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DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

November 12, 2019

The Honorable James Richard Perry
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-0701

Dear Secretary Perry:

The enclosed Defense Nuclear Facilities Safety Board Technical Report is provided for your information and use. It provides our analysis and concerns with the leak path factor methodology used in the Los Alamos National Laboratory Plutonium Facility safety basis.

Yours truly,

Bruce Hamilton
Chairman

Enclosure

c: Mr. Joe Olencz

DNFSB/TECH-44

LOS ALAMOS NATIONAL LABORATORY PLUTONIUM FACILITY LEAK PATH FACTOR METHODOLOGY

Defense Nuclear Facilities Safety Board

Technical Report

November 2019

DNFSB/TECH-44

LOS ALAMOS NATIONAL LABORATORY PLUTONIUM FACILITY LEAK PATH FACTOR METHODOLOGY

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EXECUTIVE SUMMARY

During the past two years, members of the Defense Nuclear Facilities Safety Board's (Board) staff have been reviewing the safety basis for the Los Alamos National Laboratory (LANL) Plutonium Facility (PF-4). The scope of the review included safety system deficiencies identified in the PF-4 documented safety analyses (DSA), the methodology used to calculate the facility leak path factor (LPF), and the hazard and accident analyses.

In the PF-4 DSA, the post-seismic fire evaluation basis accident results in unmitigated dose consequences to the public of 218.6 rem committed effective dose (CED). Due to seismic deficiencies with the safety class fire suppression and active ventilation systems, the primary engineered safety control credited to mitigate the dose consequences of this event is the safety class passive confinement structure. The ability of the building to passively confine material in an accident scenario is quantified in the safety basis through use of an LPF less than unity in the mitigated analysis. To determine the LPF values, LANL safety analysts relied on a suite of software packages to model the flow of radiological material driven out of the building by weather and hazardous insults to material-at-risk. Using the calculated LPF values, LANL safety analysts calculated the mitigated dose consequences for the post-seismic fire event to be 24.2 rem CED. This value is just below the Department of Energy (DOE) Standard 3009-94, Change Notice 3, *Preparation Guide for U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses*, Evaluation Guideline of 25 rem total effective dose, a threshold used to identify safety class structures, systems, and components. As part of the review, the staff team performed an independent analysis of the LPF values.

The staff team identified concerns with the statistical methodology used to derive the 95th percentile LPF for each accident scenario, inconsistencies in the LPF calculation and methodology, lack of technical basis documentation, and inadequate quality assurance for software calculations. LANL plans to update the LPF modeling as part of an overall safety basis upgrade. However. LANL plans to follow the same statistical methodology for calculating the 95th percentile LPF. Given LANL's heavy reliance on the building confinement (i.e., LPF) to mitigate the potential dose consequences to the maximally exposed offsite individual from a post-seismic fire accident, the staff team believes LANL needs to address the concerns with the statistical methodology to ensure the identified controls adequately address the hazard.

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INTRODUCTION

During the past two years, members of the Defense Nuclear Facilities Safety Board's (Board) staff have been reviewing the safety basis for the Los Alamos National Laboratory (LANL) Plutonium Facility (PF-4) [1–4]. The scope of the review included safety system deficiencies identified in the PF-4 documented safety analyses (DSA), the methodology used to calculate the facility leak path factor (LPF), and the hazard and accident analyses. The staff team conducted onsite discussions with the previous management and operating contractor, Los Alamos National Security, LLC, and National Nuclear Security Administration (NNSA) Los Alamos Field Office (NA-LA) personnel on August 29–31, 2017, December 19, 2017, and October 23–24, 2018. This report focuses on the staff team's independent analysis of the LPF values reported in the DSA.

The PF-4 safety basis relies on the building structure to adequately maintain radioactive materials during accident scenarios including scenarios that significantly exceed the Evaluation Guideline[1]. The hazard mitigation provided by the passive building structure (without active ventilation) is quantified by the LPF parameter. For the PF-4 DSA [5], the application of the LPF reduces the mitigated dose consequences marginally below the evaluation guideline for the post-seismic fire accident scenario. The staff team performed an independent analysis of the LPF values and identified concerns with the statistical methodology used to derive the 95th percentile LPF for accident scenarios, inconsistencies in the LPF calculation and methodology, lack of technical basis documentation, and inadequate quality assurance for software calculations.

In February 2019, NA-LA issued a safety evaluation report that unconditionally approved the annual update to the PF-4 safety basis [5, 6]. This update addresses long-standing conditions of approval, many of which originated in 2008, and includes efforts to modernize the hazard analysis and consolidate multiple safety basis documents. The staff team evaluated the changes made in the annual update of the safety basis and determined that the concerns related to the LPF values reported in this revision of the DSA remain applicable.

[1] DOE Standard 3009-94, Change Notice 3, *Preparation of U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [7], defines an Evaluation Guideline of 25 rem total effective dose (TED) to the offsite public as a threshold used to identify safety class controls. DOE Standard 3009-94 requires these safety class controls to prevent or mitigate the dose consequence of a potential accident to a small fraction of the Evaluation Guideline.

BACKGROUND

In the approved DSA [5], the post-seismic fire evaluation basis accident results in unmitigated dose consequences to the public of 218.6 rem committed effective dose[2] (CED). Due to seismic deficiencies with the safety class fire suppression and active ventilation systems, the primary engineered safety control credited to mitigate the dose consequences of this event is the safety class passive confinement structure.

The PF-4 DSA is atypical in the DOE defense nuclear complex in using an LPF less than unity without crediting an active confinement ventilation system. The LPF is dependent on the nature and location of the accident and the condition of various interior and exterior doors (i.e., open or closed). The LPF is also sensitive to whether an accident results in a fire and on the external wind conditions (both of these provide a driving force to move the aerosolized material out of the building). To determine LPF values, LANL safety analysts relied on a suite of software packages to model the flow of radiological material driven out of the building by weather and hazardous insults to material-at-risk.

When determining the LPF for the post-seismic fire accident, LANL safety analysts assumed that the fire would occur in five laboratory rooms and only the material on the first floor would be affected. Based on the modeling and assumptions, LANL safety analysts calculated the mitigated dose consequences for the post-seismic fire event to be 24.2 rem CED. To better understand the risk posed by the post-seismic fire accident, the staff team investigated the technical bases and overall conservatism of the PF-4 LPF methodology. During its review, the staff team found the following:

- Inappropriate methodology used to derive the 95th percentile LPF;

- Inconsistencies in the LPF calculation and methodology; and

- Lack of technical basis documentation, and inadequate quality assurance for software calculations.

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[2] For comparison to the Evaluation Guideline, DOE Standard 3009 requires radiological dose consequences to be presented as TED. TED includes both the 50 year CED and direct exposures. For the two material categories of interest in the dose consequences calculation for the post-seismic fire accident scenario at PF-4 (i.e., weapons grade plutonium-equivalent and heat source plutonium), the 50 year CED outweighs the dose consequences due to direct exposures by several orders of magnitude. Therefore, the dose consequences reported as rem CED are equivalent to rem TED and can be directly compared to the Evaluation Guideline.

LPF STATISTICAL METHODOLOGY

In the approved DSA [5], LANL safety analysts assumed that, during the evaluation basis accident scenarios, the exterior doors of the main corridors at PF-4 would be open for a five minute period as personnel evacuated the building (see Figure 1). LANL safety analysts made this assumption based on facility evacuation drills. LANL safety analysts computed LPF values associated with various accidents for this five minute period. They modeled wind flow around the building in order to determine the pressure boundary condition at the doors of the main corridors. The magnitude of the pressure influences the rate at which airborne materials exit the building, which causes LPF to be a weather-dependent input parameter to the dose consequence calculation.

LANL calculated dose consequences using a method involving distributions of the product of the downwind relative concentration (χ/Q) and LPF. To calculate LPF, LANL first performed computational fluid dynamics (CFD) simulations to estimate the pressure on the external faces of the building. Then LANL used MELCOR[3] to estimate the transport of material out of the building during an accident. LANL performed these computations for a combination of six wind speeds and eight wind directions, generating an array of 48 LPF values for each accident scenario. Next, LANL used hourly wind speed and direction data to interpolate within the computed LPF array values. This allowed LANL to generate a distribution of LPF values for each hour based on a five-year period of meteorological data[4] for each accident scenario. Then, LANL multiplied the hourly LPF values by the hourly χ/Q values to obtain a distribution of the product of LPF and χ/Q. LANL ordered these paired parameters from low to high values, and determined the 95th percentile of the product of χ/Q and LPF. Finally, LANL divided the 95th percentile of the product of χ/Q and LPF by the 95th percentile of χ/Q to obtain the LPF value for each accident scenario, which it terms LPF_{95} (see Equation 1 below). The PF-4 DSA uses LPF values with additional margin beyond LPF_{95} values calculated from the statistical methodology. These LPF values, which contain added margin, are termed *representative* LPF values (LPF_{Rep}). The PF-4 DSA states that the LPF_{Rep} values were applied due to the uncertain nature of the LPF models and the sensitivity of some of the LPF calculations to factors driven by human behavior during an accident scenario.

$$LPF_{95} \equiv \frac{\langle \frac{\chi}{Q} \times LPF \rangle_{95}}{\langle \frac{\chi}{Q} \rangle_{95}} \qquad [1]$$

The Board's staff team performed an independent analysis and identified the following concerns with LANL's statistical methodology: non-conservative LPF values; discrepancies between hourly average and five minute average wind data; and non-physical behavior in LPF arrays.

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[3] MELCOR is a software package maintained by Sandia National Laboratories that is capable of characterizing hazardous material releases to the environment.

[4] The meteorological data include wind speed and wind direction during 2003-2007.

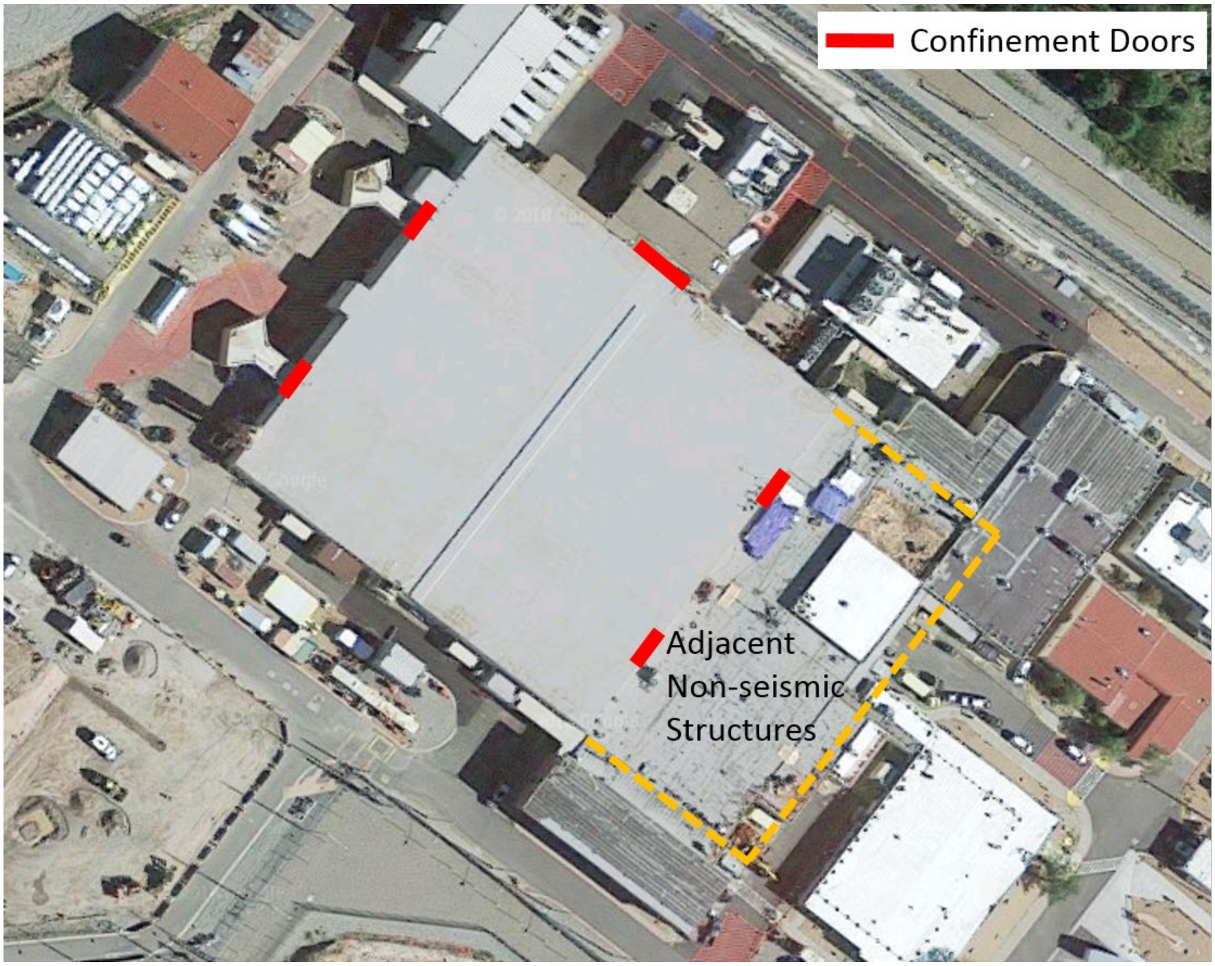

Figure 1. *Layout of PF-4 showing overhead facility view and exterior confinement doors.*

Non-conservative LPF Values—To quantify the conservatism of the LANL derived LPF_{95} values, the staff team determined LPF values and percentiles based on the meteorological data for several accident scenarios (i.e., the staff determined the full set of hourly LPF values for each scenario based on wind speed and direction over a five year period). The accident scenarios analyzed in this report are a subset of the postulated accidents in the PF-4 DSA. These were the only scenarios for which LANL could provide modeling information. The staff team was unable to analyze the post-seismic fire accident LPF values because the information LANL provided was incomplete and unclear. The staff team used two methods to convert wind direction data from 16 sectors to 8 sectors, resulting in two LPF distributions. The range reported below represents the percentile of LPF_{95} and LPF_{Rep} in both ranges. Table 1 summarizes the results of the staff team's analysis of the LPF_{95} for these accident scenarios. The staff team found that the LPF_{95} referenced in the DSA ranges from the 31^{st} to the 78^{th} percentile based on the full set of LPF values. Appendix A contains details of the staff team's analysis.

Table 1: Percentiles of LPF_{95} for several PF-4 accident scenarios		
Accident	**LPF_{95}**	**Percentile of LPF_{95} in distribution†**
Hydrogen Deflagration from Dissolution of Plutonium Metal	0.012	74th–78th
Fire in Robotic Calorimetry Room	0.043	31st–37th
Fire in TA-55 Vault	0.02	62nd–67th
Generic Glovebox Spill	0.016	60th–66th
PF-4 Basement Fire–Flammable Liquids Fire	0.26	32nd–35th

In an attempt to quantify the conservatism of LPF_{Rep} values, the staff team determined their percentiles based on the hourly LPF values for several accident scenarios, with the results summarized in Table 2.

Table 2: Percentiles of LPF_{Rep} for several PF-4 accident scenarios		
Accident	**LPF_{Rep}**	**Percentile of LPF_{Rep}**
Hydrogen Deflagration from Dissolution of Plutonium Metal	0.05	94th–95th
Fire in Robotic Calorimetry Room	0.05	45th–51st
Fire in TA-55 Vault	0.05	97th
Generic Glovebox Spill	0.05	90th–92nd
PF-4 Basement Fire–Flammable Liquids Fire	0.3	64th–69th

The staff team found that the LPF_{Rep} values that LANL safety analysts used in the dose calculations in the DSA range from the 45th to the 97th percentile. From the accidents the staff team analyzed, it is possible that the dose consequences could increase by up to a factor of two or more, had the 95th percentile LPF been used. Appendix B contains the details of the staff team's analysis.

The staff team also noted that the amount of rounding, or margin, applied to the LPF_{95} is inconsistent. The margin ranged from a factor of 1.03 to a factor of 4.17. Notably, of the sampling of accidents the staff review team analyzed, the smallest margins are applied to the post-seismic fire LPF values. Appendix B contains the margins for the accident scenarios that the staff team reviewed.

During onsite discussions, LANL personnel stated that the margin was added to the LPF_{95} to provide operational flexibility. Specifically, LANL personnel explained that if they wanted to move certain operations to a different location in PF-4, the margin applied to the LPF_{95} would ensure that the safety analysis would still be bounding. LANL personnel said that they would no longer apply this margin to the LPF_{95} value in future modeling efforts; therefore, they would use the LPF_{95} values calculated from the statistical methodology directly in future dose consequence calculations. If operations were to be moved in the facility, the dose consequences for accident scenarios associated with those operations would have to be re-analyzed.

DOE Standard 3009-94 in Section A.3, *Dose Comparison Calculations*, states that "[t]he intent is that calculations be based on reasonably conservative estimates of the various input parameters." The staff team's analysis of LANL's LPF data shows that LPF values referenced in the DSA are not reasonably conservative, given that the values are below the 95^{th} percentile in most cases. The staff team discussed this finding with LANL personnel, who stated that since χ/Q and LPF depend on the same weather, and that χ/Q and LPF are inversely proportional, it would be non-physical and unnecessarily conservative to use LPF values in higher percentiles of the five year hourly distribution along with the 95^{th} percentile of χ/Q. However, the staff team identified two concerns with LANL's argument: (1) χ/Q and LPF do not depend on the same time-averaged weather data; and (2) LPF and χ/Q are not always inversely proportional based on LANL's model. The following two sections provide additional analysis of these concerns.

Time-Averaged Weather Data—The staff team identified that the time-averaged weather data may vary significantly when evaluating χ/Q and LPF parameters. In the PF-4 DSA, the LPF estimates the amount of material released during the five minute period of time when the external corridor doors of the facility are open following an accident. External weather conditions during this five minute time are key parameters in calculating the LPF. The χ/Q parameter is also dependent on weather conditions but over a longer period (i.e., hourly time-averaged weather data). Because the LPF is dependent on shorter interval weather conditions, differences in the wind data between a 60-minute average and a shorter, five-minute average, may be significant and warrant separate analysis.

The staff team estimated how well fifteen-minute and 60-minute wind data compared over the five year period between 2003 and 2007. The team obtained 15-minute average wind data, as it was the shortest averaged data available from LANL. The staff team then computed 30- and 60-minute average wind data from the 15-minute wind data.

The staff team's analysis shows that fifteen-minute and 60-minute data differ significantly. The staff team estimated that in approximately half of the comparisons between fifteen-minute averages and the corresponding 60-minute average, either the wind direction occurred in different sectors or the wind speed differed by 20 percent or more. Due to the high occurrence of significant differences between the fifteen-minute average wind data and the 60-minute average wind data, the staff team concludes that the 60-minute average wind speed and direction values are not appropriate representations of the five-minute LPF phenomenon (i.e., χ/Q and LPF do not depend on the same time-averaged weather data). The staff team also extrapolated to five minute conditions to estimate the difference between five minute and 60-minute average wind data. The extrapolation further demonstrates the significant differences between weather conditions used to calculate χ/Q and LPF. Appendix C presents the entirety of the staff team's analysis.

During onsite discussions, LANL personnel disagreed with the staff team's analysis, particularly that LPF and χ/Q should be represented by different time intervals. During a follow-up discussion with NA-LA, NA-LA personnel said that the conservatisms in the overall accident analysis outweighed the LPF non-conservatisms identified by the staff team. However, neither LANL safety analysts nor NA-LA personnel have performed a quantitative analysis to establish the overall conservatism of the approach.

Non-physical Behavior in LPF Arrays—The staff team identified instances where the LPF arrays provided by LANL exhibited seemingly non-conservative or non-physical behavior. Although wind speed and LPF are expected to be correlated, the staff team identified instances where the LPF did not increase with wind speed. Figure 1 shows an example of such an instance where the LPF in the north-south direction (represented by the dashed line) increases monotonically with wind speed. Conversely, the LPF in the next sector, northwest-southeast (represented by the solid line), generally decreases.

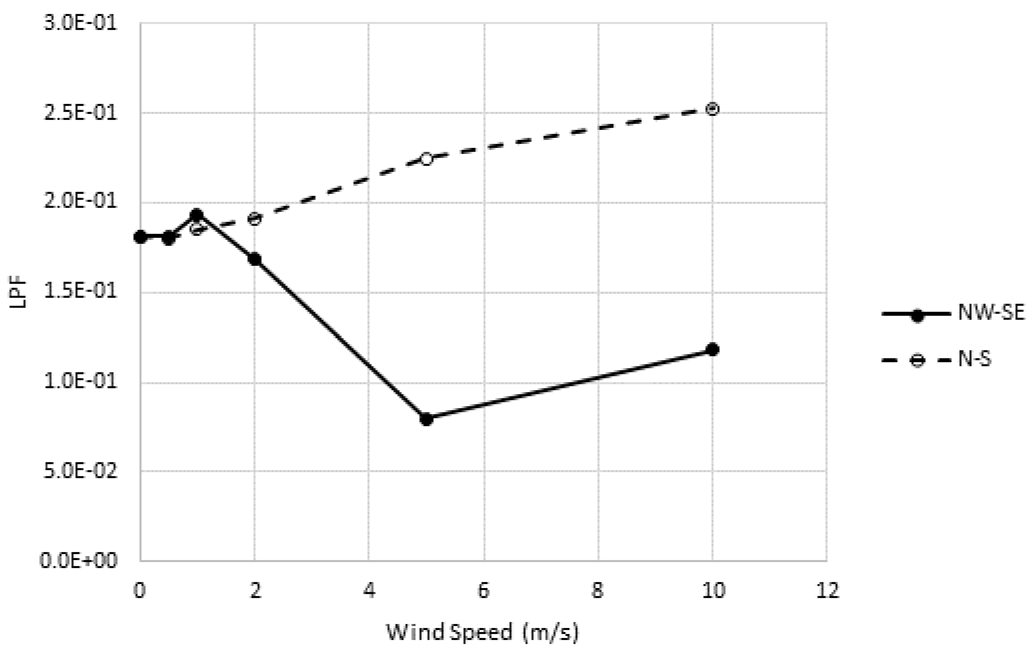

Figure 1. *An example taken from a LPF array for the post-seismic fire accident scenario.*

The staff team's discovery that the LANL calculations in some cases yield decreasing LPF values with increasing wind speeds reveals two potential non-conservative aspects in the calculations:

- LANL personnel stated that using LPF values in high percentiles in combination with the 95th percentile of χ/Q is non-physical and overly conservative because LPF values and χ/Q values are inversely proportional. However, if the LPF decreases with increasing wind speed, then χ/Q and LPF are not always inversely proportional and higher percentile LPF and χ/Q values may simultaneously exist for the same weather data. Therefore, it may not be overly conservative to use LPF values in higher percentiles with the 95th percentile of χ/Q.

- LANL personnel stated that one of the additional conservatisms in the statistical methodology is that hourly wind speed values are rounded up to the next highest wind speed in the LPF array when interpolating LPF values. For instance, if a given hourly wind speed was 3 meters per second (m/s), then the LPF selected for that hour would correspond to the LPF array at 5 m/s. Since there are cases where LPF values decrease with increasing wind speed, then rounding up to the next highest wind speed is not always conservative.

Additionally, the staff team identified instances where the LPF arrays exhibited potentially non-physical behavior, which casts doubt on the validity of the LPF values used in the DSA. Figure 2 shows an example of potentially non-physical behavior where both the south-north (represented by the dashed line) and southeast-northwest (represented by the solid line) directions track reasonably well from 0–5 m/s, then diverge after 5 m/s. Additionally, both the south-north and southeast-northwest directions have local maxima at 0.5 m/s, then decrease, then increase again.

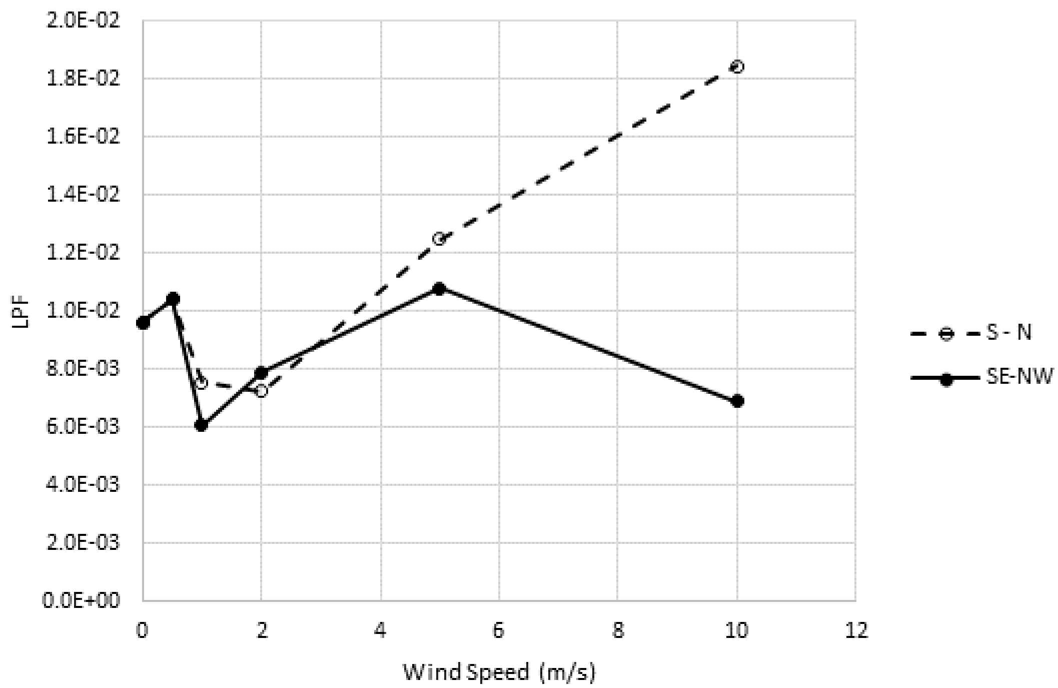

Figure 2. *An example taken from a LPF array for the vault fire accident scenario.*

During onsite discussions, LANL personnel were unable to explain the anomalous behavior but stated their intention to better understand the behavior through updated LPF modeling efforts. The staff team concludes that the erratic behavior of the LPF arrays indicates weaknesses or inaccuracies in the MELCOR and CFD modeling, and that such inaccuracies indicate that the LPF values may not be defensible.

COMPUTER MODELS SUPPORTING LPF

LANL safety analysts used several software packages in support of the statistical LPF methodology. The modeling approach taken to determine a final LPF_{95} and the progression of computational software used in each step are detailed in Figure 3.

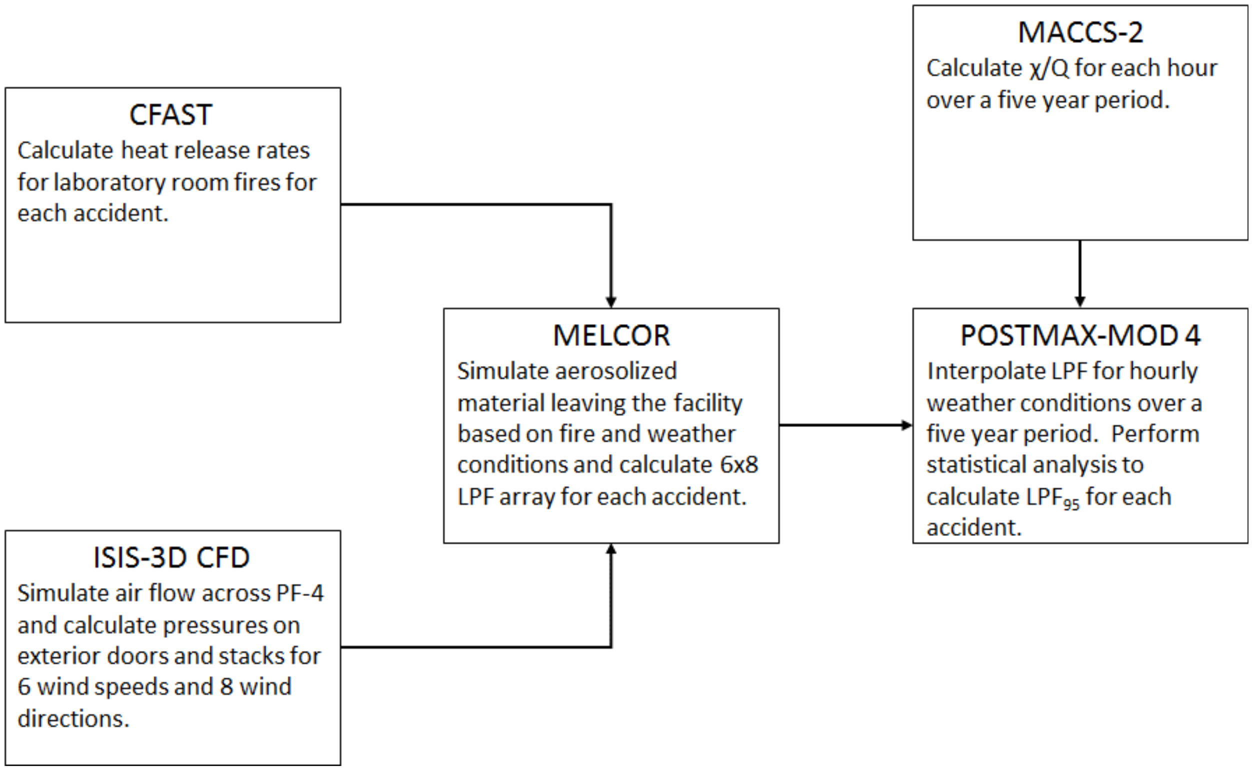

Figure 3. *Leak path factor software packages and modeling progression.*

To determine the appropriate pressure boundary conditions to assign to the external doors in the PF-4 MELCOR model, LANL subcontracted Alion Science and Technology, Inc. (Alion), to perform a CFD analysis of air flow across PF-4 [9]. Alion personnel used the ISIS-3D CFD code on a realistic model of PF-4 that includes attached performance category 3 structures. They performed steady state calculations for six uniform wind speeds and eight wind directions and reported area-averaged static pressures for different locations across the exterior of the building. LANL personnel used these results to set pressure boundary conditions for external doors and stack exhausts in the MELCOR model. During its review, the staff team noted differences between the values reported in the CFD report and those listed in the MELCOR boundary condition files. During onsite discussions, LANL personnel indicated that they also were unable to determine how the CFD-derived pressures were applied as boundary conditions in MELCOR. The MELCOR pressure boundary conditions are an important input to the model that strongly influences how much material is driven out of the building during an accident.

Additionally, the ISIS-3D CFD code is not classified as safety software, which would require software quality assurance activities like software verification and validation.

Furthermore, Suo-Anttila, et al. [10], describe the code as "currently under development for the Defense Threat Reduction Agency (DTRA) as a tool for risk assessment and engineering level analysis [emphasis added]." The Alion report provides limited validation of the code for a simplified geometry but does not discuss any software quality assurance activities to support the complex modeling of the PF-4 facility.

INADEQUATE RECORDS FOR LPF

DOE Standard 3009-94 [7] states, "All assumptions made in the accident analysis (i.e., defining points in scenario progression) are to be validated as part of the accident analysis activity…. The above guidance is not meant to imply that the DSA must contain detailed validations for all assumptions. The DSA needs to present information at a level that is considered sufficient for review and approval of the DSA. Referencing an auditable trail of information as part of the controlled supporting documentation is acceptable." The staff team found that the LPF values reported in the PF-4 DSA [5] did not have an auditable trail of information or a reproducible technical basis.

In the course of conducting its review, the staff team requested documentation supporting LPF values used for all the accident scenarios, including the post-seismic fire event (i.e., the LPF arrays based on wind speed and direction used to calculate 95^{th} percentile LPF values). In some cases, the LPF arrays appeared non-physical or incomplete, and LANL personnel were unable to find or reproduce other supporting information. Further, documentation describing the contents of LPF arrays and calculations substantiating the values reported in the DSA were unavailable. The staff team submitted multiple document requests and held multiple teleconferences with LANL personnel to obtain and interpret information. Neither NA-LA nor LANL personnel could fully explain the information that was provided to the staff team.

In addition to the difficulties in obtaining LPF array information, the staff team noted the following deficiencies in records availability:

- LANL could not provide sufficient documentation explaining how MELCOR output files corresponded to input files for specific accident scenarios.

- LANL could not provide the documentation for resolving local facility and global geographic coordinates.

- Information referenced in the PF-4 safety basis was not traceable to the cited document or the cited document was inaccurately referenced.

The staff team concluded that the records and application of quality assurance with respect to the LPF calculation were inconsistent with the requirements of Subpart A of DOE's regulation, *Nuclear Safety Management*, 10 Code of Federal Regulations (CFR) 830 [11]. Section 10 CFR 830.6 of the regulation states, "A contractor must maintain complete and accurate records as necessary to substantiate compliance with the requirements of this part." As part of the quality assurance program (QAP), 10 CFR 830.122, QAP Criterion 4(2), states, "Specify, prepare, review, approve, and maintain records." A record is defined in 10 CFR 830.3, Definitions, as follows: "Record means a completed document or other media that provides objective evidence of an item, service, or process."

In addition, NNSA should have identified the inadequate LPF technical basis documentation during its review of the DSA. DOE Order 420.1C, Change Notice 2, *Facility Safety* [12], states that DOE Elements must "Review and approve safety basis and safety design basis documents in accordance with DOE-STD-1104-2016, *Review and Approval of Nuclear Facility Safety Basis and Safety Design Basis Documents*."

DOE Standard 1104-2016 [13] states, "In accordance with the methodology used, where applicable, DSA review and approval focuses on the adequacy of the following topical areas to establish the bases for approval of the DSA: Base information; hazard and accident analyses; defense-in-depth; safety structures, systems, and components; specific administrative controls; derivation of TSRs [technical safety requirements]; and safety management programs. The DSA may be considered adequate when the SBAA [safety basis approval authority] concludes that technical justification exists regarding adequacy of each of these topical areas."

For NNSA to conclude that the hazard and accident analyses are adequate, DOE Standard 1104-2016 states, "The accident analysis methodology is clearly identified and appropriate, including identification of initial conditions and assumptions. The technical basis for source term values is provided, valid, and appropriate for the physical situation being analyzed. The completeness and level of detail in the technical basis should increase as the parameters depart from the default or bounding values described in Part 830's safe harbor methods. Supporting calculations and technical documents are identified, where appropriate, and reviewed for critical aspects of safety controls, where appropriate." It is not apparent to the staff team that NNSA fully reviewed the technical basis for the PF-4 LPF prior to approving the recently submitted DSA [5].

LPF UPGRADE PROJECT

LANL has submitted a project execution plan [14] to NA-LA that documents the plan, means, method, and controls that it will use to update the DSA to be DOE Standard 3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis,* compliant and update the atmospheric dispersion model, LPF modeling, fire modeling, and material-at-risk for the PF-4 DSA. As part of this update, LANL personnel plan to incorporate recent meteorological data for the calculation of χ/Q. They also plan to perform sensitivity analyses of releases, which evaluate a ground level release, plume buoyancy, plume meander, and building wake effects to ensure the modeling aligns with the accident progression as described in the accident analysis with LPF and fire modeling. LANL plans to update the LPF modeling by using the latest version of MELCOR to calculate the LPF for the applicable evaluation basis accidents. LANL has completed the fire modeling update and found that the reduction of combustible loading in PF-4 has resulted in lower heat release rates. Lastly, LANL plans to review the amounts of material-at-risk analyzed in the different design basis accidents (specifically the post-seismic fire accident) to more accurately reflect current programmatic needs.

LANL personnel informed the staff team that they intend to improve documentation associated with the LPF calculation as part of the LPF upgrade. LANL personnel also noted that they plan to use the ANSYS Fluent CFD software package to model the air flow across PF-4, with appropriate commercial grade dedication of the software. LANL plans to follow the same statistical methodology for calculating the LPF_{95} as described above in this planned update.

CONCLUSIONS

In the PF-4 DSA [5], LANL safety analysts rely on the building structure confinement via calculation of a LPF to reduce the unmitigated dose consequences to the public of 218.6 rem CED to 24.2 rem CED for the post-seismic fire accident. This value is just below the Evaluation Guideline, a threshold used to identify safety class structures, systems, and components. Based on the findings detailed in this report, the Board's staff team concludes that the approved PF-4 safety basis does not appropriately analyze the post-seismic fire accident scenario at PF-4. In addition, the staff team concludes that inadequate documentation and quality assurance regarding the derivation of LPF values used in the DSA challenge the efficacy of the primary control that is credited to protect the public from the consequences of a seismic event (i.e., confinement by the building structure). The staff team recognizes that the LANL contractor is currently updating LPF calculations as part of a planned safety basis upgrade. However. LANL plans to follow the same statistical methodology for calculating the 95^{th} percentile LPF. Given LANL's heavy reliance on the building confinement (i.e., LPF) to mitigate the potential dose consequences to the maximally exposed offsite individual from a post-seismic fire accident, the staff team believes LANL needs to address the concerns with the statistical methodology to ensure the identified controls adequately address the hazard.

APPENDIX A—Analysis of LPF_{95} Values

Page A-3 of Department of Energy Standard 3009-94, Change Notice 3, *Preparation Guide for U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [7], states, of the dose consequence calculations, “The intent is that calculations be based on reasonably conservative estimates of the various input parameters.” However, the staff team noted that the statistical methodology in the approved documented safety analysis (DSA) [5] may produce leak path factor (LPF) values that are not based on reasonably conservative estimates. To quantify the level of conservatism of the LPF values listed in the DSA, the staff team determined what percentiles various LPF values correspond to in the five year distribution of hourly LPF values from 2003–2007. This appendix presents the results of the staff team’s LPF conservatism analysis. The accident scenarios analyzed in this appendix are a subset of the postulated accidents in the PF-4 DSA. These were the only scenarios for which Los Alamos National Laboratory (LANL) could provide modeling information.

Table A-1 shows the staff team’s calculation of the percentiles within the five year distribution of hourly LPF values from 2003–2007 for five accident scenarios. The staff team was unable to analyze the post-seismic fire accident LPF values in this same manner because the information that LANL safety analysts provided was incomplete and unclear, as documented earlier in this report. The staff team also calculated the ratio between the actual 95th percentile ($\langle LPF \rangle_{95}$) and the LPF_{95}, and the maximum LPF value ($\langle LPF \rangle_{max}$) and the LPF_{95}, also shown in Table A-1.

Table A-1: Conservatism of LPF_{95} for several PF-4 accident scenarios

Accident	LPF_{95}	Percentile of LPF_{95} in distribution†	$\frac{\langle LPF \rangle_{95}}{LPF_{95}}$	$\frac{\langle LPF \rangle_{max}}{LPF_{95}}$
Hydrogen deflagration from dissolution of plutonium metal	0.012	74th – 78th	2.9–6.0	6.8
Fire in Robotic Calorimetry Room	0.043	31st – 37th	2.2–2.4	3.2
Fire in TA-55 Vault	0.02	62nd – 67th	2.1	2.6
Generic Glovebox Spill	0.016	60th – 66th	4.1	8.2
PF-4 Basement Fire – flammable liquids fire	0.26	32nd – 35th	1.3	1.4

† The staff team used two methods to convert wind direction data from 16 sectors to 8 sectors. This resulted in two LPF distributions. The range represents the percentile of LPF_{95} in both ranges.

As an example of how these values and distributions compare, Figure A-1 shows the five-year cumulative distribution function of the LPF for the Fire in the Robotic Calorimetry Room accident scenario, with the LPF_{95} and $\langle LPF \rangle_{95}$ identified.

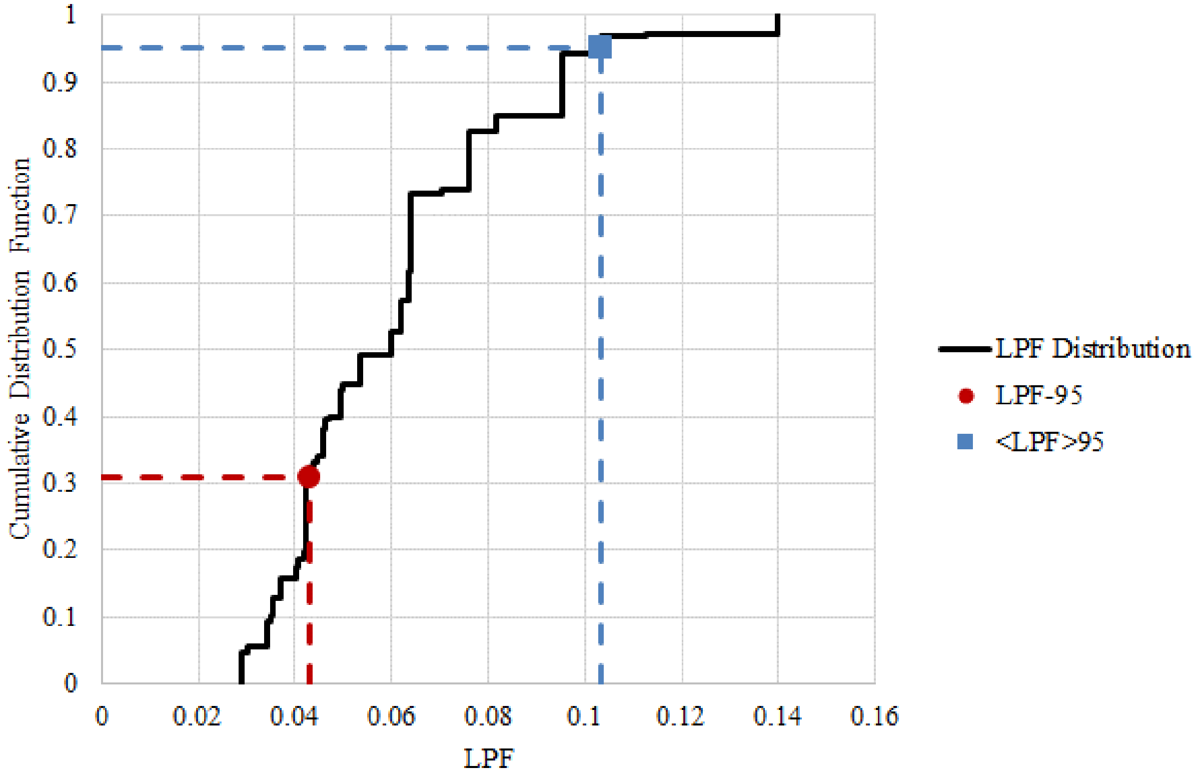

Figure A-1. *LPF_{95} and $\langle LPF \rangle_{95}$ within the five-year LPF distribution for Fire in Robotic Calorimetry Room.*

APPENDIX B—Analysis of LPF_{Rep} Values

The approved documented safety analysis (DSA) [5] uses representative leak path factor (LPF) values in the dose consequence calculations. These representative LPF (LPF_{Rep}) values bound the LPF values calculated by the statistical method described in the DSA (LPF_{95}) for the various accident scenarios. The staff team performed a calculation to determine the level of conservatism of the LPF_{Rep} values used in the dose consequence calculations in the DSA. This appendix presents the results of the staff team's LPF margin analysis.

In an attempt to quantify the conservatism of the LPF_{Rep} values, the staff team determined their percentiles within the five year distribution of hourly LPF values from 2003–2007 for five accident scenarios, as shown in Table B-1. The staff team also calculated the ratio between the actual 95th percentile ($\langle LPF \rangle_{95}$) and LPF_{Rep}, and the maximum LPF value ($\langle LPF \rangle_{max}$) and LPF_{Rep}, also shown in Table B-1.

Table B-1: Conservatism of LPF_{Rep} values for several PF-4 accident scenarios

Accident	LPF_{Rep}	Percentile of LPF_{Rep}	$\frac{\langle LPF \rangle_{95}}{LPF_{Rep}}$	$\frac{\langle LPF \rangle_{max}}{LPF_{Rep}}$
Hydrogen Deflagration from Dissolution of Plutonium Metal	0.05	94th – 95th	0.69–1.4	1.6
Fire in Robotic Calorimetry Room	0.05	45th – 51st	1.9–2.1	2.8
Fire in TA-55 Vault	0.05	97th	0.84	1.1
Generic Glovebox Spill	0.05	90th – 92nd	1.3	2.6
PF-4 Basement Fire–Flammable Liquids Fire	0.3	64th – 69th	1.1	1.2

† The staff team used two methods to convert wind direction data from 16 sectors to 8 sectors. This resulted in two LPF distributions. The range represents the percentile of LPF_{Rep} in both ranges.

In Table B-1, the ratios indicate the factor by which the dose consequences would increase if the actual 95th percentile of the LPF or the maximum LPF was used in the dose consequence calculation. From the accidents the staff team analyzed, it is possible that the dose consequences could increase by up to a factor of two or more.

The staff team was unable to analyze the post-seismic fire accident LPF values in this same manner because the information that Los Alamos National Laboratory (LANL) provided was incomplete and unclear. The 6×8 arrays for the post-seismic fire provided by LANL included values that exceeded one indicating that the MELCOR results had not yet been scaled to produce LPF values (i.e., the 6×8 arrays for the post-seismic fire accident provided by LANL are proportional to, but are not true LPF values). LANL was unable to provide an appropriate scaling factor. The staff team attempted to replicate LANL's statistical methodology using the post-seismic fire 6×8 arrays. Since the 6×8 arrays provided by LANL were not true LPF values, but proportional to LPF, the staff team is reporting percentile and ratio results for the staff team's calculated LPF^*_{95} (denoted $LPF^*_{95,staff}$ in Table B-2) where the '*' indicates that the values are not true LPF values. The staff team also calculated the actual 95th percentile of the hourly LPF^* as well as the maximum hourly LPF^* for comparison to LPF^*_{95}, as shown in Table B-2.

Table B-2: Staff team's calculated LPF^*_{95} percentiles and ratios for the post-seismic fire accident			
LPF^* array label	**Percentile of $LPF^*_{95, staff}$**	$\frac{\langle LPF^* \rangle_{95}}{LPF^*_{95,staff}}$	$\frac{\langle LPF^* \rangle_{max}}{LPF^*_{95,staff}}$
Environ-239	51st – 53rd	1.1	1.1–1.2
Environ-238	42nd	1.4–1.5	1.5–1.6
Environ-242	53rd – 58th	1.2–1.3	1.2–1.3

Table B-2 shows that the staff team's calculated LPF^*_{95} values varied between the 42nd – 58th percentiles for the post-seismic fire accident scenario. The ratio of the true 95th percentile and staff team's calculated LPF^*_{95} varied between 1.1 and 1.5. The ratio of the 100th percentile and staff team's calculated LPF^*_{95} varied between 1.1 and 1.6. Because the dose consequence for the post-seismic fire accident is 24.2 rem committed effective dose (CED), even a 10 percent increase in the LPF would cause the dose consequences to exceed the DOE Standard 3009-94, Change Notice 3, *Preparation Guide for U.S Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses* [7], Evaluation Guideline of 25 rem.

The staff team noted that the amount of rounding, or margin, LANL applied from the LPF_{95} to the LPF_{Rep} values from the DSA is inconsistent. Table B-3 shows that the DSA applies inconsistent margin across the various accident scenarios in its rounding to the representative LPF values.

Table B-3: **Calculated and representative LPF values for various accident scenarios and the ratio of the two**			
Accident Scenario	**Calculated LPF**	**Representative LPF**	**Ratio of Representative: Calculated LPFs**
Hydrogen Deflagration from Dissolution of Plutonium Metal	0.012	0.05	4.17
Fire in Robotic Calorimetry Room	0.043	0.05	1.16
Fire in TA-55 Vault	0.02	0.05	2.50
Post-Seismic Fire, 1st Floor, North Half	0.154	0.16	1.04
Post-Seismic Fire, 1st Floor, South Half	0.146	0.15	1.03
Generic Glovebox Spill	0.016	0.05	3.13
Basement Fire – Flammable Liquids	0.26	0.3	1.15

Table B-3 shows that the margin ranged from a factor of 1.03 to a factor of 4.17.

Notably, of the accidents the staff team reviewed, the smallest margins are applied to the post-seismic fire LPF values, which correspond to the accident with a dose consequence of 24.2 rem CED.

APPENDIX C—Time-Averaged Weather Data

The approved documented safety analysis (DSA) [5] does not discuss the difference between the length of time used to characterize the χ/Q and the leak path factor (LPF). The χ/Q is obtained using hourly average weather, according to relevant regulatory guidance documents (Nuclear Regulatory Commission [15], Environmental Protection Agency [16], and Department of Energy [7]). In the accident scenarios at the Plutonium Facility, the LPF represents the five minute period when the doors are assumed to be open for evacuations. Therefore, the external weather conditions during the first five minutes after an accident affect the amount of material that escapes building confinement, which is captured in the LPF. Although the LPF is dependent on weather conditions of a shorter time span (five minutes) than χ/Q, Los Alamos National Laboratory (LANL) safety analysts based the LPF calculations in the DSA on hourly wind speed and wind direction data. The staff team identified concerns with using hourly average weather data to represent the five minute weather-dependent LPF. This appendix presents the results of the staff team's wind averaging analysis.

The staff team estimated how well fifteen-minute and 60-minute wind data compare. The staff team obtained 15-minute average wind data because it was the shortest averaged data available, then computed the 30- and 60-minute average wind data from the 15-minute wind data. The staff team also extrapolated to five minute conditions to estimate the difference between five-minute and 60-minute average wind data.

To estimate how fifteen-minute wind data compares to 60-minute wind data, the staff review team created parity plots of 15-minute-versus 60-minute data and 30- versus 60-minute data. Figures C-1 and C-2 show the 15- versus 60-minute wind speed and direction comparisons, and Figures C-3 and C-4 show the 30- versus 60-minute wind speed and direction comparisons. For each comparison, the staff team calculated the coefficient of determination, or R^2 value.

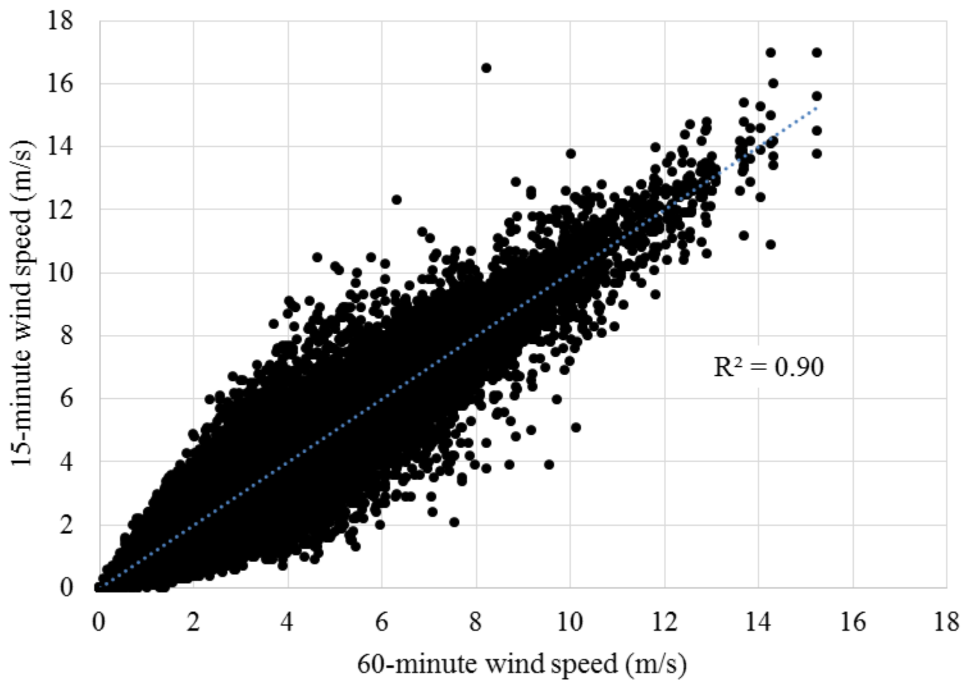

Figure C-1. *Parity plot of 15- versus 60-minute wind speed data over five-year period from 2003–2007.*

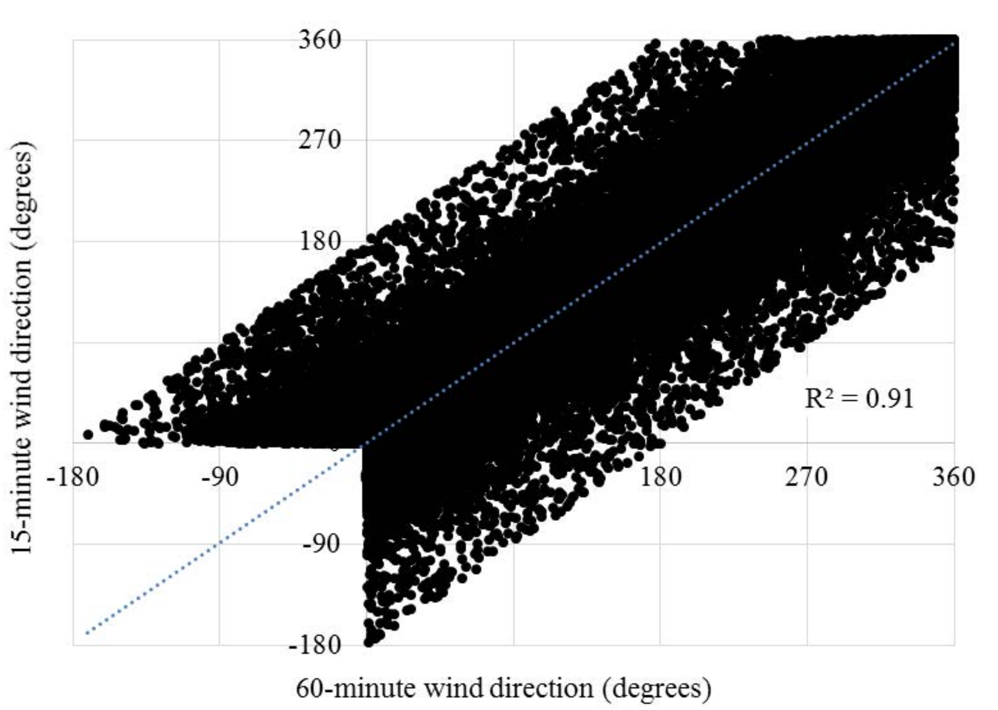

Figure C-2. *Parity plot of 15- versus 60-minute wind direction data over five-year period from 2003–2007.*

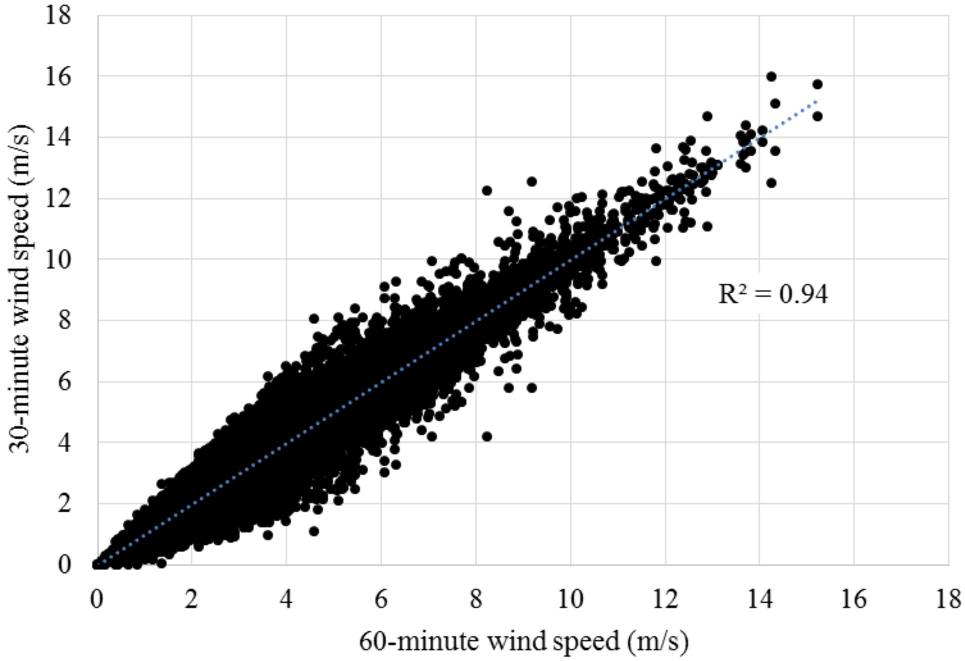

Figure C-3. *Parity plot of 30- versus 60-minute wind speed data over five-year period from 2003–2007.*

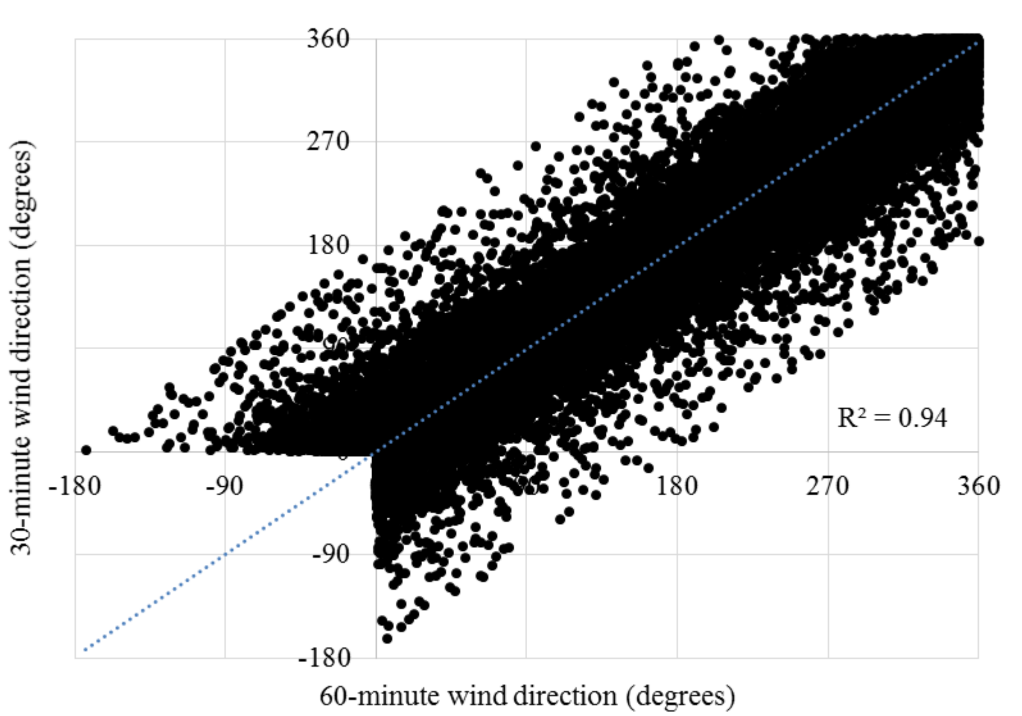

Figure C-4. *Parity plot of 30- versus 60-minute wind direction data over five-year period from 2003–2007.*

Next, the staff team compiled the R^2 values for wind speed and wind direction for 15- versus 60-minute and 30- versus 60-minute data. Figure C-5 shows the R^2 values extrapolated to five minutes to estimate the R^2 values of a five-minute versus 60-minute comparison of wind speed and wind direction. In Figure C-5, the blue circles represent the wind speed R^2 values and the red squares represent the wind direction R^2 values.

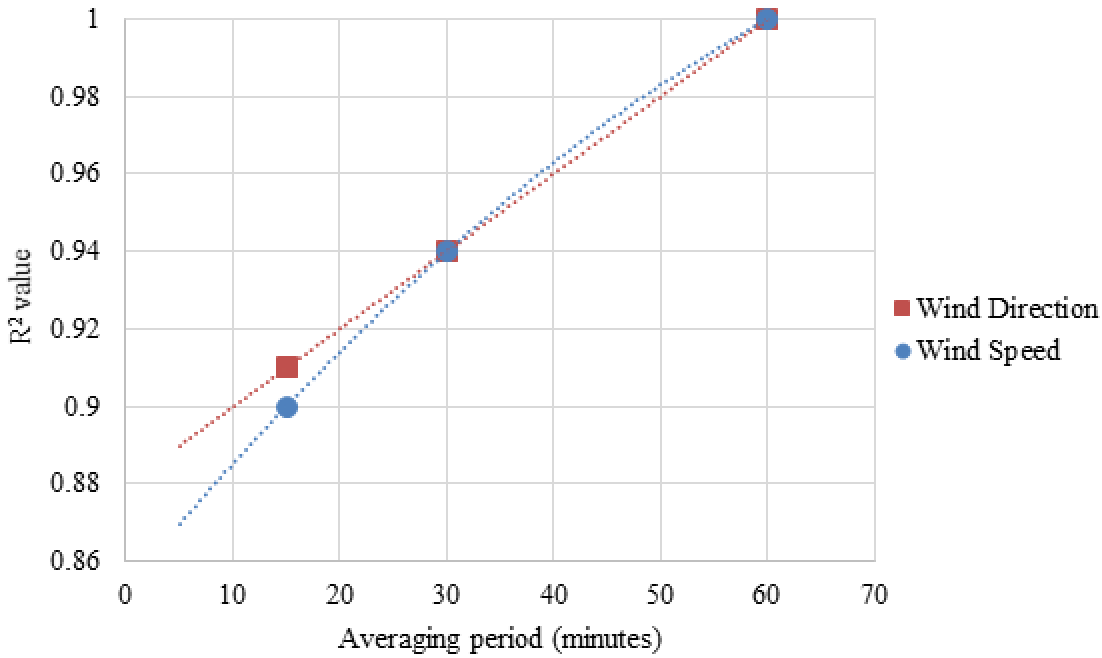

Figure C-5. *R^2 values from 15- versus 60-minute and 30- versus 60-minute wind data extrapolated to five minutes.*

The staff team used polynomial extrapolations to estimate the five-minute R^2 values because three data points were available. The extrapolation of the R^2 values in Figure C-5 estimates the five-minute R^2 values to be 0.87 for wind speed and 0.89 for wind direction.

Figures C-1 through C-5 present wind speed and wind direction as two independent variables; however, the LANL LPF calculation depends on both wind speed and wind direction together. Therefore, if either the wind speed or wind direction is different in the five-minute and 60-minute averaging periods, then the hourly LPF value will be different than the five-minute LPF value. To estimate how wind speed and wind direction compare between five- and 60-minute averaging periods, the staff team performed a multivariable analysis taking into account the correlation of both variables.

In this multivariable analysis, the staff team determined how often the wind direction from the smaller averaging period was in a different 45 degree sector compared to the 60-minute wind data or the wind speed differed by a given percentage. Figure C-6 shows the percentage of comparisons between 30- and 60-minute wind data and 15- and 60-minute wind data that met or exceeded the criteria of one sector difference or the given percentage difference of wind speed. The staff team completed the multivariable analysis using 10 percent, 20 percent, and 50 percent wind speed difference, shown in Figure C-6 by blue circles, red squares, and green triangles, respectively. The staff team extrapolated the comparisons to five minutes versus 60 minutes for each of the three wind speed differences.

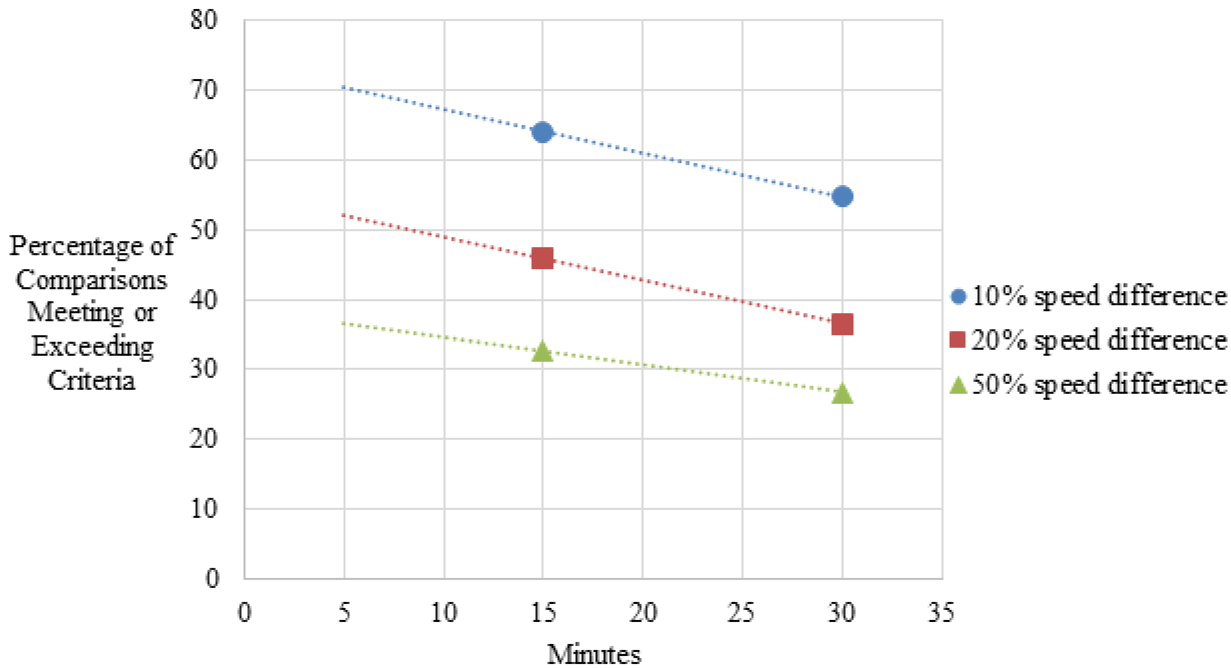

Figure C-6. *Percentage of comparisons of 15- versus 60-minute and 30- versus 60-minute data meeting or exceeding criteria of one-sector difference or given percentage speed difference, extrapolated to five minutes.*

Table C-1 shows the tabulated percentages shown in Figure C-6, including the extrapolated percentages for the five- versus 60-minute comparisons that met or exceeded the multivariable criteria of one sector difference or the given speed percentage difference.

Table C-1: Percentage of comparisons of five-, 15-, and 30- versus 60-minute wind data that meet or exceed the criteria of one sector difference or given speed percentage difference

	One sector difference or given speed percentage difference		
	10%	**20%**	**50%**
Five minute (extrapolated)	70%	52%	37%
15-minute	64%	46%	33%
30-minute	55%	36%	27%

The extrapolation to five minutes from Figure C-6 estimates that 70 percent of comparisons between five- and 60-minute wind data are different by at least one sector or have a difference in wind speed of at least 10 percent. Similarly, 52 percent of five- and 60-minute comparisons are different by at least one sector or have a wind speed difference of at least 20 percent. Finally, 37 percent of five- and 60-minute comparisons are different by at least one sector or have a wind speed difference of at least 50 percent. Due to the high frequency of significant differences between the five-minute average wind data and the 60-minute average wind data, the staff team concludes 60-minute average wind speed and direction values are not appropriate representations of the five-minute LPF phenomenon.

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