2. As discussed previously, however, the WTC site is not representative of New York City in general or any other major population center in the United States because of the unique and very high value buildings that stood on this site and which will be replaced with equally high value buildings. The replacement value reported in the FRBNY study is therefore likely to be much higher than would be expected for the average high density urban area. Taking this important point into consideration, the FRBNY data were used to derive the unit cleanup costs for high and very high density urban areas reported in Table 1.

Evacuation Cost

The cost to evacuate and relocate the population living within areas contaminated as a result of the Rad/Nuc event was calculated using unit costs derived from the RADTRAN 5 economic model. This cost is assumed to depend on the level of contamination; at higher contamination levels, the population is denied access for longer periods of time. RADTRAN 5 varies these costs in the same major categories as the D&D and Replacement Costs. Unit costs used for evacuation are presented in Table 1.

OBSERVATIONS FROM APPLICATION OF THIS METHODOLOGY

The effects of nuclear weapons have been studied and documented intensively. Fallout will decay based on the individual isotopic half-lives, the most energetic (and most dangerous) decaying in hours or days while longer-lived isotopes persist for months and years. The dose rate from fallout drops by a factor of 1,000 48 hours after detonation, and over 90% of the dose is received in the first year after a nuclear weapon event [7]. This dose response time after detonation is important when estimating the cost of cleanup, site restoration, and rebuild after a Rad/Nuc event. Figure 2 illustrates this by showing the land area requiring cleanup for different cleanup criteria (residual dose rates) for different time periods following detonation of a 13-kT nuclear weapon. As shown, the surface area requiring cleanup decreases by a factor of 10 to 100 during the second year following detonation as compared with the first year following

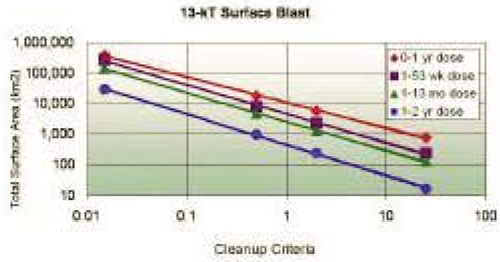


Figure 2. Area Requiring Remediation for Different Cleanup Criteria

detonation. Since cleanup would likely not be completed during the first year following detonation, this analysis estimated the cost of cleanup of that land area remaining contaminated above the cleanup criteria 1 year after detonation.

In the case of the RDD event, however, little radioactive decay will occur during the time period of remediation (first year or two). For this reason, the cost of cleanup of an RDD event was based on the land contaminated by fallout over the first year following the event.

We then took the physical plume contours for each of the three nuclear weapon yields and the five cleanup levels and plotted those in the five target locations. Figure 3 illustrates this concept with the plume 1-2 yr contour for the 100-kT nuclear weapon in New York City, NY, and San Ysidro, CA.

Figure 3. Hypothetical Plume Contours for 100-kT and 5 Cleanup Levels

The plume contours used represent a generic "wind condition." Clearly, wind conditions impact the radioactive fallout after a nuclear weapon event and the ability to value damage depends on where the damage occurs. The plume in New York City blows into the Atlantic Ocean; although not depicted here, the plume for Detroit goes into Canada and Lake Erie. For this high-level analysis, our damage assessment is limited to the continental United States and represents surface area cleanup excluding groundwater contamination.

The results of our analysis are shown in Figure 4. As anticipated, the economic consequences are highest for the largest nuclear weapon yield and the most conservative cleanup level. New York City nets the highest economic damage across the cleanup spectrum, because of its dense population and high value real estate. Note that the economic consequences for New York City across almost every cleanup level meet or exceed $10 trillion, which is roughly equivalent to the annual Gross Domestic Product (GDP) of the U.S. economy.

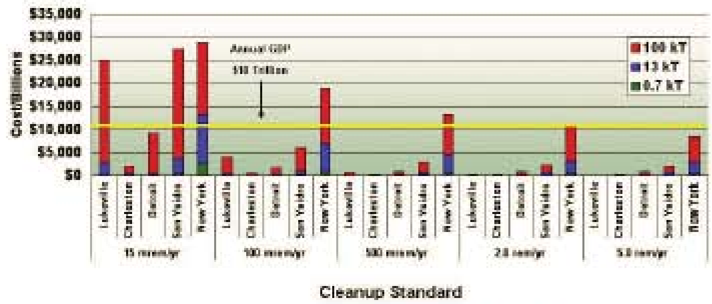
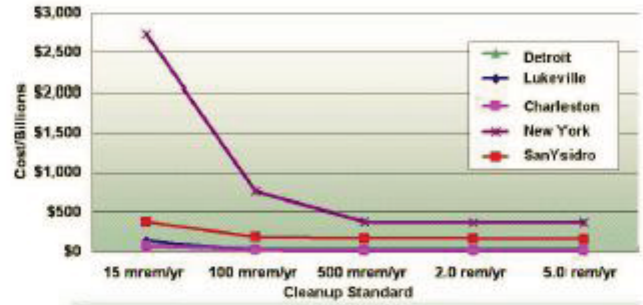


Figure 4. Consequence Summary for Hypothetical Weapon Events and Cleanup Levels

Figures 5, 6, and 7 represent the consequence summaries for each nuclear weapon event. The area impacted and requiring long-term cleanup is a function of the standard selected as represented in the data table under the graph. Individually and collectively, the economic consequences are highest for the most conservative standard evaluated.

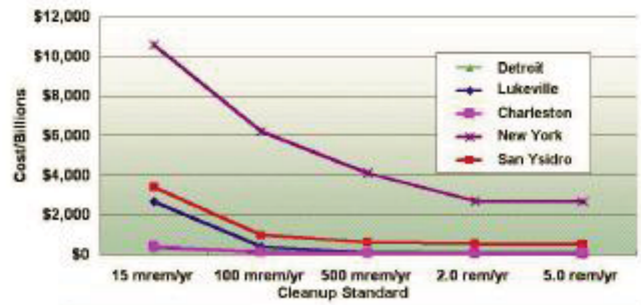
Figure 8 provides a summary of the economic consequences by the five broad categories evaluated. This representation demonstrates that it is the cleanup cost (or D&D cost) that is the largest individual contributor to economic consequences across the cleanup level spectrum until we reach the least conservative cleanup level, at which point the loss of life is the largest cleanup cost.

In the case of an RDD, the type of contamination depends only on the source material(s) (no nuclear process is involved), and the extent of contamination depends on the physical form of the source and the effectiveness of the dispersal mechanisms. The ultimate fate of the contamination (and thus long-term consequences) is dependent on a complex chain of transport, uptake, exposure, and remediation processes. Fallout from an RDD explosion would be very different from that of a nuclear weapon detonation because there would be no large thermal cloud to inject the radioactive material into the atmosphere, and the amount of radioactive material would be much less than that generated in a nuclear weapon event. A preliminary assessment of the economic consequences of a 10 kCi Cs-137 RDD in New York City is presented in Figure 9.



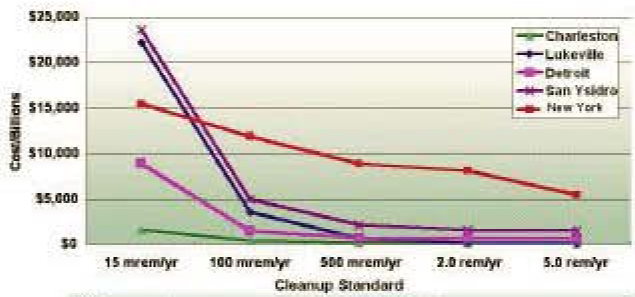
0.7 kT	Cleanup Area (km2)				
Lukeville, AZ	1,430	179	45	10	4
Charleston, SC	507	97	29	8	3
Detroit, MI	98	32	20	10	4
San Ysidro, CA	1,430	179	45	10	4
New York, NY	600	175	45	10	4

Figure 5. The 0.7-kT Weapon Event



13 kT	Cleanup Area (km2)				
Lukeville, AZ	25,507	4,249	950	238	95
Charleston, SC	2,879	830	275	117	52
Detroit, MI	502	134	37	40	29
San Ysidro, CA	26,656	4,289	960	138	95
New York, NY	9,763	2,584	474	237	95

Figure 6. The 13-kT Weapon Event



100 kT	Cleanup Area (km2)				
Lukeville, AZ	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Charleston, SC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Detroit, MI	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
San Ysidro, CA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
New York, NY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 7. The 100-kT Weapon Event

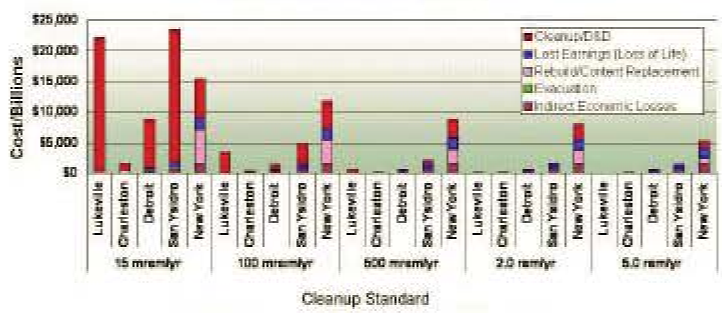


Figure 8. Summary by Five Categories Evaluated

There is virtually no loss of life with the Cs-137 event, but the cleanup cost and the cost to rebuild and/or replace buildings is once again significant, particularly for the most conservative standard (one-half of the annual U.S. GDP).

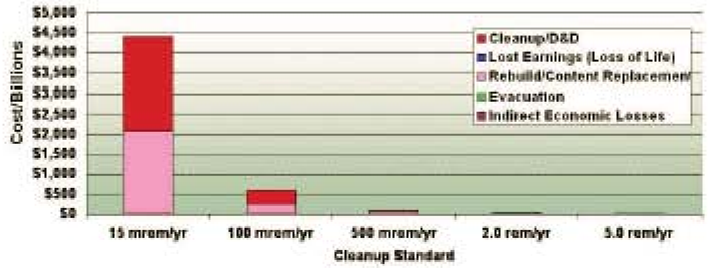


Figure 9. 10-kCi Cs-137 Detonation in New York City

CONCLUSIONS

The methodology described in this paper provides a framework for evaluating the major cost components following a nuclear weapon event. There are several observations that can be made from the results thus far:

- The economic consequences of a Rad/Nuc event are highly dependent on and closely coupled to the cleanup level selected.
- Cleanup costs generally increase dramatically for standards more stringent than 500 mrem/yr.
- Cleanup to the most conservative standard evaluated (15 mrem/yr) magnifies the economic consequences of the event irrespective of the class of target or weapon yield.
- Because such an event could potentially spread contamination very widely, even an event in a "remote" location could have huge economic consequences.
- A risk-based approach to the development and application of standards is needed.

There are no national standards for acceptable decontamination of a radiological weapon event, and the EPA standards used under CERCLA were enacted to address growing concerns about the need to clean up uncontrolled, abandoned hazardous waste sites and to address future releases of hazardous substances into the environment. Cleanup after a weapon event such as one of those described in this paper will be vastly different from the cleanup of a contaminated industrial facility or former weapons production facility. The standard selected will impact both the cost and the pace of the cleanup. Policy level attention to cleanup standards is warranted.

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APPENDIX 6

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Survey of Costs Arising From Potential Radionuclide Scattering Events - 8147

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ABSTRACT

The potential effects from scattering radioactive materials in public places include health, social, and economic consequences. These are substantial consequences relative to potential terror activities that include use of radioactive material dispersal devices (RDDs). Such an event with radionuclides released and deposited on surfaces outside and inside people's residences and places of work, commerce, and recreation will require decisions on how to recover from the event. One aspect of those decisions will be the cost to clean up the residual radioactive contamination to make the area functional again versus abandonment and/or razing and rebuilding.

Development of cleanup processes have been the subject of experiment from the beginning of the nuclear age, but formalized cost breakdowns are relatively rare and mostly applicable to long term releases in non-public sites. Pre-event cleanup cost estimation of cost for cleanup of radioactive materials released to the public environment is an issue that has seen sporadic activity over the last 20 to 30 years. This paper will briefly review several of the more important efforts to estimate the costs of remediation or razing and reconstruction of radioactively contaminated areas. The cost estimates for such recoveries will be compared in terms of 2005 dollars for the sake of consistency. Dependence of cost estimates on population density and needed degree of decontamination will be shown to be quite strong in the overall presentation of the data.

LITERATURE OVERVIEW

Techniques used for cases of released radioactive materials in the event of an accident during transport have been a principal source of cost estimating techniques. These are contained in the RADTRAN transport risk assessment codes that were first produced in 1974 for use in preparing NUREG-0170 (NRC, 1977). That version, RADTRAN I, had several revisions in succeeding issues of the code to the present version contained in RADTRAN VI. Two non-RADTRAN

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* Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

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methodologies are also notable. First, is an analysis completed to estimate the cost of cleaning up plutonium scattered as a result of a nuclear weapons accident that was completed in 1996 (Chanin, 1996). Second is a computer code developed in the UK (and apparently only usable for UK government purposes) called CONDO (Charnock, 2003). In addition, some cleanup cost estimates have been put forward in a paper (Reichmuth, 2005) for the Department of Homeland Security that gives cleanup cost estimates for high population density areas based on RADTRAN IV calculations and actual costs for remediation of the World Trade Center (WTC) site in New York City.

PROCESS USED

The methodology for estimating cleanup costs uses two principal parameters. The first and most basic is the acceptable residual level of contamination determined for each nuclide released that will avoid a given level of radiological dose to persons who will remain living/working in the contaminated area. The acceptable dose and, hence, the residual contamination level for each nuclide, is likely to be negotiated for each release event (DHS, 2007). The second parameter is the Decontamination Factor, DF, which can be rationalized in two ways:

- At any point at the site of the radioactive material release, it is the ratio of the local contamination level for a released nuclide to the acceptable residual contamination level, (DF_s)
- A measure of the capability of a given cleanup method (like water hosing) to reduce the contamination level for a given surface material. Thus, it is the ratio of contamination level before treatment to contamination level after treatment, (DF_m)

Specific cleanup technologies applied to specific surfaces and nuclides are characterized by the maximum DF_m achievable. If the DF_s is less than the effects of all the cleanup processes that could be applied sequentially, $DF_s < \Sigma DF_m$, then cleanup is successful, but if the DF_s is greater than the effects of all the cleanup processes that are applied sequentially, $DF_s > \Sigma DF_m$, then other alternatives, like razing and rebuilding, or interdiction must be applied.

The methodologies used in the all of the cited literature recognized the limitations of cleanup and employ razing or interdiction in the event that the required DF_s for a given situation could not be achieved by standard cleanup processes. For most of the early cost estimation techniques, it was assumed that a DF_m of 50 was generally attainable, but more recent data, nicely summarized in the CONDO report, suggest that a DF_m greater than 10 or so (with some isolated exceptions) is unlikely to be attained. This suggests that the earlier cost estimates would be expected to be somewhat low, since cleanup costs are generally lower than raze and rebuild or interdiction methods.

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For the data presented below the original cleanup cost estimates presented in the source documents were extracted and converted to 2005 costs using standard cost deflators (Williamson, 2006). In general, costs were stratified by the initial level of contamination as represented by DF_s values. Light contamination corresponded to a $DF_s < 5$: medium, $5 < DF_s < 10$; and heavy, $DF_s > 10$. Costs in the RADTRAN reports were further stratified by a specification relating to population density (rural, suburban, and urban) corresponding to mean population densities of about 10, 750, and 3800 persons per km^2 respectively. In the Chanin report, the urban population density values were taken to be about 1350 persons/ km^2 (corresponding to a mean population density in areas identified as urbanized by the census bureau). Reichmuth stated that population densities (PD in persons/km^2) were as follows:

Rural	0 < PD < 50
Urban	50 < PD < 3000
High Density Urban	3000 < PD < 10,000
Hyper Density Urban	10,000 < PD

As is obvious from the above, there is no strict translation of words describing population density terminology in quantitative terms, but there is enough specificity to compare various costs estimates as a function of population density.

The SNL study (Chanin, 1996) provided a fairly detailed methodology in which to estimate costs. For an urban area, the overall results that came out of the effort are shown in Table I.

Table I. Urban Area (1344 persons/km^2) Remediation Costs for Year 2005 in \$M/km^2 from Appendix G (Chanin, 1996).

	Costs per sq. km				Area Weighted Costs		
Area Usage Type	Light ($2<DF_s<5$)	Moderate ($5<DF_s<10$)	Heavy ($DF_s>10$)	Area Fraction	Light ($2<DF_s<5$)	Moderate ($5<DF_s<10$)	Heavy ($DF_s>10$)
Residential[a]	\$72.4	\$163.9	\$301.2	0.316	\$22.9	\$51.8	\$95.2
Commercial	\$195.3	\$295.5	\$851.2	0.173	\$33.8	\$51.1	\$147.3
Industrial	\$674.0	\$704.2	\$1,245.9	0.064	\$43.1	\$45.1	\$79.7
Streets	\$15.9	\$18.5	\$247.7	0.175	\$2.8	\$3.2	\$43.3
Vacant Land	\$81.1	\$85.7	\$95.2	0.272	\$22.1	\$23.3	\$25.9
Overall Cost per sq. km					\$124.6	\$174.5	\$391.4

[a] includes single and multiple family dwellings and apartment houses

Table I demonstrates the methodology used as well as results. Costs were estimated for generic land use areas and then weighted by the fraction of the overall area in that land use class. Short of repeating the considerable effort in developing the report results, what options exist for estimating the cleanup cost for higher population density areas? If data is available for the land use area fractions in the higher population area, then an estimate can be made by plugging in those values in the 5th column of Table I. In addition, an adjustment for population density can be made by noting that higher population density implies that there are more dwelling units per km² and that the costs shown in Table I are based on individual dwellings. As a result, multiplying the residential costs by a ratio of population density should adjust for higher populations in the same area. In addition, since commercial space is likely to expand with population density, the commercial values would also be adjusted in a similar manner. These are approximate methods and useful only for order of magnitude estimates. The result of such adjustments is shown in Table II.

Table II. Estimated Remediation Costs for New York City Reflecting Land Use Distribution and Population Density.

		Area Weighted				Population and Area Weighted		
Land Use	**Area Fraction**[a]	**Light** ($2<DF_s<5$)	**Moderate** ($5<DF_s<10$)	**Heavy** ($DF_s>10$)	**PD Multiple**	**Light** ($2<DF_s<5$)	**Moderate** ($5<DF_s<10$)	**Heavy** ($DF_s>10$)
Residential	0.287	$20.31	$45.99	$84.51	6.82[a]	$138.55	$313.64	$576.38
Commercial	0.164	$32.09	$48.55	$139.84	6.82[b]	$218.84	$331.12	$953.80
Industrial	0.068	$45.51	$47.55	$84.12	1.00	$45.51	$47.55	$84.12
Streets	0.250	$3.97	$4.62	$61.88	1.00	$3.97	$4.62	$61.88
Vacant Land	0.238	$19.29	$20.38	$22.64	1.00	$19.29	$20.38	$22.64
	1.00							
Overall Cost ($M/km²		$121.2	$167.1	$393.0		$426	$717	$1,699

[a] derived from New York City data (http://www.nyc.gov/html/dcp/pdf/landusefacts/landuse_tables.pdf)
[b] ratio of New York City population density to that in Table I (9166/1344 = 6.82)

The process used to produce Table II can be used to derive remediation cost estimates for other population density areas as shown by the triangle points in Figure 1. Figure 1 also contains remediation cost data from the source documents discussed above.

The Legend in Figure 1 is quite large, but is color keyed for some addition clarity. Red lines and symbols are for ($DF_s>10$), orange for ($5<DF_s<10$), and green for ($1<DF_s<5$). Purple symbols are for estimates that are unspecific about the DF_s they apply to, but the values could be as large as 50.

Figure 1 shows a fair amount of variability in the costs estimated by the various methods and sources covered in this overview. The three straight lines penciled in on the plot are intended to suggest how the costs might vary with population density and degree of contamination. The lines are a reasonable representation of much of the information, but some data points deviate substantially and will be discussed here. The two red disc points that are well above the curves are from the paper by Reichmuth and are based on estimates of cost derived to clean up and restore (not rebuild) the 16 acre WTC site in New York City after 9/11. The cost to replace the facilities is estimated to be an order of magnitude larger (not shown on the plot).

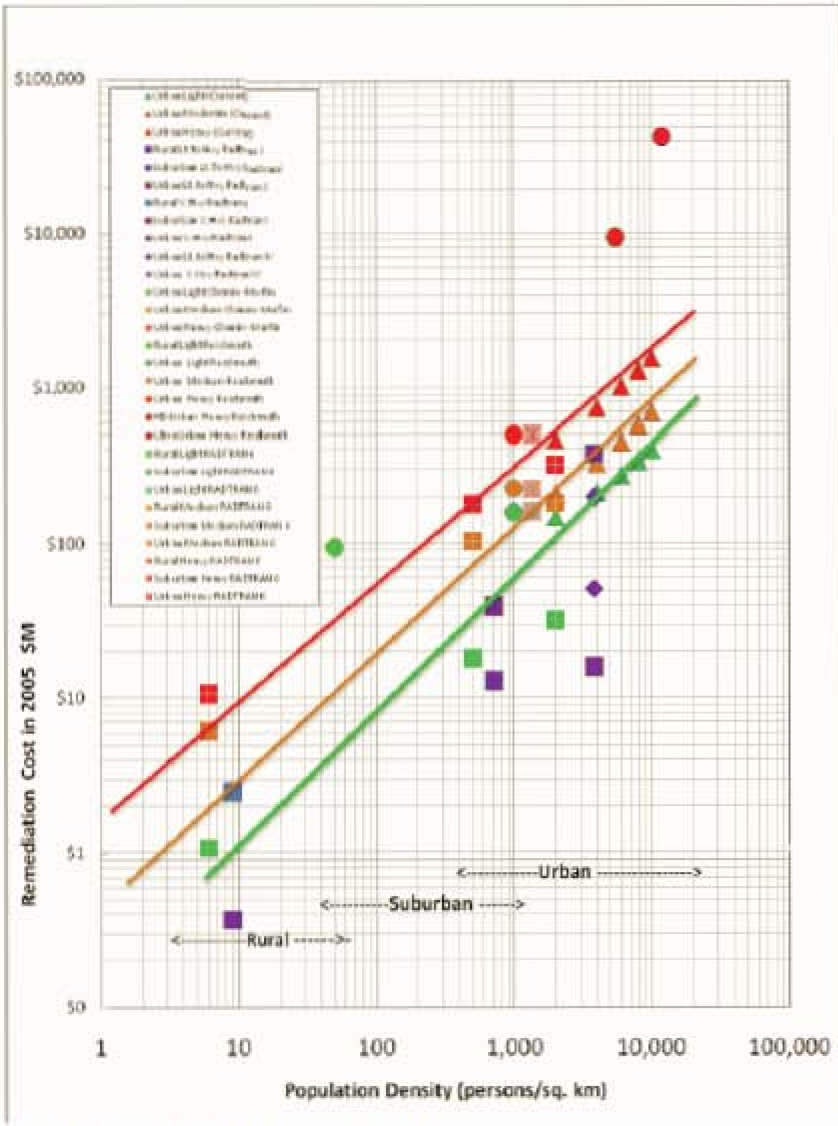

Figure 1: Remediation Cost Estimates Compared.

Since the estimated cost was based on the area of the WTC site, but the actual expenditure covered actions made over the surrounding areas and included actions somewhat beyond what would be expected in response to an RDD event, the actual cost/km^2 could be overestimated by 50% to 60%.

The purple squares below the curve represent the estimates that were done using RADTRAN I in the mid 1970's with an unsophisticated methodology. Moreover, the estimates are the oldest and most subject to uncertainty associated with selecting the best deflator statistic for updating costs. The RADTRAN 6 estimates (purple diamonds) also are below the trend lines but not as pronounced an effect as with RADTRAN 6 (Osborn, 2007). Note that the RADTRAN 6 values (squares with center crosses) fit much more closely with the other estimates and the trend lines. The trend lines favor the cost values generated by the Sandia study (Chanin, 1996), because of the detail involved in the initial estimates and the ability to project the costs to other population densities and land use area fractions.

CONCLUSION

The likelihood of a "Dirty Bomb" attack in the US or elsewhere is unknown. Most sources suggest (e. g., Karam, 2005) that the radiological consequences of such an attack are unlikely to be life threatening and that the greatest mortal danger is to persons exposed to blast from the device (assuming that is its mode of operation). However, the expenditures needed to recover from a successful attack using an RDD type device, as depicted in Figure 1, are likely to be significant from the standpoint of resources available to local or state governments. Even a device that contaminates an area of a few hundred acres (a square kilometer) to a level that requires modest remediation is likely to produce costs ranging from $10M to $300M or more depending on intensity of commercialization, population density, and details of land use in the area. As a result, it is important to put appropriate emphasis on the efforts now being taken by the Department of Energy, Nuclear Regulatory Commission, and the Department of Homeland Security to provide accountancy for radioactive materials used in the public and private sectors and to detect, as fully as possible, traffic in potential dirty bomb materials within and on the borders of the USA.

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