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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 OPERATIONS, INC. (Pilgrim Nuclear Power Station)	)	Docket No. 50-293-LR

AFFIDAVIT OF DR. NATHAN E. BIXLER CONCERNING THE BOARD'S QUESTIONS FROM BOARD MAJORITY REGARDING THE MECHANICS OF COMPUTING "MEAN CONSEQUENCES" IN SAMA ANALYSES

I, Nathan E. Bixler, do hereby state as follows:

1. I am a Principal Member of the Technical Staff in Sandia National Laboratory' ("SNL") Analysis and Modeling Department and have been at SNL for 29 years. During the past 19 years, my work has included projects for the NRC. I have a Ph. D. in Chemical Engineering and have been primarily involved in computer modeling of fluid dynamics and more recently in simulation of nuclear accidents and consequences. I have led the development and application efforts on a variety of NRC codes, including VICTORIA, RADTRAD, MACCS2, MELMACCS, and SECPOP2000. I am the SNL project manager for development and application of the WinMACCS code suite,[1] which the NRC Staff uses in performing consequence analysis for level-3 Probability Risk Assessments ("PRAs"). I am the primary instructor for a one-week class offered to NRC staff on Level-3 PRA (the P-301 course in the NRC curriculum). I am also currently working on consequence analyses for safety documentation of the Mars Science

[1] The WinMACCS code suite is the MACCS2 code with a graphical, window-based user interface.

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Laboratory Mission scheduled for 2011. I serve as the SNL consequence analysis technical lead for the State-of-the-Art Reactor Consequence Analyses project. A statement of my professional qualifications was attached to the NRC Staff's "Response to Entergy's Motion For Summary Disposition Of Pilgrim Watch Contention 3" and is available in the Agency-wide Document Access and Management System ("ADAMS") Accession No. ML071800287.

2. In this affidavit, I present my views with respect to the issues addressed in the Atomic Safety and Licensing Board's ("Board") October 26, 2010 Order. In the Order, the Board asked that the parties' experts:

> Explain at what point in the process of SAMA computations performed using the MACCS2 code the "mean consequences" referred to by the Commission in footnote 34 of CLI-10-22 are done. We are interested in the "flow of the computations," and when in that flow the "mean consequences"10 are computed, and whether that particular part of the computation is a pure mechanical application of a standard mathematical formula for determining the "mean" of a set of numbers....
>
> a. Explain (briefly and succinctly) what is computed within each of the three modules;
>
> b. Explain briefly the process of dealing with the fact that many independent variables (such as source term, meteorological conditions, evacuation) cannot be definitively predicted to be occurring at any given time and must be addressed probabilistically, and how that leads to the computation of many different potential "consequences";
>
> c. Describe generally the process for determining the consequences of each particular scenario (i.e., describe generally the selection process used for the values to be used for independent variables, and generally how those determine input or select model usage within a particular code module);
>
> d. Describe how the results of the separate computations of consequences are used to develop a representative "consequence" which is to be used for comparison to the cost of mitigation mechanisms, where in the foregoing process the computation of "mean consequences" is done or accomplished, and its relationship to the representative consequence used for the foregoing purpose.

MACCS2' Modules and Operation

3. MACCS2 consists of three modules that analyze given inputs to develop, calculate, and 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.

4. The ATMOS module uses a meteorological model that utilizes various input data, including a full year of hourly meteorological measurements (wind direction, wind velocity, precipitation, and stability class), surface roughness, source term describing the release of radioactive isotopes, particulate size corresponding to a deposition velocity, release point, and a spatial grid of the 50-mile region surrounding the plant, in this case Pilgrim. The ATMOS module assembles these data and selects 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 likelihood that wind would blow in each direction.[2] For each accident scenario, 2336 meteorological conditions[3] were modeled. The ATMOS module determines the transportation 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

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[2] A more complete description of the selection of the weather trials and the 16 compass directions is provided in paras. 12 and 13.

[3] 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.

deposited into each spatial grid cell. Finally, these calculations are repeated for each accident scenario. Pilgrim's SAMA analysis used 19 different accident scenarios (different source terms with distinct release characteristics).[4] This information for each model run is passed independently (from the ATMOS output) 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).

5. 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. CHRONC models the doses and costs of the accident related to its long-term responses and clean-up from seven days through 30 years.

6. The EARLY module uses transport and deposition results from the ATMOS module and input data regarding human population in the area to model estimated dose 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; population, land use, and 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.

7. 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.

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[4] 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.

8. 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.

9. 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. The effect of decontamination or condemnation is accounted for in the long term consequences of the doses received by members of the public and in the economic costs for the accident.

10. Once CHRONC completes its calculations for one accident scenario, the MACCS2 code assembles an output file including a statistical description of the consequences, including the mean population dose and the mean offsite economic costs. Then, separately from the MACCS2 code, these data are used by a spreadsheet to calculate the "mean consequence value" by summing the on-site economic costs, the mean of the offsite economic costs, and value of the mean offsite population dose. 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.

<u>Probabilistic Treatment of Independent Variables</u>

11. Within the MACCS2 code, only the meteorological information is treated probabilistically. Because it would not be possible to predict the precise time and weather conditions for a severe accident, it is modeled based on the historical weather patterns for the area. Each of the other input variables or data (source term, evacuation data, and decontamination information, among others) is selected based on the best estimate of the physical process expected to occur and any actions of the responders and the public. The precise treatment of the meteorological data is discussed above. Other independent input variables that are potentially uncertain but are not addressed probabilistically by MACCS2 include evacuation variables (delay times and speeds) and the respective source term for each accident (release fraction, composition, and timing), which are discussed in subsequent paragraphs.

12. The weather sampling process in ATMOS begins by binning each hour of weather data for all 8760 hours in a year. The Pilgrim SAMA analysis used 40 weather bins. Each bin contains weather data with similar characteristics.[5] The characteristics include wind speed, stability class, and precipitation intensity and timing. MACCS2 randomly selects 4 samples from each bin to represent the weather variations in the bin. Some of the weather bins contain less than 4 samples, so the total number of weather trials is 146, less than the expected 160 (4 x 40).

13. The wind directions for each of the weather samples within a weather bin determine the likelihood that the wind blows in each direction around the compass. The likelihood is the ratio of the number of weather samples for which the wind blows in a specific compass direction to the total number of weather samples in the bin. This information is often

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[5] For example, 16 of the 40 weather bins describe meteorological conditions without measurable precipitation and grouped based on wind speed and stability class.

referred to as a wind rose. Each weather bin has a different wind rose because some weather characteristics occur more frequently when the wind is blowing in certain directions. The wind rose information is used to determine the likelihood of each of the consequence results generated by forcing the wind to blow toward each of the 16 compass sectors, as described in para. 4.

14. With respect to the evacuation variables, the potential for variation in the evacuation data is not sampled but entered as discrete data sets. The uncertainty in the evacuation data is examined by performing three sensitivity studies in which the "mean consequence values" are calculated using alternative evacuation data in order to determine how sensitive the results are to variations in the modeled evacuation. For example, the "mean consequences values" are analyzed assuming delayed and slower evacuation in order to determine whether the results are sensitive to changes in the evacuation input values. In this case, Pilgrim also performed a sensitivity analysis modeling the effects of no evacuation, which provides an upper bound on the effects of delayed or slowed evacuation.

15. Each of the accident scenario's selected source term represents a spectrum of accidents. Each accident within the spectrum has its own characteristics, frequency, and potential release. The grouping of accidents is represented by a single source term, which is the best estimate the source term for that grouping of accidents. The representative source term, however, is not sampled for variation in its composition or release characteristics. For the purpose of MACCS2, the source term is treated as a known input data for each accident scenario.

16. The Pilgrim SAMA analysis estimates a source term for every unique combination of plant damage states and containment failure modes. This creates hundreds of source terms, too many to perform a consequence analysis on each. To reduce the work required for the consequence analysis, the source terms are binned to distinguish the important characteristics of the accident. The characteristics used in the binning process were the

occurrence of a vessel breach, the primary system pressure at vessel breach, the location of containment failure, the timing of containment failure, and the occurrence of core-concrete interactions. Based on these criteria, all source terms were placed into one of 19 bins.[6] The bins are defined so that all of the source terms within a bin should lead to relatively similar consequence results. Finally, a representative source term is defined for each of the 19 bins. The representative source term is a best estimate of the source terms in the bin. The set of 19 source terms defined in this way are the source terms used by MACCS2 to evaluate consequences.

17. There are a number of other uncertain input values. One of the more important of these is the deposition velocity. Deposition velocity determines the rate of deposition of the released particulates and directly influences the level of contamination within the 50-mile boundary used in the SAMA analysis. The value selected in the Pilgrim SAMA analysis is near the upper end of the range that might have been considered, which leads to a conservative estimate of the deposition within 50 miles. Other uncertain inputs include dispersion parameters, dose conversion factors, the cost of decontamination, and other economic parameters. It is highly unlikely that the overall uncertainty in the benefit is greater than the factor of six (6) already included as the upper bound in the SAMA analysis. It is also highly unlikely that an explicit treatment of these uncertainties would make any additional SAMAs cost effective.

18. In addition to the mean consequence results used in the SAMA analysis, an upper bound benefit is also used to evaluate the cost effectiveness of each SAMA. In fact, it is this upper bound value that is used to judge whether or not the SAMA is cost effective. The

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[6] Pilgrim Nuclear Power Station Applicant's Environmental Report Operating License Renewal Stage (Pilgrim ER) at E.1-43.

upper bound is calculated by multiplying the mean value by six (6).[7] This factor of six (6) accounts for significant uncertainties in the MACCS2 inputs. To put the factor of six (6) into perspective in terms of weather uncertainty, it corresponds to slightly above the 99th percentile, which corresponds to 2.4 standard deviations above the median of the distribution. That means the factor of six would be exceeded less than 1 percent of the time. This upper bound reasonably accounts for uncertainties in source term, emergency response, weather, and other physical parameters used as input to the SAMA analysis.

Determining the Consequences of a Single Accident Scenario

19. As discussed previously in paras. 3 – 10, the consequences of a single accident scenario consist of the on-site consequences, the offsite costs, and consequences resulting from the absorbed dose. The on-site consequences are not determined by the MACCS2 code. The off-site costs generally consist of the loss of economic resources due to contamination and the costs incurred to restore the land to its primary use. It also includes costs to relocate the human population temporarily or more permanently depending on the resulting contamination. The consequences of the absorbed dose are converted to dollars using a standard conversion factor of $2000/person-rem. All these separate costs are summed to provide the cost of one accident under the weather conditions prescribed by the historical meteorological data.

20. For each accident scenario, which includes modeling over 2336 different weather conditions, the costs for each single weather condition are used to determine the statistical mean (the summation of the consequences associated with the 2336 meteorological conditions weighted by the probability of each). In order to account for the risk of each particular accident scenario, the statistical mean is multiplied by the likelihood that the accident might occur during one year of reactor operation. The resulting value is the mean consequence value for that

[7] *See* Pilgrim ER at E.2-15 – E.2-44, Table E.2-1.

accident over the course of one year of operation. The steps are repeated for each accident scenario, independently. The mean consequence values for each accident scenario are then summed to get the risk for one year of plant operation. The total risk for the plant is the risk for one year multiplied by the number of years left to operate.

Comparing the Costs of Mitigation to the Mean Consequence Value

21. Whether a mitigation measure is cost beneficial is determined by comparing the costs to implement the mitigation measure to the net present value of the costs avoided from the accident scenarios over the remaining plant's lifetime if the measure were implemented (the benefit). In order to simplify the comparison, the mitigation measures are typically assumed to be 100% effective, that is, the risk associated with the accident(s) being mitigated is reduced to 0. For some cases, however, the reduction in risk is not considered 100% effective and some risk is assumed to remain after implementation of the mitigation measure. In these specific cases, the assumed reduction in risk conservatively overestimates the reduction in risk expected by the mitigation measure and thus overestimates the benefit of the selected SAMA. If the cost to implement the mitigation measure is less than the projected mean consequence value, or even the upper bound consequence value discussed in para. 18, for the accident scenario, the mitigation measure is considered cost beneficial.

Nathan E. Bixler

Sworn and subscribed to

Before me this 18th day of November, 2010.

My Commission expires 2/1/14

OFFICIAL SEAL
Lisa A. Van Leeuwen
NOTARY PUBLIC
STATE OF NEW MEXICO
My Commission Expires: 2/1/14

State of New Mexico
County of Bernalillo

Signed and affirmed before me on this 18 day of November, 2010 by Nathan E. Bixler.

Lisa A. Van Leeuwen
Notary Public's Signature
My Commission Expires: 2-1-14

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

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

CERTIFICATE OF SERVICE

I hereby certify that copies of the foregoing Affidavit of Dr. Nathan E. Bixler Concerning The Board's Questions From Board Majority Regarding The Mechanics Of Computing "Mean Consequences" In Sama Analyses have been served upon the following through deposit in the NRC's internal mail system, with copies by electronic mail, or, as indicated by an asterisk, by deposit in the U.S. Postal Service, with copies by electronic mail this 22nd day of November, 2010:

Administrative Judge
Richard F. Cole
Atomic Safety and Licensing Board Panel
Mail Stop: T-3F23
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
E-mail: Richard.Cole@nrc.gov

Administrative Judge
Ann Marshall Young, Chair
Atomic Safety and Licensing Board Panel
Mail Stop: T-3F23
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
E-mail: Ann.Young@nrc.gov

Administrative Judge
Paul B. Abramson
Atomic Safety and Licensing Board Panel
Mail Stop: T-3F23
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
E-mail: Paul.Abramson@nrc.gov

Office of Commission Appellate
Adjudication
Mail Stop: O-16G4
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
E-mail: OCAAMAIL.Resource@nrc.gov

Atomic Safety and Licensing Board
Mail Stop: T-3F23
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
(VIA INTERNAL MAIL ONLY)

Office of the Secretary
Attn: Rulemakings and Adjudications Staff
Mail Stop: O-16G4
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
E-mail: Hearing.Docket@nrc.gov

Sheila Slocum Hollis*
Duane Morris LLP
505 9th St., NW, Suite 1000
Washington, DC 20004
E-mail: sshollis@duanemorris.com

Terence A. Burke, Esq.*
Entergy Nuclear
1340 Echelon Parkway
Mail Stop: M-ECH-62
Jackson, MS 39213
E-mail: tburke@entergy.com

Mary Lampert*
148 Washington Street
Duxbury, MA 02332
E- mail: mary.lampert@comcast.net

David R. Lewis, Esq*.
Paul A. Gaukler, Esq.
Pillsbury, Winthrop, Shaw, Pittman, LLP
2300 N Street, NW
Washington, DC 20037-1137
E-mail: david.lewis@pillsburylaw.com
paul.gaukler@pillsburylaw.com

Chief Kevin M. Nord*
Fire Chief & Director Duxbury Emergency
Management Agency
668 Tremont Street
Duxbury, MA 02332
E-mail: nord@town.duxbury.ma.us

Town Manager*
Town of Plymouth
11 Lincoln St.
Plymouth, MA 02360
E-mail: marrighi@townhall.plymouth.ma.us

Richard R. MacDonald*
Town Manager
878 Tremont Street
Duxbury, MA 02332
E-mail: macdonald@town.duxbury.ma.us

Brian G. Harris
Counsel for the NRC Staff