UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
ENTERGY NUCLEAR GENERATION	)	
COMPANY AND ENTERGY NUCLEAR	)	Docket No. 50-293-LR
OPERATIONS, INC.	)	
	)	
(Pilgrim Nuclear Power Station)	)	

NRC STAFF TESTIMONY OF NATHAN E. BIXLER AND S. TINA GHOSH
CONCERNING THE IMPACT OF ALTERNATIVE METEOROLOGICAL MODELS ON THE
SEVERE ACCIDENT MITIGATION ALTERNATIVES ANALYSIS

Q1. Please state your name, occupation, and by whom you are employed.

A1a. [NEB] My name is Nathan E. Bixler. I am a Principal Member of the Technical Staff employed by Sandia National Laboratories ("Sandia"), which is operated by Lockheed-Martin for the US Department of Energy. I have been employed by Sandia for more than 28 years as an engineer and computer software researcher in the areas of accident analysis and fluid mechanics. My statement of qualifications is attached as Exhibit ("Ex.") NRC000011.

A1b. [STG] My name is S. Tina Ghosh. I am a senior program manager employed by the U.S. Nuclear Regulatory Commission (NRC). I have been employed by the NRC for over six years. My statement of qualifications is attached as Ex. NRC000012.

Q2. Please describe your current responsibilities.

A2a. [NEB] My current responsibilities for Sandia are fairly broad. They include (1) the lead role for development and application of the MACCS2 code for the Nuclear Regulatory Commission ("NRC"); (2) acting as the lead consequence analyst for the State of the Art Reactor Consequence Analysis ("SOARCA") Project for the NRC; (3) supporting the NRC in their work in the license extension process for the Pilgrim Nuclear Generating Station ("Pilgrim") and Indian Point Nuclear Generating Units 1 & 2; (4) teaching a class annually at the NRC's

Professional Development Center on Level-3 PRA (Course No. P-301); (5) developing a source term analysis capability to support the license application process for nuclear fuel recycling facilities for the NRC; (6) supporting the licensing process for a nuclear reactor under construction for Argentina's Nuclear Regulatory Authority (ARN); and (7) the lead consequence analyst to support the launch approval process for upcoming NASA missions involving nuclear materials for the DOE.

A2b. [STG] My current primary responsibility is to be the NRC lead for the State of the Art Reactor Consequence Analysis's ("SOARCA") uncertainty analysis. In my previous position as a reactor engineer in the Office of Nuclear Reactor Regulation's (NRR) Division of Risk Assessment, one of my primary responsibilities was to review SAMA analyses submitted in support of nuclear power plant license renewal applications, and write the corresponding portions of the NRC's supplemental environmental impact statements. I also reviewed risk-informed licensing applications that used level 2 and level 3 PRA results (i.e., analyses of accidents that involve potential radioactive releases outside the reactor containment). In my first position at the NRC in the Division of High-Level Waste Repository Safety in the Office of Nuclear Material Safety and Safeguards, my primary responsibility was to review different aspects of the Department of Energy's total-system performance assessment (TSPA) and pre-closure safety analysis (PCSA) for the Yucca Mountain repository license application. The TSPA is analogous to a level 3 PRA applied to a geologic waste disposal system, and the PCSA is analogous to a PRA for the waste-handling facilities in the operational phase in the Yucca Mountain license application. For my doctoral thesis at the Massachusetts Institute of Technology, I developed a sensitivity analysis method to generate risk information that would be useful for making decisions about high-level nuclear waste repositories given the uncertainty in the risk analyses. I demonstrated the application of the method using the proposed Yucca

Mountain repository as an example, and subsequently published a paper on the method in the journal, Nuclear Technology.

Q3. Please explain your duties in connection with the Staff's review of the License Renewal Application ("LRA") submitted by Entergy Nuclear Operations, Inc. ("Entergy," "Applicant" or "Licensee") for the renewal of Pilgrim's Operating License No. DPR-35.

A3a. [NEB] I was not involved in the Staff's review of the LRA.

A3b. [STG] I was not involved in the review of the LRA.

Q4. Why are you testifying here today?

A4a. [NEB] I am testifying as an expert witness on the use of the MACCS2 computer code in Pilgrim's Severe Accident Mitigation Alternatives ("SAMA") analysis. I have been asked by the NRC staff to testify concerning the use of the MACCS2 code in Pilgrim's SAMA analysis. Specifically, I am addressing how the MACCS2 code is used to predict consequences for a SAMA analysis and the effect that alternative atmospheric transport models might have on the SAMA analysis.

A4b. [STG] I am testifying regarding the staff's review of Pilgrim's SAMA analysis and the use of PRA in SAMA analyses. Specifically, I am addressing portions on how plants identify mitigation measures and their associated costs and the evaluation of risk and benefits for SAMA analyses, generally.

Q5. What did you review in order to prepare your testimony?

A5a. [NEB] I reviewed Attachment E of the Pilgrim Environmental Report;[1] portions of the NRC's Environmental Impact Statement related to Pilgrim's SAMA;[2] Pilgrim Watch's ("PW")

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[1] Pilgrim Nuclear Power Station Applicant's Environmental Report Operating License Renewal Stage, Attachment E, "Severe Accident Mitigation Alternatives Analysis," Exhibit ("Ex.") NRC000001, (2006).

contention and the supporting documents;[3] answers filed by Entergy in response to the staff of the NRC ("Staff");[4] the Board's Order admitting PW's contention;[5] the Commission's order remanding the contention and subsequent orders;[6] the Washington Safety Management WSMS-TR-07-0005, Revision 1, "Radiological Dispersion and Consequence Analysis Supporting Pilgrim Nuclear Station Severe Accident Mitigation Alternative Analysis" (May 2007) ("WSMS Report") filed in support of Entergy's Motion for Summary Disposition;[7] Dr. Egan's declaration in opposition to Entergy's Motion for Summary Disposition;[8] the MACCS2 code and its documentation;[9] NUREG-6853, which is titled "Comparison of Average Transport and Dispersion Among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model," the direct

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

[3] Request for Hearing and Petition to Intervene, Ex. NRC000003 (May 25, 2006), (Agengywide Document Access and Management System ("ADAMS") Accession No. ML061630125).

[4] Entergy's Answer to the Request for Hearing and Petition to Intervene by Pilgrim Watch and Notice of Adoption of Contention, Ex. NRC000004 (June 26, 2006) (ADAMS Accession No.ML061840216); NRC Staff's Response to Request for Hearing and Petition to Intervene Filed by Pilgrim Watch, Ex. NRC000005 (June 19, 2006) (ADAMS Accession No. ML061710086).

[5] Entergy Nuclear Generation Co. and Entergy Nuclear Operations, Inc. (Pilgrim Nuclear Power Station), LBP-06-23, 64 NRC 257 (2006).

[6] Entergy Nuclear Generation Co. and Entergy Nuclear Operations, Inc. (Pilgrim Nuclear Power Station), CLI-10-11, (Mar. 26, 2010); Pilgrim, CLI-10-15, (June 17, 2010); Pilgrim, CLI-10-22, (Aug. 27, 2010).

[7] WSMS-TR-07-0005, Revision 1, "Radiological Dispersion and Consequence Analysis Supporting Pilgrim Nuclear Station Severe Accident Mitigation Alternative Analysis," Ex. NRC000006 (May 2007)

[8] Declaration of Bruce A. Egan, Sc.D., CCM, In Support Of Pilgrim Watch's Response Opposing Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3, Ex. NRC000007, (June 20, 2007).

[9] NUREG/CR-6613, "Code Manual for MACCS2: Volume 1, User's Guide," Ex. NRC000008 (May 1998); NUREG/CR-4691, "MELCOR Accident Consequence Code System (MACCS)," Vol. 2, Ex. NRC000009 (1986).

testimony prepared by Dr. James Van Ramsdell;[10] and the Board's order setting the scope for the remanded contention.[11]

A5b. [STG] I reviewed Attachment E of the Pilgrim Environmental Report;[12] Appendix G of the NRC's Environmental Impact Statement on Pilgrim's SAMA analysis;[13] the Board's Order admitting PW's contention;[14] the Commission's order remanding the contention and subsequent orders;[15] the direct testimony prepared by Dr. James Van Ramsdell;[16] and the Board's order setting the scope for the remanded contention.[17]

Q6. Based on your review, what is your expert opinion regarding the Pilgrim Watch's Contention 3?

A6. [NEB] It is my opinion that it is highly unlikely that the issues raised by PW in Contention 3 would result in Pilgrim's SAMA analysis failing to identify potentially cost-beneficial mitigation measures even if alternative atmospheric transport models were used.

Q7. What is a SAMA analysis?

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[10] Testimony of James V. Ramsdell (January 3, 2011).

[11] Entergy Nuclear Generation Co. and Entergy Nuclear Operations, Inc. (Pilgrim Nuclear Power Station), LBP-10-__, (Sep. 23, 2010)

[12] Pilgrim Nuclear Power Station Applicant's Environmental Report Operating License Renewal Stage, Attachment E, "Severe Accident Mitigation Alternatives Analysis," Ex. NRC000001 (2006).

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

[14] Entergy Nuclear Generation Co. and Entergy Nuclear Operations, Inc. (Pilgrim Nuclear Power Station), LBP-06-23, 64 NRC 257 (2006)

[15] Entergy Nuclear Generation Co. and Entergy Nuclear Operations, Inc. (Pilgrim Nuclear Power Station), CLI-10-11, (Mar. 26, 2010); Pilgrim, CLI-10-15, (June 17, 2010); Pilgrim, CLI-10-22, (Aug. 27, 2010).

[16] Testimony of James V. Ramsdell (January 3, 2011).

[17] Entergy Nuclear Generation Co. and Entergy Nuclear Operations, Inc. (Pilgrim Nuclear Power Station), LBP-10-__, (Sep. 23, 2010)

A7. [STG] [NEB] A SAMA analysis is a systematic search for potentially cost beneficial enhancements to further reduce nuclear power plant accident risk. In particular, a SAMA analysis allows for the comparison of benefits derived from particular mitigation measures with their cost to implement. The SAMA analysis for Pilgrim uses probabilistic risk assessment ("PRA") to consider improvements and evaluate the change in economic risk that would result from those improvements.

Q8. Please describe how a SAMA analysis is performed?

A8. [STG] [NEB] The first step of a SAMA evaluation is to identify and characterize the leading contributors to core damage frequency (CDF) and offsite risk based on a plant-specific risk study or applicable studies for other plants. The next step in the process is to identify candidate SAMAs to mitigate these risk contributors. Once candidate SAMAs have been identified, an initial screening is performed to determine which SAMAs cannot be cost-beneficial. For example, if the cost of implementing a SAMA is higher than the elimination of all risk from operating the plant (called the "Maximum Achievable Benefit"), that SAMA is screened out since it cannot be cost effective. For each SAMA that survives this initial screening, a benefit assessment is performed to address how the change would affect relevant risk measures (i.e., the reduction gained in core damage frequency, offsite population dose in person-rem, and offsite economic cost risk). A cost assessment is also performed for each SAMA. To identify SAMAs that may be cost-beneficial, the net value of each SAMA is estimated.

Q9. How are the potential mitigation measures identified?

A9. [STG] Based on the dominant risk contributors, potential SAMAs are identified that could mitigate the associated risks of the particular plant, in this case Pilgrim. The contribution of external events is considered to the extent that it can be supported by available risk methods, because external events can affect whether or not a SAMA is cost-beneficial (greater reduction of risk). In some cases, a candidate SAMA may be identified to specifically mitigate risk from external events.[18] In other cases, a SAMA that may have been identified based on internal event considerations (e.g., use of portable generators to power equipment in a station blackout ("SBO")) may also reduce the risk for external events (e.g., a seismically induced SBO). In addition to this search for SAMAs that mitigate plant-specific dominant risk contributors, the SAMA analyses for other plants are typically also consulted for ideas about potential candidate SAMAs and evaluated when applicable.

Q10. How are the costs to implement a mitigating measure calculated?

A10. [STG] Cost estimates for hardware modifications can be taken from past studies performed for a similar plant, or developed on a plant-specific basis. Procedure and training cost estimates are typically estimated based on plant experience. Cost estimates are generally conservative in that they neglect certain cost factors (e.g., surveillance/maintenance, the cost of replacement power during implementation), therefore tending to increase the number of potentially cost beneficial SAMAs. Typically screening estimates are used for initial assessments and refined as appropriate if a SAMA is potentially cost-beneficial.

Q11. Can you explain what a baseline PRA is?

A11. [STG] [NEB] A PRA assesses the risk from operating nuclear power plants by answering three basic questions: (1) what can go wrong, (2) how likely is it, and (3) what are the consequences. The baseline PRA for a plant evaluates the risk of operating the plant based on its current state, i.e., without implementing any of the proposed improvements. The PRA for a commercial power reactor has traditionally been divided into three levels: level 1 is the

[18] For example, the risk from an external event might be minimized by improving the characteristics of hardware only capable of being damaged seismic event.

evaluation of the combinations of plant failures that can lead to core damage; level 2 is the evaluation of core damage progression and possible containment failure resulting in an environmental release for each core-damage sequence identified in level 1; and level 3 is the evaluation of the consequences that would result from the set of environmental releases identified in level 2. All three levels of the PRA are required to perform a SAMA analysis. The MACCS2 code is used to perform the consequence analysis in the level-3 portion of the PRA. Typically, the baseline PRA for a SAMA analysis starts with the existing most current version of the Level-1 and -2 PRA that is available for the plant at the time of the SAMA analysis. Since most plants do not have a level 3 PRA, typically the level 3 portion is developed using the MACCS2 code for the purpose of supporting the SAMA analysis. For the SAMA analysis, all potential consequences are converted into dollar amounts. Thus, the existing level-1 and --2 analysis with the new level-3 analysis typically form the baseline PRA that represents operating the plant in its current state and the corresponding economic risk. The baseline PRA also enables the calculation of the plant's "Maximum Achievable Benefit," which is the dollar amount that corresponds to all risk posed by the plant.

Q12. How is the benefit for each SAMA evaluated?

A12. [STG] [NEB] The benefit is evaluated by modifying the PRA to account for the effect of the plant improvement being evaluated, and then comparing the risk results of the baseline and modified PRAs. A single plant improvement is evaluated at a time. The effect of the plant improvement might be to decrease the likelihood of an accident or group of accidents calculated in level 1 of the PRA. Other plant improvements would have no effect on the frequency of accidents, but would diminish the outcome of some of the accidents, leading to smaller consequences. These would affect the magnitude of the source term predicted in level 2 of the PRA and result in lower consequences in level 3 of the PRA. Some plant improvements would reduce both accident frequencies and consequences. All consequences are translated to dollar amounts. The economic risk (in dollars) is reevaluated, assuming that one of the SAMAs was implemented. The benefit is the reduction in economic risk (in dollars) after implementing the SAMA compared with the baseline. This process is repeated to evaluate the benefit for each SAMA. The benefit calculated for an individual SAMA will be a fraction of the "Maximum Achievable Benefit," since an individual SAMA cannot eliminate all possible accident initiators nor mitigate all kinds of possible accidents.

Q13. How is the cost effectiveness of a SAMA evaluated?

A13. [STG] [NEB] The cost effectiveness is evaluated by comparing the benefit of the SAMA with the cost of the SAMA. The decrease in economic risk from implementing a SAMA, calculated by comparing the result of the baseline and modified PRAs (as explained in A11), is evaluated in units of dollars per year of reactor operation. In Pilgrim's case, the time period for the benefit is 20 years. The benefit over the 20-year period is evaluated by using a standard formula and discount rate to evaluate the present value of the benefit (according to guidance in NUREG/BR-0058 and NUREG/BR-0184). Elements of the benefit calculation include: averted public exposure costs, averted offsite property damage costs, averted occupational exposure costs, and averted onsite costs which include both averted cleanup and decontamination costs and averted replacement power cost. The present value of the benefit is compared with the cost of implementing the mitigation measure. The SAMA is cost effective if the benefit is greater than the cost; it is not cost effective if the benefit is less than the cost.

Q14. How are the source terms evaluated and used in a SAMA analysis?

A14. [NEB] The primary result of the level-1 and -2 portions of the PRA is the estimation of a set of source terms, each corresponding to a specific accident sequence. The number of source terms is usually too large to perform a consequence analyses on each one. To reduce the computational effort for the consequence analysis, the source terms are sorted into a set of bins, often referred to as source term groups ("STGs"). The sorting into bins is generally based on the magnitude of the release and the timing of the release. Earlier releases result in greater consequences because there may not be adequate time to evacuate the public within the Emergency Protection Zone ("EPZ"), the area within about 10 miles of the plant, before the release begins. Larger releases lead to larger doses to members of the public and greater environmental contamination to deal with in the aftermath of the accident. The set of source terms in each STG is expected to result in relatively similar consequences. In a SAMA analysis, a single source term is usually chosen to represent each STG. The representative source term may be a best estimate or a bounding source term. In the Pilgrim SAMA analysis, a best estimate source term was chosen to represent each STG. Source term groups are referred to as Collapsed Accident Progression Bins ("CAPBs") in the Pilgrim Environment Report.[19] The frequency associated with this source term is the sum of the frequencies of all sequences that fall into the STG.

Q15. How is the consequence for each accident represented by a source term calculated?

A15. [NEB] A consequence analysis is performed for each STG identified in the Level-2 portion of the PRA. The consequences are evaluated assuming that the accident occurs. The likelihood of the accident occurring during one year of plant operation is the frequency associated with the STG. The risk is the expected value of the consequences. Multiplying the frequency of a STG by the consequences that would result if an accident were to occur gives the risk per year of reactor operation for that STG. The total risk of operating the plant per year of operation is the sum of the risks for the set of STGs. Neglecting the time value of money, the risk over the remaining years of plant operation is the risk per year times the number of years the plant is

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[19] Pilgrim Nuclear Power Station Applicant's Environmental Report Operating License Renewal Stage, Attachment E, "Severe Accident Mitigation Alternatives Analysis," Ex. NRC000001, at E.1-44 (2006).

expected to operate. The time value of money is included in a SAMA analysis by using a standard formula to estimate the present value of the benefit.

Q16. What consequences are evaluated for a SAMA analysis?

A16. [NEB] Five types of consequences are considered in a SAMA analysis. The first three of these are onsite costs and include (1) the monetary value of occupational doses to decontamination workers; (2) onsite decontamination costs; and (3) the cost to replace lost power. Estimation of these costs is independent of atmospheric transport and deposition modeling. The remaining two categories are offsite costs: (4) offsite economic costs associated with evacuation and relocation of the population, decontamination of property, loss of use of property, and condemnation of property and (5) a monetary value associated with doses to members of the public. These five types of costs are added together to get the total cost that would result if an accident occurred. For each type of cost, there is a standard method to evaluate that cost. MACCS2 is the standard tool used to evaluate off-site costs (4 and 5), as described in NUREG/BR-0158. Offsite economic cost (4) is a direct output from the MACCS2 code. The cost associated with doses to the public (5) is calculated by multiplying the population dose reported in the MACCS2 output by $2000/person-rem.

The benefit associated with a SAMA is calculated by accounting for reductions in accident frequencies and reductions in accident consequences. The reduction in the economic cost risk assuming the SAMA was implemented compared with the baseline risk is the benefit of the SAMA.

Q17. Are you familiar with the term “source term” as it is used regarding SAMAs?

A17. [NEB] Yes.

Q18. What is a source term?

A18. [NEB] A source term describes the physical, chemical, and radiological composition of an atmospheric release. The information in the source term description includes the quantity of each important radionuclide released into the atmosphere, the initial time of the release relative to the start of the accident, the duration of the release, the elevation of the release, the buoyancy of the plume released, and the particle size of the released material.

Q19. How is the source term used by the MACCS2 code?

A19. [NEB] The source term is defined in the level-2 portion and used in the level-3 portion of the PRA analysis. It is used to determine the off-site economic and human health consequences for that particular source term group. Consequence analysis is the primary element of the level-3 PRA analysis. The consequence analysis, which is performed by MACCS2, uses the source terms and frequencies generated by the Level-1 and -2 portions of the PRA analysis to define the source of contamination that will spread over the 50 mi. radius surrounding the plant.

MACCS2 consists of three modules that analyze given inputs to evaluate the consequences resulting from different potential accident scenarios. The three modules are known as ATMOS, EARLY, and CHRONC. Each module uses input data provided in multiple input text files in order to complete the calculations. The modules operate sequentially: (1) ATMOS, (2) EARLY, and (3) CHRONC.

The ATMOS module uses an atmospheric transport model that uses the source terms and various other input data, including a full year of hourly meteorological measurements (wind direction, wind velocity, precipitation rate, and stability class), surface roughness, and a spatial grid of the 50-mile region surrounding the plant, in this case Pilgrim. The ATMOS module assembles these data and treats a statistically significant number of weather trials to adequately analyze the likely weather conditions that might be present during a severe accident. In Pilgrim's SAMA analysis, 146 weather trials were selected; that is 146 discrete times were selected as the point in time for the release of radioactive contamination into the environment. The wind in each of these 146 weather trials was forced to blow in all 16 compass directions based on the annual likelihood that wind would blow in each direction according to binned weather data with similar conditions.[20] For each accident scenario, 2336 meteorological conditions[21] were modeled. The ATMOS module determines the transport and deposition of contamination within the 50-mile area surrounding Pilgrim. It calculates the location of the plume and concentration of each released isotope for each spatial grid cell and further determines how much contamination falls out of the plume to be finally deposited into each spatial grid cell. Finally, these calculations are repeated for each accident scenario. Pilgrim's SAMA analysis used 19 different representative accident scenarios (different source terms with distinct release characteristics) to represent the variety of accidents that could occur.[22] This information for each model run is passed from the ATMOS module to the EARLY and CHRONC modules for determination of the dose to population and the costs, like clean-up of the contamination, evacuation, and relocation, for each meteorological condition (i.e., 2336 meteorological conditions passed to EARLY and CHRONC for each accident scenario).

Q20. How are the consequences for each accident calculated by the MACCS2 code?

A20. [NEB] EARLY and CHRONC use the information calculated by ATMOS along with additional input data to determine the doses and other consequences for separate portions of the response. EARLY models the doses and costs of the accident related to the initial response through the first seven (7) days. During this period of time, the plume passes through the grid and emergency response is implemented. CHRONC models the doses and costs of the accident related to its long-term responses and clean-up from seven days through 30 years.

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[20] Annual weather data is binned into separate files based on similar meteorological conditions including precipitation, stability, velocity and other characterizing properties.

[21] The 2336 meteorological conditions modeled for each accident scenario is the result of modeling 146 weather trials and forcing the conditions through the 16 compass directions or 146*16.

[22] Modeling the 19 different accident scenarios results in 44,384 (19*2336) models for the transportation and deposition of contamination on the surrounding 50-mile area.

The EARLY module uses transport and deposition results from the ATMOS module and input data regarding human population in the area to model estimated doses during the plume passage and from deposition for the first seven (7) days of an accident. EARLY also uses input data describing dose conversion factors, land use, economic inputs (costs for emergency response, including evacuation), a spatial grid refinement factor, relocation information, re-suspension factors, cohort definitions, evacuation data, and shielding data.

Using these input data, EARLY calculates the consequences of the accident for the first seven days. After seven days, the consequences are determined by the CHRONC module.

The CHRONC module uses the transport and deposition calculations from the ATMOS module, some of the input data for the EARLY module, and additional input data regarding per diem costs for the displaced population, decontamination costs, long-term protective action values (habitability criteria), interdiction, weathering factors, a regional land value, and food-chain dose conversion factors.

Based on these inputs, CHRONC calculates the costs or economic consequences of the accident. As part of the CHRONC module, the decision to decontaminate or condemn is made based on whether the habitability criterion could be met following decontamination. The effect of decontamination or condemnation is accounted for in the long-term consequences of the doses received by decontamination workers, doses received by members of the public, and in the economic costs for the accident.

Once CHRONC completes its calculations for one accident scenario, the MACCS2 code assembles an output file with a statistical description of the consequences, including the mean population dose and the mean offsite economic costs.

Q21. How is the SAMA analysis completed once the MACCS2 code completes its calculations?

A21. [NEB] Separately from the MACCS2 code, a spreadsheet or other similar application calculates the “mean consequence value” by summing the on-site economic costs and the

MACCS2 code outputs, including the mean of the offsite economic costs and value of the mean population dose. Once the costs for each accident scenario and weather condition are calculated by MACCS2, the “mean consequence value” for each accident scenario is determined by calculating the statistical mean of the range of consequences calculated (summation of the consequences associated with the 2336 meteorological conditions weighted by the probability of each). Further, the likelihood of the accident occurring is accounted for by multiplying the probability that the accident would occur with the costs of the particular accident if it did occur. The net present value of the consequence is determined by using discount rates of, alternatively, 3% and 7%, to account for potential variations in the discount rate. Each of the other accident scenarios’ “mean consequence value” is determined similarly. In Pilgrim’s case, 19 different accident scenarios and their representative source terms were used.

Q22. How are the source terms determined for SAMAs?

A22. [NEB] Evaluation of source terms for a SAMA analysis requires a relatively detailed model that includes a multitude of physical process models accounting for timing of safety actions taken automatically by the installed systems and any human actions affecting accident progression and containment. Any radionuclide releases outside of containment are sequentially modeled from their release from the reactor core through any release or breach in containment. Source term calculations are usually based on the Methods for Estimation of Leakages and Consequences of Releases (“MELCOR”) or Modular Accident Analysis Program (“MAAP”) computer code. The Pilgrim SAMA analysis used the MAAP code as the basis for its source term analysis. Source terms generally depend on how rapidly the accident progresses, the path by which the radionuclides escape from the reactor into containment, the path through containment (or possibly bypassing containment altogether), and the effectiveness of both passive and active safety features, especially pools and sprays, that are intended to mitigate releases by, e.g., “scrubbing” the radionuclides and/or reducing containment internal pressure driving the release.

A large number of source terms were calculated in the Pilgrim SAMA analysis, each corresponding to a specific accident sequence. Each source term was characterized as a set of release fractions corresponding to groups of radionuclides with potential for detrimental health effects. The Pilgrim SAMA used 19 STGs to characterize consequences based on the timing of release and the magnitude of release. A representative set of release fractions was assigned to each STG by calculating a frequency-weighted mean of the radionuclide release fraction for each accident within the STG. These representative STGs were used to perform the consequence analysis.

Q23. In your expert opinion, are projected transport and deposition of the radionuclides for the Pilgrim’s SAMAs conservative?

A23. [NEB] Yes, they are.

Q24. Why do conclude that transport and deposition of radionuclides is conservative?

A24. [NEB] In this regard, the Gaussian plume model utilized in the ATMOS module of the MACCS2 code is actually more conservative in estimating doses at larger distances from the point of release than the models suggested by PW. The Gaussian model ensures that any radioactive contamination travels the shortest distance to each affected area and arrives at each affected area with a more concentrated plume. As a result, the model predicts larger doses and economic impacts, because the contamination has not had additional time to decay or to be diluted by dispersion. In addition, the MACCS2 code has been compared to a LaGrangian particle tracking code, for estimating concentrations and deposition out to distances as great as

100 miles from the point of release, and produced mean results that agreed to within about a factor of two of those of the LaGrangian code within 50 miles.[23]

Q25. What is the effect of using conservative transport and deposition of radionuclides on the overall SAMAs?

A25. [NEB] Benefits predicted in a SAMA analysis increase with the concentration of radionuclides in the plume during transport and contamination of any area after deposition. Thus, conservative transport and deposition directly influence the SAMA results. I expect the conservative transport and deposition in the ATMOS module to produce conservative results for the estimated benefits. This might cause some of the SAMAs to be determined cost beneficial when they are actually not cost beneficial.

Q26. Why are you able to conclude that transport of contamination would be conservative?

A26. [NEB] The Gaussian model conservatively estimates the plume path to be as short as possible. The shorter path of travel ensures that the maximum amount of contaminant reaches the downwind areas, which then receive more accumulated radiological dose and greater economic consequences. Allowing the plume to travel along more circuitous paths increases the path length and the travel time to downwind areas, during which time the plume experiences increased dispersion, deposition, and decay, which tend to minimize the impact on downwind areas located farther from the site. Thus, the Gaussian plume model tends to maximize the estimated consequences of any particular accident.

Q27. Is it important to accurately account for radioactive decay of the released isotopes?

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[23] NUREG-6853, "Comparison of Average Transport and Dispersion Among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model," Ex. JNT000001 at 65-68.

A27. [NEB] Yes, it is very important to accurately account for the half-life of each isotope. Depending on how the model accounts for the half-lives, an overestimate or underestimate of the exposure and necessary clean-up would result. For example, ignoring the radioactive decay of the isotopes would overestimate the dose and clean-up because dose rates from the contamination would remain constant indefinitely resulting in increased dose in excess of the dose that would actually occur. Alternatively, using a single half-life to model all the isotopes would most likely reduce the radionuclides too quickly resulting in doses below what would be expected to occur in an actual accident.

The answer depends on the isotopes being modeled along with daughters that will be created and subsequently undergo radioactive decay. Properly accounting for radioactive decay is very important for the isotopes with short half-lives, i.e., half-lives that are less than or comparable to the length of the emergency phase, which is typically 1 week. Because they disappear relatively quickly, not accounting for the decay of those isotopes would lead to an overestimate of the consequences they would produce. However, not accounting for the radioactive daughters of these isotopes could lead to an under estimate of consequences. Neglecting radioactive decay would be reasonably good only for long-lived isotopes.

The majority of the isotopes that would be released during a nuclear reactor accident have half-lives that are less than one week. Thus, a simplified treatment of these half-lives would produce inaccurate results.

Neglecting or simplistically treating radioactive decay could lead to an over or under estimate of consequences, depending on the radionuclides released and the simplifications used in the model. Any results based on ignoring radioactive decay or overly simplifying the decay process would be inaccurate and unreliable.

Q28. In your expert opinion, would a SAMA analysis be sufficiently reliable to make accurate predictions if the radioactive decay was not modeled?

A28. [NEB] No.

Q29. In your expert opinion, would a SAMA analysis be sufficiently reliable to make accurate predictions if all the isotopes were assumed to have a single half-life?

A29. [NEB] No. The half-lives of the isotopes that are treated in a SAMA analysis range from about an hour to thousands of years. There is no way to accurately represent all of the half-lives by a single value.

Q30. In your expert opinion, do you believe that it would be reasonable to use an atmospheric transport model that could not account for the radioactive decay of the released isotopes?

A30. [NEB] No, I don't.

Q31. Why is failing to accurately model radioactive decay not reasonable when performing a SAMA analysis?

A31. [NEB] It would not be reasonable because most of the isotopes treated in a SAMA analysis have a relatively short half-life. These produce a dose over a few hours or a few days. They either decay to a stable isotope that has no further consequence, or they decay to another radioisotope that also must be modeled. Properly treating the initial decay and any daughter ingrowth for the isotopes that would be released during a reactor accident is an essential part of the consequence analysis.

Q32. Are you familiar with the atmospheric dispersion models (AERMOD and CALPUFF) Dr. Egan and PW have suggested would be more appropriate to use at Pilgrim?

A32. [NEB] I am somewhat familiar with these specific codes. I am familiar with the types of models that these codes represent.

Q33. In your expert opinion, would AERMOD be more appropriate for use in the SAMA analysis?

A33. AERMOD would not be appropriate for use in a SAMA analysis.

Q34. Why would AERMOD not be appropriate for use in a SAMA analysis?

A34. [NEB] AERMOD would not be more appropriate for use in a SAMA analysis than the MACCS2 code because it fails to accurately model radioactive decay and daughter ingrowth, dose pathways, dose mitigation (evacuation, relocation, and decontamination), and economic consequences and relies on overly simplistic assumptions on key issues for estimating consequences.

AERMOD was designed for short range (up to 50 km [31 mi.]) dispersion from stationary sources, and includes modeling the effect of surface terrain on the behavior of air pollution plumes and of building downwash effects. Similar to the ATMOS module in the MACCS2 code, AERMOD models plume behavior using a Gaussian plume representation. However, AERMOD is limited to modeling a single half-life per-run and, thus, is unable to specifically model the multiple different half-lives applicable to the radionuclides likely to be released during a severe accident. Further, AERMOD does not model daughter ingrowth, dose pathways, dose mitigation (evacuation, relocation, or decontamination), and does not include an economic model. Introducing all of these missing models and adding the capability to handle the multiple half-lives and decay chains required for a SAMA analysis into AERMOD would be a very large task.[24] Even if you compared AERMOD to only the ATMOS portion of the MACCS2 code, it would fail to account for radioactive decay properly. It is limited to only being able to model a single half-life and would result in unrealistic results for the consequences of an accident.

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[24] Some might suggest that AERMOD's limit to a single half-life could be avoided by iteratively running the model for each isotope. However, this would likely result in increasing the number of model runs by at least an order of magnitude. For most source terms, the initial isotopes modeled range from 40 to 70. This ignores modeling the daughters generated by the radioactive decay throughout the transport and deposition process.

Q35. In your expert opinion, would CALPUFF be more appropriate for use in the SAMA analysis?

A35. [NEB] CALPUFF would not be appropriate for use in a SAMA analysis.

Q36. Why would CALPUFF not be appropriate for use in the SAMA analysis?

A36. [NEB] CALPUFF is proposed by the EPA for applications involving long-range transport, which is typically defined as transport over distances beyond 50 km. CALPUFF uses a Gaussian puff model, where each puff follows the local wind direction. As of December 13, 2010, the most recently EPA-approved version of the CALPUFF System is Version 5.8 – Level 070623 of CALPUFF and includes changes through MCB-D. This version does not model radioactive decay for multiple isotopes, daughter ingrowth, dose pathways, dose mitigation (e.g., evacuation), or economic costs. As such, use of CALPUFF for SAMA analysis is inappropriate because it fails to model key aspects of potential radioactive release from a severe accident that are needed for a SAMA analysis. Finally, adding the additional missing models to CALPUFF that are required for a SAMA analysis would be a very large task. Even when CALPUFF is compared to just the ATMOS module, it lacks the ability to model the radioactive decay properly.

Q37. Has the Gaussian plume model used in the MACCS2 code ever been compared to models like those suggested by Pilgrim Watch?

A37. [NEB] Yes. It was compared with two Gaussian puff model codes from Pacific Northwest National Labs, RASCAL and RATCHET, and a state-of-the-art Lagrangian particle tracking code from the National Atmospheric Release Advisory Center (NARAC) at Lawrence Livermore National Laboratory called LODI. The study was documented in NUREG-6853, “Comparison of Average Transport and Dispersion Among a Gaussian, a Two-Dimensional, and a Three-Dimensional Model,” Ex. JNT000001.

Q38. What was the conclusion of that study?

A38. [NEB] The main conclusion was that the mean results computed by MACCS2 are within a factor of two (2) of those predicted by Gaussian puff models (similar to CALPUFF) and also to the results predicted by the Lagrangian particle tracking code, LODI. In fact, the largest observed deviation between mean results produced by MACCS2 and LODI was 58%. For comparison, the largest observed deviation between one of the Gaussian puff model codes, RASCAL, and LODI was 61%. Generally, MACCS2 performed as well as either of the Gaussian puff models when compared with the state-of-the-art code, LODI, for calculating mean consequence results. This conclusion sheds doubt on the assertion by Pilgrim Watch that CALPUFF is more suitable for a SAMA analysis than MACCS2. Furthermore, CALPUFF does not have all of the capabilities needed for a SAMA analysis.

Q39. Do you agree with those conclusions?

A39. [NEB] Yes. I coauthored the report.

Q40. Since you completed the study, have you become aware of any information that would make you tend to believe that conclusions are no longer valid or would be altered based on additional research?

A40. [NEB] I am not aware of any new information that would make me believe that our conclusions in the Lawrence Livermore study are no longer valid or need to be revisited.

I give this answer in the context of a PRA-type analysis where the primary results are means of the consequences. For PRA applications, special meteorological events, e.g., low-lying nocturnal jets and sea breezes, that only occur a few percent of the time do not have much effect on the overall, mean results. The Livermore study focused on mean results and showed that MACCS2, a Gaussian plume model, performed about as well as two Gaussian puff codes similar to CALPUFF.

Gaussian puff models, like CALPUFF, are generally used to recreate or simulate specific meteorological instances. For example, RASCAL, which is NRC's code for emergency response and employs a Gaussian puff model, would be used in the event of an actual radioactive release from a nuclear power plant. The emphasis for emergency response is on having an accurate picture of the plume trajectory so that officials can make informed decisions regarding sheltering and evacuation. This level of fidelity is not needed for PRA applications. The Livermore study shows that a Gaussian puff code does not produce better answers than a Gaussian plume code, like MACCS2, when consequences representing a mean over representative weather are the desired outcomes of the analysis.

Q41. In your expert opinion, are the conclusions regarding the MACCS2 code in the Lawrence Livermore study applicable to Pilgrim?

A41. [NEB] Yes. As Mr. Ramsdell explained in his testimony at p. 6-8, A14., the sea breeze effect at Pilgrim has very little impact on the SAMA analysis. I would expect that that MACCS2 code and the ATMOS module would compare favorably to higher fidelity codes if used for a SAMA analysis at Pilgrim.

Q42. In your expert opinion, would you expect the use of CALPUFF or AERMOD to identify any mitigating measures as being cost beneficial solely because of the selection of an alternative atmospheric transport model?

A42. [NEB] No. Even assuming that these codes had the full set of capabilities required for a SAMA analysis, I would expect the results to be very similar to those produced by MACCS2. Because the cost of the next most cost-beneficial SAMA is more than a factor of two greater than its benefit, I can state with a high degree of certainty that an alternative atmospheric transport model would not alter the transport and deposition of the radionuclides enough to make another SAMA potentially cost-beneficial.

Q43. Are you aware of any alternative atmospheric dispersion models that are likely to identify additional mitigation as cost beneficial?

A43. [NEB] No, I am not aware of any alternative atmospheric dispersion models that would be likely to identify additional cost-beneficial mitigation measures. Even from my experience with the highest fidelity codes like LODI, I would expect them to produce consequence results well within a factor of two (2) of those produced by MACCS2.

Q44. Why do you come to that conclusion?

A44. [NEB] I make this conclusion based on my research into the performance of the MACCS2 code with high-fidelity codes and my own experience modeling and reviewing accidents. Based on this experience and research, I would expect that the result of using more complex atmospheric transport modeling to have a relatively small effect on the predicted consequences, well within a factor of two (2).

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of	)	
	)	
ENTERGY NUCLEAR GENERATION	)	
COMPANY AND ENTERGY NUCLEAR	)	Docket No. 50-293-LR
OPERATIONS, INC.	)	
	)	
(Pilgrim Nuclear Power Station)	)	

AFFIDAVIT OF NATHAN E. BIXLER

I, Nathan E. Bixler, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications are true and correct to the best of my knowledge and belief.

Executed in Accord with 10 CFR 2.304(d).

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AFFIDAVIT OF S. TINA GHOSH

I, S. Tina Ghosh, do hereby declare under penalty of perjury that my statements in the foregoing testimony and my statement of professional qualifications are true and correct to the best of my knowledge and belief.

Executed in Accord with 10 CFR 2.304(d).
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