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ENT – O'Kula and Hanna Meteorological Testimony

January 3, 2011

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION,

Before the Atomic Safety and Licensing Board Panel

In the Matter of	)	
	)	
Entergy Nuclear Generation Company and	)	Docket No. 50-293-LR
Entergy Nuclear Operations, Inc.	)	ASLBP No. 06-848-02-LR
	)	
(Pilgrim Nuclear Power Station)	)	

Testimony of Dr. Kevin R. O'Kula and Dr. Steven R. Hanna on Meteorological Matters Pertaining to Pilgrim Watch Contention 3

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I. WITNESS BACKGROUND

A. Dr. Kevin R. O'Kula ("KRO")

Q1: Please state your full name.

A1. (KRO) My name is Kevin R. O'Kula.

Q2: By whom are you employed and what is your position?

A2. (KRO) I am an Advisory Engineer with URS Safety Management Solutions ("URS") LLC.

Q3: Please summarize your educational and professional qualifications.

A3. (KRO) My education, professional qualifications, and experience are provided in Exhibit ENT000002. Briefly summarized, I have over 28 years of experience as a technical professional and manager in the areas of safety analysis methods and guidance development, computer code evaluation and verification, probabilistic safety assessment, deterministic and probabilistic accident and consequence analysis applications for reactor and non-reactor nuclear facilities, source term evaluation, risk management, reactor materials dosimetry, and shielding. I obtained my B.S. in Applied and Engineering Physics from Cornell University in 1975, my M.S. and

Ph.D. in Nuclear Engineering from the University of Wisconsin in 1977 and 1984, respectively. My professional and educational experience is summarized in my curriculum vitae, which is attached to my declaration supporting this testimony.

In addition, I have over twenty years experience using and applying the MELCOR Accident Consequence Code System (MACCS) and the MACCS2 computer codes. I taught MACCS2 training courses for the Department of Energy ("DOE") and its contractors at Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Idaho National Laboratory, and at the DOE Safety Basis Academy. In addition, I was the lead author of a DOE guidance document on the use of MACCS and MACCS2 for DOE safety analysis applications.[1] I am also a member of the State-of-the-Art Reactor Consequence Analysis (SOARCA) Project Peer Review Committee that provides recommendations on applying MACCS2 in the context of accident phenomena and subsequent off-site consequences in the context of severe reactor accidents, to Sandia National Laboratories (SNL) and the Nuclear Regulatory Commission (NRC).

B. Dr. Steven R. Hanna ("SRH")

Q4: Please state your full name.

A4. (SRH) My name is Steven R. Hanna

Q5: By whom are you employed and what is your position?

A5. (SRH) I am president of Hanna Consultants. I am also an Adjunct Associate Professor at the Harvard School of Public Health.

Q6: Please summarize your educational and professional qualifications.

A6. (SRH) My education, professional qualifications, and experience are provided in Exhibit ENT000003. Briefly summarized, I received my B.S., M.S., and Ph.D. degrees in Meteorology from Penn State University in 1964, 1966, and 1967, respectively. I am a Fellow of the American Meteorological Society (AMS), the

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[1] MACCS2 Computer Code Application Guidance for Documented Safety Analysis, DOE-EH-4.2.1.3-Final MACCS2 Code Guidance, Final Report, U.S. Department of Energy, Washington, DC, June 2004.

1994 recipient of the AMS Award for Outstanding Contribution to the Advance of Applied Meteorology, and the 2010 recipient of the AMS Helmut E. Landsberg Award for "Significant novel and insightful contributions in applied meteorology and urban studies, including field work, data interpretation, model development, and model evaluation". I am an AMS Certified Consulting Meteorologist with over 43 years of experience; and from 1988-1997, I was Chief Editor of the *Journal of Applied Meteorology*.

I am a specialist in atmospheric turbulence and dispersion, in the analysis of meteorological and air quality data, and in the development, evaluation, and application of air quality models. I have 148 publications in peer-reviewed journals, including three in the past year. Since 1997, I have been teaching graduate level classes on atmospheric boundary layers and dispersion, first at George Mason University (1997-2002) and now at Harvard School of Public Health (since 2002).

Q7: Dr. Hanna, please elaborate on your familiarity with atmospheric transport and dispersion models such as AERMOD and CALPUFF.

A7. (SRH) I developed and evaluated numerous transport and dispersion models for the Environmental Protection Agency (EPA) as well as for the Department of Defense, Department of the Interior, and Department of Energy. In all these cases, I evaluated the models with extensive field observations and was program manager for several of the field experiment campaigns. Many scientific aspects of my Hybrid Plume Dispersion Model (HPDM) for calculating dispersion of plumes from tall stacks were used in the EPA AERMOD model. I co-developed the CALMET/CALPUFF Lagrangian puff model, which is one of the models recommended by the EPA. In 1997, I chaired the external peer review of AERMOD. I lecture on dispersion modeling, and carry out AERMOD training in my graduate level course at Harvard School of Public Health.

From 1967-1981, I was employed by the NOAA Atmospheric Turbulence and Dispersion Laboratory (ATDL) in Oak Ridge, TN. My primary role was carrying out DOE and NRC-funded research in support of their meteorological analysis and dispersion modeling concerns. My 1982 *Handbook on Atmospheric Diffusion* (co-authored by Gary Briggs and Ray Hosker) summarized my research findings and translated them into recommendations for applied dispersion models. My recommended formulas are still widely used in applied dispersion models around the world. I developed the ATCOOL model/code for cooling tower plumes, and my code was incorporated into the Seasonal/Annual Cooling Tower Impact (SACTI) model currently used for most cooling tower studies and recommended by the NRC. I developed the ATDL simple urban dispersion model, which has been adapted by EPA, DOE, and many others in their operational models. I developed the ATDL Lagrangian particle dispersion model (LPDM) and the core equations are in use in most current LPDMs.

While with the environmental consulting company, ERT, from 1981-1985, I developed several dispersion codes. The Rough Terrain Dispersion Model that I developed subsequently formed the basis for the EPA's Complex Terrain Dispersion model and later parts of the meteorological preprocessor and complex terrain module in AERMOD. I developed the Offshore and Coastal Dispersion (OCD) model for the Department of the Interior Minerals Management Service for use in assessing dispersion of emissions from offshore oil platforms and from coastal facilities. The American Petroleum Institute (API) and the Minerals Management Service (MMS) supported evaluations of OCD with tracer data from several coastal field experiments. Also during this period, I developed HPDM under support of the Electric Power Research Institute (EPRI). The focus was on power plant stack plumes, and the model was evaluated with EPRI-sponsored data from field experiments at the Kincaid, Bull Run, and Indianapolis power plants.

After five colleagues and I founded Sigma Research Corporation in 1985, I continued my plume model development and evaluation work with Sigma and its successors until 1997, when I left Sigma and formed my own company, Hanna Consultants. While at Sigma, I added an urban component to HPDM and further developed and evaluated the OCD model. In addition, first under support of the California Air Resources Board (CARB) and later under support of EPA and the National Park

Service (NPS), I was part of the Sigma team that developed CALMET/CALPUFF. I also became heavily involved in the development and evaluation of dispersion models for toxic gas releases from chemical plant accidents, and developed many algorithms in HGSYSTEM. I also led an interagency and industrial association group that was planning the development of what later became the EPA CMAQ model.

Since 1997, I have been president and chief scientist of Hanna Consultants. During this time, I have developed and evaluated an enhanced Heavy Gas System (HGSYSTEM) model for dense gas releases and an urban dispersion model for releases at street level in downtown areas. I led the DHS-sponsored Madison Square Garden 2005 tracer experiments and evaluated my urban model with those data. I also developed a Monte Carlo code to assess the uncertainties of dispersion models and applied it to CMAQ's predecessors and to AERMOD. I chaired and participated in numerous peer-review panels of DOE, DOD, EPA, NOAA, and overseas research programs, such as the 1997 EPA AERMOD peer-review panel and the 2009 peer-review of the University of Hamburg's (Germany) dispersion experiments in their wind tunnel facility.

Over the course of my career, I have included evaluations of models with field experiments as part of the justification for my models. This has led to the BOOT model evaluation code, which has been adopted by most groups. This has also led to my participation in several field experiments (including management of some) and in creation of the freely distributed Modelers Data Archive (MDA), containing electronic files (reports and data) of almost 100 field experiments.

Thus, I have extensive experience in the development and evaluation of atmospheric dispersion models for a wide range of applications, including development and evaluation of AERMOD, and CALMET/CALPUFF.

II. OVERVIEW AND SCOPE OF PROCEEDING

Q8: What is the purpose of your testimony?

A8. (KRO, SRH) The purpose of our testimony is to address, on behalf of Entergy, the adequacy of the atmospheric transport and dispersion modeling that was used in the analysis of severe accident mitigation alternatives (SAMA) for the Pilgrim Nuclear Power Station (Pilgrim). In particular, we will respond to the meteorology and transport and dispersion claims made by Pilgrim Watch ("PW") in its Contention 3

Q9: Are you familiar with PW Contention 3 and the claims that it makes?

A9. (KRO, SRH) Yes, we have reviewed the pleadings and decisions in this proceeding relating to PW Contention 3, and we are familiar with the meteorology and transport and dispersion claims that Pilgrim Watch and its consultants have made.

(KRO) In addition, I provided expert support for Entergy's motion for summary disposition of this contention earlier in this proceeding. In this regard, I am the principal author and was responsible for the preparation of the Washington Safety Management Solutions Report entitled "Radiological Dispersion and Consequence Analysis Supporting Pilgrim Nuclear Power Station Severe Accident Mitigation Alternative Analysis" Revision 1 (May 2007) ("WSMS Report"), which was prepared to address the claims raised in Pilgrim Watch Contention 3.

Q10: Are you familiar with the SAMA analysis and the meteorological, transport, and dispersion modeling that were performed for the Pilgrim Station?

A10. (KRO) Yes, as part of my work assisting Entergy in responding to Pilgrim Watch's claims, I have been involved in running a number of base case and sensitivity analyses using MACCS2 to calculate off-site consequences associated with a postulated severe accident at Pilgrim. I am therefore very familiar with and have personal knowledge of the MACCS2 modeling and assumptions used in the Pilgrim SAMA analysis.

(SRH) Similarly, in connection with the preparation of this testimony, I have carefully reviewed the data and assumptions that were used in the meteorological and atmospheric transport and dispersion modeling used in the Pilgrim SAMA analysis, as well as the modeling methodology in MACCS2 (with which I was already familiar). I have documented my review of the meteorological observations in a report entitled "Analysis of Annual Wind Roses and Precipitation within about 50 Miles of the Pilgrim Nuclear Power Station, and Use of CALMET to Calculate the Annual Distribution of Trajectories from the Pilgrim Station," Dec. 2010 ("Report"), provided as Exhibit ENT000004.

Q11: What will your testimony cover?

A11. (KRO) I will testify on: (1) the general purpose and objectives of a Severe Accident Mitigation Alternatives ("SAMA") analysis, (2) the adequacy of the MACCS2 modeling employing the Gaussian plume segment methodology performed for the Pilgrim license renewal SAMA analysis; and (3) the sensitivity analysis performed to evaluate potential uncertainties in the meteorological input parameters used in the Pilgrim SAMA analysis.

(SRH) I will testify on: (1) meteorological phenomena and patterns which form the bases of Entergy's SAMA analysis; (2) analysis and validation of meteorological inputs used in Entergy's SAMA analysis; and (3) transport and dispersion modeling.

Q12: Do you agree with Pilgrim Watch's contention that the meteorological inputs and transport and dispersion modeling supporting the Pilgrim SAMA are inadequate?

A12. (KRO, SRH) No. The meteorological inputs used and the transport and dispersion modeling that was performed are reasonable and adequate for the purpose for which they are being used, that is, to determine the average annual probabilistic off-site risk over a large area for use in a cost-benefit analysis.

Pilgrim Watch's objections appear to be based in large measure on its assumption that individual plume trajectories and the resulting single hourly maximum concentrations at single locations are important, as in an application for a major-source construction permit under the Clean Air Act. However, the SAMA analysis is based on the mean, or expected annual consequences of a set of postulated severe accident scenarios calculated over a 50-mile radius domain around the Pilgrim Station. For this purpose, MACCS2 and its embedded transport and dispersion model are appropriate for calculating reasonable estimates of the expected annual consequences.

Q13: Do you agree with the assertion in Pilgrim Watch Contention 3 that alternative meteorological and transport and dispersion modeling may have a material impact on whether additional SAMAs may become cost-beneficial?

A13. (KRO, SRH) No.

Q14: What is the basis for your disagreement?

A14. (KRO, SRH) The ATMOS atmospheric transport and dispersion model used in the MACCS2 code for the Pilgrim SAMA is suitable for the purposes of calculating expected annual off-site consequences over the domain of interest (a 50-mile area around the Pilgrim Station). Moreover, the ATMOS model used in MACCS2 is more than a straight-line Gaussian plume model (GPM), and is better described as a Gaussian plume *segment* model. The Gaussian plume *segment* model is able to account for hour-to-hour changes in atmospheric stabilities, wind speed, and precipitation during plume travel. In a model comparison exercise using observed hourly wind fields over a year in a mesoscale domain in the Midwest,[2] MACCS2 was shown to yield mean annual arc sector results (exposure and deposition) at downwind distance arcs of 10, 20, 50 and 100 miles generally within plus or minus 50% of the state-of-the-art Lagrangian particle model, LODI. (LODI is referred to as a "three-dimensional" model because its meteorological model, ADAPT, produces time and three-dimensional space variations in winds over the geographic domain). Because ADAPT/LODI is a "three-dimensional" model system, it can account for time and space variations in winds over the geographic domain more accurately than MACCS2. When averaged over all sectors for the three arc distances out to 50 miles, the agreement in arc average results was better than plus or minus 10%; thus MACCS2 closely approximates the results of the more complex LODI model. In this same study, MACCS2 compared favorably with other more complex models such as RATCHET.

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[2] Molenkamp et al., Comparison of Average Transport and Dispersion among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model, NUREG/CR-6853 (2004) (JNT000001).

Also, Pilgrim Watch's assertion that an alternate model should be used that accounts for time and space variations around the Pilgrim Station is based in large measure on its arguments concerning the potential impact of the "sea breeze" phenomenon. First, however, the on-site Pilgrim Station meteorological observations used in the SAMA analysis already capture the effects of sea and land breezes and other wind phenomena. Second, annual wind roses (which show the frequency that the wind is blowing in each of 16 wind directions) from official weather sites in the larger domain are similar to the annual wind rose for the Pilgrim Station (i.e., the Pilgrim data are representative not only of what is occurring at the Station but also what is occurring inland and offshore).

(SRH) Finally, to put this issue to rest, I have used CALMET (the meteorological processor in CALPUFF) along with meteorological observations from 26 surface weather stations (plus the Pilgrim Station's meteorological observations), and observations from the two Radiosonde (upper air) stations throughout the area to examine wind trajectories in order to determine whether the modeling in MACCS2 is reasonably representative. Using this three-dimensional, variable trajectory analysis with data from multiple weather stations, I produced wind trajectory roses that are comparable with the wind rose representing the Pilgrim data that were used in the MACCS2 analysis. The wind trajectory roses from the CALMET analysis show the percentage of wind trajectories originating from the Station that reach each of the polar grid elements (bounded by two distance radial arcs and by the edges of a 22.5° wind direction sector) used to estimate off-site consequences in MACCS2. Because the Gaussian plume segment model in MACCS2 does not vary wind direction for a plume initiated in any hour as it passes over the domain and crosses the 50-mile domain boundary in subsequent hours, the wind rose from the Pilgrim Station observations that were used in the MACCS2 modeling reflects the percentage of trajectories that would reach each grid element, assuming straight-line trajectories. Comparing the annual 2001 CALMET trajectory roses with the annual 2001 Pilgrim Station wind rose shows that the percentage of the trajectories that are projected to reach each radial grid element differ only by a small amount – a few percent at most.

I explain the study performed and the results in much greater detail later in my testimony as well as in my Report (ENT000004).

(KRO) I then took the wind and trajectory roses produced by Dr. Hanna and estimated quantitatively how the small differences would affect the MACCS2 results. Because the off-site population dose and economic consequences in any grid element are proportional to the population in that grid element, one may use the population in each grid element as a surrogate for the off-site consequences. In addition, by multiplying the population in each grid element by the annual percentage of trajectories that reach the grid element and summing the results, one can derive an Exposure Index (EI) comparison between the two different models.

Comparing the EI produced from the CALMET trajectory roses with the EI produced by the MACCS2-based Pilgrim wind rose shows that the impact on the results of the Pilgrim SAMA analysis would be less than four percent. This small difference has no effect on the overall results of the Pilgrim SAMA analysis. For the next SAMA to become potentially cost-beneficial, the benefit would need to increase by more than a factor of two, i.e., more than 100%. Therefore, small changes in annualized wind direction are inconsequential for purposes of the Pilgrim SAMA analysis.

III. <u>BACKGROUND DISCUSSION</u>

A. OVERVIEW OF SAMA ANALYSES AND THE MACCS2 CODE

Q15: Please describe the purpose of a SAMA analysis.

A15. (KRO) The purpose of a SAMA analysis is to identify potential changes to a nuclear power plant, or its operations, that could reduce the risk (the likelihood or the impact, or both) of a severe reactor accident for which the benefit of implementing the change outweighs the cost of implementation. These potential changes are referred to as SAMAs or SAMA candidates. Guidance issued by the Nuclear Energy Institute (NEI), NEI-05-01 (Rev A),[3] and endorsed by the NRC states that, "[t]he purpose of

[3] Nuclear Energy Institute, NEI-05-01 Rev. A, Nuclear Energy Institute Severe Accident Mitigation Alternatives (SAMA) Analysis Guidance Document (Nov. 2005).

the analysis is to identify SAMA candidates that have the potential to reduce severe accident risk and to determine if implementation of each SAMA candidate is cost beneficial." A severe accident is a beyond design basis accident that could result in substantial damage to the reactor core, whether or not there are serious off-site consequences. Changes to the nuclear power plant that could reduce the risk of a severe accident include, for example, plant modifications (such as the use of additional engineering safety features) or operational changes such as improved procedures, and augmented training of control room and plant personnel.

Q16: Conceptually, how is a SAMA analysis performed?

A16. (KRO) To determine whether a SAMA is cost-beneficial, it is necessary to determine the expected value or benefit of implementing a SAMA (i.e., the expected value of the risk averted by the SAMA), which is compared to the cost of implementing the SAMA. Accordingly, a SAMA analysis is a probabilistic analysis focused on long-term and spatially averaged impacts from severe accident events for the purpose of making cost-benefit evaluations. The analysis simulates the travel of and deposition from a set of postulated radiological releases based on a year's worth of site-specific meteorological data to predict the probabilistic consequences over the 50-mile radius area around the site. The ultimate goal is a cost-benefit analysis comparing the expected value of the avoided consequences against the cost of implementing specific preventative or mitigative measures.

Because they are concerned with mean expected consequences SAMA analyses are not designed to model precisely a single radiological release event under specific meteorological conditions at a single moment in time. Instead, a SAMA analysis models numerous accident release conditions that could, based on probabilistic analysis, occur at any time under varying weather conditions during a one-year period to develop the expected annual average outcome of the potential impacts for the entire 50-mile radius area of interest.

Q17: Does the function and purpose of a SAMA analysis differ from the function and purpose of emergency response?

A17. (KRO) Yes. The function and purpose of a SAMA analysis is fundamentally different from an analysis focusing on emergency response. As discussed above, the outcome of a SAMA analysis is a list of potential plant improvements that meet the criteria of being cost-beneficial and provide a significant reduction in total risk. To be cost-beneficial and provide a significant reduction in total risk means the plant improvements need to consider annual population-weighted impacts to a fifty-mile region from accident conditions that could occur under varying weather conditions.

In the case of emergency response, the primary interest would be in predicting a single individual plume path and dose impacts for purposes of taking early, preventative measures and protecting close-in populations. The focus is on anticipating the path and impacts of an individual plume occurring at a specific time under real-time meteorological conditions, and not on determining the annual consequences over a broad area from a distribution of potential consequence outcomes in order to make a cost-benefit evaluation.

The actual plume behavior is very important for emergency response especially to population groups within ten miles of the point of release and within the Emergency Planning Zone (EPZ), particularly for critical decisions regarding potential protective action recommendations in the event of a radiological release. Protective actions such as evacuation and sheltering are planned based on potential releases, and assume conservative, single-plume effects, applying adverse weather conditions. Implementation in the case of an actual accident would use real-time observed weather conditions, as well as dispatched teams to make measurements in the field to track the plume and develop the appropriate emergency action recommendations.

SAMA analyses, therefore, have an entirely different purpose from that of emergency response. Unlike emergency response, a SAMA analysis is not intended to model a single event under specific meteorological conditions at a single moment in time. Instead, a SAMA analysis is interested in average, long-term impacts such as population dose and economic cost consequences in a fifty-mile region from highly unlikely, severe accident events. These impacts are weighted by the probability of many weather sequences and plume directions.

Q18: What is the general approach for performing a SAMA analysis?

A18. (KRO) SAMA analyses consist of multiple sequential steps that generally proceed as outlined in NEI guidance document NEI 05-01 (Rev. A), as follows:

1) Determine the total severe accident risks, consisting of the off-site dose and economic impacts. Severe accident risk is determined using plant specific probabilistic safety assessment (PSA) models, also referred to as probabilistic risk assessment (PRA) models, to assess what can go wrong, how likely is it, and what are the resulting consequences. The PSA may be described in three sequential steps, or Levels. The first is the Level 1 PSA, which estimates the frequency of accidents that cause damage to the nuclear reactor core, and includes estimating the core damage frequency (CDF). The next step is the Level 2 PSA, which starts with the Level 1 core damage accidents, and estimates the frequency of accidents that release radioactivity from the nuclear power plant into the environment. The final step is the Level 3 PSA, which starts with the Level 2 radioactivity release accidents, and estimates the consequences in terms of impacts to public and the environment.

2) Determine the monetary value of the total severe accident risk. The total severe accident risk (the total probability weighted consequences) is the maximum benefit a SAMA could achieve if it eliminated all risk.

3) Identify potential SAMA candidates that could prevent core damage and significant releases from containment. SAMA candidates are based on the plant-specific PSA, plant-specific Individual Plant Examination (IPE) and Individual Plant External Event Examination (IPEEE) recommendations, and recommendations from similar type plants throughout the nuclear industry.

4) Perform a preliminary screening of SAMA candidates to eliminate SAMAs that have already been implemented, that cannot be implemented because they are not

applicable to the plant's specific design, or whose cost to implement is significantly greater than the monetary value of the total severe accident risk calculated in step 2.

5) Perform a final screening of SAMA candidates by estimating the benefit of the severe accident risk that could be averted by implementing each remaining SAMA candidate and comparing the benefit to the estimated cost for implementing the SAMA developed on a conceptual basis.

6) Perform sensitivity analyses that evaluate how changes to assumptions and uncertainties in the SAMA analysis would affect the overall cost-benefit analysis outcome.

7) Identify conclusions. Summarize results and identify any potentially cost-beneficial SAMA candidates.

Pilgrim followed this sequential process outlined in NEI 05-01 (Rev. A) in performing its SAMA analysis. See License Renewal Application (LRA) Environmental Report (ER), Appendix E of the Pilgrim LRA, Section 4.21 (Exhibit ENT000005).[4] The focus of this testimony is on the meteorological inputs to and the computer modeling of the atmospheric transport and dispersion of the radioactive plume in step 1 and their impacts on the overall SAMA analysis, which form the issues for hearing based on the Commission's decision in CLI-10-11 and CLI-10-22.

Q19: Is there computer-modeling software that is generally accepted in the nuclear industry for performing the consequence determination in the SAMA analyses?

A19. (KRO) Yes. To the best of my knowledge, all SAMA analyses for plants seeking license renewal in the United States have applied the MACCS2 code, or one of its predecessors. The MACCS2 code is the only computer model used in the United States for performing the consequence portion of a full SAMA analysis. Entergy

[4] Section 4.21 of the Pilgrim LRA ER is the "Severe Accident Mitigation Alternatives" section of the ER. The Pilgrim "Severe Accident Mitigation Alternatives Analysis" (Exhibit ENT000006) is Attachment E to the Pilgrim LRA ER. Subsequent to the filing of the LRA, there were four LRA amendments which amended the SAMA analysis as it appears in the LRA ER. These are LRA Amendment 4 (Exhibit ENT000007); LRA Amendment 7, Attachment D (Exhibit ENT000008); LRA Amendment 9, Attachment E (Exhibit ENT000009); and, LRA Amendment 10, Attachment C (Exhibit ENT000010). The LRA ER itself was not updated to incorporate these amendments.

used the MACCS2 code, version 1.12, in its original SAMA analysis documented in the Attachment E to the Pilgrim LRA ER (Exhibit ENT000006). Subsequently, however, Entergy used version 1.13.1 of MACCS2 for the analysis in response to the NRC's request for additional information (ENT000007), and the results of the current SAMA analysis are based on its application.

Q20: Please describe the origin and general use of the MACCS2 Code.

A20. (KRO) The NRC sponsored the development of the MACCS code as a successor to the CRAC2 code to evaluate impacts of severe accidents at nuclear power plants on the surrounding public. Its development was a collaborative effort by numerous industry professionals. Prior to its use for regulatory purposes, MACCS was first used in the NUREG-1150[5] PSA study and was independently verified by Idaho National Engineering and Environmental Laboratory.[6] After verification, the NRC released MACCS, Version 1.5.1 1 for unrestricted use. MACCS was used for PSAs at commercial reactors (both U.S. and international), as well as non-reactor nuclear facilities.

Originally released in 1997, MACCS2 was developed as an improved version of the MACCS code. The NRC developed MACCS2 to evaluate the potential impacts of severe accidents at nuclear power plants on the surrounding public. The MACCS2 code simulates the atmospheric release of radioactivity, the direction, speed of travel, and dispersion (spread and dilution) of the plume based on meteorological inputs; and ultimately, MACCS2 calculates radiological health and economic impacts. It considers, among other things, phenomena related to atmospheric transport and deposition under time variant meteorology, short and long-term mitigative actions, potential exposure pathways, deterministic and stochastic health effects, and economic costs.

The MACCS2 code is periodically updated and subject to peer review as part of the continual improvement process in its software life cycle. The NRC and Sandia

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5 NUREG-1150, Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants (Dec. 1990).

6 NUREG/CR-5376, C. A. Dobbe et al., Quality Assurance and Verification of the MACCS Code, Version 1.5, Idaho National Engineering Laboratory (1990).

National Laboratories have invested in maintenance and extension of the MACCS2 code to support severe accident consequence assessment and PSA/SAMA analyses. Currently, the NRC and Sandia National Laboratories are engaged in a peer review activity called the State-of-the-Art Reactor Consequence Analysis (SOARCA) Project. One of its objectives is to identify whether any improvements are necessary to ensure that MACCS2 is suitable for current and future reactor plant severe accident analyses, such as those analyzed in SAMA analyses.

Q21: Has the SOARCA peer review recommended any changes to the MACCS2 code that would affect the modeling of the atmospheric transport and dispersion of a radioactive plume?

A21. (KRO) No. The improvements recommended by the SOARCA Peer Review Committee are still in draft and have not been finalized. However, to date, the committee has not identified any recommendations concerning any of the meteorological or atmospheric transport and dispersion modeling issues raised by the Pilgrim Watch Contention 3. It is implicitly accepted that the atmospheric transport and dispersion model (ATMOS) within MACCS2 is currently adequate for its purpose, and the SOARCA version of MACCS2 still employs the Gaussian plume segment model. Overall, the focus of the SOARCA Project is generally on improved understanding of source term phenomena, consequence evaluation sensitivity to counter-measures, and more accurate health effects models. While enhancements have been implemented in the SOARCA version of MACCS2, those changes may be characterized as simplifying user input, providing more parameter sampling capability, improving the interface with the source term phase of analysis, and enhancing sensitivity analysis capabilities. There are no near-term plans to introduce new algorithms or methodologies that would substantively affect the MACCS2 calculation of the risk estimates obtained for the Pilgrim SAMA studies.

Q22: Please describe the various embedded modules and phases used in the MACCS2 code and their purpose.

A22. (KRO) The MACCS2 code executes three modules in sequence to calculate consequence and risk values necessary for a SAMA analysis. The first is ATMOS, which calculates the air and ground radioactivity concentrations, plume size, and timing information for all plume segments as a function of downwind distance. The results of the ATMOS calculations are stored for subsequent use by EARLY and CHRONC. The second module is EARLY, which uses radioactivity concentrations calculated by ATMOS and other inputs (e.g. population) to calculate consequences due to radiation exposure in the emergency phase (the first seven days) from the time of release. The last module is CHRONC, which uses radioactivity concentrations calculated by ATMOS and other inputs (e.g. population and economic data) to calculate the long-term doses due to exposure after the emergency phase and the economic impacts from each accident sequence.

The meteorological concerns raised in Contention 3 and discussed in this testimony solely relate to the ATMOS module and its meteorological inputs.

Q23: What are the impacts or consequences ultimately computed as part of the SAMA analysis?

A23. (KRO) The key *consequence* values of interest computed by MACCS2 are: (1) total off-site population dose (person-sievert);[7] and the (2) total off-site economic cost calculated in dollars.

In order to obtain corresponding *risk* values for population dose and off-site economic costs, the off-site population dose and off-site economic cost consequence values are multiplied (outside of the MACCS2 code) by the calculated severe accident frequency results obtained from the plant-specific PSA and related information. This results in the key *risk* values of interest for determining potentially cost-beneficial SAMAs, i.e., (1) population dose risk (PDR) in units of person-rem/year; and (2) the off-site economic cost risk (OECR) in units of dollars/year.

[7] The sievert is a unit of dose, (biological effect due to radiation). However, the units are usually converted to units of dose that are more familiar, i.e., "rem" where one (1) sievert = 100 rem, and population dose is usually discussed in terms of person-rem.

Q24: Please explain how the key *consequence* and *risk* values for off-site population dose and total economic cost are computed.

A24. (KRO) There are multiple steps in the calculation sequence and several modules in the MACCS2 structure for performing the calculations to derive the total off-site population dose and PDR and the total off-site economic cost and the OECR. These steps are as follows:

First, the user enters into MACCS2 the different accident sequences (referred to as postulated accident scenarios) which encompass the full range of severe accident scenarios evaluated for the SAMA analysis, each uniquely describing the amount of radioactive release, the timing, elevation, and the energy released. The postulated accident scenarios are obtained from site-specific PSA and related information.

Second, the region surrounding the facility (in which the accident releases are modeled and for which consequences are calculated) is divided into a polar coordinate grid with the plant at its center, similar to Figure 1 below, which depicts the 16 standard meteorological wind direction sectors that are used in MACCS2/ATMOS applications.

For the Pilgrim site, this polar grid is comprised of a series of radial rings centered at the Pilgrim Station with boundaries at radii of 0.33, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 20, 30, 40, and 50 miles. As seen in Figure 1, each of the radial rings marked by these boundaries is transected by 16 wind direction sectors emanating from the plant, each of 22.5-degree width. Each sector represents a standard compass wind direction (e.g., NW, SSE, etc.). As a result, each ring of the radial spatial grid is divided into 16 radial sectors of 22.5-degree width, for a total of 15 rings x 16 sectors, or 240 spatial or "grid" elements. Figure 2 below shows the specific polar coordinate grid for the Pilgrim SAMA analysis overlaid on an Eastern Massachusetts map. Note that, as in Figure 1, radial boundaries are shown for 10, 20, 30, 40, and 50 miles only. There are ten rings marking distances of 0.33, 1, 2, 3, 4, 5, 6, 7, 8, and 9 miles that are not shown in Figures 1 and 2.

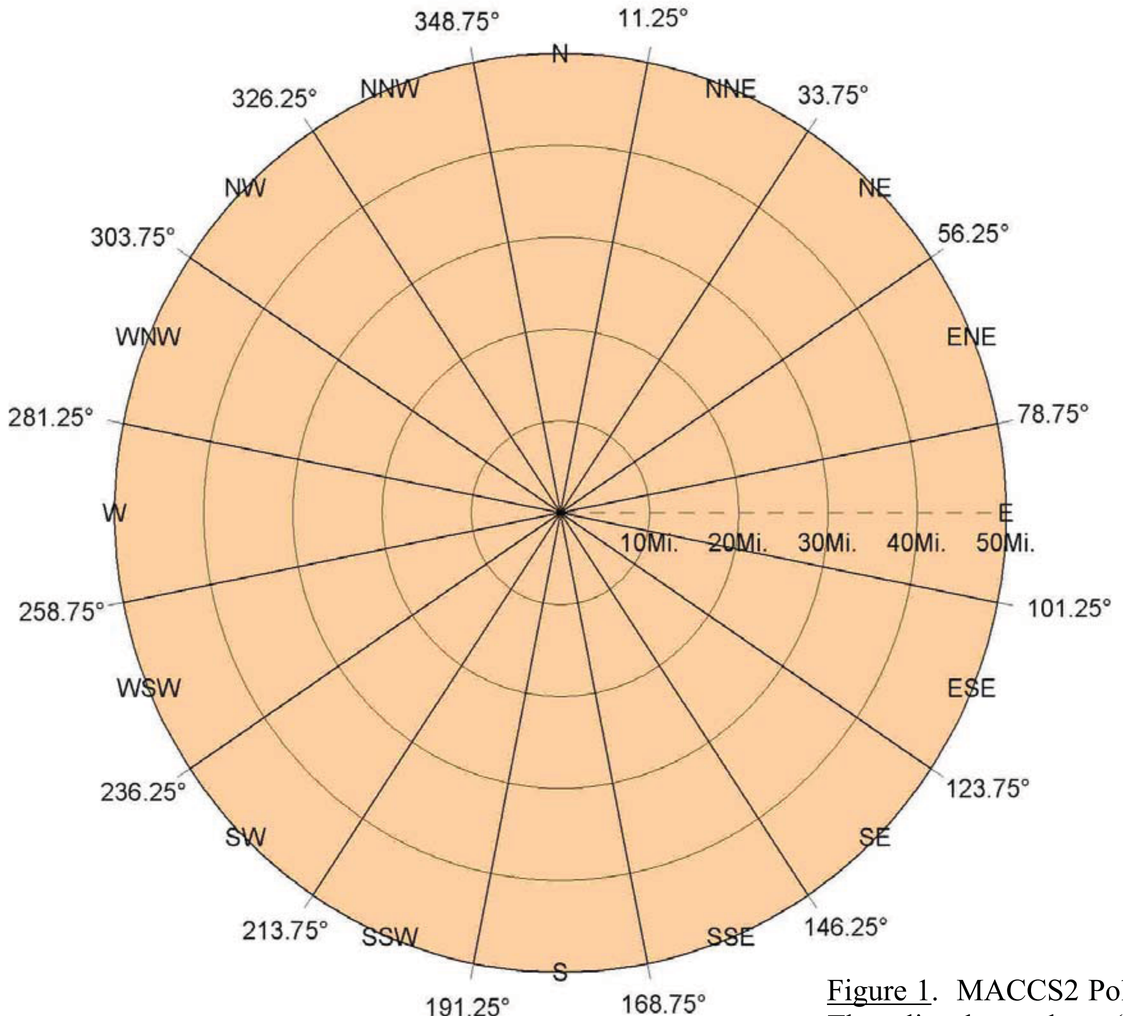

Figure 1. MACCS2 Polar Coordinate Grid. The listed angles (given in degrees clockwise from north and in standard compass directions) are assumed for standard meteorological wind direction sectors in MACCS2/ATMOS applications. The radial rings are also shown in 10-mile increments.

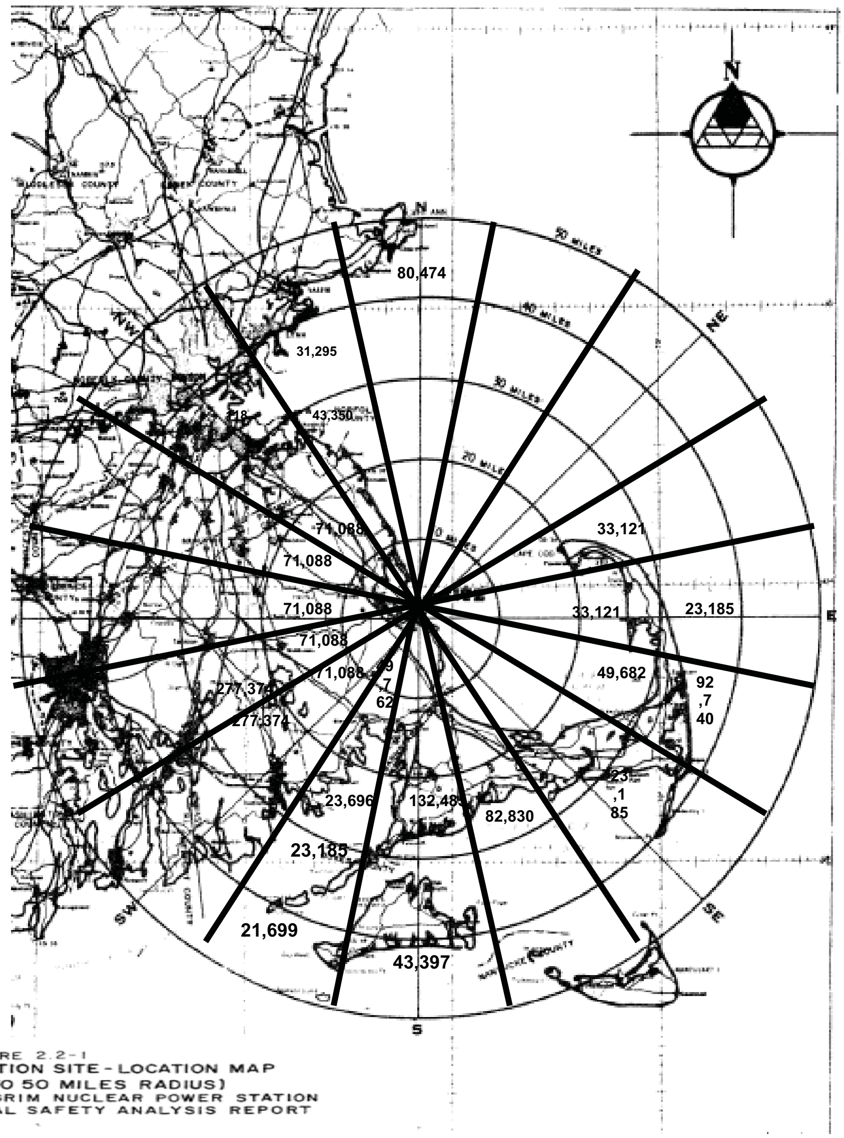

Figure 2. Radial grid overlay out to 50 miles for SAMA analysis at Pilgrim.

Third, as discussed in more detail in answer A36 and A37 below, one year's worth of hourly weather observations are categorized based on atmospheric stability, wind speed, and precipitation meteorological conditions that occur throughout the year into a series of weather bins. The weather bins used in a MACCS2 analysis for SAMA applications usually number about 40, and are input to MACCS2 to represent the different type of weather conditions under which a release may occur. Each hour of weather data, for a total of 8,760 hourly weather observations, is assigned to one of these weather bins as an initiation point of a weather sequence used to model simulated radioactive releases.

Fourth, for each postulated accident scenario, a series of radioactive releases are simulated based on weather sequences randomly selected from the different weather bins in order to account for the full range of different meteorological conditions under which a release may occur. For each simulated radioactive release, ATMOS models the transport and dispersion using the Gaussian plume segment model based on the meteorological conditions for the initial hour of the release and for hours immediately subsequent to the release for the period of time the plume remains within the 50-mile radius SAMA domain. ATMOS calculates the air and ground radioactivity concentrations within each grid spatial element of the polar grid over which that plume passes.

Fifth, using the output information from ATMOS, and the population, land use, and economic data, and interdiction model applicable to each grid spatial element (defined by a 22.5 degree sector and by two radial distances), MACCS2 calculates the off-site population dose and off-site economic cost during the short-term phase (lasting seven days from the time of the release) and the subsequent long-term phase (approximately 30 years) for each simulated radioactive release. MACCS2 does this by calculating the population dose and economic cost for each of the individual grid spatial elements affected by the simulated radiological release and then summing the results over all of the grid spatial elements.

Sixth, the carrying out of steps four and five for the series of simulated radioactive releases that are modeled for each of the postulated accident scenarios leads to a distribution of population dose results and a distribution of off-site economic cost results for each postulated accident scenario. Each result is weighted by its probability of occurrence. For the Pilgrim SAMA analysis, steps four and five produce for each postulated accident scenario a population dose distribution of 2,336 results (derived in A37 below). Similarly, steps four and five produce for each postulated accident scenario an off-site economic cost distribution of 2,336 results. The arithmetic means or expected results of the population dose and the off-site economic cost for each postulated accident scenario are determined and reported in the MACCS2 calculation.

Seventh, for each postulated accident scenario, the arithmetic mean of the population dose distribution as computed by MACCS2 is multiplied by the mean annual frequency of occurrence of the accident scenario to provide the population dose risk (PDR) for each accident scenario. The individual PDRs for the different accident scenarios are summed to determine the overall PDR for the SAMA analysis.

Similarly, for each postulated accident scenario, the arithmetic mean of the off-site economic cost distribution as computed by MACCS2 is multiplied by the mean annual frequency of occurrence of the accident scenario to provide the off-site economic cost risk (OECR) for each accident scenario. The individual OECRs for the different accident scenarios are summed to determine the overall OECR for the SAMA analysis.

The calculations of the PDR and OECR occur outside of MACCS2.

B. THE ATMOS MODULE AND GAUSSIAN DISTRIBUTION

Q25: Please describe generally the ATMOS module of MACCS2.

A25. (KRO, SRH) As discussed above, ATMOS is a module in MACCS2 that performs the atmospheric transport and dispersion modeling necessary to predict the consequences of a postulated release of a radioactive plume due to a severe accident. A key aspect of ATMOS is that it uses a Gaussian plume segment model, as described in more detail below, to simulate the radioactive plume's transport, dispersion, and deposition from the source location to a distance 50 miles away. For each simulated radioactive plume release, ATMOS performs all of the calculations pertaining to atmospheric transport, dispersion, and deposition of the plume, as well as the radioactive decay that occurs in the plume. The resulting outputs of the ATMOS calculations are stored for subsequent use by EARLY and CHRONC. In addition to the air and ground concentrations, ATMOS stores information on wind direction, arrival and departure times, and plume dimensions.

Q26: Please explain what is meant by atmospheric transport and dispersion modeling.

A26. (SRH) *Atmospheric transport* modeling is the mathematical simulation of the movement, caused by the mean wind field (wind speed and direction averaged over 15 minutes to one hour), of the center of a pollutant cloud or plume, consisting of a gaseous emission, or particulate matter, or both. *Atmospheric dispersion* modeling is the simulation of how air pollutants disperse or spread in the atmosphere due to turbulent wind motions, which vary from second to second. The term also includes processes such as deposition and chemical reactions, which are determined from the pollutant concentration distributions. Atmospheric transport and dispersion modeling is performed with computer programs that solve fundamental mathematical equations and algorithms.

The inputs for an atmospheric transport and dispersion model are the characteristic of the release being modeled, such as release amount, duration of the release, time at which the release begins, sensible heat flux (proportional to the rate at which the plume gas volume is released from the source and the difference in temperature between the plume and the ambient air), and elevation, as well as meteorological variables, such as wind speed and direction, stability class, and rainfall rate and amount. These inputs affect the transport and dispersion of a plume. The outputs of the transport and dispersion model are concentrations or dosages (concentrations summed over time), and/or deposition to the ground surface of the pollutant for some averaging or sampling time over the geographic domain of interest.

Q27: Please describe the basic physics modeled by an atmospheric transport and dispersion model.

A27. (SRH) In this section, I describe, generally, the basic physics of atmospheric transport and dispersion. However, throughout my testimony I will explain these concepts in greater detail.

The transport and dispersion of substances in the atmosphere are determined by atmospheric properties such as wind speed and atmospheric stability. In many cases, the "pollutant" is a relatively inert and non-buoyant material that simply follows the wind flow. The atmospheric wind flow has many scales of motion and is always turbulent, causing dispersion. Lower frequency wind motions (with time scales of a few minutes or more) may cause meandering of the cloud or plume and can lead to curved trajectories.

The rate of dispersion depends on the roughness of the surface (e.g., large paved parking lot, mowed grass, urban buildings, field of corn, forest, lake or bay, etc.), the wind speed, and the atmospheric stability (e.g., stable at night and unstable during the day). Dispersion is usually larger during the day when the atmosphere is less stable and there is more mixing caused by the turbulent atmosphere due to the sun's heating of the ground surface and generation of convection. Comparatively, dispersion is usually less at night when the atmosphere is more stable because of the presence of inversions (temperature increases with height), which inhibit mixing. When the wind speed is strong, there is much turbulent mixing caused by wind shears at any time of the day or night, and the stability tends towards "neutral" conditions, which are in between stable and unstable.

The maximum vertical height or layer in the atmosphere through which relatively vigorous mixing can occur is referred to as the "mixing height." Typically, the mixing height is determined by several factors, such as the amount of convective mixing due to daytime heating by the sun and the amount of mechanical mixing due to the wind blowing across the rough ground surface.

Q28: Please explain the difference between dilution and dispersion.

A28. (SRH) In atmospheric transport and dispersion models, dilution is considered to be the effect of the mean (time averaged) atmospheric flow, with speed u, passing by the source location. Most industrial sources have source emission rates, Q, in units of mass released per unit time. Thus for a given Q, the source emissions are diluted by the mean flow, u, such that concentration C (in mass per unit volume) is inversely proportional to u (i.e., C ~ Q/u). Some texts use the analogy of emission into a pipe with air flowing through it. If the flow speed doubles, there is twice as much air volume available for "diluting" the mass emission and the concentration is reduced in half.

In contrast, dispersion is the result of rapid turbulent (random) fluctuations in winds. Dispersion causes the edges of a visible plume to spread outwards in time or distance, which decreases concentration levels in the middle of the plume. Both dilution and dispersion are accounted for in all transport and dispersion models and contribute to decreases in concentration in time or distance.

Q29: Are there different types of atmospheric transport and dispersion models?

A29. (SRH) Yes. Because atmospheric transport and dispersion models are used for a multitude of purposes by many different agencies and groups, there are numerous plume transport and dispersion models. As mentioned earlier, it is understood that the term "atmospheric transport and dispersion models" includes the estimation of both concentration and deposition, as well as various processes such as removal by rain and chemical reactions. The models can be grouped into the following general categories.

Straight-line Gaussian plume models: These models are based on the Gaussian or normal crosswind distribution of concentration, described below, and simulate plume transport and dispersion based on meteorological and plume inputs during the one hour (or other basic time period) of the release. These inputs are not changed during the simulation.

Plume element or segment models: These models simulate a pollutant release as a series of one or more elements or segments, which are transported and dispersed based on changing meteorological conditions from hour to hour.[8] For example, the initial transport and dispersion of a plume segment may be simulated using the

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8 Plume element or segment models are described generally in NRC Regulatory Guide 1.111, "Methods for Estimating Atmospheric Transport and Dispersion of Gaseous Effluents in Routine Releases from Light-Water-Cooled Reactors," Rev. 1 (1977).

Gaussian plume formula based on meteorological inputs during the hour at the time of the release. On an hourly basis thereafter (or whatever time period is chosen), new, updated meteorological data for that current hour are used to simulate the plume segment's transport and dispersion. The ATMOS module in MACCS2 is an example of a dispersion model in this category.

Lagrangian puff models: These models simulate the plume as discrete puffs with approximate spherical shapes and simulate the transport and dispersion of the individual puffs with changing wind speed and direction over a multi-hour period based on wind fields established by a separate wind field model. Lagrangian puff models calculate the movement of each puff in steps of time that march forward from one time, t_1, to the next time, t_2, with time increment, $\Delta t = t_2 - t_1$, which usually equals a few seconds near the source and increases to a longer time period at larger distances. It is assumed that the mean wind speed and direction and the stability and all other ambient conditions remain constant during this time increment Δt. The atmospheric dispersion of the puffs during the time increment Δt is typically calculated using a Gaussian formula. The final estimated concentration and deposition at each time and location are calculated by summing the contributions from each puff that has an arbitrary non-zero impact.

Lagrangian particle models: These models use the same type of wind fields that are used by Lagrangian puff models but follow individual "particles." A particle is usually assumed to be a small parcel of inert non-buoyant air. Thousands of particles are followed by the model, where the particle's motion is randomly chosen based on knowledge of the variance of turbulent speeds and their time scale. Concentration is calculated by counting the numbers of particles within a given small grid box over a given averaging time.

Three dimensional time dependent numerical models: These models solve the basic equations of motion, state, energy, and other relevant processes using a 3-D grid and marching the solution forward in time steps. At the small scale, such as for application in the near field around a power plant or chemical processing plant, these are called Computational Fluid Dynamics (CFD) models. At large regional and continental scales, the meteorological portions of the model are the same as the weather forecast models used at the National Center for Environmental Prediction (NCEP)

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The type of transport and dispersion model that is used generally depends on the specific application and the agency that is overseeing the study. The Gaussian plume model is one of the oldest dispersion models and was the basis for most of the operational transport and dispersion models developed and used in the 1940s through the 1980s by the EPA, NRC, DOD and other agencies for many applications, such as the modeling of plumes emitted by an industrial stack. The Gaussian plume formula is an integral part of the more advanced, sophisticated models made possible by today's increased computing power and new theoretical developments and is still widely used today.

Q30: Please explain the concept of the Gaussian plume dispersion model.

A30. (SRH) A Gaussian plume dispersion model assumes that the atmospheric content being modeled has a Gaussian shape or distribution in a crosswind (lateral and vertical) direction for continuous releases (and also in the wind direction for instantaneous releases, or puffs). The Gaussian (or normal) distribution is true of most environmental variables. As its name implies, the model assumes a Gaussian (sometimes called a bell-shaped or normal) distribution of concentration characterized by a mean and a standard deviation. Generally speaking, a Gaussian distribution describes, at least approximately, any variable that tends to cluster around the mean. In the specific case of atmospheric dispersion modeling of a postulated radioactive release, a Gaussian distribution means that, as the plume is carried downwind from its emission source, the cross-wind (horizontal and vertical) distributions of concentrations ("C") of radioactivity within the plume can be approximated by assuming that the highest concentrations occur on the horizontal and vertical midlines of the plume, with the distribution about these midlines characterized by Gaussian- or bell-shaped concentration profiles.

The Gaussian distribution formula is the key component of nearly all transport and dispersion models for industrial stacks. For example, for concentrations, $C(y-y_o)$, at a horizontal cross-wind distance y from the plume centerline located at y_o, the Gaussian distribution formula can be written as a one-line equation:

$$C(y-y_o)/C(0) = \exp((y-y_o)^2/2\sigma_y^2) \qquad \text{(Equation 1)}$$

where σ_y is the standard deviation of the distribution in the crosswind y direction and C (0) is the concentration at the middle of the plume, where $y = y_o$.

The Gaussian plume model itself can be expressed in the following way, incorporating the Gaussian crosswind distributions in the y and z (vertical) directions:

$$C(y-y_o, z = 0) = \{Q/(\pi u \sigma_y \sigma_z)\} \cdot \{\exp(-(y-y_o)^2/2\sigma_y^2)\} \cdot \{\exp(-H^2/2\sigma_z^2)\} \qquad \text{(Equation 2)}$$

where concentrations are being estimated at ground level ($z = 0$), and H is the initial height of the centerline of the plume. As in equation 1, y is the crosswind horizontal (lateral) direction, and y_o is the y location of the plume centerline (where C is a maximum with magnitude C(0)). The Gaussian distribution shape is also assumed for the vertical direction for which the dispersion coefficient is σ_z. Both σ_y and σ_z continually increase approximately linearly with downwind distance. The model calculates σ_y (and σ_z) as a function of downwind distance using standard formulas and inputs of stability class. A schematic diagram of the plume that is being simulated is given in Figure 3, adapted from a figure in Turner's Workbook of Atmospheric Dispersion Estimates (1970). Note that, in the figure, $y_o = 0$.

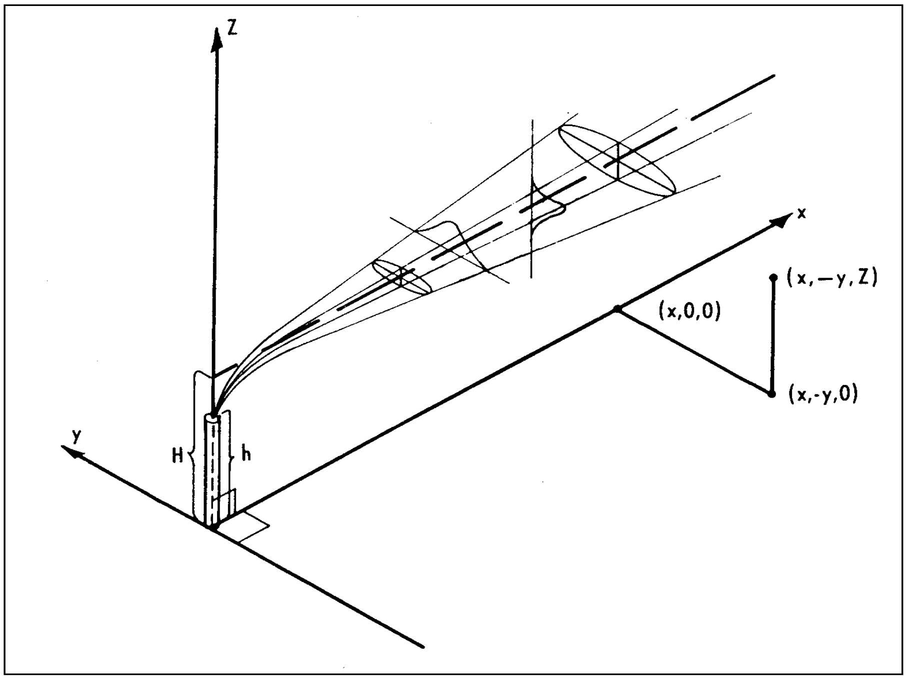

Figure 3. Gaussian plume growth in downwind (x), horizontal (y), and vertical (z) directions (from Turner (1970)). The Gaussian shapes (bell-shaped curves) are shown for the y and z components.

Q31: Please describe in more detail the meaning of the dispersion coefficients, σ_y and σ_z.

A31. (SRH) As shown in equation (1), the Gaussian shape characterizes the distribution by a mean and a standard deviation, σ_y and σ_z, for the lateral and vertical crosswind directions, respectively. One must estimate appropriate dispersion coefficients in order to calculate the concentrations. A key issue with the use of the Gaussian dispersion equation in the 1950's was how to identify these dispersion coefficients. Researchers worldwide carried out many field experiments where tracer plumes were released, concentrations sampled, and σ_y and σ_z were determined from the observations.

This research is summarized in English meteorologist Frank Pasquill's 1962 "Atmospheric Diffusion" textbook. Pasquill carried out many of the experiments himself, contributed much to the dispersion coefficient parameterization, and "invented" the letters A through F stability class scheme to determine the stability class and the dispersion coefficients. Importantly, field experiments by the Atomic

Energy Commission and the Department of Defense in the 1950s and 1960s (e.g., Prairie Grass and Hanford) and further model development resulted in what is now known as the Pasquill-Gifford dispersion curves, which allow the plume spread to be calculated as a function of stability class and downwind distance. Additional field experiments were run by EPA in the 1980s to extend the Pasquill-Gifford dispersion curves based on observed field data for a variety of source types and terrain conditions.

Because the dispersion coefficients in the Gaussian plume model were calibrated in about 1960 by Pasquill, Gifford, and others to observations in field experiments, the Gaussian plume model has been shown to be reasonably close to actual experiment observations. In fact, many of the atmospheric dispersion models, such as the Lagrangian puff and particle models and the three-dimensional time dependent numerical models, were calibrated to the same field experiment data. As a result, the outputs from these more complex models are often similar to the outputs from the Gaussian plume model.

Q32: Please explain what is meant by atmospheric stability and how the temperature gradient data taken from meteorological observation is used to determine the atmospheric stability class.

A32. (SRH) The amount of turbulence in the ambient atmosphere has a major effect on plume dispersion. Turbulence increases the entrainment and mixing of atmospheric air into the plume and thereby acts to reduce the concentration of radioactivity in the plume. The rate at which any materials, including radioactive materials, disperse in the atmosphere depends on the magnitude of the turbulence in the ambient atmosphere. The greater the turbulence, the greater is the plume dispersion. Unstable atmospheric conditions cause enhanced turbulence. Conversely, stable atmospheric conditions inhibit turbulence. But the atmosphere is always turbulent (i.e., not laminar).

Atmospheric turbulence is related to both the change of temperature with height and wind speed, together with the surface characteristics. There is more turbulence, and hence a larger rate of dispersion, during the daytime (unstable conditions), due to the effects of the sun's warming of the surface, than the nighttime (stable conditions).

The most commonly used method of categorizing the amount of atmospheric turbulence present is the method developed and published by Pasquill in England in 1961. Atmospheric stability is generally categorized into six classes (now referred to as the Pasquill Stability Classes), that range from highly unstable (stability category A) to very stable (stability category F).

Because atmospheric stability affects dispersion, ATMOS requires inputs of atmospheric stability. The A through F stability classes that are input to ATMOS are based on the magnitudes of the temperature gradient between different elevations on a meteorological tower as determined by NRC regulatory guidance provided in Regulatory Guides 1.111 and 1.23.[9]

Q33: Please describe the basic principles of the specific Gaussian plume model used in ATMOS for the Pilgrim SAMA analysis.

A33. (SRH, KRO) ATMOS uses a Gaussian plume *segment* model to determine plume concentrations and deposition, which differs in key respects from the standard *straight-line* Gaussian plume model. The standard straight-line Gaussian plume model, which has been the most widely-used dispersion model for many decades and forms the basis for many of today's atmospheric dispersion models, assumes that the same wind speed, wind direction, stability, mixing depth, rain rate, and other variables apply for the entire averaging period (usually one hour) and over the entire plume trajectory, even at distances from the source of tens of miles.

ATMOS uses a Gaussian plume segment model, not a standard straight-line model. In the application for the Pilgrim SAMA analysis, the Gaussian plume segment model in ATMOS assumes that the length of the segment is equal to the wind speed times the duration of the release. For the first hour of the release, the plume segment is governed by the meteorological input data specified for that hour, but for subsequent

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9 NRC Regulatory Guide 1.23 Rev. 1, Radiological Dispersion and Consequence Analysis Supporting Pilgrim Nuclear Power Station Severe Accident Mitigation Alternative Analysis (Mar. 2007).

hours, the meteorological data other than wind direction is updated. For example, a plume segment with an initial wind speed of 10 mph at the time of release would travel for ten miles (or 16 km) during the first hour. During this hour, the plume would have a dispersion rate as determined by the meteorological data (wind speed and stability) for that hour. For the next hour, however, the plume segment has its dispersion rate, speed, and the precipitation that affects it determined by the new hour's meteorological conditions. And so on, until the plume passes over the 50-mile radius circle (the outer edge of the SAMA modeling domain). The only major meteorological input that does not change from hour to hour is the wind direction.

Q34: Please describe the inputs required for the atmospheric transport and dispersion modeling performed by ATMOS.

A34. (KRO, SRH) ATMOS, like all transport and dispersion models, requires meteorological observations and source term information. Meteorological observations include hourly wind speed and direction, atmospheric stability class (based on observed temperature gradient across two levels of a meteorological tower), seasonal mixing layer heights, and precipitation.

ATMOS also requires source term information, describing the amount of radioactivity for each radionuclide released. This includes the amount of radioactivity released over a given time, and its characteristics (radioactive decay chain data, particle sizes for aerosols and deposition characteristics, etc.). Also required are the associated plume physical parameters, such as height of release, release duration and heat content (proportional to the difference between the plume and ambient air temperatures), and initial plume dimensions (height and width).

Because ATMOS takes into account the surface characteristics over the region of transport, ATMOS requires the user to specify the surface roughness length, z_o, which is a single value assumed to be characteristic of the fifty-mile region of interest surrounding the site. The surface roughness length is one indication of the mechanical mixing caused by surface elements, such as vegetation and structures.

Q35: Please comment on the seasonal mixing height typically used for SAMA analyses.

A35. (SRH) As previously discussed in A27, the mixing height represents the top of the layer through which relatively vigorous atmospheric mixing will take place. On days with a strong inversion above the mixing height, the plume is unlikely to disperse significantly above the mixing height (i.e., the "cap" to mixing). Mixing heights and their strengths vary by time of day and by season. However, on average the mixing height is about 1000 m (3,280 ft) in the U.S., with slightly larger values over the deserts, and slightly smaller values over regions such as the Los Angeles basin. NOAA has generated seasonal estimates of mixing height across the U.S. and these values are used in MACCS2/ATMOS. The MACCS2/ATMOS model uses the seasonal afternoon mixing heights, which are appropriate for transport distances (out to 50 miles) important for the SAMA analysis.

Q36: Please describe the weather binning and sequencing process, previously referred to in A24, ATMOS performs as part of its atmospheric transport and dispersion modeling of the radioactive plume.

A36. (KRO) ATMOS selects the weather data used for modeling by means of a two-step sampling technique where a full year, or 8,760 hours of hourly weather data, is used. Each of these hours serves as the initiation point of a potential simulated release, and each hour is categorized and assigned to a weather bin. The two steps are: (1) weather data assessment and (2) random sampling of weather bins and sequencing. The two-step process described here is the general method that has been applied to SAMA analyses at nuclear facilities in the US.

The **first** step is a *weather data assessment* of the 8,760 hourly (1-year) weather data. This assessment provides information about the various types of weather contained in the 1-year data set and the relative frequency of these weather types. The weather data assessment is performed by sorting the weather data into categories or bins that provide a realistic representation of the year's weather without overlooking those kinds of weather that can lead to major consequence impacts. Typical of a SAMA analysis, the Pilgrim SAMA analysis uses 40 weather categories, or bins, which are defined in terms of stability class, wind speed, and incidence of precipitation. During the MACCS2 simulation, each weather bin is randomly sampled to identify a set of weather sequences.

Within each weather bin there are sets of weather sequences. Each weather sequence consists of a starting time followed by the subsequent hourly weather data necessary to simulate the release until the plume reaches and crosses the 50-mile boundary of the SAMA domain. Each of the 8,760 hourly data points serves as a starting time for a weather sequence. Following the binning process, the starting hour of each of the 8,760 weather sequences will have been assigned to one and only one weather bin or weather category. The probability of occurrence of a weather bin, is the ratio of the total number of weather sequences in the bin to the total number of weather sequences in the year's weather data set, or 8,760 sequences.

The **second** step is statistically random sampling of the weather bins. ATMOS selects on a statistically random basis a set of weather sequences from each of the weather bins. The usual practice for a PSA or a SAMA application is to select four weather sequences from each bin in a manner that assures representativeness. For the Pilgrim SAMA analysis, 40 weather sequence bins are defined and the sampling process yields 146 randomly chosen weather sequences. This is fewer than 4 times 40 = 160 weather sequences because six of the weather bins have fewer than four sequences, and in those six cases all sequences are selected from the weather bin. As a result, the Pilgrim SAMA analysis contains 146 weather sequences. By statistically sampling from each of the 40 weather bins, MACCS2 is able to simulate the full year's weather data. The sampling process therefore ensures representation of each weather category, which is important for realistic representation of the annual weather data. This method of weather data sampling using MACCS2 is the general approach applied to PSA and SAMA analyses.

Q37: Please explain how MACCS2 utilizes the random weather sequences chosen from the weather binning process for evaluation.

A37. (KRO) As described in A24 step 4, a radiological release is simulated under the meteorological conditions defined by a weather sequence, and the simulation is repeated for each of the weather sequences chosen in the sampling process. This process is repeated for each postulated accident scenario. For each simulated release, ATMOS calculates the transport and dispersion of the radioactive plume throughout the different grid elements (delineated by direction sectors and distances) and the population doses and economic costs are calculated as described above in A24. For the Pilgrim SAMA analysis, this produces 146 simulation results for each accident scenario (34 weather bins times the four randomly chosen weather sequences from each of these weather bins, or 136 results, and ten from the six bins that had fewer than four weather sequences, or 136 + 10 = 146).

As previously discussed, for each of the simulations the Gaussian plume segment model permits hourly changes in all of the meteorological variables except direction of the wind. Therefore, while the model accounts for hour-to-hour changes in wind speed, stability, and precipitation, for each simulation the wind direction remains unchanged, blowing in one of the 16 principal polar sector directions (e.g. north) as specified by the initial hour's meteorological inputs for the weather sequence. Thus, in our example, the plume will travel and disperse in the northerly direction and ATMOS will provide air and ground deposition concentrations for each of the affected spatial grid elements in the affected regions of the polar coordinate grid. These air and ground deposition concentrations are used to calculate population dose and economic consequences based on the population and economic input data for each of the affected grid elements.

For each of the 146 sampled meteorological sequences, MACCS2 recalculates the results for each weather sequence simulation assuming that the wind blows in each of the other 15 polar wind direction sectors in order to account for the occurrences of the wind blowing in these other wind direction sectors under the type of weather conditions described by that bin. Applied to our example weather sequence simulation for the wind blowing to the north, the same weather sequence with the same transport and dispersion results is now assumed to occur for the wind blowing in each of the other 15 sectors, but weighted by the relative frequency that the wind blows in that direction for the specific weather bin.

For each of these additional 15 assumed simulations, the air and ground deposition concentrations calculated by MACCS2 for the weather sequence simulation will now affect different spatial grid elements, each with distinct population and economic activity statistics. MACCS2 sums the population doses for a specified direction and creates a total population dose. The result is assigned the probability of the weather sequence times the probability that the wind blows in the specified direction for the specific weather bin. This process produces 16 population dose results (including the original northerly simulation in our example) for each weather sequence, each weighted by the probability of the weather sequence times the probability that the wind blows in the specified direction for the specific weather bin. Therefore, in total, there are 146 x 16 = 2,336 results for the population dose, each with a probability of occurrence. The mean off-site population dose is determined from the set of 2,336 results.

The same approach is applied to off-site economic costs. Therefore, there are also 146 x 16 = 2,336 results for off-site economic costs, each with a probability of occurrence, from which the mean off-site economic cost is determined.

The sampling described is a standard technique in weather bin sampling for consequence codes supporting Probabilistic Safety Analysis and therefore, SAMA analysis applications. It is an efficient computational technique especially suited for probabilistic sampling of many weather conditions that takes into account directional dependences of wind and population distributions and economic statistics.

MACCS2 repeats the process described in this answer for each of the postulated accident scenarios. As discussed above, the arithmetic means or averages of the off-site population dose and off-site economic cost distributions (each consisting of 2,336 results) are determined for each accident scenario. In turn, these are multiplied, outside of MACCS2, by the mean annual frequency of occurrence of the accident scenario to provide the mean PDR and OECR for each accident scenario. The individual PDRs and OECRs for the different accident scenarios are then summed to determine the overall PDR and OECR for the plant's SAMA analysis.

C. PILGRIM'S LICENSE RENEWAL SAMA ANALYSIS USING THE MACCS2 CODE

Q38: Please generally describe how the Pilgrim SAMA analysis was performed using the MACCS2 Code.

A38. (KRO) Pilgrim performed its SAMA analysis following the general guidance of NEI 05-01 (Rev. A). In accordance with NEI 05-01 (Rev. A), the SAMA analysis was based on the Pilgrim plant-specific Level 3 PSA. The PSA was used to develop a set of 19 accident scenarios and the source term characteristics associated with each of the postulated accident scenarios.[10] MACCS2 was used to calculate the consequences caused by each of the 19 accident scenarios. As is the standard practice for cost-benefit analysis, and based on the area that might be impacted by a severe accident, the area of interest covered a 50-mile radius area surrounding the Pilgrim Station.

Each accident sequence bin represents a postulated accident sequence defined in the Pilgrim PSA and the source term characteristics associated with that particular accident sequence. Included in this information is the amount and type of radionuclides released, the timing, duration, height, heat content (thermal energy) of the release, whether collocated structures are influencing the release, and other parameters. Table 1 in Attachment 1 shows the atmospheric release characteristics input information (other than the radioactive source term) for MACCS2 for each of the accident scenarios evaluated in the Pilgrim SAMA analysis.

As described in A37 above, for each of the 19 accident scenarios, 2,336 simulations were run to evaluate postulated consequences under different meteorological conditions using Pilgrim site-specific meteorological data. The mean or average consequence results obtained for each of the 19 accident scenarios were multiplied by the frequency of occurrence of the accident scenario, and then summed to yield the overall PDR and OECR for the Pilgrim SAMA analysis.

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[10] Also referred to as collapsed accident progression bins in the Pilgrim ER Attachment E (ENT000006) and in the WSMS 2007 report.

Q39: Would you please describe the meteorological data sources used for the Pilgrim SAMA analysis?

A39. (KRO) As described above, the SAMA analysis requires numerous meteorological inputs. As described in the LRA ER, Attachment E (ENT000006), Pilgrim obtained the required hourly meteorological data from two sources: (1) the Pilgrim onsite meteorological monitoring system and (2) the Automated Surface Observatory System (ASOS) at Plymouth Municipal Airport.

Hourly meteorological data for the wind direction, wind speed, and stability class inputs used in ATMOS for the Pilgrim SAMA analysis were taken from the 33 ft and 220 ft levels of the upper meteorological tower on the Pilgrim site. There are two meteorological towers on the Pilgrim Station site. The original tower, referred to as the "lower tower," is 160 ft tall and is located off the main parking lot. The second tower, referred to as the "upper tower," is located north of the main stack building. The upper tower is newer and has data collection heights of 220 ft and 33 ft, and is the designated data source for MACCS2 input. The 160 ft lower tower is still operational, but is used as a backup data source.

Pilgrim used year 2001 hourly data from the upper tower's 33-ft level as the input data for wind speed and direction for the SAMA analysis. In a relatively small number of instances where measurements from the upper tower were incomplete, data were obtained either from the lower tower, which has data collection heights of 160 ft and 33 ft, or in some cases interpolated estimates based on other valid measurements were used. This data replacement protocol follows the applicable guidance of NUREG-0917[11] and NRC Regulatory Guide 1.23, Rev. 1.

As discussed above, stability class is based on the observed vertical temperature gradient. The atmospheric stability class for each hour was determined from the temperature difference in observed temperatures between the 220 ft and 33 ft levels of the upper tower. The stability class estimates use the methodology specified in Reg. Guide 1.23, Rev. 1.

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[11] NUREG-0917, Nuclear Regulatory Commission Staff Computer Programs for use with Meteorological Data (Jul. 1992).

Pilgrim used year 2001 hourly precipitation observations from the ASOS weather observing system at the Plymouth Municipal Airport. The data were converted to MACCS2 input format, which requires precipitation to have units of hundredths of an inch per hour.

The above hourly meteorological data inputs for the SAMA analysis are contained in a single data file consisting of one-year's worth of hourly records (i.e., 8,760 data points) for each of the above data inputs.

The meteorological data input file also includes the seasonal mixing layer heights used for the SAMA analysis. These seasonal mixing heights were based on mixing height data provided by the National Climatic Data Center for the area surrounding Pilgrim Station.[12] The afternoon mixing layer heights used in the SAMA analysis for the four seasons, winter, spring, summer, and autumn, are as follows: 1000 m, 1300 m, 1300 m, and 800 m.

Q40: Why did Pilgrim utilize only one year of data for the SAMA analysis?

A40. (KRO) The use of one year of data is standard practice for performing SAMA analyses so long as the data are determined to be representative and typical. Furthermore, the MACCS2 code, version 1.13.1, requires and can process only one year's worth of hourly meteorological data. No additional years of meteorological data are required to run MACCS2.

Q41: Why did Entergy choose to utilize 2001 weather data in its SAMA analysis?

A41. (KRO, SRH) Pilgrim used weather data from calendar year 2001 for the SAMA analysis because of their completeness and representativeness. The 2001 data set is the most complete (approximately 98%) in terms of data recovery in the time period 1996-2001 from the Pilgrim onsite meteorological monitoring system and was the most recent set of data available at the time the SAMA analysis was performed in 2002. The 2001 observations were evaluated by Entergy and determined to be

[12] The mixing height data provided by the National Climatic Data Center were calculated using the Holzworth method, which is a standard method for calculating mixing heights used for Gaussian plume transport and dispersion modeling.

representative of the meteorological observations gathered during the several year collection period at the Pilgrim site. This conclusion about representativeness was confirmed by further review and evaluation of the annual wind roses from 1996 through 2001 in the Report (ENT000004) discussed in Section IV.B.1 of the testimony below.

Q42: What were the base case results for the SAMA analysis?

A42. (KRO) The base case results for the MACCS2 portion of the SAMA analysis are shown in Table 2 in Attachment 1.[13] The table shows the base case mean *consequence* values computed by MACCS2: (1) total off-site population dose and (2) total off-site economic cost, for each of the postulated 19 accident scenarios (labeled Collapsed Accident Progression Bins (CAPBs)). As discussed in steps 6 and 7 of A24, these two consequence values for each of the 19 accident scenarios are multiplied by the frequency of the accident scenario to calculate the PDR and OECR values for each accident scenario. The PDR and OECR results for each accident scenario, calculated outside of MACCS2, and the sums of the 19 PDRs and the 19 OECRs are also shown in Table 2.

Q43: How are the off-site consequences distributed spatially?

A43. (KRO) As shown in Table 3 below, the off-site population dose risk, in decreasing order of population dose risk contribution, is as follows: 1.) 38% in the 30 – 40 mile ring; 2.) 27% in the 20 – 30 mile ring; 3.) 18% in the 40 – 50 mile ring; 4.) 12% in the 10 – 20 mile ring; and 5.) 4% in the 0-10 mile region. The order is based on MACCS2 base case results that show the dose-dominant conditions arise in the simulation with the intersection of high exposure conditions and high population levels. Thus, over 95% of the population dose risk occurs in the 10 to 50 mile range and 83% occurs in the 20 to 50 mile range.

Approximately the same spatial distribution of results was found with the off-site economic costs. Because off-site economic costs are calculated on a per person basis,

[13] This table is a revision to the original SAMA analysis documented in the Pilgrim Environmental Report (Table E.1-15). Entergy revised the table in response to a request for additional information (ENT000010).

higher economic costs will occur in grid elements where the ground contamination levels and the population levels are high. The percentage contribution of the off-site economic cost risk (OECR) by radial ring region surrounding the plant are by decreasing order: 1.) 37% in the 30 – 40 mile ring; 2.) 26% in the 20 – 30 mile ring; 3) 16% in the 40 – 50 mile ring; 4) 15% in the 10 – 20 mile ring; and 6% in the 0-10 mile region. Thus, about 94% of the off-site economic cost risk occurs in the 10 to 50 mile range and 79% occurs in the 20 to 50 mile range.

The percentage of contribution to the Pilgrim SAMA PDR and OECR by distance ring is shown in Table 3 immediately below.

Table 3. Contribution to Pilgrim SAMA PDR and OECR by Distance Ring

Ring Distance Interval	PDR	OECR
(0-10 miles)	4.22%	6.18%
(10-20 miles)	12.42%	14.84%
(20-30 miles)	27.40%	26.09%
(30-40 miles)	37.83%	37.39%
(40-50 miles)	18.12%	15.50%
TOTAL	100.00%	100.00%

Q44: What is the significance of the fact, for our purposes here, that the largest PDR and OECR impacts are in the 20-50 mile range?

A44. (KRO) The primary inputs that have the largest effect are 1) the size of the source term (i.e., amount of radioactivity released), 2) the parameters controlling the long-term phase after the accident, and 3) the population levels impacted in the 20 mile to 50 mile spatial region. Because the land contamination result is the principal contributor to the long-term population dose and economic costs, hourly variations in plume behavior and individual plume travel trajectories are of secondary importance to these long-term, longer-distance (out to 50 miles) land contamination impacts. Consequently, population dose and economic cost results are relatively insensitive to individual plume transport behavior.

Q45: Please describe generally how Pilgrim used the MACCS2 results (OECR and PDR) in performing the SAMA cost benefit evaluation.

A45. (KRO) The methodology used to determine potentially cost beneficial SAMAs is based primarily on the NRC guidance for performing cost benefit analysis, NUREG/BR-0184, Regulatory Analysis Technical Evaluation Handbook,[14] and NUREG/BR-0058, Rev. 4, Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission.[15] This methodology computes a net value for each SAMA based on: (1) the off-site risks, i.e., the PDR and OECR; (2) the on-site exposure costs and on-site economic costs (calculated with a formula provided by NUREG/BR-0184); and, (3) the cost of the enhancement, i.e., the cost of implementing the SAMA through changes to the nuclear power plant or its operations to reduce the risk.

The methodology weighs the cost of implementing a particular SAMA against the benefit of implementing the SAMA, which is the cost avoided or averted. A SAMA is a modification to the plant or its method of operation that decreases the frequency of an accident sequence, or the amount of radiation released during an accident sequences. The SAMA benefit, or the cost avoided or averted, is the difference between the severe accident cost for the existing plant and the cost with the SAMA implemented. If the Net Value of a SAMA is negative, the cost of implementation of the SAMA is larger than the benefit, the SAMA is not considered as potentially cost-beneficial, and is eliminated from additional consideration.

Quantitatively stated the formula for making these determinations is as follows:

Net Value = Averted Cost ("AC") - Cost of Enhancement ("COE") (i.e., cost of implementing the SAMA)

where,

Averted Cost = APE + AOC + AOE+ AOSC (Equation 3)

and,

[14] NUREG/BR-0184, Regulatory Analysis Technical Evaluation Handbook (Jan. 1997).

[15] NUREG/BR-0058, Rev. 4, Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission (Sept. 2004)

APE = averted public exposure costs ($), based on the calculated PDR

AOC = averted off-site economic costs ($), based on the calculated OECR

AOE = averted occupational exposure costs ($), i.e. on-site exposure costs.

AOSC = averted on-site costs ($), i.e. on-site clean up and decontamination cost, and replacement power cost.

Q46: Please describe the results of the Pilgrim SAMA analysis using the above methodology.

A46. (KRO) For relevant purposes here, in the Pilgrim SAMA analysis, the averted public exposure costs (APE) attributable to the PDR contributes about 32% of the total benefit. The averted off-site economic costs (AOC) attributable to the OECR contribute about 54% of the total benefit. Thus, 86% of the overall SAMA benefit is attributable to the PDR and OECR. The remaining 14% of the SAMA benefit is a combination of on-sites costs, the averted occupational exposure, and the averted on-site costs, including on-site decontamination and replacement power. The overall results of the SAMA analysis are documented in Table G-4 in NUREG-1437, Supplement 29.[16]

Q47: Based on the results of the SAMA analysis, how big would a modeling sensitivity change or bias have to be to change the results of the Pilgrim SAMA analysis?

A47. (KRO) The results show that for the next potentially cost-beneficial SAMA, SAMA 8, the approximate cost of implementing the SAMA (>$5,000,000) is more than twice the benefit ($2,410,000), or the cost avoided, from implementing the SAMA. The significance of this fact for our purposes here is that the benefit, or cost averted, must therefore increase by more than approximately a factor of two before the next SAMA is potentially cost beneficial. More precisely, the sum of the OECR and PDR, which together comprise most (86%) of the averted cost benefit, would need to increase by a

[16] Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Supplement 29 Regarding Pilgrim Nuclear Power Station, NUREG-1437 (July 2007) (NRC000002).

more than a factor of two before another SAMA would be considered potentially cost beneficial.

IV. <u>DISCUSSION OF PILGRIM WATCH'S METEOROLOGICAL, TRANSPORT, AND DISPERSION MODELING CLAIMS</u>

A. Appropriateness of the Gaussian Plume Segment Model as Implemented in ATMOS

1. <u>*The Gaussian Plume Segment Model is Adequate*</u>

Q48: Pilgrim Watch claims that the Gaussian plume model is inappropriate for use at Pilgrim. Do you agree?

A48. (KRO, SRH) No, we disagree. As has been discussed earlier in this testimony, the atmospheric transport and dispersion model used in the ATMOS module of MACCS2 is described more accurately as a Gaussian plume segment model. The Gaussian plume segment model allows hourly changes in the meteorological input data other than wind direction. In a SAMA cost-benefit analysis, where annual expected consequences over a large domain are calculated based on the likelihood of different weather conditions occurring over a year, the Gaussian plume segment model used by MACCS2 is more than adequate to provide a reasonable estimate of the mean annual off-site consequences for SAMA cost benefit determinations.

Furthermore, Pilgrim Watch's claims that the Gaussian plume model in MACCS2 is inappropriate ignore the purpose of a SAMA analysis – which is to calculate long-term annual consequences over a 50-mile radius region to support the SAMA cost-benefit analysis. Pilgrim Watch's claims are focused on tracking the direction of individual plumes and estimating maximum short-term impacts at a single location for emergency response purposes, which, as described in A17 above, has an entirely different function and purpose than SAMA analyses. The tracking of individual plumes is not required for computing a long-term annual consequence summed over a broad area because, over time, plume curvature effects and other short-term effects tend to even out.

In general, over a year, the directional frequencies of impacts are proportional to the annual wind direction frequencies. For example, if the annual frequencies of wind directions blowing towards the northeast (NE) quadrant are twice those towards the southeast (SE) quadrant, then the annual averaged concentrations in the NE quadrant would generally be about twice those in the SE quadrant. While an individual trajectory at a given hour may curve in some direction, it will generally be balanced over the year by individual trajectories that curve in the opposite direction. Thus, for purposes of performing a SAMA analysis, which focuses on summed effects over time and space, taking into account hundreds of different wind patterns on a statistical basis, as done by MACCS2, is more than adequate.

Furthermore, it is important to consider the primary goal of the SAMA analysis, which involves weighting the concentration distributions by the population. Since the population is input as a single value over a 22.5° wind direction sector between two radial distances (usually a ten-mile increment, say from 20 miles to 30 miles), it follows that the details of the crosswind distribution of concentrations do not matter much. Of primary importance is the crosswind integrated concentration, which is obtained by integrating equation (2) across the y direction, i.e., the entire width of the plume. For example, if at some downwind direction, the concentration were a uniform 1 g/m^3 over a plume width of 1 km, and the population density (people per unit area) were constant, the crosswind integral would be the same as a situation with a uniform concentration of 0.1 g/m^3 over a plume width of 10 km.

Q49: Pilgrim Watch claims that the use of the Gaussian plume model for the Pilgrim SAMA analysis is inadequate because the ATMOS module cannot account for changes in meteorology during its simulation. Is this correct?

A49. (KRO) No. As explained in A33, the ATMOS module in MACCS2 uses a Gaussian plume segment model that takes into account hour-to-hour changes in meteorology as the plume moves across the 50-mile radius domain. During a multi-hour simulation of a plume released during a given hour, ATMOS assumes the plume moves in the same direction during subsequent hours; however, other meteorological conditions, such as wind speed, stability, and precipitation, are permitted to change from hour-to-hour. That is, in ATMOS, once a plume segment is released and moving over the polar coordinate grid, the wind speed, stability, and precipitation can vary on an hourly basis in accordance with the meteorological data input file.

Q50: Does the ATMOS module's use of a constant wind or plume direction for an assumed release make the use of ATMOS inadequate for purposes of SAMA analyses?

A50. (KRO, SRH) No. For purposes of a SAMA analysis one is interested in the mean annual consequences (i.e., off-site population dose and economic costs) occurring based on a year and over the potentially affected 50-mile radius SAMA domain. ATMOS takes into account different meteorological patterns on a statistical basis by performing multiple runs for each accident scenario for the numerous meteorological conditions that are characteristic of the Pilgrim environment. See A36 and A37. Therefore, ATMOS produces results based on a large number of representative weather events, specifically 2,336 results for the Pilgrim SAMA analysis, each weighted by the probability of the representative weather sequence and the wind direction. To calculate the expected or mean results, the model needs only to identify the likelihood of the plume reaching any portion of 50-mile grid and the corresponding air and land concentrations. MACCS2 achieves this goal by considering the results from 2,336 plume travel trajectories. Consequently, the details of a particular plume's trajectory do not have a material impact on the statistical expected value, or mean, of the overall SAMA analysis because the unique behavior in this wind trajectory for a specific plume will tend to be compensated by the trajectories of other plumes. The annual summed impact from all the weather sequences adequately approximates the likelihood of a plume reaching a location and its concentration at that location. Therefore, taking into account a multitude of wind patterns on a statistical basis, and probabilistically sampling from a full year of hourly conditions, as done by ATMOS, produces a reasonable estimate of the mean consequences – one that is sufficient for the SAMA application.

2. *Comparison to Other Models*

Q51: In your experience, have other atmospheric dispersion modeling software codes been used by nuclear power plant licensees to support their SAMA analysis relicensing efforts?

A51. (KRO) To the best of my knowledge, the MACCS2 code (and its predecessors), including the ATMOS module and its embedded Gaussian plume segment model, is the only software that has been applied to meet the consequence analysis portion of the regulatory requirements for a SAMA analysis. MACCS2-based results have been accepted by the NRC for PSA/SAMA applications, and have been used since the inception of SAMA cost/benefit determinations, including numerous coastal locations such as Pilgrim.

Q52: Pilgrim Watch and its expert Dr. Bruce Egan claim that there are more appropriate computer models and atmospheric transport and atmospheric dispersion methodologies for the Pilgrim site, such as those required by the EPA, e.g., CALPUFF, and AERMOD. Do you agree?

A52. (SRH) No, we disagree. First, there is nothing unique about the Pilgrim site that makes use of the MACCS2 code and the ATMOS module inappropriate for Pilgrim site. Second, using different codes for performing detailed modeling of individual plume transport and dispersion will not significantly improve the accuracy of the SAMA analyses, nor will it necessarily identify any new SAMAs.

Pilgrim Watch's claim of the need to use these models is but another example of its focus on individual plume tracking for the purposes of emergency planning as opposed to the long-term integrated consequences used for SAMA analyses. The codes referenced by Pilgrim Watch and its expert, Dr. Bruce Egan, (AERMOD and CALPUFF) were developed by EPA to better predict individual plume behavior in order to meet specific regulatory requirements of the Clean Air Act, which differ from the objectives of a SAMA analysis. The focus of the EPA applications is usually the maximum concentration at any location within the larger geographic domain being modeled. Also, in addition to long term annual averaged concentrations, EPA Clean Air Act applications require consideration of maximum short-term (e.g. one-hour, eight-hour and/or 24-hour, depending on the pollutant) averaged concentrations at a specific location. Modeling individual plumes for determining such worst-case scenarios at specific locations is distinctly different from the annual estimations and weighting by population and economic activity over a 50-mile radius required for a SAMA analysis. The short-term fluctuations in wind direction that may affect a single plume trajectory will cancel each other over a long period of time. Also, any local high concentrations, say on a hillside near the stack, have little effect on the summed concentration over the entire geographic domain.

Q53: May you explain this difference in EPA modeling further?

A53. (SRH) The Clean Air Act requires EPA to set National Ambient Air Quality Standards (NAAQS) for common pollutants from numerous and diverse sources. The Clean Air Act establishes two types of NAAQS – "Primary" standards to protect public health, including the health of "sensitive" populations such as asthmatics, children, and the elderly; and "Secondary" standards to protect public welfare, including protection against visibility impairment, damage to animals, crops, vegetation, and buildings. The purpose of the NAAQS Primary and Secondary standards for the protection of public health and welfare and the resultant dispersion modeling to implement that purpose differs from the purpose of NRC's SAMA analysis. Generally speaking, the required EPA modeling focuses on evaluating worst-case scenarios for purposes of establishing emission limits for the regulated pollutants (e.g., ozone, NO_2, SO_2, PM2.5, PM10, lead), especially limits for stationary sources of the emissions, such as a power plants and manufacturing facilities. The limits are often determined in part by the modeled maximum short-term concentration at a point anywhere on the domain. Codes such as AERMOD and CALPUFF were developed by EPA to provide estimates of maximum ambient air concentrations resulting from stationary sources, especially in the context of New Source Review (NSR).[17]

[17] In broad outline, the NSR program is a permitting process established by the Clean Air Act that requires a company to obtain a permit prior to construction if it proposes to build a new facility (or any modifications to existing facilities) that would create a significant increase of a regulated pollutant. Often, an applicant must obtain a Prevention of Significant Deterioration (PSD) permit, which is required for new major sources or a major source making a major modification under the federal and state NSR rules, an applicant, among other things, must perform an air quality impact analysis.

For example, EPA's NAAQS restricts emissions of carbon monoxide such that maximum concentrations at any downwind position do not exceed 9 parts per-million (ppm) based on an 8-hour rolling average time. The 8-hour standard is met when the 3-year average of the 4th-highest daily maximum 8-hour average does not exceed 0.075 ppm at any one monitor. Codes such as AERMOD and CALPUFF would also be used to predict the 8-hour average for the Prevention of Significant Deterioration (PSD) determination. Comparatively, SAMA analyses uses MACCS2 and ATMOS to predict long-term (annual) impacts summed over a broad geographic area (e.g., a circle with a radius of 50 miles) used for cost-benefit analysis.

Although AERMOD and CALPUFF can be used to develop annual averages over a broad area similar to MACCS2, they were specifically developed to perform the type of worst case analyses previously described. For example, AERMOD and CALPUFF require the user to specify the receptor locations where concentrations will be calculated, and specific important locations can be identified for evaluation, such as a school (i.e., a "sensitive population"). Additionally, both AERMOD and CALPUFF have a "postprocessor" that automatically searches through calculated hourly concentrations at all receptor locations across the domain and which selects the maximum concentrations (following NAAQS averaging times and other criteria) at the specific locations, plus identifying the maximum anywhere in the domain.

Q54: Please describe AERMOD's purpose and function, and how it differs from the Gaussian plume segment model used in ATMOS.

A54. (SRH) AERMOD is similar to ATMOS in that both are atmospheric transport and dispersion models. The AERMOD model was formally proposed by EPA in April 2000, and officially adopted in November 2005 as a replacement for EPA's previously approved model, the Industrial Source Complex (ISC) Short Term model.

The main purpose of this air quality impact analysis is to demonstrate that new emissions emitted from a proposed major stationary source or major modification, in conjunction with other applicable emissions increases and decreases from existing sources, will not cause or contribute to a violation of any applicable NAAQS or PSD "increment" (i.e., a sub-NAAQS budget level). Generally, the analysis will involve (1) an assessment of existing air quality, which may include ambient monitoring data and air quality dispersion modeling results, and (2) predictions, using dispersion modeling, of ambient concentrations that will result from the applicant's proposed project and future growth associated with the project.

The ISC model is a standard straight-line Gaussian plume model. AERMOD is one of EPA's preferred models for specific regulatory requirements and it includes features to model the effects of high terrain, which is important for determining maximum short-term averages of an hour or a few hours of pollutant concentrations at any location. AERMOD must be run for each hour of a multiyear period (5 years is recommended) as required under the Clean Air Act. However, its basic formulation is nearly the same as the earlier Gaussian plume models.

Concerning the scientific aspects of a comparison with ATMOS, AERMOD is a straight-line Gaussian plume model that incorporates updated treatments of several components, such as boundary layer profiles of wind speed and temperature, atmospheric stability, building downwash, and terrain impact. These enhancements enable direct calculation of the Gaussian plume dispersion parameters, σ_y and σ_z, based on meteorological inputs instead of using the Pasquill discrete stability classes and discrete mixing height values. But otherwise, the Gaussian plume dispersion formula is used (see Equation 2). AERMOD also includes features for modeling plume impact on high terrain and for modeling plume downwash due to building influences, referred to above.

While AERMOD has these features, it still assumes, like the straight line Gaussian plume model, that plume concentrations out to about 30 to 50 miles are simulated using the meteorological conditions observed during a given hour. Although some of the methodologies in AERMOD are more modern when compared to ATMOS, it produces nearly the same predictions as the earlier Gaussian plume models.

One important distinction is that although both utilize the same Gaussian crosswind shape or distribution model, as noted above ATMOS uses a Gaussian plume segment model while AERMOD uses a standard Gaussian plume model. As discussed previously, the segment model used in ATMOS allows meteorological parameters such as stability, wind speed, and precipitation to vary from hour-to-hour along the plume trajectory until it reaches the edge of the SAMA domain at a radius of 50 miles. The straight-line model used in AERMOD is not capable of modifying the meteorological parameters for a release at a certain hour to account for changes observed in subsequent hours. As a Gaussian plume model using standard stability classes and dispersion curves, the Gaussian plume segment model in ATMOS has been implicitly "fit" to basic field experiments such as Prairie Grass, which were also the fundamental field data set for the evaluation of AERMOD.

Q55: Please describe CALPUFF's purpose, function, and how it differs from the Gaussian plume segment model used in ATMOS.

A55. (SRH) Like ATMOS and AERMOD, CALPUFF is an atmospheric transport and dispersion model. The EPA's CALPUFF dispersion model is classified as a Lagrangian puff model. The term "Lagrangian" means that the center of the pollutant cloud or puff or plume is following the wind as it changes direction and speed over a multi-hour period. CALPUFF uses the CALMET meteorological processor, which develops 3-D time dependent meteorological fields across the geographic domain for use by the CALPUFF Lagrangian puff dispersion model.

When wind fields or stability classes are variable in time and space, the plume trajectory calculated using the CALMET outputs may be curved and the CALPUFF cloud may have variable dispersion rates, neither of which is considered in the standard Gaussian plume model, AERMOD. Considering these variations is important for EPA requirements where maximum concentration averaged over an hour or a few hours at any location in a broad area must be calculated for each hour during a multiyear period, as required under the Clean Air Act.

As discussed above, Lagrangian puff models, such as CALPUFF, model pollutant clouds as puffs, and calculate each puff's individual concentration and deposition as a function of distance and time. The CALPUFF model calculates the movement of each puff in steps of time that march forward from one time, t_1, to the next time, t_2, with time increment $\Delta t = t_2 - t_1$, which usually equals a few seconds near the source and increases to a longer time period at larger distances. It is assumed that the wind speed and direction and the stability and all other ambient conditions remain constant during this time increment Δt. The atmospheric dispersion of the puff during the time increment Δt is calculated assuming a Gaussian crosswind distribution. The total concentration and deposition at each time and location are calculated by summing the contributions from each puff that has an arbitrary non-zero impact. For example, at any given time, there may be a few puffs that are overlapping the receptor location.

The CALMET meteorological processor develops 3-D time dependent meteorological fields using observations from several locations in the domain. The resulting meteorological fields are used by the CALPUFF Lagrangian puff dispersion model. CALMET uses meteorological inputs, such as wind speed and direction and cloudiness, from several surface sites in the domain or area that has been defined for the modeling exercise. Weather data are also obtained from a few official National Weather Service (NWS) upper air sites, where meteorological variables are observed by a rising balloon. These NWS upper air sites are separated by about 200 miles across the United States. CALMET also uses inputs for the terrain heights and the land use. Terrain elevations, available in standard electronic files, are input to the model. The terrain data are used to parameterize slope flows and curvatures around mountain ranges and valley channeling. The model uses an interpolation and extrapolation method based on weighting each observation by the inverse square of the distance from the observation site to the point of interest. Using the upper air observations, the model also extrapolates the surface observations upwards in order to generate a full 3-D field. The CALMET outputs are used by CALPUFF to move the puffs around the domain and to determine their rate of dispersion.

CALPUFF is designed so that it reduces to a standard Gaussian plume model, such as ISC or AERMOD, in the limit of constant meteorological conditions in time and space across the geographic domain. Because all of these models have been calibrated with the same set of field observations, their accuracy is about the same.

Q56: Dr. Hanna, based on your experience and use of the codes suggested by Pilgrim Watch, do they provide more accurate or better results than ATMOS/MACCS2?

A56. (SRH) No. It is not necessarily true that more sophisticated or complex models will be better or more accurate models. ATMOS includes parameterizations of boundary layers and dispersion that were originally derived from fundamental dispersion field experiments, such as the Prairie Grass and Porton Down studies. Thus, like all models, ATMOS has been implicitly "fit" to these basic field experiments. Notably, AERMOD, CALPUFF, and most other models were calibrated with the same sets of field observations and, as a result, their accuracy is about the same.

I have been a continuing advocate of models that are as simple as possible but still capture the basic physics. Because of the fundamental turbulent variability of the atmosphere, models can never be perfect. For example, wind flow models have been found to have a fundamental random uncertainty of about 2 mph, or about 1 m/s, at best. Thus, once a model is able to provide predictions with this accuracy, there is no more sophisticated or complex model that would be capable of showing statistically significant improvements. Similarly, for dispersion models, we recognize a basic random minimum uncertainty that "can't be beat."

Q57: Have other experts in this field compared the results of complex codes, such as AERMOD and CALPUFF, to the ATMOS module?

A57. (SRH) Yes. Studies have shown that because all the models have been calibrated against, and produce similar agreement with available field data sets, the results taken from these models are similar. An extensive study by Molenkamp et al. (2004) (JNT000001), discussed below, showed that ATMOS/MACCS2 was able to predict concentrations within the same range as more complex Lagrangian models, these being ADAPT/LODI, RASCAL, and RATCHET.

RASCAL and RATCHET are Lagrangian puff models comparable to CALMET/CALPUFF. ADAPT/LODI is a Lagrangian particle model, which is similar to the RATCHET and CALPUFF Lagrangian puff models, but follows particles around the domain instead of puffs. Thus, just because a model is more complex than ATMOS does not mean that its predictions are "more accurate or better" than those of MACCS2/ATMOS.

Q58: Please discuss the Molenkamp et al. comparison of the results from the Gaussian plume segment model used in ATMOS and results from "more complex" models.

A58. (KRO, SRH) Molenkamp et al. (2004) (JNT000001) compared four NRC or DOE-developed atmospheric transport and dispersion models using one year of hourly-observed meteorological data from many weather sites in a large domain in the Midwest, referred to as the Southern Great Plains (SGP), centered on Oklahoma and Kansas. The general gradual slope of the SGP is upwards from the southeast to the northwest, with a total increase in elevation of about 607m (1991 ft) over a distance of 400 km (248.5 mi) for a mean slope of 0.15%. There are, however, many river valleys, hills and other irregularities in the terrain across the SGP domain.

This study compared the following models:

(1) A state-of-the-art, Lagrangian particle model, ADAPT/LODI. This model employs two modules – the ADAPT code used to estimate the wind field in three dimensions (3-D) based on thousands of weather observations throughout the region, and the LODI code used to estimate the gaseous and particulate material transport and dispersion. The ADAPT/LODI model system possesses the ability to take into account both terrain changes and time and space variability of weather.

(2) The MACCS2 model with its ATMOS module is the same model as used in the Pilgrim SAMA analysis. This model is described in Molenkamp et al. (JNT000001) as a one-dimensional straight-line Gaussian model that the NRC uses for estimating off-site consequences for a Probabilistic Safety Assessment (PSA) and for cost/benefit calculations.

(3) Two models, RASCAL and RATCHET, both of which use two-dimensional variations in meteorological inputs, with slightly different representations of dispersion and of deposition. The first code is RASCAL 3.0, which was used in NRC's Incident Response Center for response to radiological emergencies. The second code is RATCHET, which is similar to RASCAL but has more sophisticated dispersion and deposition modeling capabilities than RASCAL.[18] Both RASCAL 3.0 and RATCHET are Lagrangian puff models, similar to CALPUFF.

The evaluation included comparisons of simulated concentrations and deposition for the different arc sectors at a series of one-mile wide rings at various distances downwind over a distance of 100 miles from the hypothetical source location. The model results in the tables presented by Molenkamp et al. (JNT000001) for the one-mile wide rings represent averages over arc rings at nominal downwind distances, where the ring at that distance has a width of 1 mile and extends around the circle. For example, the 20 mile ring listed in the tables actually implies an average from 19 to 20 miles. It is important to note that there were no pollutants or tracers released and no observations of concentrations or depositions. Therefore the results presented by Molenkamp et al. (JNT000001) and further discussed below are strictly model-to-model comparisons.

The major conclusion by Molenkamp et al. (JNT000001) is “Nearly all the annual average ring exposures and depositions and a great majority of the arc sector values for MACCS2, RASCAL, and RATCHET are within a factor of two of the corresponding ADAPT/LODI values” (last sentence in abstract).

For comparison with the 50-mile radius area used in the Pilgrim SAMA analysis, the results for the annual average ring exposures and depositions for distances at 50 miles or less are of particular interest. Table 5 shows the series of results from Molenkamp et al. (JNT000001) for non-depositing species exposure, depositing species exposure, and deposition for one-mile wide arcs at downwind distances of 10, 20, and 50 miles. The listed numbers are based on information presented in Tables 14, 15, and 16 in Molenkamp et al. (JNT000001). For each downwind one-mile arc, the table shows the concentration exposure calculated by MACCS2, RASCAL, RATCHET and ADAPT/LODI and the ratio of the results of each to the ADAPT/LODI calculated result.

[18] At the time of this code-to-code study in 2004, the NRC was evaluating whether to incorporate some of RATCHET’s more advanced capabilities in a revision to RASCAL. The results from RATCHET discussed in the Molenkamp study and provided here refer to a developmental version of RASCAL that incorporates the dispersion and deposition modules from the original RATCHET code.

Table 5. Table Comparison of MACCS2, RASCAL, and RATCHET to the Three-Dimensional Model ADAPT/LODI. (Based on Tables 14, 15, and 16 from Molenkamp et al. (2004) (JNT000001)

Non-Depositing Species Arc Average Exposure (Bq-s/m^3) & Ratio to ADAPT/LODI							
Model	10 miles		20 miles		50 miles		Average of 10-, 20-, and 50-mile ratios
	Exposure (Bq-s/m^3)	Ratio	Exposure (Bq-s/m^3)	Ratio	Exposure (Bq-s/m^3)	Ratio	
MACCS2	8.02×10^7	1.58	2.39×10^7	1.01	4.77×10^6	0.64	1.08
RASCAL	7.32×10^7	1.45	3.09×10^7	1.30	8.41×10^6	1.12	1.29
RATCHET	3.24×10^7	0.64	1.33×10^7	0.56	3.59×10^6	0.48	0.56
LODI	5.06×10^7	1.00	2.36×10^7	1.00	7.49×10^6	1.00	1.00

Depositing Species Arc Average Exposure (Bq-s/m^3) & Ratio to ADAPT/LODI							
Model	10 miles		20 miles		50 miles		Average of 10-, 20-, and 50-mile ratios
	Exposure (Bq-s/m^3)	Ratio	Exposure (Bq-s/m^3)	Ratio	Exposure (Bq-s/m^3)	Ratio	
MACCS2	5.18×10^7	1.41	1.40×10^7	1.05	2.49×10^6	0.81	1.09
RASCAL	5.91×10^7	1.61	2.01×10^7	1.50	3.94×10^6	1.28	1.46
RATCHET	2.89×10^7	0.79	1.09×10^7	0.81	2.69×10^6	0.88	0.83
LODI	3.68×10^7	1.00	1.34×10^7	1.00	3.07×10^6	1.00	1.00

Arc Average Deposition (Bq/m^2) & Ratio to ADAPT/LODI							
Model	10 miles		20 miles		50 miles		Average of 10-, 20-, and 50-mile ratios
	Deposition (Bq/m^2)	Ratio	Deposition (Bq/m^2)	Ratio	Deposition (Bq/m^2)	Ratio	
MACCS2	5.57×10^5	1.21	1.53×10^5	0.96	2.87×10^4	0.78	0.98
RASCAL	7.20×10^5	1.56	2.34×10^5	1.46	4.71×10^4	1.29	1.44
RATCHET	3.10×10^5	0.67	1.06×10^5	0.66	2.63×10^4	0.71	0.68
LODI	4.62×10^5	1.00	1.60×10^5	1.00	3.67×10^4	1.00	1.00

For the closest arc-average results (i.e., at 10 miles), the comparison shows that the MACCS2 results were 58%, 41%, and 21% larger than the ADAPT/LODI results for non-depositing exposure, depositing exposure, and deposition, respectively. For the arc average results at 20 miles, the same comparison shows that the MACCS2 results are 1% larger, 5% larger, and 4% smaller. At 50 miles, the MACCS2 results are 36%, 19%, and 22% smaller.

The averages of the three arc average ratios of MACCS2 to ADAPT/LODI calculations for non-depositing exposure, depositing exposure, and deposition for the 10-mile, 20-mile, and 50-mile rings are 1.08, 1.09, and 0.98, respectively. A ratio greater than one means that the MACCS2 model results are larger than the ADAPT/LODI results, and a ratio less than one means that the MACCS2 model results are smaller than the ADAPT/LODI results. In other words, when averaged over all distances out to 50 miles, the agreement in arc average results between MACCS2 and ADAPT/LODI is better than plus or minus 10%.

The averages of the three arc average ratios of RASCAL to ADAPT/LODI calculations for non-depositing exposure, depositing exposure, and deposition for the 10-mile, 20-mile, and 50-mile rings are 1.29, 1.46, and 1.44, respectively. Therefore, the RASCAL results are larger than the ADAPT/LODI results by an average of about 40%. Similarly, the RASCAL results are slightly larger than the MACCS2 results. The average of the three arc average ratios for RASCAL to MACCS2 for non-depositing exposure, depositing exposure, and deposition for the 10-mile, 20-mile, and 50-mile rings is 1.20, 1.34, and 1.46, respectively.

The model most similar to CALPUFF, RATCHET, gives results that are somewhat smaller than the ADAPT/LODI results. The averages of the three arc average ratios of RATCHET to ADAPT/LODI calculations for non-depositing exposure, depositing exposure, and deposition for the 10-mile, 20-mile, and 50-mile rings are 0.56, 0.83, and 0.68, respectively. Therefore, the RATCHET results are smaller than the ADAPT/LODI results by about 31%. Similarly, the RATCHET results were smaller than the MACCS2 results. The averages of the three arc average ratios of the RATCHET results to the MACCS2 results for non-depositing exposure, depositing exposure, and deposition for the 10-mile, 20-mile, and 50-mile rings are 0.52, 0.76, and 0.69, respectively. Thus, in the Molenkamp et al. study (JNT000001), MACCS2 tended to predict slightly larger consequences relative to RATCHET, and predict slightly smaller consequences relative to RASCAL. However, as pointed out in Molenkamp et al.'s (JNT000001) conclusions, the differences are not large. It can be concluded that the four model results are quite similar.

While other results were reported in the Molenkamp et al. study (JNT000001), the four comparisons shown in Table 5 provide particular insight into the relative performance of the MACCS2 code relative to more complex models for obtaining mean annual results over a grid size comparable to that used in SAMA analysis. All of the arc averages and the great majority of the 192 arc-sector average exposures and depositions are within a factor of two when comparing MACCS2 to the state-of-the-art model, ADAPT/LODI. Similar comparisons of RASCAL and RATCHET to ADAPT/LODI also indicate that most exposures and depositions predictions by those models are within a factor of two of LODI's predictions.

Q59: Is it feasible to run the MACCS2 model using AERMOD or CALPUFF for the atmospheric and dispersion model in place of ATMOS?

A59. (KRO, SRH) Currently this is not feasible without significant changes and effort. One cannot simply plug AERMOD or CALPUFF into the MACCS2 code in place of the ATMOS module. Replacing the ATMOS module with AERMOD or CALPUFF or another meteorological model and dispersion model would be a very complicated process, particularly since neither AERMOD nor CALPUFF is designed to model radiological doses, including long-term doses. Software verification and validation, and other software quality assurance processes following such a change, as discussed below, would be time consuming as well as resource and cost-intensive.

Q60: Describe the complications involved with integrating a different meteorological and transport and dispersion model such as AERMOD or CALPUFF, into the MACCS2 code.

A60. (KRO, SRH) The modules used in MACCS2 are closely integrated and designed to work sequentially. Although ATMOS, AERMOD, and CALPUFF are all atmospheric transport and dispersion models, there are logistical, software, and technical interface issues that preclude interchangeability. MACCS2 is not designed to accept outputs from either AERMOD or CALPUFF, and those models are not designed to accept source emissions information from MACCS2. Replacing ATMOS with either AERMOD or CALPUFF would require development of an entirely new set of software for SAMA analysis. To integrate AERMOD or CALPUFF into MACCS2 would constitute a significant undertaking, on behalf of not only Entergy, but the NRC and the industry as well. First, the software codes are written in different languages and are not compatible. Second, new data and mathematical routines that share information would have to be written, and data input/output connections among modules would have to be reorganized. Third, software quality assurance testing, obtaining comparison to earlier results, documentation of user guidance, model descriptions, and other requirements would need to be completed. Fourth, training among licensees and regulators would need to take place. Fifth, a regulatory framework, with the necessary reviews and approvals, would need to be created and implemented, including new NRC standard review plans for the staff and industry guidance.

Thus, replacing the ATMOS module with AERMOD or CALPUFF would constitute an entire new modeling programming system that would require extensive work and testing to assure that the code as modified would work as intended. It took EPA about eight years to develop AERMOD and another eight years to evaluate and accept AERMOD as a regulatory basis for complying with EPA requirements. With the rollout of any new regulatory code, there is a need to extensively check the solution against previous versions and scenarios. And because all three models (ATMOS, AERMOD, and CALPUFF) are likely to produce similar results, having been calibrated against the same set of field data, such an effort is likely to, in the end, not make much of a difference.

B. Appropriateness of Pilgrim's Meteorological Input Data for the SAMA Analysis

1. Meteorological Data Inputs

Q61: Have you evaluated whether the 2001 meteorological data used for the Pilgrim SAMA analysis are representative and typical for the Pilgrim site and the region being modeled?

A61. (SRH) Yes, I have. I compared the 2001 Pilgrim annual wind roses to wind roses for other years from the Pilgrim site and the Plymouth Municipal Airport 2001 annual precipitation data to precipitation data for other years from the Plymouth Municipal Airport. Additionally, I compared these data from Pilgrim and Plymouth to data from other weather sites within the 50-mile region of the SAMA analysis. I also compared the Pilgrim 2001 annual average wind speed with those from the other weather sites. The results of my evaluation are in my Report (ENT000004).

Q62: What did you conclude from your evaluation?

A62. (SRH) My analysis of the meteorological data confirmed that the distributions of the annual wind rose (at Pilgrim) and the annual precipitation (at Plymouth) during the year 2001 are representative of other years at Pilgrim and Plymouth as well as other weather sites in the general area. I also concluded that the annual average wind speed at Pilgrim was at the low end of the range of the annual average wind speed at other sites for 2001, due to the location of the Pilgrim meteorological tower in an area with fields and trees. However, the MACCS2-simulated concentrations would be conservative due to the use of wind speeds that are smaller than those at most other sites in the domain.

Q63: How did you go about comparing the 2001 Pilgrim site wind rose data to wind rose data for other years from the Pilgrim site?

A63. (SRH) Using annual wind roses, I compared the 2001 annual frequencies of the winds by direction for the Pilgrim site to the annual frequencies of the winds by direction for the Pilgrim site for 1996 through 2000.

Q64: Please describe what a wind rose is.

A64. (SRH) A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind direction is distributed at a particular location and can be used to graphically depict the predominant transport directions of an area's winds. Figure 1, provided in A24 illustrates the polar coordinate system of gridding, and the 16 wind direction sectors used based on standard compass directions.

Figure 4 is an example of an annual wind rose for the Pilgrim 2001 data from the 33 ft level of the upper meteorological tower. These data were used as input to the SAMA analysis. The frequencies of hourly-observed winds over the year 2001 are plotted for the 16 compass directions: N (north), NNE (north northeast), NE (northeast), ENE (east northeast), E (east), ESE (east southeast), SE (southeast), SSE (south southeast) S (south), SSW (south southwest), SW (southwest), WSW (west southwest), W (west), WNW (west northwest), NW (northwest) and NNW (north northwest). In this wind rose and in the Report (ENT000004), it is assumed that a N (north) wind is a wind blowing towards the north. Color bands are used to show the ranges of wind speed for each direction. The direction of the rose petal with the longest spoke is the wind direction with the greatest frequency.

In the wind roses, a given "wind direction" is actually a wind direction sector. Since there are 360 degrees in the entire circle and there are 16 "wind directions," each wind direction sector has angular width 360/16 = 22.5 degrees. Thus, any hourly-observed wind direction within that 22.5-degree sector is assigned to that sector designation (e.g., NE, NNE, etc.).

The 2001 wind rose for the Pilgrim 33 ft level (Figure 4) shows that the predominant wind directions for the Pilgrim site for 2001 were towards the quadrant from north to east. The wind rose shows that winds traveling in the north-northeast direction had the highest frequency of occurrence, about 16%; that winds traveling in the northeast direction had the second highest frequency of occurrence, about 12%; and that winds traveling in the east-northeast direction had the third highest frequency of occurrence, of about 10%. The wind direction with the lowest frequency of occurrence for 2001 (somewhat less than 3%) was to the north-northwest.

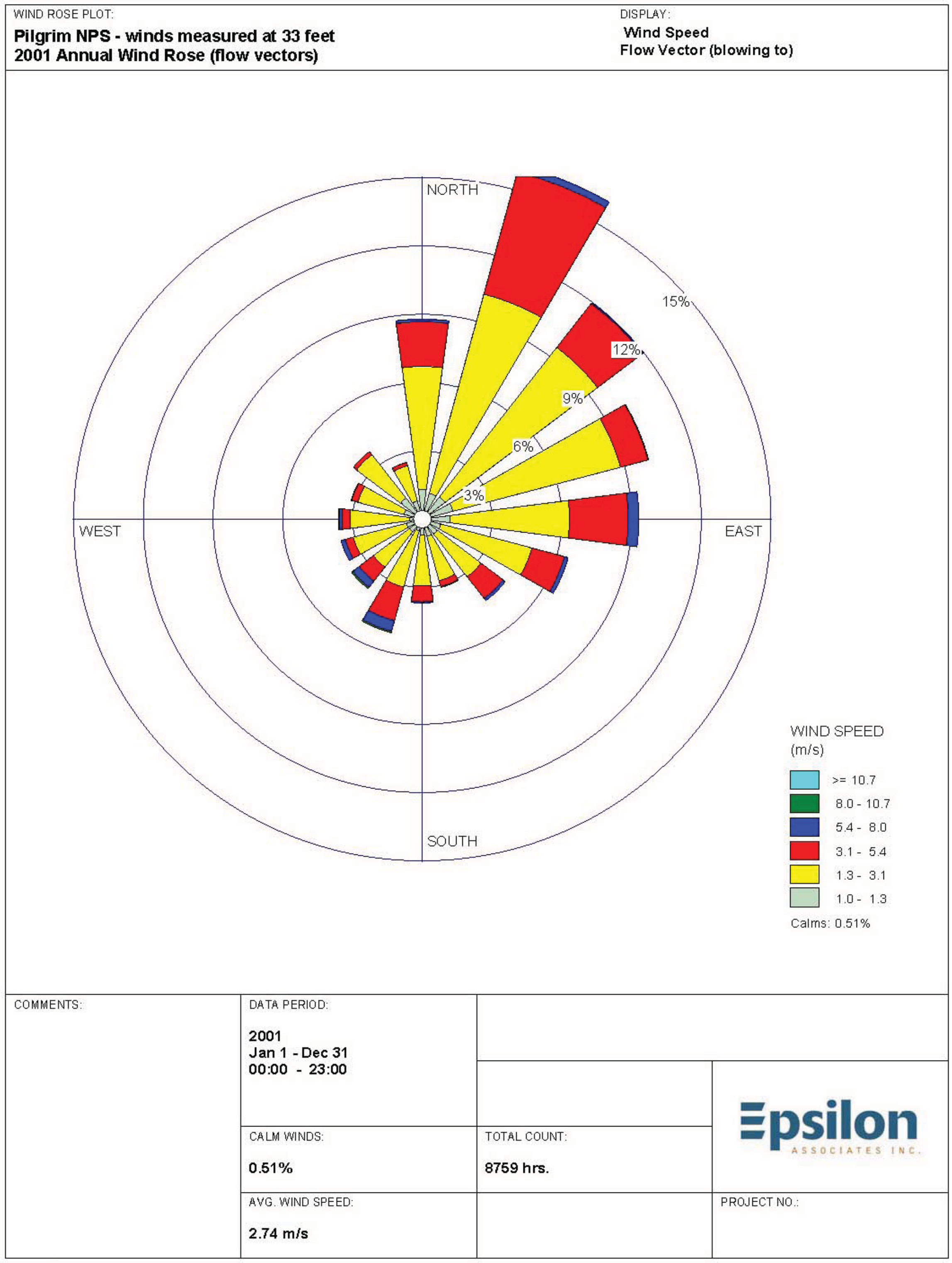

Figure 4. Annual wind rose for the Pilgrim 33 ft level for 2001.

Q65: What did you conclude from your comparison of the 2001 Pilgrim annual wind rose to the annual wind roses for 1996-2000?

A65. (SRH) I concluded that the 2001 Pilgrim annual wind rose is reasonably representative of the annual wind roses from the other years at the Pilgrim site. In meteorology, the term "representative" means that a certain meteorological observation at a specific location and for a specific time period is "within the normal expected range."

I evaluated the representativeness of the Pilgrim 2001 annual wind rose both qualitatively (viewing the annual wind roses for 1996-2001 for similarities and differences) as will as quantitatively. The wind roses for all six years are provided in Appendix A of my Report (ENT000004). A visual comparison of the other five wind roses to the 2001 wind rose shows that the six annual wind roses look "visually" very similar. The relative occurrence of high and low frequencies at a particular direction from year to year is similar across the different years. The predominant directions for all the years are the directions to the quadrant from north to east.

Furthermore, a quantitative comparison in Table 3 of the Report (ENT000004) shows that, more than half of the time, the percentage that the wind is blowing towards any of the direction sectors varies by less than 1% from year to year, and has a maximum variation of 3% for the sectors towards the NNE. Table 3 of the Report (ENT000004) also shows that the number of times that a year has the maximum or minimum over the 16 sectors varies somewhat from year to year, and that there is no year that stands out as a major outlier. The numbers for the year 2001 are within the range of statistical expectation. In fact, out of the six years, 2001 has the fewest cases of having a maximum or minimum.

Thus, it is concluded that the 2001 annual wind rose at the Pilgrim Station is representative of other years.

Q66: Please describe the evaluation that you performed to determine the representativeness of the 2001 Pilgrim annual wind rose for the 50-mile radius geographic region for which the SAMA analysis was performed.

A66. (SRH) In order to evaluate whether the Pilgrim 2001 annual wind rose derived from the meteorological input data used for the SAMA analysis was representative of the 50-mile region, I obtained hourly wind data from other weather observing sites within 50 miles of Pilgrim and used the data to generate figures containing annual wind roses. The purpose for doing this comparison was to ensure that there are no significant shifts in annual wind roses at other locations that might suggest that the SAMA plume travel directions around the circle based on the Pilgrim data were not representative of the total domain.

To perform this evaluation, we considered meteorological data for 2001 available from about 30 weather sites in the archives of the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). We focused on sites within or just outside the 50-mile radius circle surrounding the Pilgrim plant. The NCDC archives meteorological data from all "official" weather sites in the U.S. (and in the world) and these data are retained for the period of record (sometimes many decades). Table 1 of my Report identifies the surface weather station sites for which we obtained certified NCDC meteorological data and the 13 for which we performed a wind rose comparison to the Pilgrim 2001 annual wind rose. The Table also indicates which sites were used in the CALMET analysis (described later in answers A92 through A105). We did not use NCDC sites for which less than 50% of the data were available for the year 2001. In addition to the NCDC land sites, we obtained from the NCDC the hourly meteorological observations from the Boston Approach Buoy, which is in the Atlantic Ocean about 28 miles north of the Pilgrim Station and is about 15 miles east of Boston Logan airport. This is an official NOAA site. We also obtained data from two NOAA buoys far outside of the 50-mile circle, but these were used only for the CALMET analysis.

Besides the certified NCDC data, we obtained meteorological data from the Wind Energy Program of the Renewable Energy Trust of the Massachusetts Technical Collaborative. They operate a wind network in eastern Massachusetts and use the data for wind energy planning. Although no data from this network are available from 2001, there are a few sites close to the Pilgrim Station and along the coast between Pilgrim and Boston (Kingston, Scituate, and Quincy) that have data available for 2006-2007. We generated annual wind roses for those sites for use in our evaluation.

Finally, we searched a list of special coastal sites operated by WeatherFlow, a private company who provides coastal weather data (mostly from sites within a short distance of the sea) to subscribers primarily for use by sailors and windsurfers. Data from a site adjacent to the beach in Duxbury for 2001 were available and were acquired and used for the evaluation. This site is located 8.5 miles NNW of the Pilgrim Station.

In total, annual wind rose comparisons to the 2001 Pilgrim annual wind rose were done for 18 weather sites. Figure 9 of my Report (ENT000004) identifies the location of the sites for which an annual wind rose comparison to the Pilgrim 2001 annual wind rose was performed. These sites are spread throughout the 50-mile SAMA region. Plymouth Municipal Airport, Kingston, and Duxbury are within 8.5 miles of the Pilgrim Station, and all but one of the others are scattered relatively uniformly over the land portion of the domain. The only overwater site is the Boston Approach Buoy, although many of the "land" sites are very close to the coast, including several on Cape Cod. There are a few major sites (such as Boston Logan Airport and East Milton (Blue Hill)) that have data records extending back more than 100 years.

After plotting annual wind roses from these various sources, we compared them with the onsite annual wind rose from 2001 for the 33 ft level of the Pilgrim meteorological tower.

Q67: What were the results of your evaluation?

A67. (SRH) We used both visual and quantitative comparisons to evaluate the various wind roses compared to the Pilgrim 2001 wind rose. Appendix B of my Report (ENT000004) contains figures of the annual wind roses for each site that was included in the comparison; the figure for each site provides a direct comparison of the annual wind rose for the other site to the Pilgrim 2001 wind rose (with the Pilgrim wind rose on the left and the wind rose for other site on the right). Additionally, Figure 10 of my Report (ENT000004) provides a direct visual comparison of the wind roses from Pilgrim and from Plymouth Municipal Airport in the same format used in Appendix B. It is easy for the eye to "see" that the 18 wind roses from the other sites "look" similar to the 2001 Pilgrim annual wind rose. They all have predominate winds blowing towards the eastern sector, and far fewer winds blowing towards the western sector.

These visual comparisons of the 2001 annual Pilgrim wind roses to the wind roses for the other sites indicate that the Pilgrim 2001 wind direction data are reasonably representative of the 50-mile SAMA region. None of the wind roses from these other official weather sites in the region show significant changes in the predominate wind direction distributions from the 2001 Pilgrim wind rose that suggests any substantively different weather pattern away from the Pilgrim site that would affect the travel of the plume so as to significantly affect the SAMA analysis. Such visual comparisons are often made in meteorological evaluations to evaluate the representativeness of meteorological data.

Q68: You also referred to quantitative evaluations performed of the wind roses. Please describe the quantitative evaluation that you performed and the results and conclusions drawn from the evaluation.

A68. (SRH) A quantitative evaluation was performed for the wind roses discussed above (Pilgrim 33 ft plus 18 other sites spread throughout the region).

For the quantitative evaluation, Table 4 of my Report (ENT000004) identifies the percentage of the wind direction towards each of the 16 wind rose petals (direction sectors), for each site. Additionally, Table 4 shows the range for the non-Pilgrim sites of the fraction or percentage of wind blowing towards each wind rose petal, or direction. Table 4 also identifies the site that has the minimum frequency for each direction and the site with maximum frequency for each direction.

From this quantitative evaluation, it is seen that no one site in the table predominates. Each site has zero to four “maxima” or “minima” in various 22.5-degree direction sectors, and with one exception (SE), the Pilgrim wind direction frequency by sector is within the range of the other 18 sites. Furthermore, while there are some anomalies in the frequencies for certain 22½ ° wind direction sectors, when summed over several adjacent sectors, these anomalies are greatly muted. Table 5 of the Report (ENT000004) shows the sum of the wind direction frequencies of wind directions towards the S clockwise through the NNW for each site. This 180° hemisphere sector represents winds blowing towards the west, where nearly all of the population is located. As expected from the known dominance of winds towards the east in all wind roses, the summed frequency towards the western half of the circle ranges from 25.8% to 37.4% with an average of 31.2%. The Pilgrim 33 ft value is 29.4%, slightly below the average and well within the range.

Thus, the statistical behavior of all the sites is similar, and the Pilgrim site wind direction frequencies are within the range of statistical expectation for the other 18 sites.

Q69: What do you therefore conclude from your comparison of the 2001 Pilgrim annual wind rose with annual wind roses from other weather sites within the 50-mile SAMA analysis region?

A69. (SRH) I conclude that there is no significant difference in annual wind direction patterns at different locations in the region. My conclusion is based on the fact that all of the 2001 annual wind roses have the same basic distributions, with most winds blowing towards the north to east quadrant. Winds blow towards the south to west quadrant less frequently, and even fewer winds towards the west to north quadrant. There are some shifts from one site to the other as would be expected over the domain of this size, but the fundamental characteristics are the same. There is no change in annual wind directions that would significantly affect the Pilgrim SAMA analysis.

Q70: Please describe the evaluation that you performed to determine the representativeness of the 2001 Pilgrim annual wind speed for the 50-mile radius geographic region for which the SAMA analysis was performed.

A70. (SRH) The wind roses for the 33 ft level of the Pilgrim site and for the other 18 sites in the SAMA domain described above contain the average annual wind speed (calculated without accounting for calms) in a block in the lower left of the figure. The wind roses themselves indicate different colors on the direction petals for different wind speed ranges. In Table 6 of my Report (ENT000004), we compare the average annual wind speeds (calculated so that calms are accounted for) of the 19 sites. It is seen that the Pilgrim Station annual average wind speed, at 2.73 m/s, is the smallest of the group by about 0.06 m/s (the Norwood annual average wind speed is 2.79 m/s). The average of the 18 "non-Pilgrim" annual wind speeds is 3.79 m/s and the range is from 2.79 m/s at Norwood to 5.62 m/s at East Milton Blue Hill Observatory. However, it is easy to explain the slightly smaller annual averaged wind speed at the Pilgrim site because it is in an area of fields and trees whereas all of the other sites are in flat open airport environments, on tall towers in open areas (the Massachusetts Energy sites), on a hilltop (East Milton Blue Hill Observatory), on the beach (Duxbury), or surrounded by open ocean (Boston Approach Buoy).

When we use standard atmospheric boundary layer wind formulas to estimate the "effective" Pilgrim 33 ft wind speed as if it were over a flat airport, that effective wind speed is in the range of the others.

More importantly for the SAMA analysis, use of the slightly lower wind speed at Pilgrim is conservative because, as discussed in A28 above, concentrations are always approximately inversely proportional to wind speed (that is, if wind speed increases by about 10%, concentrations decrease by about 10%). Here the average wind speed for the non-Pilgrim sites is about 1 m/s (about 37%) greater than the 2001 Pilgrim 33 ft annual wind speed used in the SAMA analysis, which suggests a conservatism of about 37% in the Pilgrim SAMA analysis due to the smaller wind speeds used in the analysis.

Q71: Please describe the evaluation that you performed to determine the representativeness of the 2001 Plymouth Municipal Airport annual precipitation data used in the Pilgrim SAMA analysis.

A71. (SRH) To evaluate the time and space representativeness of the Plymouth Municipal Airport annual precipitation data, we obtained precipitation data from NCDC for nine sites in the 50-mile SAMA region for the years 1995-2009. The nine sites for which data were obtained are Plymouth, Boston Logan, Taunton, Brockton, East Wareham, Hingham, Middleboro, New Bedford, and Rochester. These nine sites were chosen because they are spread over the region of interest. Figure 2 of my Report (ENT000004) depicts the location of these nine sites in comparison to the Pilgrim site and the 50-mile SAMA analysis region.

Q72: What were the results of your evaluation?

A72. Figure 11 in my Report (ENT000004) shows the annual precipitation for Plymouth Municipal Airport for 1995 through 2009 (except for two years for which more than one month of data is missing) and the annual precipitation for the other eight sites for the same period. The Figure shows that the 2001 precipitation for Plymouth (used for the SAMA analysis) is (1) about in the middle of the annual precipitation for Plymouth for the other years between 1995 and 2009, and (2) also about in the middle of the annual precipitation for the other eight sites for 2001 and for the 15 year period of 1995 to 2009. Thus, the 2001 annual precipitation from Plymouth is not an outlier in time or in space. It is reasonably representative of the 2001 annual precipitation for the area, and it is reasonably representative of the 15-year time period for the area.

2. <u>Coastal Breezes</u>

Q73: Pilgrim Watch claims that the Pilgrim SAMA analysis inadequately accounts for sea breezes because of its reliance on meteorological data from a single site and use of the Gaussian plume methodology. Do you agree?

A73. (SRH, KRO) No, we do not agree with Pilgrim Watch that the SAMA analysis inadequately accounts for sea breezes. Pilgrim used wind data gathered from its on-site meteorological towers for the MACCS2 portion of the SAMA analysis. Both the primary and backup data collection towers are located less than ¼ mile from the coastline. If there is a coastal breeze on-site, it is recorded by the on-site meteorological towers and has been included as part of the MACCS2 calculation. Thus, the 2001 Pilgrim hourly meteorological data used in the SAMA analysis captures the coastal breeze effect, including any sea breeze blowing inland during the day and any land breeze blowing offshore during the night.

Furthermore, as we discuss below, the sea breeze and land breeze are seasonal, localized effects that occur only a fraction of the year with average inland and offshore penetrations of up to 10 miles or so. The localized effects of sea breezes onto land during the day are typically offset by offshore land breezes at night. In other words, for each change of wind direction caused by a sea breeze during the day, there is often an opposite change of direction caused by the land breeze at night. Therefore, when calculating the long term annual conditions in a SAMA analysis, these effects would likely approximately cancel out.

Q74: As requested by the Atomic Safety and Licensing Board (the "Board"), please describe the spatial and time-dependent patterns of the coastal breeze phenomenon.

A74. (SRH) Coastal breezes are generated by differences in land and water surface temperatures, which cause differences in surface pressures. Sea and land breezes are thermal circulations resulting from the presence of relatively lower pressures over the warmer surface and higher pressures over the cooler surface. This pressure differential exerts a force that causes the air near the surface to try to flow from high to low pressure. However, the exact wind direction depends on many factors. During mid-summer at the Pilgrim Station, the water temperature is typically about 65° to 70°F, with little day-night variation. The land temperature on a typical summer day is 80°F in the afternoon and 60°F at night. Thus, during the day this temperature and pressure difference may cause air flows from sea to land (sea breeze) and during the night, it may cause air flows from land to sea (land breeze). The coastal breezes occur as long as the local pressure difference is strong enough to overcome the prevailing larger scale pressure gradients, which generally cause the "synoptic wind," which is the larger scale wind. For example, if there is a 20 mph synoptic or large scale wind from the west blowing across New England on a hot summer day, it is unlikely that a sea breeze will be evident along the coastline.

Thus, the existence and the timing and strength of the coastal breezes and their penetration distance from the coast depend on several factors. These include mixing height, regional air temperature, mixed layer stability, synoptic wind speed (due to the regional pressure gradients and flows), coastal orientation, and other meteorological factors. Also, due to the turning of the earth on its axis, there is an additional apparent force (the Coriolis force), which causes a slow turning of the sea or land breeze directions over a few hours.

As stated in the previous paragraph, coastal breezes caused by the land-water pressure differential can be offset by the general large-scale pressure field and resultant synoptic winds. Thus, there are a limited number of days per year where coastal breezes could occur, are not offset by synoptic winds, and are noticeable. For example, the thermal gradient may cause a sea breeze component with a 1 mph wind speed inland, but this cannot overwhelm a 10 mph synoptic offshore flow. The net result is that the 10 mph offshore wind is reduced to 9 mph. The same thing happens with land breezes, but less frequently since the annual wind roses (see Figure 4) show that most synoptic wind directions at Pilgrim (and most other northeastern U.S. locations) are from the west (or offshore at Pilgrim).

Because of the limited range of the thermal circulations resulting from the land-water pressure differential and the offsetting synoptic winds, sea and land breezes usually do not extend more than a few miles from the coast. On days with significant sea breezes, they average about 5 to 10 miles inland penetration, with occasional larger values of up to 30 miles or so, and smaller values as little as only a few 100 feet. At the distance where the sea breeze stops there is a vertical motion upwards that sometimes leads to clouds, and at a height of 2000 or 3000 feet, there is a return flow back to the coast. At the coast, or slightly offshore, there is a downward motion to complete the sea breeze circulation. During nighttime land breezes, the direction of the circulation reverses.

The standard sea and land breeze cycle occurs in the late spring and summer along the New England coast, when daytime land temperatures are usually warmer than the ocean temperatures. But for the other half of the year, from late fall to winter, when daytime temperatures are usually cooler than ocean temperatures, there is more likely a land (offshore) breeze generated. The SAMA analysis covers the entire year and thus includes both types of daytime coastal breeze phenomena.

Q75: As requested by the Board, what is the frequency of occurrence of coastal sea and land breezes?

A75. (SRH) As described above, sea and land breezes occur for a limited number of days during the year, depending on many meteorological factors. Spengler et al. (1978) (referenced by Pilgrim Watch) analyzed several summer months at the Pilgrim site and estimated that the Pilgrim coastal area experiences about 45 days per year during the summer months where the thermal gradient is sufficient and the synoptic winds are weak enough for a noticeable sea breeze. The durations of the observed sea breezes were a few hours, which is typical for sea breezes. Other studies show similar results.

Usually days with a noticeable sea breeze (blowing inland) are days with light synoptic winds, and therefore there is also an opposing land breeze (blowing offshore) at night, which is often stronger. Considering that these winds are also turning with time, over the day the various wind directions will cancel each other especially when performing an annual mean evaluation as done in SAMA analyses.

Q76: Based on your experience, how do coastal breezes impact radiological doses and plume dispersion?

A76. (SRH) Coastal land and sea breezes are a type of mesoscale or medium range phenomena that lead to relatively slow (over an hour or two) fluctuations in wind speeds and directions over 90° to 180°. Therefore, they would be likely to increase lateral dispersion and reduce concentrations and dosages at specific locations near the centerline of the plume over a given time period ranging from one to several hours. Accordingly, for a period of time up to about a day, because of the broad (as much as 180 °) variations in wind direction during a coastal breeze episode, sea and land breezes are not a concentrating phenomenon (increasing the maximum plume centerline concentration). Rather they are a dispersive one (lowering the maximum plume centerline concentration and thereby lowering projected dose at that location and for that time period). Thus, for applications such as the SAMA analysis, the sea breeze phenomenon generally has the beneficial effect of decreasing doses at specific locations where the maximum concentration would occur and for specific time periods rather than increasing them. Over the whole year and over the whole SAMA geographic domain, though, the coastal breeze phenomenon would have little net effect.

Q77: You stated that the Pilgrim SAMA analysis accounted for sea breezes by virtue of the fact that coastal breezes are included in the Pilgrim 2001 meteorological data that were used as inputs to the MACCS2 model. How did the Pilgrim SAMA analysis use the coastal breeze data?

A77. (KRO) As stated, coastal breezes, including sea and land breezes, were captured by the Pilgrim on-site meteorological tower during 2001 and were therefore included as part of the MACCS2 calculation. Moreover, because the Gaussian plume segment model in MACCS2 does not vary wind direction once a plume release has occurred, MACCS2 would in fact treat sea breezes conservatively as if, once a plume was released during a specific hour with a specific wind direction, it would proceed in that direction for the entire 50-mile range. However, as mentioned in A74, sea and land breeze effects are generally localized within 10 miles of the coast. In other words, while a typical sea breeze would penetrate inland about 10 miles or less, MACCS2 would model any plume initiated during a sea breeze event as continuing to travel in the same direction out to 50 miles, and thus would model these plumes as reaching the more heavily populated inland areas. As discussed in Answer A43, approximately 83% of the SAMA off-site population dose consequences occur in the 20 to 50 mile range from the Pilgrim plant. Accordingly, the Pilgrim SAMA analysis conservatively accounts for the sea breezes by assuming that they had impacts throughout the 50-mile range, and not just the 10-mile range near the coast where such breezes might be localized.

Q78: Pilgrim Watch has suggested that sea breezes may *increase* concentrations for coastal locations because they may draw contaminants inland that would otherwise be directed offshore or be carried aloft, thereby subjecting inhabitants of coastal communities to larger doses. What is your response?

A78. (SRH) Pilgrim Watch hypothesizes specific short-term scenarios for which the ability to track an individual plume and determine concentrations and depositions at specific locations are important, as would be the case for emergency response or for EPA air permit applications. However, the Pilgrim SAMA analysis is focused on expected annual consequences integrated over an area with radius 50 miles, based on use of one year of hourly meteorological data. While over the course of a year it is possible that a hypothetically simulated plume during one or two hours could be redirected onshore by an individual sea breeze, thereby increasing impacts, it is also true that a hypothetically simulated plume during another hour could be redirected offshore by an individual land breeze yielding no impacts. Because the SAMA analysis simulates postulated plume travel based on weather scenarios experienced over the course of a year, which includes both sea breezes and land breezes, there is little net change on an expected annual basis over a broad area.

Q79: Pilgrim Watch also claims that inclusion of sea breeze data in the Pilgrim site meteorological file is inadequate because coast line orientation and topography strongly influence wind patterns, such as frequency and direction and strength of onshore winds and therefore, because sea breeze is highly temporal and spatially dependent, meteorological data from additional sites are necessary. Do you agree?

A79. (KRO, SRH) No. The Pilgrim data are adequate for purposes of SAMA analysis which sums population dose and economic consequences over a broad area (50-mile radius domain) and over a long time frame (approximately 30 years) from characterization of a year of meteorological data from the Pilgrim region. Pilgrim Watch again is focused on modeling or tracking of individual plumes that is of concern for emergency response or worst-case purposes, but which is completely different from the function of SAMA analyses.

As described in A67-A69, the comparisons of annual wind roses for other coastal sites show that, on an annual basis for purposes of a SAMA analysis, the Pilgrim site's observed wind directions for 2001 are representative of other coastal sites.

Other sites near the coast that were part of the wind rose evaluation in the Report (ENT000004) are Kingston, Duxbury, Scituate, Quincy, and Boston (to the north) and New Bedford, Otis, and Chatham (to the south). The coast near these sites has a variety of orientations, nearness to bays or beaches, and nearness to local hills. Comparison of the 2001 annual wind roses for these sites with the Pilgrim 2001 annual wind rose show that the annual wind patterns for these sites are closely similar to those for the Pilgrim site. See Report (ENT000004) at B-19 (Kingston), B-22 (Duxbury), B-21 (Scituate), B-20 (Quincy), B-13 (Boston), B-8 (New Bedford), B-6 (Otis), and B-12 (Chatham). With regards to the four weather sites around Plymouth Bay (Pilgrim Station, Plymouth, Kingston, and Duxbury), the Report (ENT000004) also shows that there are no significant variations in the annual wind roses. See Report (ENT000004) at B-4 (Pilgrim), B-7 (Plymouth), B-19 (Kingston), and B-22 (Duxbury). Moreover, comparisons of the Pilgrim 2001 annual wind rose to inland sites, beyond typical sea breeze range such as Taunton, shows that there is little net change from the Pilgrim 2001 annual wind rose used in a SAMA analysis. See Report (ENT000004) at B-11 (Taunton).

Thus, the 2001 annual wind roses show no dramatic differences that would affect the long term and broad area impacts produced by a SAMA analysis. The locally temporal and spatial dependencies of individual sea breezes average out over the year so as not to affect the results of the SAMA analysis.

This is further confirmed by the CALMET trajectory analysis (referred to earlier and fully discussed in Section IV.C.2 below). The CALMET trajectory analysis used the observed winds from 26 official near-surface and two official radiosonde (upper air) sites on the or near the SAMA domain to generate a best-fit wind field for use in calculating the trajectories. As fully discussed in Section IV.C.2 below, there are only small differences between the 2001 Pilgrim annual wind rose and the 2001 CALMET-generated annual trajectory rose at various distances from the Pilgrim Station. This serves to demonstrate and further confirm that occasional sea or land breeze observations at specific sites have only a minor effect on the full year of wind observations over the domain.

Q80: Please discuss the Board's questions regarding the radioactive deposition distribution caused by each individual occurrence of a sea breeze and how it would differ from that expected using a straight-line Gaussian plume model, and the resultant cost differential.

A80. (KRO, SRH) The SAMA analysis performed for Pilgrim does not focus on or produce outputs of the calculation of individual radioactive deposition results from a single occurrence of a short-term weather phenomenon. Rather, the SAMA cost-benefit analysis sums population dose and economic consequences across a 50 mile radius based on one-year's worth of hourly meteorological data. As such, MACCS2 considers the entire year's worth of meteorological data collected, which in the case of the Pilgrim SAMA analysis includes all coastal breezes. Since deposition is in general proportional to concentration, our statements above regarding concentration are applicable to deposition.

Furthermore, the deposition that would occur from an individual sea breeze occurrence is conservatively accounted for in the SAMA analysis. As described in A74, sea breezes are localized phenomena that generally occur within 10 miles of the coast. As a result, any deposition impacts from a typical single sea breeze would generally be limited to 10 miles inland. Nevertheless, MACCS2 treats all winds, including sea breezes, as prevailing winds that travel the entire 50-miles considered in the SAMA analysis, not merely 10 miles in the case of coastal breezes. Therefore, the actual deposition distribution impacts caused by an <u>individual</u> sea breeze occurrence would be less than the deposition distribution impacts calculated by a straight-line Gaussian plume segment model.

(SRH) Finally, sea breeze is a limited phenomenon. Coastal sea and land breezes occur only about forty or fifty days per year, very roughly about 10 to 15% of the year, and for a limited duration of about 6 hours on each day. Moreover, for every day when there is a sea breeze blowing on shore, during the same day there is typically a nighttime land breeze blowing offshore – and the effects would be balanced over an annual period. Thus, the resulting cost differential from considering radioactive deposition distributions of individual coastal breezes would be negligible due to their relative infrequency and the resulting averaging effect of sea and land breezes over the course of a year. This fact is confirmed by the CALMET trajectory analysis discussed in Section IV.C.2 below.

Q81: Based on your understanding of coastal breezes and the Pilgrim SAMA analysis, are there any aspects of the coastal breeze phenomenon that the Pilgrim SAMA analysis failed to take into account that could lead to additional SAMAs becoming cost beneficial?

A81. (KRO, SRH) No. This answer is based on the fact that (1) the SAMA analysis is interested in expected consequences over a 50-mile radius domain based on a year of weather data and not the tracking of individual plumes; (2) on an annual basis, sea breezes during the day are generally offset by land breezes at night; (3) Pilgrim's hourly meteorological observations included coastal breezes to the extent that they existed in 2001; and, (4) coastal breezes are dispersive over a several-hour period. Thus, we conclude that Pilgrim's SAMA analysis adequately takes coastal breezes into account, and that these breezes would not significantly alter the overall impacts estimated by MACCS2 and the conclusions regarding those SAMAs that are potentially cost-beneficial.

3. Hot Spots and the Treatment of Plumes Blowing out to Sea

Q82: Pilgrim Watch argues that the Pilgrim SAMA analysis improperly ignores plumes headed out to sea because the plumes will remain tightly concentrated due to reduced turbulence over the ocean until the wind blows the plumes back over land leading to "hot spots." Can you please comment on Pilgrim Watch's claims?

A82. (KRO, SRH) Pilgrim Watch's hot spot claims are both technically incorrect and immaterial. The claim that the plume will remain tightly concentrated over water is based on a fundamental misunderstanding of atmospheric dispersion. As explained below, plumes in the atmospheric boundary layer always disperse significantly and never remain "tightly concentrated." Even under very stable conditions, for a plume released at a height of 10 m (33 ft), the plume centerline concentration at ground level will decrease by a factor of approximately 45 from its peak (which occurs at a distance of 0.3 to 0.4 km (0.19 to 0.25 mi) from the source) by the time it reaches a distance of ten km (6.2 miles) from the source.

More generally, Pilgrim Watch's hot spot claims are irrelevant for SAMA analyses. Its claims are based on a single plume and set of weather conditions occurring during a limited period of time. As our testimony addresses, the SAMA analysis is not focused on tracking individual plumes. Rather, the focus is on the mean or expected consequences over a large domain for a set of 19 postulated accident scenarios (obtained from the Pilgrim PSA) for many different weather sequences occurring over a year. The results identify the annual expected consequences for the set of accident scenarios in order to perform a cost benefit analysis. Whether or not the SAMA analysis can predict infrequently occurring speculative plume concentrations as a result of hypothetical weather conditions is irrelevant to this analysis.

Q83: Please comment generally on the technical validity of Pilgrim Watch's claim of "hot spots" allegedly caused by plumes remaining "tightly concentrated" due to reduced turbulence.

A83. (SRH) The use of the term "hot spots" is inappropriate and a misnomer because plumes travelling over land and water behave generally the same and always disperse significantly as they travel. As plumes disperse, their centerline concentrations always decrease. The greater the distance travelled, the greater the dispersion and hence the less concentration on the plume centerline.

It is well recognized that concentrations (C) at ground level on the center of a plume released from near ground level will decrease with travel distance (x) between distances x_1 and x_2 at approximately the following relation:

$$C_2/C_1 = (x_2/x_1)^{-p}, \qquad \text{(Equation 4)}$$

where C_1 is the concentration at distance x_1 and C_2 is the concentration at distance x_2. Observations and dispersion theories show that p is equal to a value between 1 and 2. This relation is also valid for concentrations at travel times t_2 and t_1, where t_2 is greater than t_1. This formula is equally applicable for plume travel over sea and land. The relation is found everywhere in the atmospheric boundary layer (for distances where the initial source height becomes unimportant) and can be shown by solving the basic equations.

Some examples of dispersion model-simulated results are given in Figure 5,[19] which shows normalized maximum (plume centerline, at $y = y_o$) ground level concentration, $(\chi)(u)/Q$, as a function of distance from the source under Class F atmospheric conditions. The symbol, χ, is often used, interchangeably with the symbol, C, for concentration. The letter u is the wind speed (at a height of about 10 m), and Q is the source mass emission rate. The normalization procedure is frequently used when plotting data in scientific analyses, and in this case is consistent with the Gaussian plume equation (2) above. By normalizing by u and Q, any observation data from different days and different field experiments can be plotted on the same graph (such as Figure 5) and the data should "collapse" on the same curve.

As explained in A32, Class F represents very stable atmospheric conditions with low turbulence and therefore reduced dispersion. Class F conditions are usually considered worst-case.

Figure 5 illustrates how concentrations decrease with distance under these very stable, worst case atmospheric conditions. It shows the variation with downwind distance, x, of the normalized plume centerline maximum ground level concentration for different initial plume release heights, H, which range from a ground level release (H = 0) to a release height, H, of 200 m above ground. The mixing height, L, is also considered, but has only a minor effect here. The curves in Figure 5 are based on the Gaussian plume equation, but they also can be considered to represent a best fit through the field experiment observations, since the model's parameterizations were derived from the observations.

Note in Figure 5 that, for release heights, H, greater than zero, the concentrations near the source (at very small distances) are nearly zero. This is because the plume is located entirely above the ground surface at small distances. As distances increase, the bottom of the plume is calculated to disperse to the ground surface, and normalized concentrations rise to a peak, which is different for each H. As the

[19] Figure 5 is from the widely used Turner (1970) Workbook of Atmospheric Dispersion Estimates, which was used as the basis for the EPA Gaussian plume models. D.B. Turner worked in the EPA Air Modeling Division.

release height, H, increases, the peak normalized concentration decreases and occurs at larger downwind distances.

The $(\chi)(u)/Q$ curves in Figure 5 were calculated by Turner (1970) assuming rural conditions over land, where nearly all of the early field experiments took place. However, the same curves would apply for rougher surfaces (e.g., forest or city) or smoother surfaces (e.g., mud flats or desert over land, or for most over water scenarios), but with the curves slightly shifted down or up, respectively. As Turner suggests, the magnitude of the shift can be approximated by multiplying the $(\chi)(u)/Q$ values by $(z_{o1}/z_{o2})^{1/5}$, where z_{o1} is the surface roughness of about 3 to 10 cm appropriate for the original Figure 5 curves, and z_{o2} is the surface roughness of the new terrain of interest. However, any change in χ (i.e., C) due to changes in surface roughness will be less because there will be corresponding changes in u, the wind speed as discussed in A85.

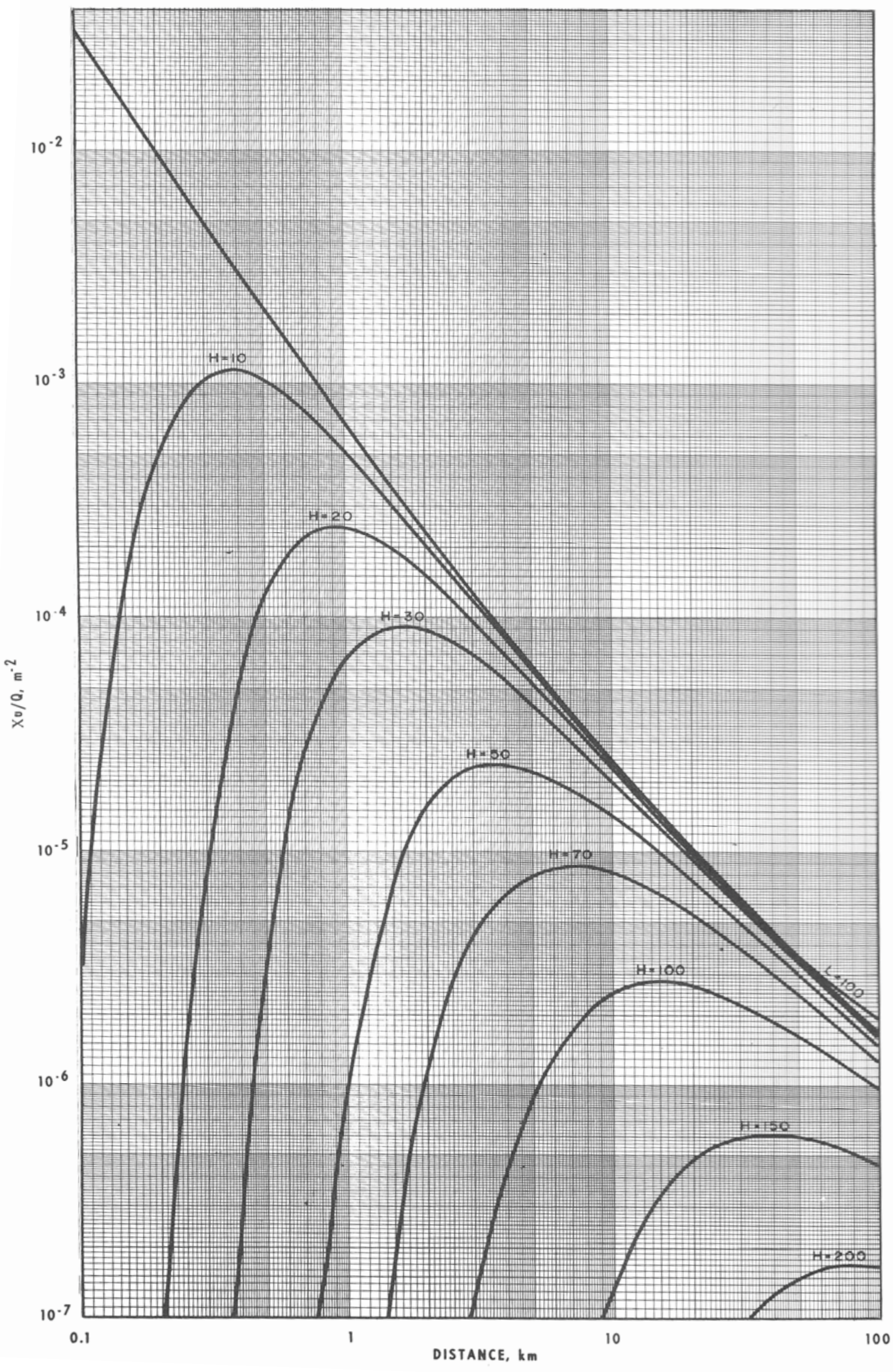

Figure 5. Maximum ground level concentration (χ)(u)/Q as a function of distance where χ is concentration in g m^{-2}, u is wind speed in m/s, Q is mass emission rate in g/s, and L is mixing height. The figure is from Turner's (1970) Workbook.

Q84: What do these curves show with respect to decrease in concentration as a function of distance for a simulated radioactive plume released at 33 ft, or 10 meters, as for the Pilgrim SAMA analysis?

A84. (SRH) Looking at the H=10 m curve in Figure 5, we see that, at a distance, x, of approximately 0.3 to 0.4 km, the plume has reached the ground and $(\chi)(u)/Q$ reaches its peak. Notably, as the distance from the source reaches 5 km (3.1 miles), we can see that the normalized concentration, $(\chi)(u)/Q$, has been reduced by more than an order of magnitude, i.e., close to a factor of 20 from its peak. At a distance from the source of 10 km (6.2 miles), $(\chi)(u)/Q$ has been reduced approximately by a factor of 45 from its peak; at 20 km (12.4 miles) from the source, $(\chi)(u)/Q$ has been reduced by more than two orders of magnitude (approximately a factor of 110 to 115) from its peak, and so on extending out to 100 km (62 mi) from the source. At 100 km (62 mi), the normalized concentrations have decreased by a total factor of about 700 since the peak was reached. This amount of decrease in normalized concentration would happen at the given distances following a trajectory of plume travel, no matter what path the trajectory followed.

Thus, postulated releases disperse significantly, as they travel, even under the most stable conditions.

Q85: You stated that the curves in Figure 5 were based on rural conditions over land. How would the normalized concentrations calculated above in A84 change if they were calculated for plumes traveling over the ocean?

A85. (SRH) As discussed in A83, the basic scientific aspects of atmospheric transport and dispersion are the same over land and water. Accordingly, Equation 4 above, which describes the variation of maximum plume centerline concentration as a function of distance or time, is equally applicable for plume travel over sea and land.

Therefore, the specific curves in Figure 5 developed for very stable Class F conditions over rural land are equally applicable to very stable conditions over the ocean, with the exception noted in A83 that the curves would be shifted slightly upward given the smoother surface over the ocean water compared to land.

Accordingly, the amount of reduction in normalized surface-level maximum plume centerline concentrations as a function of distance described in A84 would be equally applicable to transport over the ocean. This large reduction in normalized maximum plume centerline concentration as a function of distance overwhelms in a relatively short distance any slight increase in normalized maximum plume centerline concentration due to the smoother water surface.

For distances beyond where the peak normalized concentration is reached, any larger normalized plume centerline concentrations over the water compared to land are due to the relative smoothness of the water surface compared to land surface roughness features. Assuming the 1/5 power law relation from Turner's (1970) Workbook (described in A83 above and also discussed in A110), it follows that concentrations would increase by approximately a factor of 2.5 for each factor of 100 decrease in surface roughness. Using the roughnesses previously given in A83 for the curves in Figure 5 and the accepted roughnesses for water (in the range of 0.01 cm to 0.1 cm), the peak near-field maximum concentration over water would be approximately a factor of 2 to 4 greater than that over rural land areas surfaces used to develop Figure 5. However, the large reduction of normalized concentrations with distance shown in Figure 5 would still apply and the concentration over water would therefore still be quickly decreasing by a factor of about 10 or 30 for each factor of ten increase in distance, as discussed in A84 above.

Any slight increases in plume centerline concentration over the ocean surface would tend to be reduced due to the greater wind speed that typically occurs over the ocean compared to land surfaces. The wind speed is larger over water than over land, for all other conditions the same. This is because, for the same synoptic (large-scale) wind speed at the mixing height, there is less drag or friction over a smoother water surface in general than over the land. For example, the Report (ENT000004) shows that the observed annual averaged 5 m wind speed (extrapolated to 10 m) at the Boston Approach Buoy (15 miles off the Boston coast) is about twice the observed 10 m wind speed at the Pilgrim Station (on-land in a mix of fields and forests).

In any transport and dispersion model, the concentrations are inversely proportional to the wind speed, so a larger wind speed over water would lead to more dilution and hence a smaller concentration over water. The factor of 2 greater wind speed over the ocean compared to that at the Pilgrim Station would, by itself, contribute to a reduction of maximum concentrations over the water by approximately a factor of 2.

In summary, Pilgrim Watch's claim that plumes remain "tightly concentrated" as they travel out over the ocean and come back onto land as "hot spots" simply lacks any technical merit. All plumes rapidly disperse even if they travel under worst-case "very stable" conditions.

Q86: Have you reviewed the following documents referenced by Pilgrim Watch: (1) *J. Beyea*, Report To The Massachusetts Attorney General On The Potential Consequences Of A Spent, May 2006; (2) *M. Zagar and M. Tjernström, et. al*, New England Coastal Boundary Layer Modeling, 2004; and, (3) *W. Angevine, et. al.*, Modeling of the Coastal Boundary Layer and Pollutant Transport in New England, Jan. 2006?

A86. (SRH) Yes.

Q87: Please briefly describe the Beyea Report and whether it supports Pilgrim Watch's hot spot claim.

A87. (SRH) Based on my review, Beyea's report provides little technical support for Pilgrim Watch's hot spot claim and is not relevant to Pilgrim's SAMA analysis. Beyea only briefly raises at pages 11-12 of his paper the potential specter of "hot spots" (Beyea's words), with no supporting scientific justification. Beyea is not a meteorologist and he provides no scientific rationale to support his conjecture.

Q88: Please briefly describe the 2004 and 2006 Zagar and Angevine papers referenced by Beyea and Pilgrim Watch and whether they support Pilgrim Watch's hot spot claim.

A88. (SRH) The 2004 and 2006 Zagar and Angevine papers primarily concern ozone episodes with relatively large concentrations over a broad (500 – 1000 km) region in summer. Neither paper uses the term "hot spots." Rather Zagar and Angevine confirm the well-known effect that stable meteorological conditions can sometimes occur over the ocean during hot summer days with offshore winds. Because both papers concern analysis of field observations that are intentionally focused on worst-case summertime scenarios for regional ozone concentrations over the ocean, they are not relevant for SAMA analysis based on annual summed consequences, weighted by population in specific geographic sectors over the 50-mile radius domain, for an entirely different pollutant from a point source. Ozone is a secondary pollutant formed mainly by reactions among released pollutants such as nitrogen oxides and volatile organic compounds, where the emissions and the area of high ozone concentrations cover an area with size ranging from hundreds of km to 1000 km.

Furthermore, it is well-known as reported in Zagar and Angevine that stable conditions sometimes exist over the ocean during the summer (due to warm air passing over colder water). However, these impacts of a few days of stable conditions over the ocean during the summer on the overall SAMA analysis, which covers the entire year, would be offset by unstable conditions over the ocean during some periods during the winter (due to cold air passing over warmer water) that result in increased dispersion and lower concentrations. Furthermore, equally stable meteorological conditions can exist over land during the summer during many nights, which is directly accounted for by the Gaussian plume segment model in the SAMA analysis. Therefore, the analyses of periods with relatively high regional ozone concentration during a summer field experiment described in the 2004 and 2006 Zagar and Angevine papers are not relevant for a SAMA analysis.

Q89: Please respond to the Board's questions regarding the annual frequency of occurrence of Pilgrim Watch's claimed hot spot effect and the duration and the spatial and time-dependent pattern of wind and other meteorological parameters associated with each such occurrence. Please also discuss the radioactive deposition you would expect and how that deposition would differ from the Gaussian plume model and the resultant cost differential, if any, caused by these differences.

A89. (SRH) As discussed above, "hot spots," as claimed by Pilgrim Watch, simply do not exist. Therefore, one cannot estimate their occurrence or spatial and time-dependent pattern.

Pilgrim Watch's speculative claim of hot spots requires the confluence of impossible circumstances. First, the postulated release must remain "tightly concentrated" as it travels out to sea. As explained, even under very stable conditions plumes disperse significantly as they travel (e.g., concentrations decrease by at least a factor of 30 in the near field and a factor of ten or more at larger distances for each factor of ten increase in downwind distance). Next, the postulated release must travel out to sea and back, being carried by a variable wind field which does not cause the "tightly concentrated" release to disperse. Again, even under very stable conditions plumes disperse significantly as they travel.

Therefore, the facts show that by the time such a postulated release reached land after first traveling out to sea, the plume would be significantly dispersed and maximum plume centerline concentrations greatly reduced having generally traveled a much further distance than if the plume had traveled directly over land.

When we talk about concentrations, we are also implicitly talking about deposition and therefore the above statements about concentration also apply to deposition. Dry deposition is always proportional to concentration, with the dry deposition velocity providing the proportionality constant. Wet deposition is proportional to concentration, too, but with a need to know rain rate and wet removal rate.

Furthermore, as pointed out in A48, it is important to consider the primary goals and the methodology of the SAMA analysis, which involves weighting the calculated concentration distributions by the population. Since the population is input as a single value over a 22.5° wind direction sector between two radial distances (usually a ten mile increment, say from 20 miles to 30 miles), it follows that the details of the cross-wind concentration distribution does not matter much and that the total cross-wind integrated (summed) concentration is much more important. As mentioned in A48, if the concentration were a uniform 1 g/m^3 over a plume width of 1000 m, and the population density (people per unit area) were constant, the cross wind integral would be the same (1000 g/m^2) as a situation with a uniform concentration of 0.1 g/m^3 over a plume width of 10,000 m. The previous paragraphs in this answer and A83-A85 focus on plume maximum centerline concentrations, but it is clearly the crosswind integrated concentration that is of primary importance in the SAMA results.

Finally, the CALMET analysis discussed in Section IV.C.2 below shows that there is no consistent, frequently occurring pattern of wind blowing out to sea and then reversing direction and heading for the coast that might conceivably affect the time and space integrated results of the SAMA analysis. The comparison of the CALMET and Pilgrim roses shows slightly more CALMET trajectories towards the north-north-west, but this difference and other differences between the CALMET and Pilgrim roses are minor and have negligible impact on the SAMA analysis as discussed in Section IV.C.2 below.

In short, "hot spots," as hypothesized by Pilgrim Watch, do not exist and therefore do not impact deposition or cost differentials, and ultimately have no impact on Pilgrim's SAMA analysis.

C. Sensitivity and Supplemental Analyses Evaluating the Adequacy of Gaussian Plume Segment Model and the Pilgrim Meteorological Input for Purposes of a SAMA Analysis

Q90: Did you perform any sensitivity analyses or further evaluation in response to Pilgrim Watch's claims that the Gaussian plume segment model utilized for the SAMA analysis is inadequate because it does not account for changes in wind direction once a plume is released?

A90. (KRO, SRH) Yes, we did several studies. Entergy performed a sensitivity analysis using MACCS2 to take into account the possibility of changing wind trajectories. Additionally, as explained beginning at Q92: and in the Report (ENT000004), we performed an evaluation using the CALMET wind fields to track individual plumes, based on observed meteorological data from official NCDC weather stations in the region.

1. Sensitivity Analysis Using MACCS2

Q91: Please describe the MACCS2 sensitivity analysis performed to estimate the effects of taking into account changing wind directions on the SAMA analysis.

A91. (KRO) In connection with the previous motion for summary disposition, a sensitivity analysis was performed to determine whether taking into account changing wind direction inputs could impact the overall SAMA analysis. The sensitivity analysis estimated the effects of a change in wind direction inputs to the MACCS2 consequences analysis by choosing different meteorological input data occurring an hour earlier in the weather sequences analyzed for seven accident scenarios with a release duration of 2.5 hours. Because MACCS2 "reads" weather inputs on an hourly basis, different hourly weather input data could be selected for these accident sequence bins relative to those selected in the base case. The seven accident scenarios for which this change was made in the sensitivity analysis account for more than 93% of the SAMA risk, i.e., more than 93% of the overall PDR, and more than 93% of the overall OECR.

The sensitivity case resulted in a relatively small 3% increase in both the PDR and OECR costs relative to the base case. This increase is much less than the factor of more than two required to affect the results of the SAMA analysis, and therefore this change to the sampled weather used in the MACCS2 runs produced no significant impact on the results. This result is not surprising because the specific details of a plume segment's travel (including initial direction) will have little impact on the overall mean result obtained from a large number of weather events, each sending the postulated plume segment in a different direction. The primary purpose of the computer model such as MACCS2 is to determine the probability and the concentration that the radioactivity reaches any portion of the 50-mile region. Thus, a single plume segment's variations in travel according to a single meteorological set of conditions, including the initial direction, are not critical for a SAMA analysis. What is important is that the expected value from all the selected weather sequences adequately estimates the probability of a plume segment reaching a specific location, and its concentration at that location, for use in determining the area-wide total population dose and off-site economic cost impact consequences for the entire year.

2. *Supplemental Analysis Using CALMET*

Q92: Did you do any other evaluations to demonstrate that the Pilgrim 2001 hourly wind observations used in the SAMA analysis were representative of the 50-mile region?

A92. (SRH) Yes. We used CALMET and observed hourly wind observations from numerous local sources to generate hourly wind trajectories across the region of interest to determine annual wind trajectory roses at various distances from the source on the polar grid comprising the region of the SAMA analysis. A wind trajectory rose has the same format as a wind direction rose, as described in A64, which included an example annual wind rose for 2001 from the Pilgrim 33 ft level (used in the SAMA analysis). The difference is that the wind rose uses observed wind directions for determining the annual frequency for each direction, while the trajectory rose in the CALMET evaluation uses the direction a plume trajectory is going when it passes over a given distance arc from the Pilgrim Station as the basis for determining the annual frequency for each wind direction. The Report (ENT000004) describes this analysis in detail.

Q93: Please explain how you performed the wind trajectory analysis and its purpose.

A93. (SRH) The purpose of the CALMET wind trajectory analysis was to evaluate and confirm that, even if the time and spatially variable observed winds over the domain are directly accounted for, the annual trajectory rose is very similar to the 2001 Pilgrim 33 foot annual wind rose used in the Pilgrim SAMA analysis. Based on meteorological data from the region of interest, we used the EPA CALMET wind model to produce a three-dimensional spatially variable wind field over the domain for each hour of 2001. Using this spatially-variable wind field, we then calculated trajectories for hypothetical plumes released each hour from the Pilgrim plant, and noted at what point they passed the radial arcs at one mile increments from 1 to 10 miles, and at 20, 30, 40 and 50 miles, corresponding to the same radial arcs used to define the spatial grid elements in the MACCS2 code. We then developed annual trajectory roses (for 8756 hourly trajectories[20]) at these different locations to compare with the observed Pilgrim 2001 annual wind rose, which was input to MACCS2/ATMOS in the SAMA analysis.

Q94: Please explain why you used CALMET.

A94. (SRH) We used CALMET after surveying the available wind field models and after contacting several developers of alternate models (such as the NOAA HYSPLIT

[20] The number of trajectory hours, 8756, is four hours less than the number of hours in a year because the data that were acquired are in Greenwich Mean Time, whereas the Pilgrim site is on Eastern Time.

model), in order to find out which of the models best allowed trajectories to be calculated for all hours of 2001. CALMET was the best choice because its wind outputs could more easily be used to calculate trajectories. Additionally, CALMET is the most widely used and accepted technology in the U.S. for developing spatially-variable wind fields that can be used to take into account changes in plume travel direction as a result of changes in the wind on an hourly basis. As briefly described in Answer A55, CALMET develops three-dimensional time dependent meteorological fields for use by the CALPUFF Lagrangian puff dispersion model.

CALMET is an independent "stand-alone" code. We did not subsequently run CALPUFF because the main contention is the accuracy of the plume trajectories used in the SAMA analysis and whether they are affected substantially by the observed variable wind fields, which can be evaluated directly by CALMET.

CALMET uses inputs of hourly-observed winds at several surface sites on the domain, as well as at a few upper air sites. The upper air sites refer to locations where radiosonde balloons are released twice each day and transmit weather information observed as they rise through the atmosphere. Using the upper air observations, the model interpolates and extrapolates the surface observations upwards in order to generate a full three-dimensional wind field. The model uses an interpolation and extrapolation method based on weighting each observation by the inverse square of the distance from the observation site to the point of interest and then imposing mass conservation. CALMET also uses inputs of terrain elevations and land use, plus cloudiness and rain. The terrain elevations are used to parameterize slope flows and curvatures around mountain ranges and valley channeling. Using these inputs, CALMET is able to calculate, for the year 2001 in our case, hourly spatially variable wind fields used to produce the trajectory roses necessary for this analysis.

Q95: How did you perform the CALMET wind trajectory analysis?

A95. (SRH) A detailed explanation of the CALMET wind trajectory analysis is included in my Report (ENT000004).

First, we chose a geographic domain for modeling. CALMET requires a rectangular domain, and it is preferable to extend the model domain and employ meteorological observing sites extending at least 12.4 miles (20 km) outside of the primary area, which, in our case, is a 50 mile (80 km) radius circle around Pilgrim. See Report (ENT000004) Figure 3. Use of meteorological data from beyond the 50-mile radius assures that there are sufficient data to interpolate wind fields at the edges and beyond the 50-mile radius circle. Therefore, we chose a square domain with 200 km (125-mile) sides, centered on the Pilgrim facility. We then divided the geographic domain into a grid whose elements are square with 4 km (2.5 miles) sides. We selected 4 km because it provides an adequate resolution for the terrain features and is often used for CALMET runs for EPA applications.

Second, we characterized the terrain for modeling, which encompasses terrain elevations ranging from sea level to approximately 300 meters above mean sea level on the northwestern edge of the domain. As stated above, the horizontal grid spacing resolution of 4 km adequately represents the variations of the coastline and the terrain elevations in the area. The eastern portion of the CALMET domain is over the ocean. The terrain near the coastline is relatively flat except for a few small to moderate hills. The gridded terrain elevations for the modeling domain were prepared using the United States Geological Survey (USGS) digital elevation models and data from USGS topographic maps. Figure 5 in the Report (ENT000004) shows the terrain elevations of the modeling domain.

Third, we selected NCDC meteorological sites in the area with adequate quality hourly data for 2001, thus using all the reasonably available data of sufficient reliability. The 26 selected sites with near-surface measurements (usually at heights of 10 m or less) in the square domain are shown in Figure 4 and listed in Table 1 of the Report (ENT000004). NCDC provided certified meteorological data for the analysis for each of these sites. In addition, we also obtained from NCDC certified "upper air" data from Chatham, MA; Gray, ME; Albany, NY; and Islip, NY. These data are from radiosonde balloons released at 7 am and 7 pm Eastern time each day. Our CALMET runs used the Chatham and Gray data because they are the closest of the four sites to Pilgrim, and they are recommended for use by the Massachusetts Department of Environmental Protection. Using these data, we completed preliminary runs to assure the data entered did not produce any errors and to assure the model settings were correct.

Fourth, we chose trajectory heights of 328 ft, 656 ft, and 1,640 ft (100, 200, and 500 m), so as to cover the range of possible plume heights in the MACCS2/ATMOS calculation (Note that a plume well mixed from 0 to 1000 m will have an average height of 500 m). It is expected that, for the Pilgrim SAMA analysis where the typical mixing height is 1000 m (3,280 ft), the plumes will usually become well mixed through the vertical layer from the surface to 1000 m (3,280 ft) by a downwind distance of about 10 miles, and will remain well mixed vertically at larger distances. Thus, the trajectories at 500 m (1,640 ft) are the most useful for comparative analysis. During the analysis, a trajectory at these three heights is initiated at the Pilgrim Station for each hour. The trajectory follows the speed and direction of the CALMET 3-D wind fields wherever the trajectory is located during a given time period. Note that the trajectory always remains at the height that it was started.

Last, we used CALMET to produce spatially variable wind fields over the domain for each hour of 2001. Given the hourly CALMET-generated wind fields for the entire year, we "released" a trajectory from the Pilgrim Station at the beginning of each hour, and followed the trajectory until it passed the 50 mile circle, noting where (i.e., the angular position in degrees, as in Figure 1) each trajectory passed the radial arcs at one mile increments from 1 to 10 miles, and at 20, 30, 40 and 50 miles (corresponding to the same radial arcs used to define the grid elements in the MACCS2 code) for plume elevations of 100, 200, and 500 m. We counted the angular position where each trajectory passed these arcs. Thus at each radius, over a year there would be 8,756 instances where trajectories passed the circle. The statistical distribution around the circle was determined and used to generate annual trajectory roses, for comparison with the annual Pilgrim wind rose used in the SAMA analysis.

Q96: Please summarize the results of the Trajectory Analysis.

A96. (SRH) I conclude that any short-term differences in observed winds across the SAMA domain have little effect on the annual frequencies of trajectory directions. The visual and quantitative comparisons of annual trajectory roses for the three levels and the 14 distance arcs versus the annual wind rose from the Pilgrim Station suggest that the annual Pilgrim wind rose used in the SAMA analysis is similar to the annual calculated trajectory roses. In particular, for the dominant winds towards the east in this geographic area, most of the trajectories pass over the water. The fractions of wind directions towards the more populated areas to the northwest and west relatively are small for both the trajectory roses and the Pilgrim wind rose.

For comparison, take the following examples. In the first, Figure 6 (Report (ENT000004) Figure 12) compares, side-by-side, the Pilgrim 2001 wind rose and the 2001 annual trajectory rose at the 100 m height at a downwind distance of 1 mile. The trajectory rose in the right-hand panel shows how often the hourly trajectory will be at particular wind direction sectors (22.5° degrees wide) as it crosses the 1-mile arc. Second, Figure 7 (Report (ENT000004) Figure 13) shows the same type of side-by-side comparison but for the 2001 annual trajectory rose at the 500 m height at a downwind distance of 50 miles. The 500 m level is appropriate for larger distances, where the plume is more likely to be well mixed from the surface to the seasonal mixing heights used in the analysis, which range from about 800 m to 1300 m. Visually comparing both the 1 mile/100 m and the 50 mile/500 m trajectories to the 2001 Pilgrim wind rose used as inputs to MACCS2 for the SAMA analysis shows clear similarity.[21]

[21] My Report includes the full array of the trajectory frequency distributions; 100 meters is presented in Appendix C, 200 meters in Appendix D, and 500 meters in Appendix E.

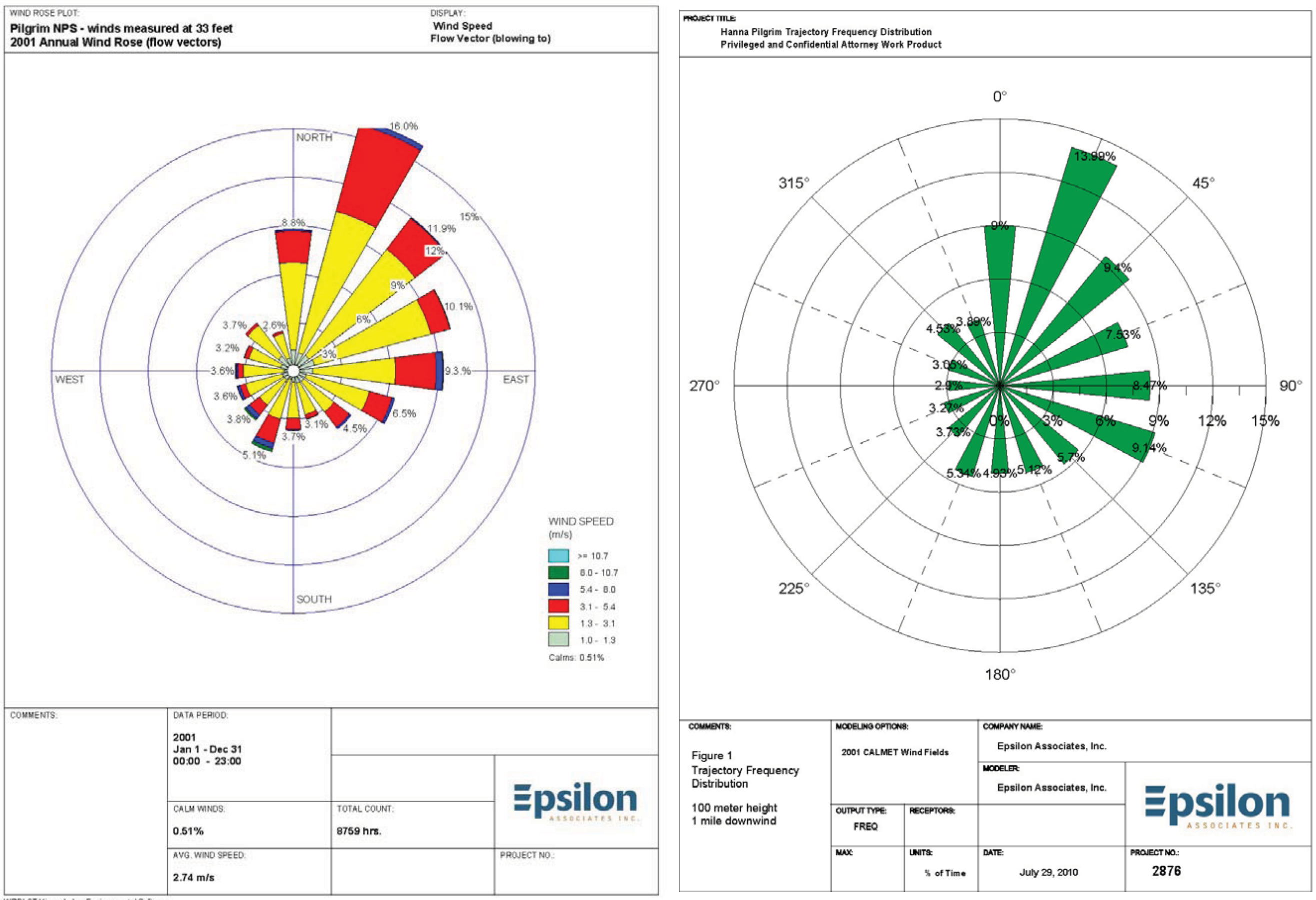

Figure 6. CALMET-generated trajectory rose at 100 m (328 ft) height and 1-mile (1.6 km) distance (right panel). Pilgrim 33 ft (10 m) annual wind rose (left panel)

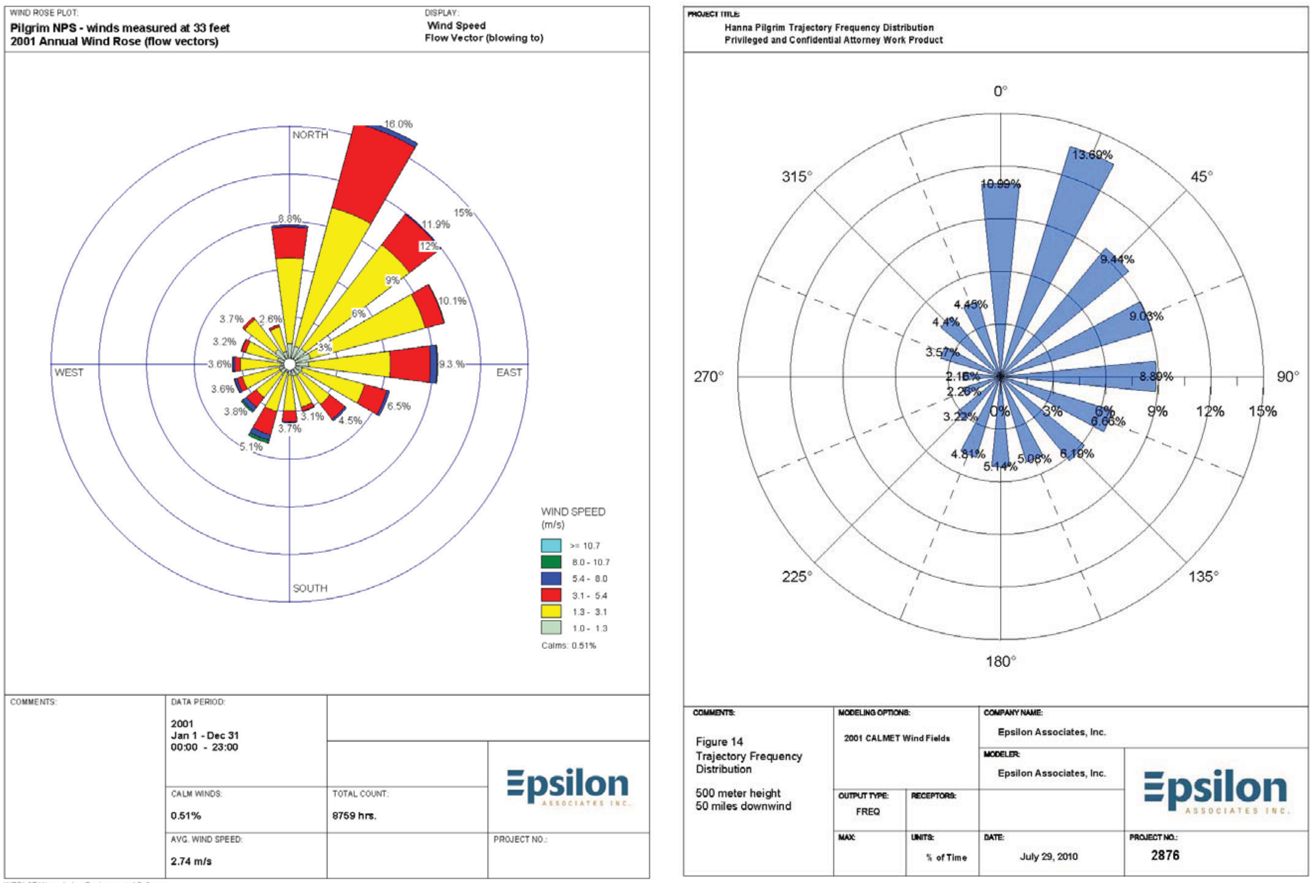

Figure 7. CALMET generated trajectory rose at 500m (1,640 ft.) height and 50 miles (80.5km) distance (right panel). Pilgrim 33ft. (10m) annual wind rose (left panel).

Q97: Can you comment on how the Trajectory Analysis further validates the use of the Gaussian plume segment model?

A97. (SRH) Based on the Trajectory Analysis, we have determined that, for the Pilgrim SAMA analysis, the Gaussian plume segment model with constant wind direction for a plume released at a given hour used in ATMOS and the three-dimensional CALMET trajectory model produce similar results. The ATMOS model assumes that the wind direction observed during the hour of the release persists over the duration of the plume trajectory until it passes the 50-mile arc (however, as discussed earlier, because ATMOS is a plume segment model, it does account for hour-to-hour changes in wind speed, stability, and precipitation along the plume trajectory). For the example from the previous question, the CALMET trajectories at the 500 m elevation at the 50-mile radius have traversed the entire area and have been affected by any sea breeze and terrain impacts to the extent they exist and are accounted for by the wind observations throughout the Pilgrim SAMA domain and by the CALMET model. Based on the three-dimensional CALMET model, the trajectory rose is still very similar to the Pilgrim met tower wind rose in Figure 7 (Report (ENT000004) Figure 13). Thus, it is again clear that short-term differences in observed winds have little effect on the annual wind direction frequencies. Ultimately, when one is interested in annual distributions summed over time and over the Pilgrim SAMA domain, the ability to account for short-term time and space variations of meteorology does not significantly enhance the accuracy of the SAMA analysis.

Q98: Can you draw any conclusions from the Trajectory Analysis with regards to the sea breeze?

A98. (SRH) Yes. The CALMET analysis confirms that there is no significant impact due to coastal breezes, including sea breezes, as observed by the 26 surface wind stations and used as inputs to CALMET, on the results of the analysis as discussed above.

Q99: Is the Trajectory Analysis of the SAMA-domain wind data of any relevance to Pilgrim Watch's "hot spots" claims?

A99. (SRH) Yes. The CALMET analysis using extensive meteorological observations over the SAMA domain discussed above confirms that there is no significant directional bias in winds at other locations (e.g., due to the plume heading out to sea and then turning inshore to land) that would alter the annual SAMA results, summed over one year and throughout the 50 mile radius domain. Note that this analysis included meteorological data from a buoy in the ocean 15 miles east of the Boston shoreline. That buoy would obviously reflect flow over the ocean at some distance from the coast and would influence trajectories that happen to pass close to that site.

Q100: Did you do any quantitative comparisons of the trajectory roses with the Pilgrim wind rose?

A100. (SRH) Yes. Table 6 (Report (ENT000004) Table 7) contains a quantitative comparison of the visual comparison presented in the two panels of Figure 7 (Report (ENT000004) Figure 13) between the Pilgrim 2001 annual wind direction frequencies and the CALMET 500 m elevation trajectories at a distance of 50 miles from the Pilgrim site. The trajectories at a distance of 50 miles are the furthest from the Pilgrim site and therefore are the most likely to show deviation from the Pilgrim wind rose.

The table first lists the 16 wind direction sectors. The second and third columns list the percentages that were written on the wind direction petals in Figure 7 (Report (ENT000004) Figure 13), for the CALMET trajectory analysis (500 m elevation trajectories, at a distance of 50 miles from the Pilgrim Station), and for the 33 ft level of the Pilgrim meteorological tower (used in the SAMA analysis). The final column lists the difference between the CALMET trajectory and the Pilgrim 33 ft percentages for each direction sector. The root mean square (RMS) difference (i.e., the standard deviation) of the 16 numbers is 1.5% and the mean absolute difference is 1.3%. No sector difference is larger than 2.6 %. For the "western" 180 degree half circle (from S through NNW), where most of the land and population are located, there is only a 0.7 % difference in total percentage (30.1% for the CALMET trajectories and 29.4% for the Pilgrim 33 ft level). Thus, it can be concluded from Table 6 that there is minimal difference between the 2001 annual wind roses from the CALMET trajectories (500 m level and 50-mile distance) and the 33 ft Pilgrim observation. This CALMET trajectory level and distance is very relevant for the SAMA analysis, since the bulk of the population is at distances greater than 20 miles. Based on the quantitative comparison, I concluded that there is minimal difference between the 2001 annual wind roses from the CALMET trajectories (500 m level and 50-mile distance) and the 33 ft Pilgrim observation.

Table 6. Comparison of annual 2001 wind direction frequencies from the CALMET trajectory analysis (500 m elevation trajectories, at a distance of 50 miles from the Pilgrim Station), with wind direction frequencies from the 33 ft level of the Pilgrim meteorological tower (used in the SAMA analysis).

Wind Direction (blowing towards) Compass Direction	CALMET Trajectory 500 m (1,640 ft) Elevation and 50 mile Distance	Pilgrim 33 ft	Difference
N	11.0%	8.8%	2.2%
NNE	13.7%	16.1%	-2.4%
NE	9.4%	12.0%	-2.6%
ENE	9.0%	10.1%	-1.1%
E	8.9%	9.3%	-0.4%
ESE	6.7%	6.5%	0.2%
SE	6.2%	4.5%	1.7%
SSE	5.1%	3.1%	2.0%
S	5.1%	3.7%	1.4%
SSW	4.8%	5.2%	-0.4%
SW	3.2%	3.8%	-0.6%
WSW	2.3%	3.6%	-1.3%
W	2.2%	3.6%	-1.4%
WNW	3.6%	3.2%	0.4%
NW	4.4%	3.7%	0.7%
NNW	4.5%	2.6%	1.9%

Q101: Did you perform any other calculations to quantitatively compare the results of the wind trajectory analysis with the Pilgrim SAMA analysis?

A101. (KRO) Yes, we continued the analysis described in A100 and carried out a quantitative comparison of the trajectory roses with the wind rose for the Pilgrim Station in the MACCS2 analysis by calculating a composite site-specific index called the Exposure Index (EI). The EI is a function of the population distribution surrounding the plant of interest weighted by the site-specific wind direction frequency. PSA and SAMA experience shows that that the PDR and OECR are primarily affected by the population distribution and long-term, average wind direction frequencies. Secondary factors, such as terrain, precipitation, and stability class have some effect on these risks, but their impact is not as important. Thus, a comparison of the exposure indices provides a first-order, quantitative comparison for calculating the PDR and OECR.

Q102: Please explain the EI and its significance.

A102. (KRO) It is useful to point out what the EI means in practical terms. The EI is a relative measure of the population potentially affected by a radiological release. The EI is influenced by the way that the population is distributed, and the way that regional wind directions over the course of a year are distributed. Quantitatively, the EI is proportional to the mean annual wind direction frequencies weighted by population in those sectors.

Because the PDR and OECR are strongly dependent on wind-directed radiological exposures to high population densities, the EI can provide an indication of relative change between the models for estimating the impact of using different wind direction frequencies. In other words, if population and regional characteristics are held constant, the relative change in EI, from the MACCS2 based SAMA wind rose in one case to the CALMET based trajectory rose case in the other will indicate the relative change in SAMA PDR and OECR that would result from using the CALMET based trajectory rose instead of the Pilgrim SAMA wind rose.

For example, if the EI based on the CALMET trajectory rose were significantly different from the EI based on the Pilgrim SAMA, MACCS2-based wind rose, then we would expect significant changes in PDR and OECR quantities to follow accordingly. If there is negligible difference in the EIs for the CALMET trajectory rose and the Pilgrim SAMA, MACCS2-based wind rose, then negligible difference in their PDRs and OECRs would follow accordingly. As we have defined earlier, the magnitude of change in PDR and OECR would need to be more than a factor of two to cause the next SAMA to become potentially cost-beneficial.

Q103: Please explain how you performed the EI calculation and evaluation.

A103. (KRO) Because the EI is a quantitative measure of the effect of mean annual wind direction frequencies weighted by population density, by holding the population distribution constant while varying the basis for the wind direction frequency we can estimate the impact on the PDR and OECR from the use of different wind direction frequency distributions.

In calculating the EI, we utilized three different wind direction frequencies: (1) the Pilgrim SAMA analysis wind rose as processed by the MACCS2 code; (2) the CALMET trajectory roses at the 500-m elevation; and (3) the CALMET trajectory roses at the 100-m elevation. The EI was calculated by weighting the wind direction percentages for each of 80 polar coordinate elements around the Pilgrim site (i.e., the sixteen radial sectors in each of five distance regions: 0 – 10 miles; 10 – 20 miles; 20 – 30 miles; 30 – 40 miles; and 40 – 50 miles) by the population in that grid element, and summing the results.

This approach of using the EI to regress severe accident risk calculations is similar to the approach used by the NRC Staff in the Generic Environmental Impact Statement on License Renewal, NUREG-1437 at section 5.3.3.2.1.

The analysis was first performed by calculating the EI over the entire 50-mile polar grid using the Pilgrim population distribution from the SAMA analysis and the MACCS2 wind rose output (based on the Pilgrim wind observations at the single 33-ft height). The CALMET trajectory roses were then applied in another calculation of the EI for first, the height of 500 m, and then second, for the height of 100 m. In each case, the same population distribution is used and the only difference is based on whether the CALMET trajectory rose or the MACCS2 wind rose is used. The calculations of the EI for MACCS2 wind rose and the CALMET 500 m and 100 m trajectories are provided in Exhibit ENT000011.

Q104: How does the EI calculated using the wind trajectory roses developed using CALMET compare to the EI calculated for the Pilgrim SAMA analysis?

A104. (KRO) As shown in Table 7, the total CALMET-based EI for the 50-mile SAMA domain using the 500-m trajectory rose data is 3.24% higher than the MACCS2-based EI. The total CALMET-based EI for the 50-mile SAMA domain using the

100-m trajectory rose data is 13.80% higher than the Pilgrim MACCS2 SAMA-based EI.

(KRO, SRH) As already explained above, the 500-m result is the more representative of the CALMET wind trajectories in the 10 – 50 mile region of the 50-mile grid considered in these analyses (where more than 90% of the PDR and OECR risks resides) because the plume will usually be fully mixed to the mixing height by ten miles from the site. The seasonal mixing heights used in the SAMA analysis range from 800 to 1300 m, and therefore the 500-m CALMET trajectory rose (which represents a mixing height of 1000 m) best represents the mixing of the plume beyond 10 miles. So this means that the CALMET and the Pilgrim SAMA, MACCS2-based EI results are most appropriately compared as being within 3.24% of each other.

Table 7. MACCS2 Wind Rose and CALMET Trajectory Rose Exposure Index Summary Results.

Distance Range for EI Calculation	0 to 10 miles	10 miles to 20 miles	20 miles to 30 miles	30 miles to 40 miles	40 miles to 50 miles	Total
Population	166,113	619,601	1,659,861	3,197,941	1,847,128	7,490,644
Population Exposure Index						
MACCS2 EI for Distance Range	6,263	22,516	66,220	120,502	66,927	282,429
CALMET 500m trajectory EI for Distance Range	6,433	24,230	64,871	123,038	73,016	291,589
CALMET 500m EI to MACCS2 EI, expressed as a percent	102.71%	107.61%	97.96%	102.10%	109.10%	103.24%
CALMET 100m Trajectory EI for Distance Range	6,698	25,567	69,530	139,719	79,883	321,396
Ratio of CALMET 100m EI to MACCS2 EI, expressed as a percent	106.93%	113.55%	105.00%	115.95%	119.36%	113.80%

(KRO) The end result of this comparison is that the PDR and OECR quantitative results reported in the SAMA analysis would not change nearly enough to identify another SAMA as cost effective if we were to use a CALMET-based methodology. This is because there needs to be more than a factor of two increase in the SAMA benefit before another SAMA in the analysis would be considered potentially cost beneficial. Neither the 500 m nor the 100 m EI comes close to the factor of more than two for another SAMA to be considered potentially cost beneficial.

Q105: What did you conclude from your analysis?

A105. (SRH, KRO) Based on our analysis, we conclude that the SAMA MACCS2 analysis, utilizing ATMOS and its Gaussian plume segment model, sufficiently considers varying wind fields. The use of an alternate atmospheric transport and dispersion model that considers time and spatially variable wind fields, as opposed to ATMOS, will have little effect on the outcome of the SAMA cost-benefit analysis. Our conclusions are based on the fact that the calculated EI from CALMET is within 4% of the EI from ATMOS. The CALMET evaluation shows that, for purposes of calculating annual impacts, the use of the Gaussian plume segment atmospheric transport model (which allows for hour-to-hour changes in wind speed, stability, and precipitation, but does not allow for a change in wind direction for a plume trajectory initiated at a given hour) with the on-site Pilgrim meteorological data is appropriate for the Pilgrim SAMA analysis.

D. Pilgrim SAMA Analysis Conservative Treatment of Terrain

Q106: Please describe the terrain in the Pilgrim vicinity and the 50-mile region for which the SAMA analysis is performed.

A106. (SRH) The terrain surrounding the Pilgrim Station throughout the 50-mile region of the Pilgrim SAMA analysis is relatively flat on average with a few hills of height of about 300 to 600 ft within 10 miles of the coast and 900 ft in the western edge of the domain (near the "Worcester Hills"). In general, there is no rugged terrain or narrow valley features. The most notable, but isolated, terrain features surrounding the Pilgrim site are (a) Pine Hill adjacent to the site (330 ft tall and about 0.6 miles NW of the plant), (b) Cape Cod Bay with a broad circular coastline in the area of the Pilgrim Station, and (c) Blue Hill, approximately 635 ft in elevation, about 10 miles south of Boston (and about 30 miles NW of Pilgrim). Report (ENT000004) Figures 5 and 6 show the terrain elevations and the land use map, respectively, used for the CALMET Trajectory Analysis.

Q107: For purposes of a SAMA analysis what are the effects of terrain, or topographical features such as large hills, on a plume?

A107. (SRH) In the near field, say at distances less than one or two miles, when plumes from a stack may be small and may impact the side of the hill, there may be a short term (a few hour) concentration impact in that small area. This impact may be of interest for an EPA-based worst-case analysis, but not for a SAMA that focuses on annual sums of population dose and economic costs over a year and over the 50-mile radius area.

From the viewpoint of the entire 50-mile radius SAMA area, terrain features such as hills have a dispersive effect on a plume once the plume passes over and around the features. For example, when topographical features, such as a large hill, intervene between a source and an observation point, one of the significant effects is that the plume becomes more disperse and less concentrated than it would have been otherwise.

Thus, from the point of view of the large SAMA domain, terrain features such as Pine Hill and Blue Hill would have a dispersive effect on the plume as the plume passes over and around them, making the plume concentration less than it otherwise would have been, and therefore having less impact on persons and property on the far downwind side of the terrain feature.

Q108: What are the effects of Cape Cod Bay, which you mention as one of the notable terrain features in the area of the Pilgrim site?

A108. (SRH) Often the term "terrain features" is expanded to include different types of surfaces, such as forests, cities, and water bodies. The rate of dispersion over the water, such as over Cape Cod Bay, is sometimes greater and sometimes less than over land. The differences are mostly due to stability effects, which are partly determined by the air-water temperature difference. Because we are simulating a full year of meteorological conditions, we have roughly as many time periods when the air is warmer than the water and therefore the atmosphere is stable (less dispersive) as time periods when the air is cooler than the water and therefore the atmosphere is unstable (more dispersive).

Additionally, the roughness of the surface can have a small effect on dispersion and dilution. As described earlier, a rough rule used by many dispersion models is that the vertical dispersion coefficient, σ_z, varies with the 1/5 power of the surface roughness length. Unlike over land, the overwater roughness depends on wind speed, since higher wind speeds cause larger waves and hence a larger effective roughness. In general, the surface roughness length is less over water than over land which would tend to decrease vertical dispersion and hence to increase concentrations. However, for other conditions the same, over water the wind speed is greater than over land, which would enhance dilution and tend to decrease concentrations. The two effects would tend to counter each other, although the decreased dispersion effect is likely to be slightly larger than the increased dilution effect, causing a slight increase in concentration over water.

Thus over the full year, the annual summed concentrations and dosages over Cape Cod Bay are expected to be not significantly different from those over land because the seasonal and daily stability differences and roughness differences tend to cancel each other out.

Q109: To what extent does the ATMOS module in MACCS2 model terrain effects?

A109. (KRO, SRH) The Gaussian plume segment model does not directly model terrain features such as the possible effects of plumes impacting on the side of large hills. Because the ATMOS Gaussian plume segment model assumes a flat uniform terrain, in situations where the plume is faced with a topographical terrain obstacle, such as Pine Hill or Blue Hill, the model ignores the presence of the obstacle and does not model the plume segment travel over or around the obstacle.

As explained in A107 above, hills such as Pine Hill or Blue Hill have a dispersive effect on the plume after the plume passes over and around them which decrease the plume's concentration as it travels a few miles farther downwind. As a result, ATMOS would overestimate concentrations in the plume at distances several miles downwind of the obstacle that are important for a SAMA analysis. For the Pilgrim SAMA analysis, where concentrations and dosages are weighted by population, the largest contribution to the population dose and the economic effects occur at distances from about 20 to 50 miles, where the large population in the Boston metropolitan area is located. Thus, for purposes of the Pilgrim SAMA analysis ignoring the dispersive effects of topographical obstacles, such as Pine Hill or Blue Hill, is conservative and results in the overestimation of the consequences.

Q110: Does the ATMOS module in MACCS2 provide any mechanism to account for mechanical mixing due to surface features?

A110. (KRO, SRH) Yes it does. While the MACCS2 code does not model the terrain singular features, such as hills and valleys, it does provide for the input of a surface roughness length for the entire region of interest to account for the mechanical mixing due to small-scale surface features. The surface roughness length (z_o) is a measure of the mechanical mixing effects due to the presence of small-scale surface features such as grass, crops and other vegetation, brush and trees, and buildings. As surface roughness length decreases, there will be less mechanical mixing due to surface features and MACCS2/ATMOS simulated plume concentrations will be somewhat larger.

As an approximation rule, z_o is approximately 0.1 times the average height of roughness elements located on the transport region of interest, between the point of release and downwind populations. The ratio of concentrations using a new surface roughness length (z_{onew}) relative to concentrations using a reference surface roughness length (z_{oref}), can be approximated (assuming other ATMOS inputs are held the same) by $(z_{onew}/ z_{oref})^{1/5}$. For example, based on this approximation and for all other conditions the same, use of a 100-cm surface roughness length relative to a

3-cm surface roughness length would result in half the concentration $(100/3)^{-1/5} \approx ½ = 0.5$.

Q111: What assumptions did the Pilgrim SAMA analysis use for surface roughness?

A111. (KRO) The Pilgrim SAMA MACCS2 calculations use a 10-cm surface roughness length. Table 8 lists approximate surface roughness lengths for different surface types (Columns 1 and 2) that are suggested for use in the MACCS Model Description report.[22] Table 8 indicates that a surface roughness length of 10-cm is characteristic of tall grasses and crops. However, much of the land region surrounding the Pilgrim site consists of forest and suburban and urban areas with trees and structures much taller than three feet. Report (ENT000004) Figure 6 identifies the dominant land use categories by 2.5 mile-square grid areas for the 50 mi radius circle around the Pilgrim Station based on United States Geological Survey (USGS) land use data. The land use data show that the predominant land use categories in the Pilgrim 50-mile radius region are forest and urban.

Therefore, larger values for the surface roughness length could be justified for the land portion of the 50-mile region around Pilgrim, especially in areas 20 to 40 miles downwind in directions towards the more populated sectors. Based on the land use surrounding the Pilgrim Station, use of a surface roughness length of 100 cm, characteristic of forests, suburbs and urban areas, would be reasonable based on the MACCS Model Description report.

Table 8 below shows the effect on the vertical dispersion parameter (σ_z) with a change in surface roughness length (z_o = new), from a reference surface roughness length of 10 cm used in the Pilgrim SAMA MACCS2 analysis (Column 3), and the resulting change in dose (Column 4). For example, according to the table, which is based on the above 1/5 power law assumed in the MACCS2/ATMOS model, using a surface roughness length of 100 cm would reduce the overall concentration or dose by 37% compared to the use of a surface roughness length of 10 cm in the Pilgrim SAMA analysis.

[22] NUREG/CR-4691, Jow et. al, MELCOR Accident Consequence Code System (MACCS) Model Description (Feb. 1990).

Thus, the Pilgrim SAMA analysis has been modeled conservatively using a surface roughness length of 10 cm whereas a reasonable basis exists to apply a surface roughness length value on the order of 100 cm, with a resulting reduction in concentrations and doses.

Table 8. Representative Surface Roughness Lengths based on Surface Type (Based on Table 2.3 in Jow et al. (1990)).

Surface Type	**Surface Roughness Length, (cm)**	σ_z **(z_0=new) /**σ_z**(z_o=10 cm)**	**Reduction in Dose, relative to z_o=10 cm**
Lawns	1	N/A*	N/A*
Tall grass, crops	10-15	1.00 – 1.08	0% - 8%
Countryside	30	1.25	20%
Suburbs	100	1.58	37%
Forests	20 – 200	1.15 – 1.82	13% - 45%
Urban	100 – 300	1.58 – 1.97	37% - 49%
*N/A = Not applicable in this comparison to z_o = 10 cm			

Q112: Pilgrim Watch argues that the Gaussian plume segment model used in MACCS2 is inadequate because it fails to take into account topographical terrain features. Do you agree?

A112. (KRO, SRH) No. For the reasons stated above, the Gaussian plume segment model in ATMOS is conservative for purposes of performing a SAMA analysis, where the bulk of the population is several miles downwind of the terrain features.

Q113: Pilgrim Watch also claims that the ATMOS is inadequate because it does not take into account the effect that terrain features can have on wind field patterns. What is your response?

A113. (SRH) The effects of terrain features on wind field patterns referred to by Pilgrim Watch are generally localized and have little impact on annual summed consequences over a large area, such as the 50-mile SAMA region. While such localized effects may sometimes be important for determining worst-case short-term effects, as required under the EPA Clean Air Act, they are far less important for the annual consequences over the SAMA area calculated by MACCS2.

This minimal impact of terrain on regional wind field patterns is confirmed by the Wind Rose and Wind Trajectory analyses discussed above. As explained in the Report (ENT000004), we compared the annual 2001 wind rose at Pilgrim with the wind roses from other coastal sites and found they were similar. We are fortunate to have four meteorological sites around Cape Cod Bay within 10 miles of the Pilgrim Station. From S to N these are Pilgrim Station, Plymouth, Kingston, and Duxbury. The observed annual wind roses from those four sites are very similar, as discussed and shown in the Report (ENT000004). See Report (ENT000004) at B-4 (Pilgrim), B-7 (Plymouth), B-19 (Kingston), and B-22 (Duxbury). Thus, coastal terrain features did not significantly impact the annual wind roses at other coastal locations sites so as produce significant different annual wind patterns important for SAMA analysis purposes.

The CALMET trajectory analysis further confirmed the minimal impact of terrain on annual wind field patterns important for SAMA analyses. As explained in the Report (ENT000004), as part of the Wind Trajectory analysis, we used CALMET to produce wind fields that specifically take into account observations at sites influenced by local topography, including the coastline, Pine Hill, and other features. Based on the produced wind fields – which took into account complexities caused by the terrain and coastline – we determined that the difference in exposure between an analysis with ATMOS ignoring terrain and an analysis with CALMET considering terrain was less than 4%.

Thus, any impact of topography and other terrain features on wind field patterns is localized and has minimal, inconsequential impact on the results of the SAMA analyses.

Q114: What are your conclusions regarding the adequacy of the MACCS2 ATMOS Gaussian plume segment model treatment of terrain.

A114. (KRO, SRH) For purposes of identifying whether any SAMAs are cost beneficial, the MACCS2 methodology for accounting for terrain effects and its conservative application (from the viewpoint of the entire 50-mile radius area and the one-year period) by Pilgrim is adequate. As stated, over a broad area downwind of terrain features, those features generally have a dispersive effect on a plume that decreases its concentration and therefore its consequences. Any short-term near-field impacts of the plume on terrain are localized and have only a minor impact on the SAMA analysis. Furthermore, the Pilgrim SAMA analysis uses a conservative roughness factor which introduces additional conservatism in the analysis.

E. Other Contention 3 Issues

1. *Onsite Dispersion*

Q115: Did Pilgrim utilize ATMOS to model radiological dispersion within 100 meters of the source?

A115. (KRO) No. The MACCS2 code was only used to calculate off-site consequences, and there are no off-site areas within 100 meters of any release point. As discussed in Answer A45, the Pilgrim SAMA analysis used the methodology established by the NRC in NUREG/BR-0184 and NUREG/BR-0058, Rev. 4 to calculate on-site exposure and economic costs, and so did not use the MACCS2 code for these purposes.

Q116: In response to this explanation previously provided by Entergy, Pilgrim Watch claims that Pilgrim ignored resuspension of materials deposited onsite. Is that correct?

A116. (KRO) No. For the Pilgrim SAMA analysis, the first polar grid ring for purposes of calculating air and ground deposition concentrations was 530 meters or approximately 0.33 miles. The MACCS2 Pilgrim SAMA analysis calculated deposition of radioactive materials within this 0.33-mile ring with no distinction of whether the deposition was on-site or off-site. (Part of this area is on-site and part is off-site.) Furthermore, all plume materials deposited within this 0.33-mile ring were subject to resuspension in the Pilgrim SAMA analysis as provided for by the MACCS2 code.[23]

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[23] During the seven-day emergency phase, MACCS2 accounts for resuspension by assuming that deposited radioactivity reenters the ambient wind stream due to mechanical agitation by wind, vehicular traffic, etc. The resulting plume is modeled using the applicable meteorological input data, with MACCS2 calculating the resulting dose consequences

Additionally, an examination of the amount of activity that deposits out by the first radius of 0.33 miles in the MACCS2 model for Pilgrim shows that a negligible amount of the radioactive plume material that is subject to deposition, e.g., only about 2%, will have deposited by that point. As stated, all of this material, even though negligible, was subject to resuspension in the Pilgrim SAMA analysis.

Thus, the Pilgrim SAMA analysis fully considers resuspension of all radioactive materials deposited within the first 530-meter polar coordinate ring which includes the site. Moreover, the consideration of this resuspended material deposited within this region is negligible in the MACCS2 overall cost-benefit analysis.

2. Long Range Use

Q117: Pilgrim Watch claims that the use of the Gaussian plume model should be limited to 50 kilometers, or 31 miles. Do you agree?

A117. (SRH, KRO) No, we do not agree. The first reason is that MACCS2/ATMOS does not use a standard Gaussian plume model such as AERMOD (EPA's near-field model). Rather, MACCS2/ATMOS uses a Gaussian plume segment model, which allows wind speed, stability, and precipitation to change from one hour to the next along the plume trajectory. Even if MACCS2/ATMOS were a standard Gaussian plume model such as AERMOD, there would be no technically justifiable reason to limit its use to 50 km. Nor does the NRC restrict the use of MACCS2 to 50 km. The range for which the Gaussian plume model may be used is understood to depend on various factors, such as significant changes in weather or terrain patterns over the range of distances and times modeled.

Thus, Pilgrim Watch's challenge to the long-range use of MACCS2 may be based on its mistaken reliance on EPA regulation. The EPA guidance documents do not specifically restrict the use of AERMOD to distances less than 50 km (32 mi).

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which are included in the total dose consequences. In the CHRONC phase, MACCS2 uses simpler methods to account for resuspension

Q118: Is it reasonable to use the MACCS2 Gaussian plume segment model in the 50-mile radius region surrounding the Pilgrim Station?

A118. (SRH) Yes. Here, the Gaussian plume segment model is reasonable for calculating expected annual consequences in the 50-mile range. Unlike the standard Gaussian plume model, the MACCS2 model updates the meteorological data, except for wind direction, on an hourly basis. Furthermore, the wind rose and the CALMET trajectory rose comparisons discussed above show the similarity of wind directions within the 50 miles and that no significant change in the SAMA analysis would result from considering time and spatially variable regional weather data.

Moreover, there are no major terrain features that would significantly impact the plume at the major population areas within across the 50-mile range, and as discussed above, the Pilgrim SAMA analysis conservatively accounts for terrain for purposes of calculating annual mean consequences summed over the 50-mile SAMA domain.

V. CONCLUSIONS

Q119: What do you conclude from your evaluation of the different claims raised by Pilgrim Watch as to the adequacy of the use of the Gaussian plume segment model and the MACCS2 code, as employed in the Pilgrim SAMA analysis?

A119. (KRO, SRH) We conclude that the meteorological inputs used and the transport and dispersion modeling that Pilgrim performed were reasonable and adequate to determine the average annual probabilistic off-site risk over a large area for use in a SAMA cost-benefit analysis.

The ATMOS atmospheric transport and dispersion model used in the MACCS2 code for the Pilgrim SAMA analysis is suitable for the purpose of calculating mean annual off-site consequences over the 50-mile SAMA domain. The Gaussian plume segment model, as employed in the MACCS2 code for the Pilgrim SAMA analysis, provides a reasonable and adequate basis for determining whether SAMAs are cost-beneficial to implement.

The use of alternative dispersion models for the SAMA analysis would have no material impact on the analysis and would result in no additional SAMAs becoming cost beneficial. Comparisons between MACCS2 and more complex atmospheric transport and dispersion models in an area in the Midwest show that, in general, the calculated consequence results agree within a margin of plus or minus 10%.

The 2001 meteorological data are representative and adequate for use in the Pilgrim SAMA analysis. Analysis of the meteorological data confirms that the meteorological data are representative of other years and of the region as a whole.

Pilgrim's SAMA analysis adequately takes sea breezes into account, since the Pilgrim Station meteorological towers are located within ¼ mile of the coast and capture the local sea and land breezes. Comparisons of the Pilgrim wind rose with wind roses at 18 other sites in the SAMA domain show that there are no major differences. Furthermore, comparisons of the Pilgrim wind rose with the CALMET trajectory roses, which use the observations from the 26 surface wind sites in the area, also shows insignificant differences. As such, the occurrence of the sea breeze phenomenon would not significantly alter the overall impacts estimated by MACCS2. More importantly, the phenomenon would not make any additional SAMA's potentially cost beneficial.

"Hot spots," as defined by Pilgrim Watch, do not exist and have no impact on the Pilgrim SAMA analysis. Even under the most stable conditions, plumes will always disperse at a large rate, with about a factor of 10 to 30 decrease in concentration with each factor of ten increase in distance travelled. Furthermore, the CALMET analysis shows that there is no pattern of wind blowing out to sea and then reversing direction and heading for the coast that could affect the SAMA analysis outcomes.

The CALMET trajectory analysis described in the Report (ENT000004) confirms that consideration of time and spatially variable wind fields, such as sea breezes, would have no significant impact on the SAMA analysis results. The trajectory analysis shows that there is no pattern in the wind trajectories that could impact the SAMA analysis outcome. The Exposure Index comparison shows that a CALMET based methodology that takes into account time and spatially variable wind fields would have negligible results (less that 4%) on SAMA analysis – far less than the factor of more than two increase in benefits necessary to cause additional SAMAs to become potentially cost beneficial.

For purposes of identifying whether any SAMAs are cost beneficial, the MACCS2 methodology for accounting for regular terrain effects and its conservative application over the 50-mile SAMA domain is adequate.

In sum, we conclude that the Pilgrim SAMA analysis meteorological “inputs,” including the meteorological data and the Gaussian plume segment atmospheric transport and dispersion model embedded in MACCS2, were sufficient and reasonably applied in the SAMA analysis and that changes to the meteorological “inputs” would not introduce any additional potentially cost beneficial SAMAs.

ATTACHMENT 1

Tables 1 and 2 Referenced in Text

Table 1. (Table 2 from WSMS (2007) Release Characteristics of Pilgrim Releases for the SAMA Accident Sequence Bins (described as Collapsed Accident Progression Bins in the SAMA study)

Release Mode	Frequency (per year)	Time of Release After Shutdown, (seconds)	Release Duration, (seconds)	Release Height, (m)	Sensible Heat Release Rate in Plume, (W)
CAPB-1	9.51E-08	2.20E+04	9.00E+03	30.	2.61E+05
CAPB-2	1.27E-08	2.20E+04	9.00E+03	30.	2.50E+05
CAPB-3	2.39E-09	2.20E+04	9.00E+03	30.	2.50E+05
CAPB-4	3.29E-09	1.83E+04	3.56E+03	30.	1.10E+07
CAPB-5	2.73E-09	2.53E+04	7.93E+03	30.	8.34E+06
CAPB-6	7.95E-09	2.56E+04	8.11E+03	30.	8.23E+06
CAPB-7	7.93E-09	2.61E+04	8.46E+03	30.	8.03E+06
CAPB-8	2.06E-08	2.00E+04	4.59E+03	30.	1.04E+07
CAPB-9	9.25E-09	2.44E+04	8.87E+03	30.	4.18E+06
CAPB-10	8.53E-08	2.60E+04	8.40E+03	30.	8.06E+06
CAPB-11	4.35E-08	2.60E+04	8.40E+03	30.	8.06E+06
CAPB-12	1.70E-06	4.64E+04	9.00E+03	30.	7.59E+06
CAPB-13	2.30E-09	2.71E+04	9.00E+03	30.	1.80E+06
CAPB-14	2.26E-06	4.46E+04	9.00E+03	30.	7.08E+06
CAPB-15	2.12E-06	4.62E+04	9.00E+03	30.	7.60E+06
CAPB-16	1.18E-09	2.12E+04	9.00E+03	30.	2.50E+05
CAPB-17	6.91E-09	2.14E+04	9.00E+03	30.	2.50E+05
CAPB-18	4.61E-10	2.12E+04	9.00E+03	30.	2.50E+05
CAPB-19	2.43E-08	2.18E+04	9.00E+03	30.	2.50E+05

Table 2. (Table 1 from WSMS (2007)). Mean Consequence and Risk Values for Base Case Population Dose and Off-site Economic Cost – (Numerically Equivalent to Table E.1-15 of LRA (ENT000006)

Release Mode	Frequency (per year)	Population Dose (person-Sv)*	Off-site Economic Cost ($)	Population Dose Risk,** (person-rem)/year)	Off-site Economic Cost Risk** Risk,($/year)
CAPB-1	9.51E-08	5.77E-01	3.82E+06	5.49E-06	3.63E-01
CAPB-2	1.27E-08	1.21E+02	7.18E+06	1.53E-04	9.08E-02
CAPB-3	2.39E-09	1.28E+02	7.31E+06	3.06E-05	1.75E-02
CAPB-4	3.29E-09	1.50E+04	4.93E+09	4.94E-03	1.62E+01
CAPB-5	2.73E-09	1.92E+04	6.15E+09	5.24E-03	1.68E+01
CAPB-6	7.95E-09	1.60E+04	4.35E+09	1.27E-02	3.46E+01
CAPB-7	7.93E-09	1.78E+04	5.25E+09	1.41E-02	4.16E+01
CAPB-8	2.06E-08	4.42E+04	1.68E+10	9.10E-02	3.46E+02
CAPB-9	9.25E-09	2.54E+04	9.26E+09	2.35E-02	8.56E+01
CAPB-10	8.53E-08	4.74E+04	1.72E+10	4.05E-01	1.47E+03
CAPB-11	4.35E-08	3.72E+04	1.29E+10	1.62E-01	5.61E+02
CAPB-12	1.70E-06	1.18E+02	4.85E+06	2.01E-02	8.25E+00
CAPB-13	2.30E-09	8.48E+03	8.36E+08	1.95E-03	1.93E+00
CAPB-14	2.26E-06	1.69E+04	4.96E+09	3.82E+00	1.12E+04
CAPB-15	2.12E-06	4.65E+04	1.80E+10	9.86E+00	3.82E+04
CAPB-16	1.18E-09	1.93E+04	6.28E+09	2.27E-03	7.40E+00
CAPB-17	6.91E-09	5.12E+04	1.98E+10	3.54E-02	1.37E+02
CAPB-18	4.61E-10	2.58E+04	8.43E+09	1.19E-03	3.88E+00
CAPB-19	2.43E-08	5.72E+04	2.11E+10	1.39E-01	5.12E+02
TOTALS				1.46E+01	5.26E+04

* 1 person-Sv = 100 person-rem

** Calculated as follows: PDR (person-rem/year) = Release mode frequency (per year) X Population Dose (person-Sv) X 100 rem/Sv; OECR ($/year) = Release mode frequency (per year) X Off-site Economic Cost ($)