The Deputy Secretary of Energy
Washington, DC 20585

September 28, 2012

The Honorable Peter S. Winokur
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, DC 20004-2901

Dear Mr. Chairman:

Thank you for your letter of July 18, 2012, regarding seismic analysis of the Los Alamos National Laboratory (LANL) Plutonium Facility (PF-4). We share your commitment to assure the seismic integrity of PF-4, and to identify and remedy any structural vulnerabilities that adversely affect that commitment.

The National Nuclear Security Administration (NNSA) and LANL have been working methodically to evaluate PF-4 to understand how the facility would perform if subjected to an earthquake. This effort has already resulted in several structural improvements to assure the safe operations of PF-4. As part of a deliberative process outlined in national consensus codes and standards, NNSA and LANL have progressed from relatively simple calculations and modeling approaches to more sophisticated methods (referred to as static nonlinear pushover analysis), to provide additional detail and confidence that we have identified all the facility structural elements that require upgrading. The initial results of the nonlinear pushover analysis are complete and have undergone an independent peer review. The final report thoroughly documenting the methodology and the results will be issued as soon as the peer review comments are addressed.

As part of our overall approach, the Department of Energy (DOE) and NNSA are working to ensure that our analytical methods are validated and our results are technically correct. It is crucial that the decisions we make regarding this vital facility be of the highest quality and take into account the views of the Defense Nuclear Facilities Safety Board (DNFSB or Board). In that spirit, and as I committed to you in our last phone call on this subject, I am directing that NNSA immediately initiate an action to evaluate PF-4 using a second modeling approach, termed a modal loading analysis. I have also directed the NNSA staff to consult with the DNFSB staff to ensure that the premises underpinning the modal loading analysis take the DNFSB technical perspective into account.

In addition, I suggest that our staff continue to work together to ensure that we all clearly understand the work and results that have been completed as well as the path forward to complete the remaining planned analysis and testing. We would also like to discuss our plans to address any structural elements of PF-4 that will be upgraded. As you know, we are committed to capturing those plans in the PF-4 Seismic Project Execution Plan.

Your letter requested information on three items related to NNSA's model and approach for conducting the nonlinear static pushover analysis of PF-4. Enclosure 1 to this letter provides specific NNSA responses and the other enclosures provide supporting information. In addition to this letter, much of the detailed information you requested is included in the initial pushover analysis documentation that was provided to the Defense Nuclear Facilities Safety Board staff on September 2, 2012.

Please feel free to contact me or Thomas P. D'Agostino, Administrator, National Nuclear Security Administration, if you have any additional questions.

Sincerely yours,

Daniel B. Poneman

cc: M. Campagnone, HS.1-1
Thomas P. D'Agostino, NA-1

Enclosure 1 - Detailed Responses to the Questions in the Defense Nuclear Facilities Safety Board (DNFSB or Board) letter dated July 18, 2012

This enclosure provides responses to the three questions in your July 18, 2012, letter. Additional supporting information is provided in subsequent enclosures. The National Nuclear Security Administration (NNSA) has been, and will continue to work with your staff to discuss and address technical issues that are raised during the detailed review of this information.

Item 1: Provide a description of the identification and technical basis for each key assumption to be applied to the static nonlinear analysis model, with particular emphasis on the nonlinear elements and how the characteristics and parameters for each were selected.

On September 2, 2012, NNSA provided the DNFSB staff revision A of the calculation documenting the results of the pushover analysis. The calculation included several enclosures that describe how the model was constructed, the technical assumptions used, and how the nonlinear elements were identified and modeled. Two independent peer reviewers are currently evaluating the analysis documentation. The final calculation will be released as soon as the comments are addressed and the appropriate quality assurance reviews are complete.

A key assumption that affects how PF-4 behaves and the overall results of the analysis is the strength of the service chase roof slab (SCRS) joints. The SCRS joint stiffness used in the initial model runs is based on a detailed analysis that was used for displacement studies in December 2011. Strength is based on American Concrete (ACI) code capacity, considering shear friction. The revision 0 calculation included several runs assuming reduced stiffness and assuming rebar bond slip.

To provide additional confidence in the stiffness of the SCRS joint used in the model, testing is being conducted using a full-scale mock up of the joint and various load configurations. The first of nine tests was conducted on September 13, 2012, and the data of the full test sequence are expected by the middle of November. The testing configuration and conduct of the tests have been reviewed by the Board staff, and comments and suggested improvements incorporated in the test plan. If the results of these tests indicate a significant difference from the assumed stiffness of the SCRS joint, the affected parameters will be changed in the model and additional runs conducted. All modeling performed after the SCRS testing is complete will use the strength determined from the testing.

Additionally, NNSA will evaluate any comments that are identified during internal and external reviews of the calculation and supporting documents. If changes in the model or assumptions are needed to address any of these comments or to provide additional confidence in the analytical results, these changes will be incorporated in the model and additional runs will be conducted to evaluate the effects of the changes. A more detailed summary of how the model was developed, the key assumptions, and development of the nonlinear elements is provided in Enclosure 2, *Summary of Key Assumptions and Parameters used in the PF-4 Seismic Model*. An overview of the planned activities in FY 13, sequences of these activities, and major decision points are provided in Enclosure 4, *Preliminary Sequence of Events for FY 13*.

<u>Item 2</u>: Provide a detailed description of the approach to be taken in applying loads to the model to simulate the dynamic (degraded) behavior during an earthquake.

NNSA previously completed a dynamic linear analysis of PF-4 that identified several structural elements where demand exceeded capacity. NNSA completed facility modifications to correct those issues, for example, the construction to modify the roof. The dynamic linear analysis identified other elements of the facility that have high demand-to-capacity ratios or stresses that would produce plastic deformation. Conducting a static nonlinear pushover analysis is the next step of analytical methods identified in ASCE 41-06, *Seismic Rehabilitation of Existing Buildings*, to further evaluate specific elements in the facility and identify whether deficiencies exist that need to be corrected. Therefore, NNSA is conducting its pushover analysis to further evaluate the confinement and load-bearing capabilities of these structural elements in design-basis and beyond-design-basis earthquakes.

The industry codes do not explicitly define how the seismic loads should be applied in the pushover analysis. Therefore, based on expert judgment of the modelers and peer reviewers, NNSA is using a loading approach that conservatively maximizes the load on each of the structural elements of concern in order to inform engineering judgments about the acceptability or the need to modify any of the specific structural elements of concern. This analysis builds on the work completed and the loads determined from the previous linear dynamic analysis. The current NNSA static nonlinear pushover analysis approach uses load combinations in all three directions, with the loads in each direction assumed to all be in-phase with each other, resulting in conservatively large forces. A more detailed summary of the loading method used by NNSA up to this point is provided in Enclosure 3, *Details of Approach used to develop the Loads used in the Pushover Analysis Model Runs*. A complete description of this loading method is detailed in revision 0 of the seismic calculation provided to the Board staff on September 2, 2012.

NNSA has discussed with LANL whether additional runs of the model are necessary and whether additional modeling and analysis of the worst case upward load on the column capitals is warranted. Based on this review, the NNSA has determined that additional modeling and analysis of the effects on the 100 % upward load on the lab floor column capitals is needed to determine whether the upward loading will cause the column capitals to fail. NNSA will include this additional analysis in the FY 13 work scope. Additional loading cases may also be identified using the current LANL model following completion of the LANL peer review and additional reviews from seismic experts within DOE.

To ensure that the overall results and any planned modifications to address identified vulnerabilities are both necessary and sufficient, NNSA is working with the Department of Energy (DOE) Office of Health, Safety, and Security to fund completion of a separate pushover analysis using an a modal loading approach as soon as possible. The additional analysis will reflect resolution of internal and external technical comments on the assumptions and inputs as described in the response to first question (including the strength of the SCRS joint as determined from the testing program.) The method for identifying the loads to use for the modal loading approach will be developed in an open manner with any input and suggestions welcomed from the Board staff. The initial sequence and scheduling of the follow on analysis using the modal loading approach is provided in Enclosure 4, *Preliminary Sequence and Timing of Planned FY 13 Activities.*

Item 3: Provide the static analysis acceptance criteria.

As part of the pushover analysis, NNSA used methods described in industry codes to calculate the limit on deflection for each structural component of interest, typically referred to as the drift limit, beyond which the strength of the structural component would be exceeded and it would begin to behave inelasticly. The loads in the model were incrementally increased until the drift limit was reached. The seismic loading that resulted in the component drift limit being reached was identified and then converted to a probability of component failure, given the conditional probability of the seismic event and corresponding loading. The probability of component failure was then compared to the applicable performance goal in DOE Standard 1020, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, January 2002. For PF-4, the safety function of the structure is to provide confinement of hazardous materials, which corresponds to a performance category (PC) 3 structure. DOE Standard 1020 sets an acceptable performance goal for a PC-3 structure at an annual probability of exceedance of about 10^{-4} of damage beyond which hazardous material confinement and safety related functions are impaired. DOE Standard 1020 and other consensus codes have not addressed what the collapse performance should be, given the stated performance goal for the facility is confinement; however, given that confinement is a more stringent requirement than collapse prevention, it follows that collapse prevention would have an annual probability of exceedance that is less than 10^{-4}.

As stated earlier, the ultimate objective of the NNSA structural analysis is to identify the complete set of structural elements that require upgrading and to develop effective solutions to implement the needed improvements. The first fundamental step is to identify all the components that are candidates for improvements. These will include all elements whose failure contributes to exceeding the PC-3 performance goal for confinement in DOE STD 1020 and all components whose failure is identified as potentially leading to a partial or full facility collapse. NNSA and Los Alamos National Security, LLC, (LANS) will identify the available options to upgrade these components and will decide which modifications to pursue based on a variety of attributes, including the effectiveness, feasibility, practicality ,cost, risk reduction, and schedule of the individual options. NNSA will execute its line management decision-making in a completely transparent manner and will clearly document its decisions and the basis for the decisions in the PF-4 seismic project execution plan. NNSA and LANS will also document in the PF-4 Safety Basis the rationale for selecting needed structural upgrades and how the selected upgrades provide adequate protection for the public in both the short and long term.

Based on the initial results of the pushover analysis in the revision 0 calculation, LANS declared a Potential Inadequacy in Safety Analysis (PISA) for the Plutonium Facility (PF-4) based on new information that indicated the probability of failure for a design basis seismic event exceeded the 10^{-4}/yr performance goal in DOE STD-1020. While the limiting individual structural elements each met the 10^{-4}/yr performance goal separately, the overall facility probability of exceedance was conservatively determined to exceed $1x10^{-4}$/yr, which exceeds the DOE STD-1020 performance goal. On September 5, 2012, LANS determined this information resulted in positive unreviewed safety question (USQ), requiring federal approval. NNSA and LANS have also started assessing options to strengthen the limiting structural elements.

DOE STD-1020 states that for structures, systems and components not meeting the criteria and which cannot be easily remedied, budgets and schedule for required strengthening must be established on a prioritized basis. NNSA is currently evaluating the information provided by LANS in order to determine the appropriate actions and response. In any event, NNSA will follow all nuclear safety regulatory requirements as well as the guidance provided in the Deputy Secretary's memorandum of September 17, 2012, on adequate protection. NNSA is also evaluating proposed technical solutions to address the identified structural vulnerabilities. NNSA will use the current seismic model to ensure that the suite of proposed solutions provides sufficient reduction in probability of failure prior to initiating any planned modifications. This will be done once consensus is reached on the technical adequacy of the model as described in the response to question 1. Lastly, NNSA plans to charter a highly competent technical review panel to review the methodology and results of the completed analyses and the proposed technical solutions to help NNSA ensure that all needed structural improvements have been identified and addressed. The sequence of events and the initial schedule for convening the technical panel are described in Enclosure 4, *Preliminary Sequence and Timing of Planned FY 13 Activities*.

NNSA and LANS will document its long-term plans in revisions to the PF-4 seismic project execution plan (PEP). The next revision of the PEP will be issued in November 2012. We will also continue to keep you informed as part of our periodic briefings.

Enclosure 2 – Summary of Key Assumptions and Parameters used in the PF-4 Seismic Model

Key modeling assumptions are based on information from Department of Energy (DOE) Standard 1020 and the following applicable industry standards:

- American Society of Civil Engineers, ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities,*2005
- American Society of Civil Engineers, ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings,* 2006
- Federal Emergency Management Agency, FEMA 440, *Improvement of Nonlinear Static Analysis Procedures,* 2005

Some of the more important key inputs and modeling assumptions are:

- The modeling uses a commercial finite element code with nonlinear modeling capabilities and automatic step sub-division to aid convergence. The model was developed from the 2011 linear elastic model [including improvements suggested by the Defense Nuclear Facilities Safety Board (DNFSB or Board) staff] and has about 23,000 nodes.

- The non-linear analysis is being done in a manner to determine the probability of onset of strength degradation, which is beyond loss of building confinement, to gain insight on collapse failure mechanisms.

    - This is being done by developing loads for both the 50 percent and 80 percent non-exceedance probabilities and developing member capacities at the 50% and 95/98% (consensus standards and codes) capacities. This allows for a more formal development of element fragility curves. The fragility curves are then convolved with the seismic hazard curves to estimate the annual probabilities of failure. The methodology is consistent with the documents that formed the basis for DOE STD 1020 as well as probabilistic risk assessments of nuclear power plants.

    - To support this, a number of cases are being run with median and code-based capacities and with load combinations described in Enclosure 3.

- Nonlinearity is being introduced into the model iteratively, by increasing the load, determining locations where inelastic behavior would develop, adding non-linear springs, and repeating until behavior is established over the load-range of interest.

- Nonlinear behavior is lumped into spring elements so that the analyst can directly control the ultimate capacity and shape of the load-deflection curves for structural members. This simplifies benchmarking to experimental data and provides explicit insight into the structure's nonlinear behavior.

    - For example, for shear walls, the finite element mesh is split and nonlinear shear springs are inserted between the double nodes. The nonlinear spring constant is assigned by subtracting out the linear elastic stiffness component. The nonlinear springs for some nodes are modified to ensure geometrically compatible motions.

- For the roof diaphragm, nonlinear springs are inserted to represent the flexibility of the service chase roof joints that run along four east-west gridlines. Essentially, the roof mesh is split at the service chase joints, and nonlinear north-south springs are inserted between the double nodes.

- For both the roof and floor diaphragm, shear flexibility is modeled by adding nonlinear springs at the mid-span of each bay.

- For main floor columns and walls, nonlinear springs are introduced horizontally and vertically at the main floor intersection to capture out-of-plane bending. For main floor columns, flexural springs are placed at the bottom of the roof girders, the service chase wall-beam, and the main floor. Results are checked during post-processing for reasonableness, and the springs are reassigned, as appropriate.

- For the basement columns, nonlinear flexural springs are placed at the base of the column capitals. During post-processing of the computer results, the column deflections and loads are checked for reasonableness, and the spring assignments are further refined, as appropriate.

- Further detail is provided in the initial report and appendixes provided to the board staff on September 2, 2012.

- Shear wall stiffness is based on literature (i.e., modified compression field theory, which involves a truss model with softening diagonal compression struts). Drift limits are derived from an established standard (NUREG/CR-6104).

- Column flexural stiffness is derived from moment-curvature analysis and includes rotation due to bond-slip at the end. Key parameters compare well to code; shear capacity is code-based (ASCE/SEI 41-06). Drift limits are derived from the literature and are based on statistical analysis of approximately 250 experiments. Detailed references and basis for the drift limits are provided in the appendices to the calculation provided to the board staff.

    - The 2011 linear elastic analysis demonstrated that the columns do not meet the shear strength criteria per American Concrete Institute (ACI) 349. The consequences of column shear failure drove the decision in 2011 to perform nonlinear static analysis. It was postulated that, although the columns would fail in shear, vertical load carrying capacity would not be lost due to the limited lateral displacement. Since there is no consensus standard on this topic, acceptance criteria were developed through literature searches for experimental data. The nonlinear static analysis was initially intended to resolve this potential partial collapse mode.

- Roof service chase joint stiffness is based on the detailed model of the service chase that was used for displacement studies in December 2011. Strength is based on American Concrete (ACI) code capacity, considering shear friction. Separate models are being run assuming reduced stiffness and assuming rebar bond slip.

- Roof girders flexural stiffness is derived from moment-curvature analysis; shear capacity is based on ACI code capacity.

- Punching shear capacity for laboratory floor slabs is based on ACI code.
- Lateral displacement limits as well as rotation limits are based on those provided in ASCE/SEI 41-06 for various limit states. Lateral displacement limits are being used for the concrete shear walls, and rotation limits are being used for the ends of columns and beams.

Enclosure 3 - Details of Approach Used to Develop the Loads Used in the Initial Pushover Analysis Model

The loads used in the analyses were identified consistent with the requirements and guidance in Department of Energy (DOE) Standard 1020 and the following applicable industry standards:

- American Society of Civil Engineers, ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities,*2005
- American Society of Civil Engineers, ASCE/SEI 41-06, *Seismic Rehabilitation of Existing Buildings,* 2006
- Federal Emergency Management Agency, FEMA 440, *Improvement of Nonlinear Static Analysis Procedures,* 2005

National consensus codes focus on horizontal loading and do not explicitly consider multi-directional seismic input. For this analysis, gravity loads (e.g., dead loads) are first applied followed by various directional combinations of seismic loads that are incrementally increased until displacement limits are reached, at which point the analysis terminates. The load combinations chosen are consistent with guidance in ASCE/SEI 43-05, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities,* 2005, and are as follows:

- Pushover Median Model, 100% South
- Pushover Median Model, 100% South, 40% Down
- Pushover Median Model, 100% South, 40% Up
- Pushover Median Model, 40% South, 100% Down
- Pushover Median Model, 100% South, 40% Down, 40% East
- Pushover Median Model, 100% South, 40% Down, 40% West

Note: The North/South load cases have the loads chosen in the southern direction since this creates worst-case tension in the roof diaphragm and across the service chase roof joints. As indicated previously, the National Nuclear Security Administration (NNSA) and Los Alamos National Security, LLC, (LANS) are planning additional evaluation of loading cases.

Additional runs of the model were conducted to investigate sensitivity of the results to changes from median parameters and sensitivity of the assumed stiffness of the service chase roof slab (SCRS) joint. These included:

- Pushover 98 per cent Exceedance Capacity Model, 100 percent South, 40 per cent Down
- Pushover 84 per cent Exceedance Stiffness Model, 100 percent South, 40 per cent Down
- 80 percent NEP Loads with Median Model, 100 percent South, 40 percent Down
- Pushover Soft Roof Joint with Median Model, 100 percent South, 40 percent Down

The load vectors being used in this analysis are based on the results of the 2011 dynamic linear elastic analysis, which used prescribed time histories. The loads are determined for both 50 percent and 80 percent non-exceedance accelerations to support the median and high-load-case calculations, used to derive the fragility curves and the structural failure probabilities (i.e., onset of strength degradation).

The applied loads are the product of mass and acceleration, with the masses and accelerations taken for each individual node from the 2011 linear analysis. The total loads at each level of the structure have been compared to the story shear forces from the 2011 linear analysis to ensure reasonableness. The employed methodology is consistent with national consensus codes (e.g., FEMA 356 Section 3.3.3.2.3), which allow for the lateral load distribution proportional to the story shear distribution. For horizontal loads, this is also consistent with guidance in section C 3.2.4 of ASCE/SEI 41-06, that demands should be based on the likely distribution of horizontal inertial forces. The 2011 accelerations also provide a means to address the vertical loads, since there is limited explicit guidance in ASCE/SEI 41-06 or other codes for assigning vertical loads.

NNSA and the Los Alamos National Laboratory (LANL) will conduct a second type of static non-linear pushover analysis using a modal loading approach starting as soon as possible. NNSA has concluded that this additional analysis is helpful to validate and improve confidence in the results of the overall combined analysis and to ensure that all appropriate structural weaknesses are identified and proposed repairs are both necessary and sufficient to ensure that PF-4 can continue to operate in a manner that provides adequate protection to the public.

NNSA will work with LANL, the subcontractor performing the analysis, and the Board staff to develop and execute an acceptable alternate approach starting as soon as possible.

Enclosure 4 - Preliminary Sequence and Projected Timing of Planned FY 13 Activities

There are several activities that need to be completed to ensure that PF-4 continues to meet Department of Energy (DOE) Standards, is operated safely, and provides adequate protection of the public. Some of these activities need to be completed in sequence, and some can be completed in parallel with several iterations conducted. The following is a general sequence and current projected timeframe[1] for conducting some of key activities that need to be completed to ensure this overall goal is achieved:

1) Issue the final report detailing the modeling and results that have been completed thus far [i.e., finalize the document provided in draft to the Defense Nuclear Facilities Safety Board (DNFSB or Board) on September 2, 2012].
2) Complete, review, and revise as necessary the existing Los Alamos National Laboratory (LANL) model and pushover analysis. This is necessary to ensure there is a high level of confidence that the results of the pushover analysis identify all components that may require structural improvements. (October 2012)
3) Perform additional analysis to evaluate loading in the up direction. (October –November 2012)
4) Develop and execute a second static nonlinear pushover analysis using a modal loading approach. (Start in October 2012)
5) Complete the service chase joint testing and document in a final report. Perform additional analyses as necessary to ensure that the strength of the service chase roof slab joints is modeled correctly. All subsequent model runs will use the strength and stiffness determined from the testing. (December 2012)
6) Evaluate situations where individual components or combined failure mechanisms do not meet or are close to the established performance goal or could lead to facility collapse and identify the safety impact per the requirements in 10 CFR 830 and the September 2012 memo from the Deputy Secretary to the Central Technical Authorities on Adequate Protection. (Initial evaluation completed in September 2012 and updated as new information is provided based on results of additional analysis)
7) Execute the Nuclear Safety Rule (10 CFR 830) process for potential inadequacy in safety analysis to address applicable requirements of nuclear safety rule and document conditions that assure adequate protection of the public. (October 2012)
8) Identify the set of necessary facility component repairs and establish a prioritized plan for the necessary repairs. Document this plan in revision to the Project Execution Plan. (Initial update to PEP in November 2012 and periodic updates as new information is available)
9) Conduct a comprehensive independent technical review to ensure that the analysis and results are comprehensive and sound and that planned activities are sufficient to resolve identified deficiencies. (Scheduled when all analytical results are available – initial estimate is April 2013)
10) Implement repairs necessary to ensure that needed upgrades are completed. (TBD, the details of individual structural improvement plans will be documented in updates to PEP)

[1] This timeline represents NNSA's best estimate but may be subject to change.