Joyce L. Connery, Chair
Thomas A. Summers, Vice Chair

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Washington, DC 20004-2901

July 25, 2024

The Honorable Jennifer M. Granholm
Secretary of Energy
U.S. Department of Energy
1000 Independence Avenue, SW
Washington, DC 20585-1000

Dear Secretary Granholm:

The Nevada National Security Site contractor, Mission Support and Test Services, LLC (MSTS), is executing the Enhanced Capabilities for Subcritical Experiments (ECSE) projects at the Principal Underground Laboratory for Subcritical Experimentation (PULSE). Completion of these projects will introduce new diagnostics for subcritical experiments and provide the National Nuclear Security Administration (NNSA) data to support stockpile stewardship. The Defense Nuclear Facilities Safety Board (Board) reviewed the safety design basis documents for two projects in the ECSE portfolio and evaluated seismic faults within PULSE.

The Board found that NNSA has not adequately characterized the seismic faults. As discussed in the enclosed staff report, this means that the design of seismic safety controls for PULSE and other defense nuclear facilities at the site, including the Device Assembly Facility, may not account for the earthquake risk associated with these faults and these controls may not perform their intended safety function during and after a seismic event.

The Board also identified several safety issues in the safety design basis documents, which are discussed further in the enclosed staff report. While MSTS plans to address most of the safety issues, several remain unresolved. These unresolved safety concerns include: (1) an inadequate control set for movement of the subcritical experiment package, (2) unevaluated effects from changing the performance criterion for the vessel confinement system, and (3) inadequate means of egress for workers from the facility.

Pursuant to 42 United States Code § 2286b(d), the Board requests that NNSA provide a written report and briefing within 120 days that address the following safety questions:

- What actions has NNSA taken or planned to characterize the seismic faults present in the PULSE drifts to ensure that the new seismic-related controls will be able to perform their safety functions?

- The U.S. Department of Energy directives require major modification projects to follow the hierarchy of controls when selecting a safety control strategy. This framework prefers engineered safety controls over administrative safety controls. The safety design basis documents for the ECSE projects discuss a planned improvement to procure an improved shipping container for the subcritical experiment package to reduce reliance on administrative controls, but this effort is not included in the ECSE portfolio. What is NNSA's plan and schedule for procuring and implementing the new shipping container to ensure safe operations at PULSE as the subcritical experiment mission expands?

- The design of the vessel confinement system does not meet all requirements of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section VIII, Division 3: *Alternative Rules for Construction of High Pressure Vessels*. For each requirement not met, what equivalent means will NNSA use to demonstrate that in total, the vessel will adequately perform its safety function of confining radiological material prior to, during, and after experiment execution?

- What actions has NNSA taken or planned to improve the means of egress to ensure that workers can adequately evacuate the PULSE facility during accidents or incidents?

Sincerely,

Joyce L. Connery
Chair

Enclosure

c: The Honorable Jill Hruby, Administrator, National Nuclear Security Administration
Dr. David Bowman, Manager, NNSA Nevada Field Office
Mr. Joe Olencz, Director, Office of the Departmental Representative to the Board

DEFENSE NUCLEAR FACILITIES SAFETY BOARD

Staff Report

May 9, 2024

Safety Posture of the Principal Underground Laboratory for Subcritical Experimentation and Associated Major Modification Projects

Summary. The management and operating contractor at the Nevada National Security Site (NNSS), Mission Support and Test Services, LLC (MSTS), is executing the Enhanced Capabilities for Subcritical Experiments (ECSE) projects at the Principal Underground Laboratory for Subcritical Experimentation (PULSE – formerly the U1a Complex). The ECSE projects include the U1a Complex Enhancements Project (UCEP) and the Z-Pinch Experimental Underground System (ZEUS) test bed project, both of which are major modification projects to the existing facility. The scope of these projects includes constructing new experiment operation areas and installing new diagnostic equipment. The new equipment will help the National Nuclear Security Administration (NNSA) collect better data during subcritical experiment execution, which will be used to support stockpile stewardship.

Members of the Defense Nuclear Facilities Safety Board's (Board) staff reviewed the safety design basis documents for UCEP and the ZEUS test bed project [1, 2] to assess the adequacy of the safety analyses and controls credited to protect workers and the public. The staff team also conducted a review of seismic faults within PULSE. The staff team reviewed many geological reports and maps from NNSS, conducted walkdowns in the underground tunnels at PULSE, and observed a correlated fault at Yucca Flat.

The staff team identified several safety issues during its review of the safety design basis documents and PULSE seismic faults. While MSTS plans to address most of the safety issues in the next revision to the documents, the following remain unresolved:

- ***Uncharacterized Seismic Faults in PULSE:*** Faults are extensively present within PULSE. However, neither NNSA nor NNSS personnel have adequately characterized the seismic faults in the PULSE underground tunnels to determine whether they are active. Confirmation that these faults are active would have significant safety implications because the seismic design for both existing and new safety controls in PULSE does not account for the effects of seismic shaking and displacements caused by the faults within the facility. As a result, these controls may not be able to perform their intended safety function during and after a seismic event. Similarly, the seismic hazard may be underestimated for other NNSS facilities, including the Device Assembly Facility (DAF).

- ***Inadequate Control Set for Subcritical Experiment Movements:*** In both safety design basis documents, MSTS continues to rely on specific administrative controls (SAC) for scenarios in which the subcritical experiment package is impacted by a

thermal or electrical insult while being moved. MSTS procuring a new shipping container would provide the protection needed for these scenarios.

- ***Unevaluated Effects from Changes to the Vessel Confinement System's Performance Criterion:*** MSTS has not evaluated the impact of changing a performance criterion for the vessel confinement system. As a result, the safety control strategy credited to confine or contain radiological material during experiment execution may not be able to perform its intended safety functions.

- ***Inadequate Means of Egress for Workers:*** The proposed configuration of the drifts does not comply with life safety requirements. As a result, workers may not have a means to evacuate the facility if certain accidents were to occur in PULSE.

Background. PULSE is a hazard category 2 defense nuclear facility at NNSS consisting of a series of mined vertical shafts, horizontal drifts, and alcoves. The underground facility is located approximately 1,000 feet below the surface. NNSA performs subcritical experiments at PULSE in support of the Stockpile Stewardship Program. A subcritical experiment package consists of special nuclear material (SNM) mated with high explosives that is designed so there is no reasonable likelihood of a self-sustaining nuclear fission chain reaction. The Nuclear Weapons Laboratories (NWL)[1] design the subcritical experiment package, process the SNM at the home laboratory, and mate the high explosives to the SNM at DAF.

Accident scenarios with the highest potential dose consequences to the public and co-located worker are those that result in high explosive initiation within the subcritical experiment package leading to dispersal of SNM. Falling objects (either from equipment failure or a seismic event), fires, or application of electrical energy can initiate such an explosion. Explosion scenarios can occur either above or below ground. In the absence of safety controls, both scenarios result in potential dose consequences to the public that challenge the Evaluation Guideline (i.e., 25 rem total effective dose) established in the U.S. Department of Energy (DOE) Standard 3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*. Additionally, the unmitigated dose to the co-located worker at 100 meters exceeds 100 rem total effective dose. When potential dose consequences to these receptors are estimated to be this high, DOE Standard 3009-2014 requires safety controls to reduce the risk associated with the accident (i.e., by preventing or mitigating the consequences).

Nuclear operations at PULSE begin when the subcritical experiment package arrives in an approved shipping container. Operators lower the container underground using the U1h hoist and move it to a Zero Room, which is an area in the drifts that can be sealed off during experiments. In the Zero Room, operators remove the experiment package from the shipping container and place it in an assembly fixture for up to a few weeks while they set up diagnostic equipment. When ready to execute the experiment, operators insert the package into a vessel confinement system, which they then seal off. The vessel confinement system consists of a spherical vessel, isolation valves, piping, fittings, and in-line filters. Operators also seal off the

[1] The NWLs involved in subcritical experimentation at PULSE are Los Alamos National Laboratory (LANL) and Lawrence Livermore National Laboratory (LLNL).

Zero Room before they execute the experiment. During the experiment, the NWLs collect data that can be used to support nuclear weapon stockpile certification. After experiment execution, operators vent the vessel confinement system and move it (with internal post-execution debris) to an entombment drift where it is grouted in place.

In 2014, NNSA approved the mission need for the ECSE projects to improve the existing capabilities at PULSE. This approval includes procuring a high energy x-ray diagnostic capability to measure the late stages of implosion and a neutron diagnostic capability to infer neutron multiplication during an implosion [3]. When NNSA completes the ECSE projects, the final facility configuration will include three Zero Rooms that are capable of housing an SNM package (i.e., each Zero Room can contain one subcritical experiment package). The ECSE projects consist of the following:

- ***Advanced Sources and Detectors (ASD) Project*:** A major equipment installation project that will install a high-energy linear accelerator (referred to as Scorpius) capable of producing four pulsed radiographs that can obtain experimental data further into the implosion event than existing equipment.

- ***UCEP:*** A major modification to PULSE that includes the design, mining, and infrastructure needed to support ASD. This project includes creation of a new Zero Room and safety controls.

- ***ZEUS Test Bed[2]Facility Infrastructure Project:*** A major modification to PULSE that will create a new Zero Room and install the Neutron Diagnosed Subcritical Experiments equipment.

MSTS has developed a preliminary documented safety analysis (PDSA) for UCEP [1] and a draft PDSA for the ZEUS test bed project [2]. MSTS developed both safety design basis documents in accordance with the requirements and guidance in DOE Standard 3009-2014. The Board's staff team reviewed the PDSA for UCEP and interacted with site personnel during the week of March 20, 2023. Based on this interaction, MSTS agreed with several issues identified by the staff team and plans to address most of them in the next revision of the PDSA.

Shortly after this first interaction, MSTS completed the draft PDSA for ZEUS. Given the similarities between the two projects, the staff team performed a limited review of the draft ZEUS PDSA that focused on how it differed from the UCEP PDSA. The staff team interacted with site personnel on the draft ZEUS PDSA, follow-up items for UCEP, and other supporting documents during the week of October 16, 2023. From its review of the draft ZEUS PDSA, the staff team found that MSTS had taken steps to address some issues from the UCEP PDSA. MSTS again agreed with several of the additional issues and plans to address most of them in the final ZEUS PDSA.

During this review, the team identified references to faults present in the PULSE facility. Specifically, a geological report from 1989 [4] stated that PULSE is located within Quaternary[3]

[2] The "test bed" is the combination of a Zero Room, entombment drift, and diagnostic equipment.
[3] Quaternary is a geological period beginning approximately 2.6 million years ago and continuing to the present.

alluvium. According to the U.S. Geological Survey (USGS), Quaternary faults are active or capable faults that can potentially trigger both earthquakes and displacements [5].

Most of the faults in PULSE are covered behind drift walls lined with shotcrete, which covers up evidence of faulting. The only limited exposure is along the U1a.01 drift. The staff team walked down the U1a.01 drift to observe and measure the orientation and dipping of faults, as well as observe locations where the fault distribution map indicated faulting was present. NNSS geologists explained what they observed and measured about the faults before mining operators covered them in shotcrete. The staff team also observed a fault scarp in Yucca Flat that correlates to the faults within PULSE and reviewed all available geological reports, pictures, and maps that discussed the faults within PULSE.

Discussion. The discussion below summarizes several safety concerns the staff team identified during its review of the ECSE safety design basis documents and seismic faults within PULSE. Appendix A includes additional information on the seismic faults. Appendix B includes additional details related to the ECSE safety design basis documents.

Uncharacterized Seismic Faults in PULSE—Seismic faults are extensively exposed within the PULSE tunnels with more than 50 individual locations based on the fault distribution map (Figure 1). Although these faults are dispersed across various tunnel sections and not directly interconnected, they are part of the fault system, as some can be linked to form longer faults based on their orientations and fault types. NNSS geologists currently consider the faults present in PULSE to have occurred in the Tertiary period[4] instead of the Quaternary period. Evidence from NNSS geological reports [6–9], along with observations during the staff team's walkdowns, indicate that the faults within the PULSE tunnels could be younger and potentially be Quaternary.

Faults within PULSE, if active, can trigger earthquake vibrations that could potentially initiate the high explosive within the subcritical experiment package. Both ECSE subprojects credit several controls for seismic accident scenarios, such as the Zero Room structure, anchoring for overhead equipment in the Zero Room, and the fire extinguishing system. Seismic design requirements for these controls rely on an earthquake database managed by USGS which does not currently account for the faults within PULSE. Accordingly, the seismic hazard may exceed design requirements, and these safety controls may not be able to perform their intended safety function during or after a seismic event.

[4] Tertiary is a geological period spanning from 65.5 million to 2.6 million years ago.

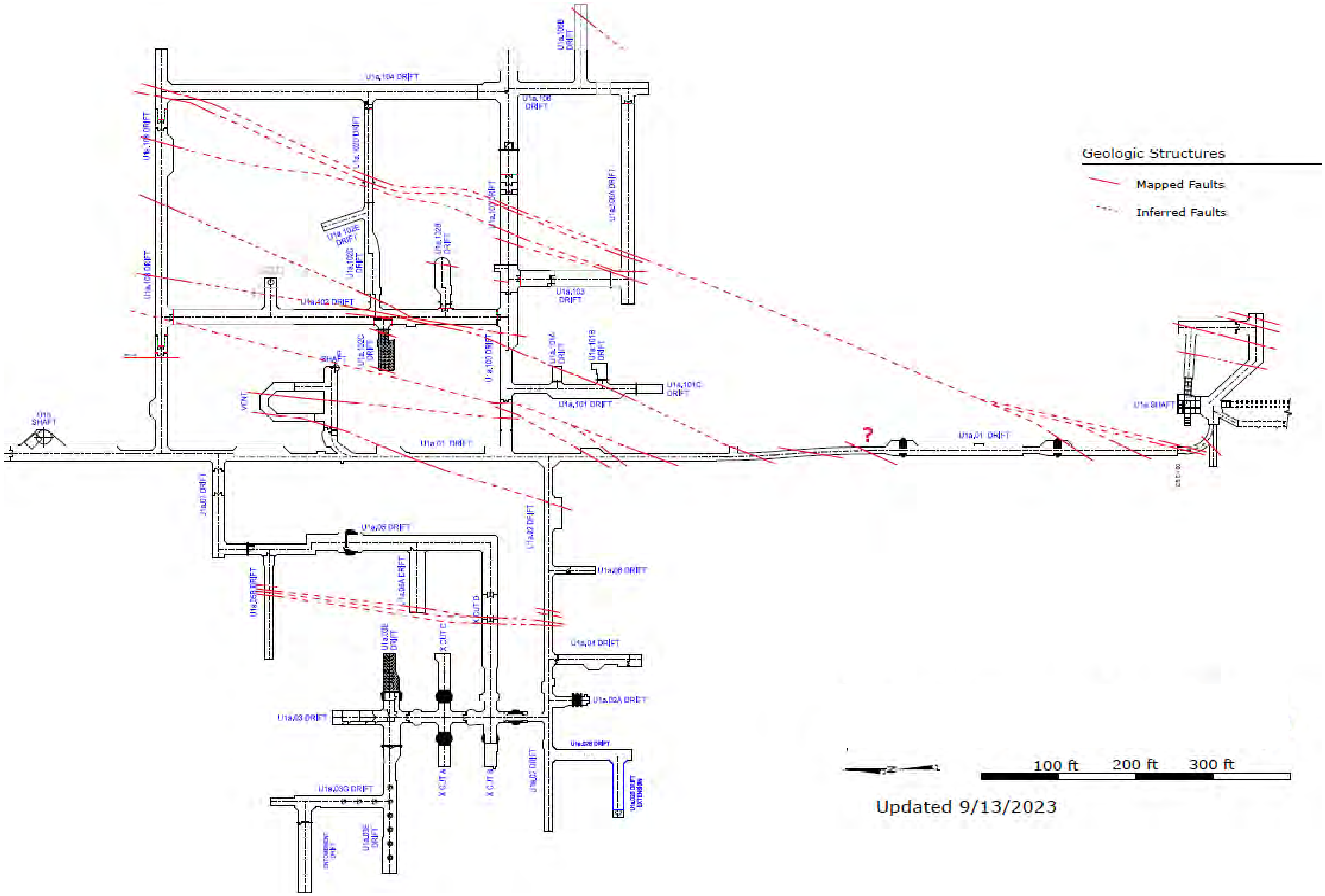

Figure 1. *Fault distribution within PULSE [10]. Solid red lines indicate observed faults and dashed red lines indicate inferred faults.*

The safety design basis documents for the ECSE projects do not analyze a fault displacement hazard scenario. NNSS personnel consider this scenario to be bounded by the analyzed scenario in which a seismic event results in overhead equipment falling onto a subcritical experiment package [2]. The safety design basis documents credit the shipping container to protect the subcritical experiment. The magnitude of a fault displacement is typically proportional to the dimension of the faults [11]. Given that the dimensions of the faults in PULSE are uncharacterized, the potential magnitude of the fault displacement event is unknown but could potentially be 17 feet or greater (Figure 2). The shipping container may not be able to fully protect the subcritical experiment from a severe displacement. As a result, the ECSE safety basis documentation should analyze this event separately as a unique hazard.

Because the PULSE faults are not included in the USGS database, all NNSS facilities (e.g., DAF) may be underestimating the seismic hazard. Also, important NNSS infrastructure, such as highways and electrical transmission lines, could be potentially severed due to fault displacement.

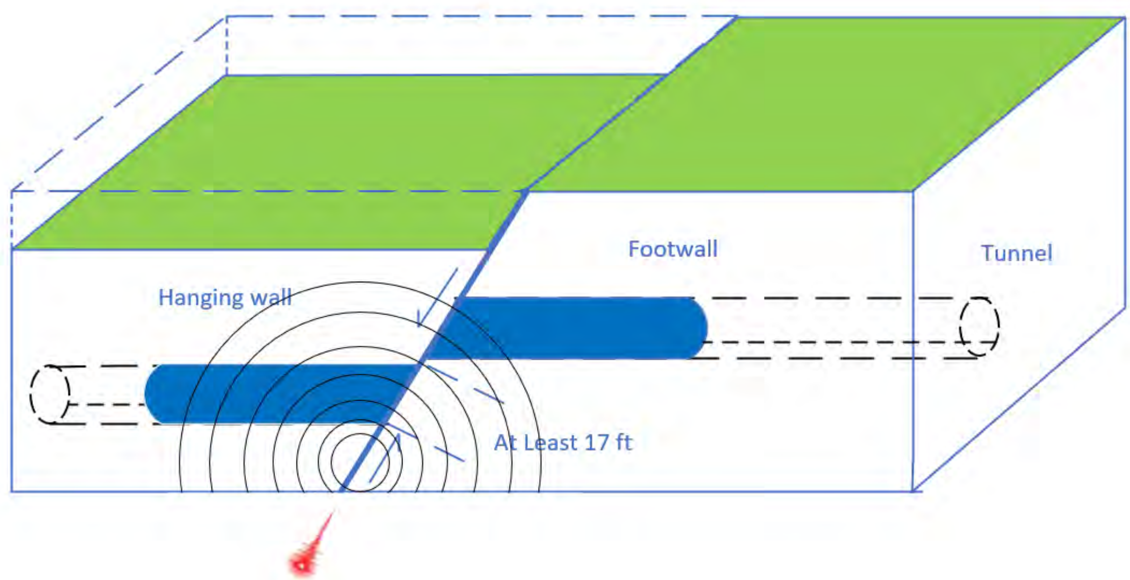

Figure 2. *Potential impact of faults within PULSE, displacing drifts and triggering earthquake vibrations.*

Inadequate Control Set for Subcritical Experiment Movements—In the UCEP and draft ZEUS PDSAs, MSTS continues to rely on SACs for hazard scenarios in which the subcritical experiment package is impacted by a thermal or electrical insult while being moved to a Zero Room. Either of these insults to the subcritical experiment could result in an above ground or below ground explosion. MSTS has used this control strategy since 2018 after it found that the current shipping container cannot be assured to provide protection from electrical and thermal insults. While SACs can be effective safety controls, they are often less reliable than engineered controls because they rely on a human action. On December 19, 2018, the Board communicated its concern with MSTS's overreliance on SACs as the control strategy for hazard scenarios involving electrical and thermal insults [12]. Additionally, the Board emphasized the need for a more robust shipping container (i.e., a viable engineered control) in a letter to the Secretary of Energy dated December 1, 2021 [13].

In addition to revising the control strategy, MSTS also identified a planned improvement to evaluate alternate shipping containers for the subcritical experiment package. In 2019, an integrated project team that consisted of personnel from MSTS, LANL, and LLNL completed an analysis of alternatives for the container [14]. The integrated project team identified functional requirements that describe what the shipping container must do or accomplish to achieve its function(s). From the analysis, the integrated project team stated, "A single existing available container could not be identified that fully meets all the NWL specified dimensional requirements and maximum payload weight while simultaneously providing the desired level of protection against postulated mechanical, thermal, and electrical hazards." The integrated project team concluded that procuring a new shipping container was its preferred option.

The UCEP and draft ZEUS PDSAs include a planned improvement to procure an improved shipping container for the subcritical experiment package. During the staff team's review interaction, LANL personnel—the design authority for the new container—provided a status update on this effort. LANL personnel stated that although the conceptual design for a new container is complete, they cannot proceed further until funding is secured. Currently, the funding for the new container comes from the LANL weapons program rather than from the funds for the major modification projects at PULSE.

Chapter I of DOE Order 420.1C, *Facility Safety*, includes requirements for safety design of DOE hazard category 1, 2, and 3 facilities, which also apply to major modification projects. One requirement states that the facility "must be designed to…provide hazard controls for prevention and mitigation of hazardous material releases and for defense in depth, consistent with the hierarchy described in DOE-STD-1189-2016." Section 4.1.4 of DOE Standard 1189-2016, *Integration of Safety into the Design Process*, describes the hierarchy of controls and states that "SSCs [structures, systems, and components] are preferred over administrative controls." Additionally, DOE Standard 1186-2016, *Specific Administrative Controls*, states, "While SACs can provide acceptable and effective controls, they should only be used if adequate engineered controls are not readily available."

MSTS should credit the shipping container in the PDSAs to protect the subcritical experiment package from mechanical, electrical, and thermal insults while it is being transported to the Zero Room. Additionally, MSTS should include design and procurement of a new shipping container in the scope of the major modification projects, just like it included other credited safety controls that were identified in the safety analysis. Procurement of the new shipping container will improve the control strategy at PULSE by reducing reliance on SACs. It will also improve safety at DAF and when transporting an experimental package to PULSE.

Unevaluated Effects from Changes to the Vessel Confinement System's Performance Criterion—Prior to experiment execution, MSTS personnel place the subcritical experiment package into the vessel of the vessel confinement system, which they then seal. The vessel confinement system is a steel structure that is designed to withstand the high pressures expected during experiment execution. It is credited as a safety significant control in the safety design basis documents for the ECSE projects and the existing safety basis for PULSE. Its safety function is to provide confinement of SNM prior to, during, and after experiment execution.

In 2022, MSTS declared a potential inadequacy of the safety analysis related to a performance criterion for the vessel confinement system requiring that the vessel be designed in accordance with the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 3: *Alternative Rules for Construction of High Pressure Vessels* (B&PV Code) [15]. After an NNSA operational awareness assessment [16], MSTS learned that the vessel did not meet several requirements from the B&PV Code. After consulting with the NWLs, MSTS revised the performance criterion to require the vessel design to meet requirements established by the NWLs. However, MSTS and the NWLs did not evaluate how this change affected the bounding failure scenario for the vessel confinement system.

Specifically, the NWLs determined that the worst-case failure of the vessel confinement system would be a 1.5-inch breach from a failed diagnostic cover on the vessel [17, 18]. One of the bases for this determination was that the vessel was designed in accordance with the B&PV Code. The NWLs did not reassess this determination after changing the performance criterion for the vessel. The bounding failure scenario for the vessel confinement system is important because the NWLs use the pressure rise in the Zero Room from a 1.5-inch breach to determine the design pressure of the containment plugs [19]. The containment plugs are part of the credited Zero Room structure boundary. MSTS relies on them to seal the Zero Room during experiment execution and to contain any SNM in the Zero Room if the vessel confinement system were to fail. If a breach larger than 1.5 inches were to occur, such as the failure of a radiographic cover on the vessel, then the resulting pressure increase in the Zero Room may exceed the design pressure of the containment plug. Failure of both safety controls could expose PULSE facility workers to a radiological release.

The NWLs have had issues finding vendors with the appropriate capabilities to meet the B&PV Code. Additionally, they expressed concerns with fully complying with all requirements in the B&PV Code. For example, the B&PV Code requires that a hydrostatic overpressure test be performed on each assembled vessel. This test is completed to ensure that there are no undetected defects introduced during fabrication and assembly. The NWLs do not require this test for each assembled vessel. While the vessel weldments are subjected to this testing, some other pressure retaining parts (e.g., diagnostic covers, valves, and instrument penetrations) that constitute the vessel confinement system are not. The NWLs are concerned that performing a hydrostatic overpressure test on a completely assembled vessel could damage diagnostics. The NWLs require that a 125 percent dynamic overpressure test be performed on one assembled vessel in a series. The NWLs consider this test to bound the hydrostatic overpressure test.

The NWLs' approach to pressure testing is in direct contradiction to the B&PV Code and associated code interpretations. Moreover, the NWLs have not demonstrated how their construction requirements meet the intent of the B&PV Code. The NWLs should identify which requirements from the B&PV Code are not being fully met and justify how the vessel confinement system will still be able to perform its safety function. If it is determined that the vessel confinement system cannot perform its safety function, then MSTS should consider larger breach failures and assess the adequacy of the credited containment plug designs at the higher pressure.

Inadequate Means of Egress for Workers—The proposed configuration of drifts in PULSE does not comply with life safety requirements. The staff team found the following examples:

- The single means of egress from the ZEUS Zero Room drifts exceeds what is allowed in National Fire Protection Association (NFPA) 101, *Life Safety Code*. NFPA 101 states that the maximum common path of travel is 50 feet for non-sprinklered areas and 100 feet for sprinklered areas. The most remote section of the ZEUS Zero Room is more than 100 feet from where two exits are available.

- MSTS plans to install a rotary uninterruptible power source in an alcove that is open to the means of egress. DOE Standard 1066-2016, *Fire Protection*, requires that the room with this system be separated from the means of egress by walls with at least a two-hour fire resistance rating.

Based on these examples, if an accident were to occur in PULSE, workers might not have an adequate means to escape the facility. MSTS should consider options to comply with NFPA 101, such as mining an alternative means of egress or pursuing an equivalency or exemption. MSTS should also update its safety and health program description document [20] to align with the means of egress requirements for industrial occupancies in NFPA 101. Lastly, MSTS should install a fire-rated wall to separate the rotary uninterruptible power source from the means of egress.

Conclusion. The staff team identified several safety issues during its review of the ECSE safety design basis documents and seismic faults within PULSE.

NNSS needs to fully investigate and characterize the seismic faults within PULSE to mitigate potential ground motion hazards and displacement impacts. The age of the faults, and therefore whether they are active, can be determined through trenching, geophysical profiling, or finding dateable materials inside tunnels. If the faults are active, their dimensions should be characterized to determine if they meet the criteria to be included in the USGS's earthquake database. This will better inform DOE of the risk associated with these faults for the safety of PULSE, DAF, and other NNSS defense nuclear facilities.

While MSTS plans to address most of the safety issues identified in safety design basis documents in their next revisions, several remain unresolved, including: (1) the inadequate control set for subcritical experiment movements, (2) unevaluated effects from changing the performance criterion for the vessel confinement system, and (3) an inadequate means of egress for workers. These issues could be resolved by designing and procuring a new shipping container for the subcritical experiment package; identifying which requirements from the ASME B&PV Code are not being fully met for the design of the vessel confinement system, and justifying why that is acceptable; and updating the means of egress from the facility so that it complies with life safety requirements.

Appendix A: Seismic Faults Within the Principal Underground Laboratory for Subcritical Experimentation at the Nevada National Security Site

Background. The Board's staff team reviewed the safety design basis documents for the Enhanced Capabilities for Subcritical Experiments (ECSE) projects [1] at the Principal Underground Laboratory for Subcritical Experimentation (PULSE, formerly known as the U1a Complex). During that review, the staff identified references to faults present in the PULSE facility. Specifically, a geological report from 1989 [4] stated that PULSE is located within Quaternary[5] alluvium. According to the U.S. Geological Survey (USGS), Quaternary faults are active or capable faults that can potentially trigger both earthquakes and displacements [5].

Most of the faults in PULSE are covered behind drift walls lined with shotcrete, which obscures the ability to inspect the outcrops for evidence of faulting. The only limited exposure is along the U1a.01 drift. The staff team performed walkdowns along the U1a.01 drift to observe and measure the orientation and dipping of faults, as well as observe locations where the fault distribution map indicated faulting was present. Nevada National Security Site (NNSS) geologists explained what they observed and measured about the faults taken before mining operators covered them in shotcrete. The staff team also observed a fault scarp in Yucca Flat that correlates to the faults within PULSE and reviewed all available geological reports, pictures, and maps that discussed the faults within PULSE.

Extensive Presence of Seismic Faults within PULSE. Seismic faults are extensively exposed within the tunnels with more than 50 individual locations based on the fault distribution map (Figure A-1). These faults are primarily normal faults. In this type of fault, the block above the fault line moves downward relative to the block below (Figure A-2). The faults observed in the U1a.01 drift predominantly strike in a north-south or northeast direction with a dipping angle of approximately 80 degrees, consistent with the descriptions in NNSS geological reports.

Although these faults are dispersed across various tunnel sections and not directly interconnected, they are part of the fault system, as some can be linked to form longer faults based on their orientations and fault types. The longest ones can potentially extend more than 1,000 feet (Figure A-1). These faults also have displacements of more than 17 feet, which exceeds the height of the tunnels in the drifts east of the U1a.01 drift [6]. Fault displacements west of the U1a.01 drift are relatively smaller, less than the height of drifts. Polished surfaces (termed "slickensides") and rocks formed by grinding (termed fault gouges) due to movement along both sides of faults are common, indicating previous earthquake activity (Figure A-3). The staff team's walkdowns within the tunnels affirmed the descriptions including the fault orientations and attitudes provided in the NNSS reports [6–9].

Uncertain Age of Seismic Faults in PULSE. USGS defines Quaternary faults as capable of generating earthquakes and ground displacements. USGS uses the Quaternary Fault and Fold Database to calculate the national earthquake hazard map. NNSS geologists consider the faults present in PULSE to have occurred in the Tertiary period[6] instead of the Quaternary period.

[5] Quaternary is a geological period beginning approximately 2.6 million years ago and continuing to the present.
[6] Tertiary is a geological period spanning from 65.5 million to 2.6 million years ago.

NNSS geologists stated that the faults truncate a unique volcanic ash layer claimed to be from the Tertiary period. According to NNSS geologists, the ash layer lies beneath the tunnel floor and was exposed during earlier deep excavations [6]. NNSS geologists inferred the age of the ash layer based on petrographic examination. This method compared the ash layer's mineral content with that of another Tertiary rock but is not as reliable as methods such as isotopic dating because similar mineral content could be found in non-Tertiary rocks. No official NNSS geological reports document the age of the ash layer.

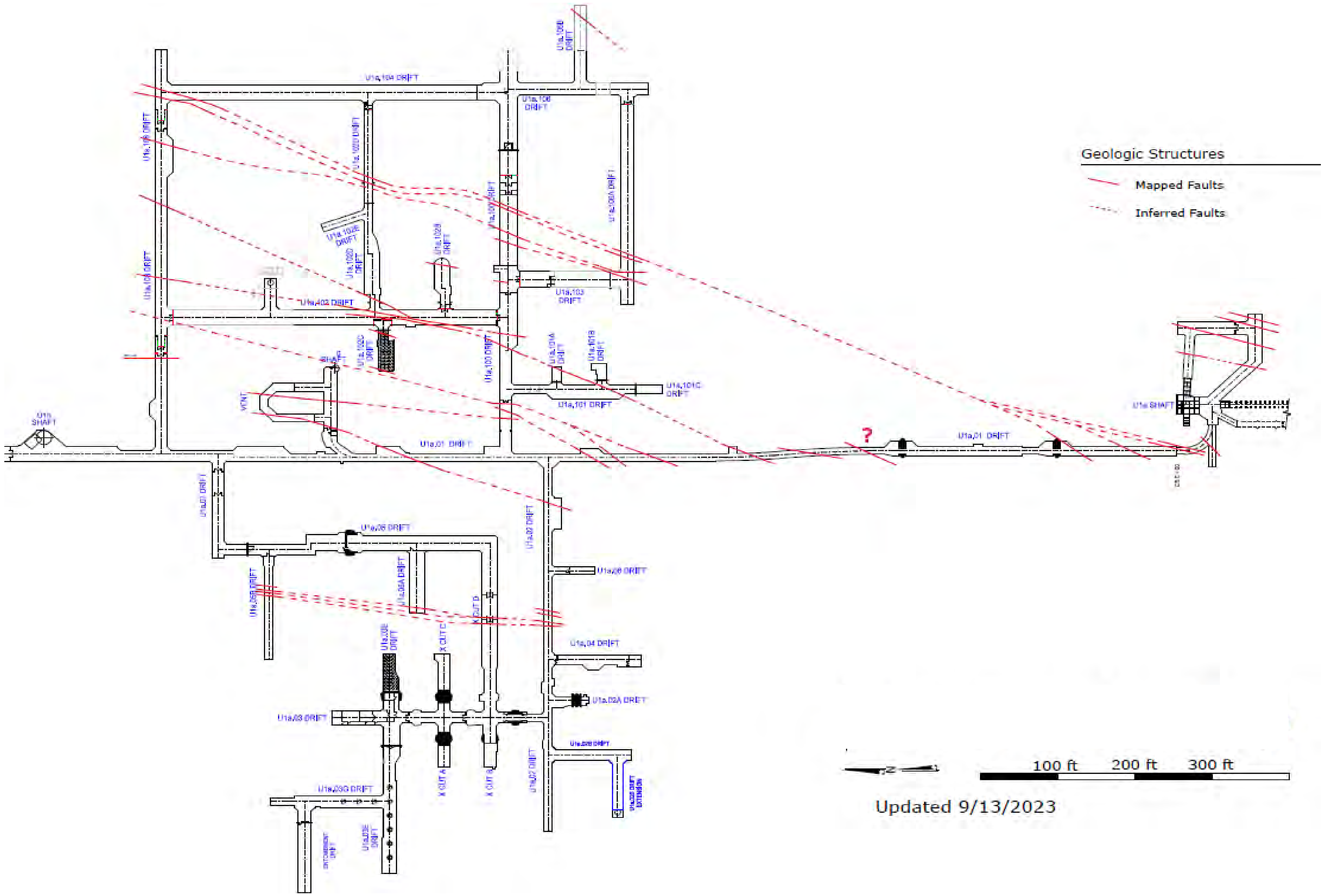

Figure A-1. *Fault distribution within PULSE [10]. Solid red lines indicate observed faults and dashed red lines indicate inferred faults.*

Even if the ash layer was deposited in the Tertiary period, that would not mean faulting necessarily occurred in the Tertiary period. This is because evidence from NNSS geological reports [6–9], along with observations during the staff team's walkdowns, indicate that the faults within PULSE not only displaced the ash layer but also displaced alluvium layers younger than the ash layer, extending beyond the tunnel ceiling. These faults could terminate anywhere between immediately above the tunnel ceiling and the ground surface. In undisturbed sedimentary layers, the younger sedimentary layers are closer to the surface. This suggests that the age of the faults within the tunnel could be younger than the age of the tunnel-level deposits they displaced and older than the present ground surface, which they did not penetrate.

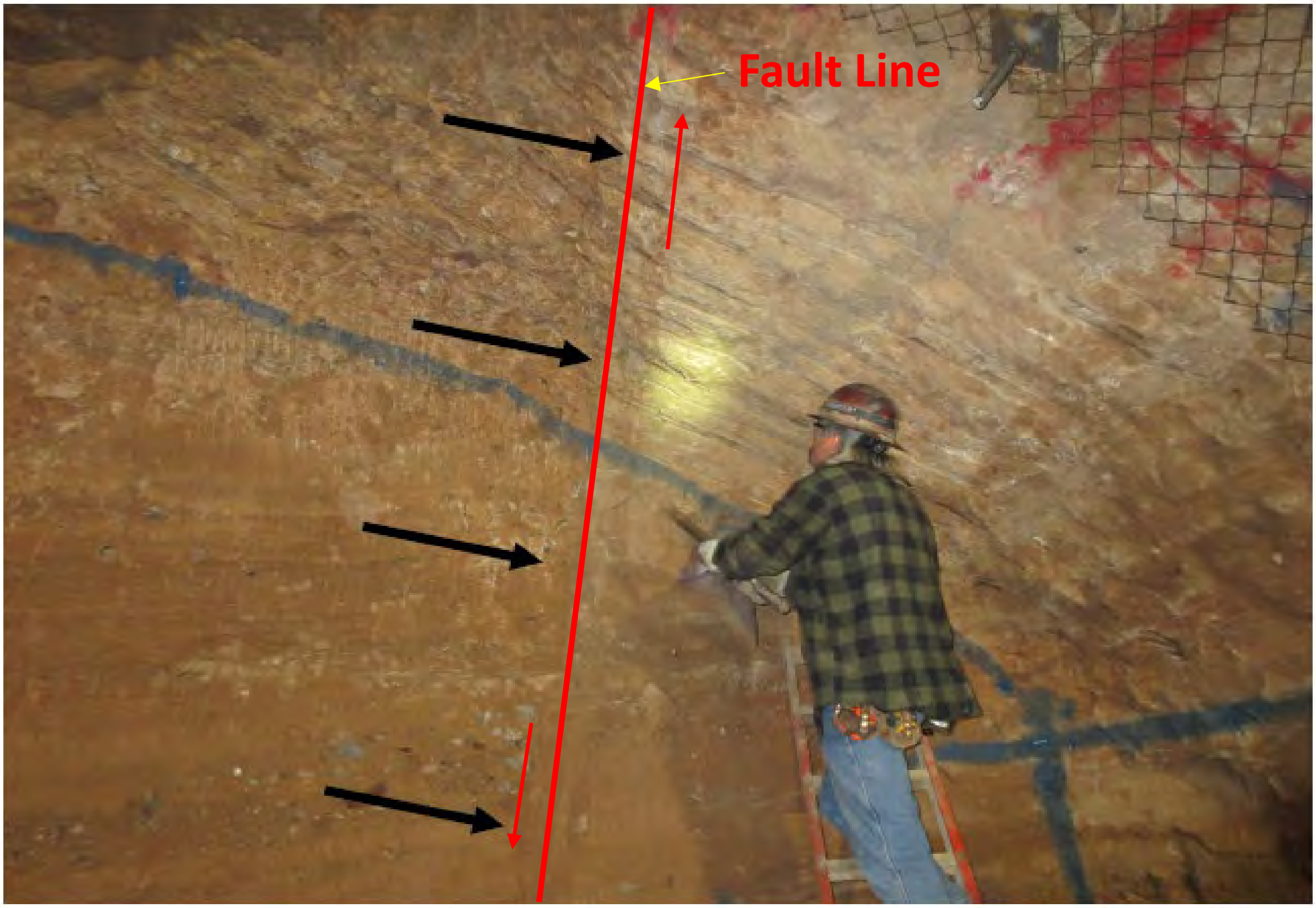

Figure A-2. *NNSS Photo [7] shows that a nearly vertical fault displaced sedimentary layers. Fault line is indicated with a red line. Note that the nearly horizontal sedimentary layer with gravels at the bottom left was discontinued near the red line.*

A NNSS geological report published in 2003 estimates that the faults exposed at the tunnel level (about 900 feet beneath the surface) also displaced the layers closer to the surface at a depth of around 450 feet [6]. This means that the faults are from an even younger Quaternary age because the layers closer to the surface are generally younger. However, NNSS geologists now consider this report inaccurate because the displacement at the shallow depth was inferred rather than directly measured. NNSS geologists plan to update this report.

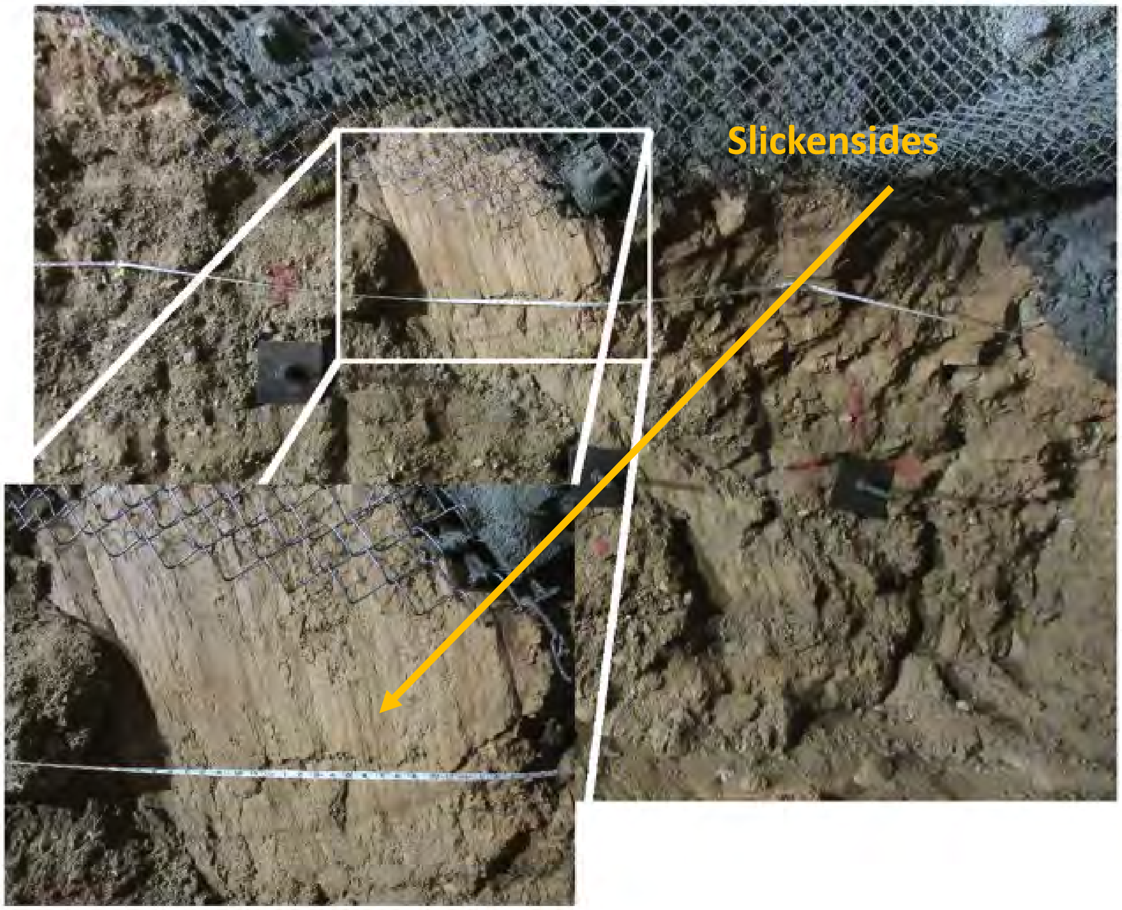

Figure A-3. *NNSS photo [7] shows fault slickensides indicating past rapid movement along the fault.*

Lastly, the 1989 geological report indicates that the entire PULSE facility is situated within Quaternary alluvium [4]. Subsequent reports describing the faults have not mentioned their age [6–9]. An NNSS geologist stated that the age of the PULSE faults is inferred to be similar to the Yucca Flat fault, which USGS considers to be Quaternary. Presently, NNSS geologists portray the 1989 report as out-of-date and inaccurate regarding the age of the faults. They also rejected the notion that the faults within the tunnels correlate with the Yucca Flat fault in terms of age but did not provide evidence to support their revised position.

Neither the NNSS geologists nor the staff team have found fossils or dateable materials that can identify the age of the faults. Without knowing the age of the youngest sedimentary layers, the age of the faults within the drifts remains uncertain and could potentially be Quaternary.

PULSE Safety Implications. According to the safety design basis document for the ECSE project [1], "NPH [natural phenomena hazard] events are initiators for explosions, fires and loss of confinement." Faults within PULSE, if active, can trigger earthquake vibrations and, therefore, potentially result in high explosive initiation within the subcritical experiment package leading to the dispersal of special nuclear material. An earthquake-induced explosion scenario could have moderate unmitigated consequences to the public (7.3 rem) and high unmitigated consequences to co-located workers (>100 rem).

Both subprojects of ECSE, the U1a Complex Enhancements Project and the Z-Pinch Experimental Underground System test bed project [2], credit several controls for seismic accident scenarios, such as the Zero Room structure, anchoring for overhead equipment in the Zero Room, and the fire extinguishing system. The applicable performance criterion for these controls is that they meet seismic design category (SDC)-2 requirements. Department of Energy (DOE) Standard 1020-2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities* [21], requires SDC-2 controls to be designed in accordance with the International Building Code (IBC)-2015, *International Building Code* [22]. The USGS National Earthquake Hazard Maps inform seismic design parameters in IBC-2015. Due to the unknown age of the faults within PULSE, NNSS personnel have not informed USGS of their existence.[7] As a result, the earthquake hazard maps do not account for the hazard associated with the faults in PULSE. Given that the design of controls required to meet SDC-2 requirements relies on these hazard maps, the controls may not be able to perform their intended safety function during or after a seismic event. This inadequacy could potentially allow a seismic event to result in high explosive initiation within the subcritical experiment package, leading to the dispersal of special nuclear material.

Separately, the safety design basis document for the ECSE projects does not currently analyze a fault displacement hazard scenario. NNSS personnel consider the fault displacement scenario to be bounded by the analyzed scenario in which a seismic event results in overhead equipment falling onto the subcritical experiment package that is being transported to the Zero Room [2]. For this scenario, NNSS personnel credit the shipping container to protect the subcritical experiment. Additionally, NNSS personnel stated that a normal faulting earthquake in the alluvium would not cause a displacement as large as the drift height and that the resulting event would be like sand falling onto the shipping container.

The magnitude of the fault displacement is typically proportional to the dimension of the faults [11]. Given that NNSS personnel have not characterized the dimensions of the faults in PULSE (e.g., the faults could extend to the north or south for many miles), the potential magnitude of the fault displacement event is unknown. Additionally, normal faulting events could displace the underlying layers, which could consist of various hard rocks. If a more severe displacement were to occur, then the shipping container may not be able to fully protect the

[7] For a fault to be included in the USGS National Seismic Hazard Model (which provides the data for the National Earthquake Hazard Maps), the fault must have all the following characteristics: definitive evidence of Quaternary activity; available information in peer-reviewed published literature; and a length greater than 7 kilometers, defined through mapping.

subcritical experiment (Figure A-4). As a result, the ECSE safety basis documentation should analyze this event separately as a unique hazard.

Safety Implications for the Device Assembly Facility (DAF) and Other NNSS Facilities. DAF is located about seven miles away from PULSE. The DAF structure is credited as an SDC-3 control. According to DOE Standard 1020-2016 and American Society of Civil Engineers Standard 43, *Seismic Design Criteria for Structures, Systems and Components in Nuclear Facilities* [23], a site-specific probabilistic seismic hazard analysis (PSHA) is required for a nuclear facility with SDC-3 controls. A PSHA should at least be inclusive of all the significant earthquake sources within a 200-mile radius. However, the existing PSHA for DAF does not include the faults within PULSE [24]. Therefore, the seismic hazard for DAF may be underestimated if the faults within PULSE are considered to be active.

In addition, due to the exclusion of PULSE faults in the U.S. Quaternary Fault and Fold Database, all NNSS facilities that use the National Earthquake Hazard Maps as a basis to determine their seismic design may potentially be underestimated. This includes all NNSS facilities with SDC-1 and SDC-2 structures, systems, and components. Important NNSS infrastructure, such as highways and electrical transmission lines, could be potentially severed due to fault displacement.

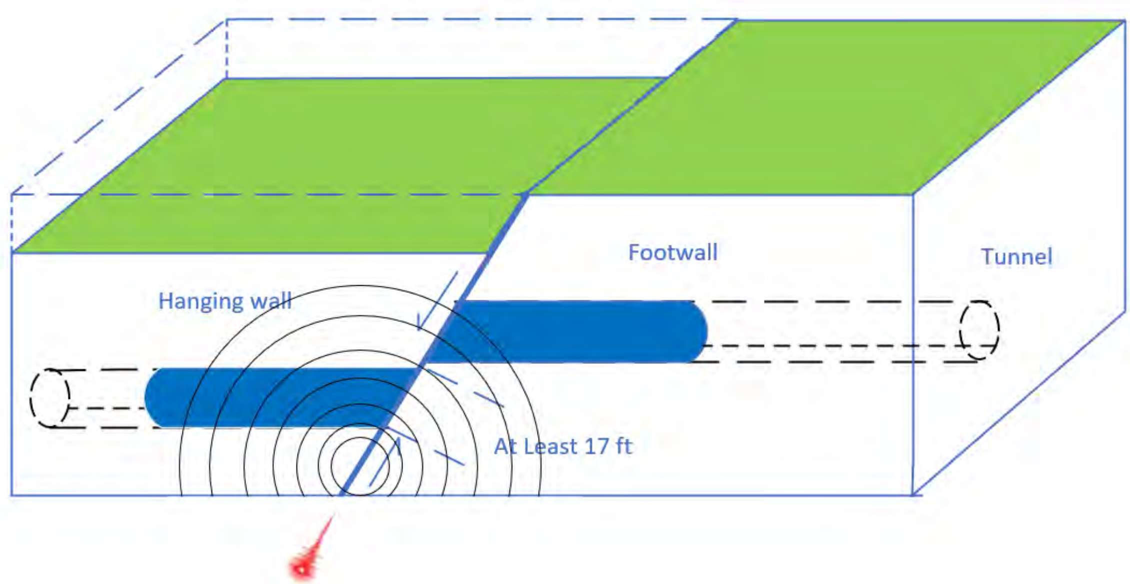

Figure A-4. *Potential impact of faults within PULSE, displacing drifts and triggering earthquake vibrations.*

Conclusions. The staff team concludes that NNSS needs to fully investigate and characterize the seismic faults within PULSE to mitigate potential ground motion hazards and displacement impacts. The age of the faults, and therefore whether they are active, can be determined through trenching, geophysical profiling, or finding dateable materials inside tunnels. If the faults are active, their dimensions should be characterized to determine if they meet the criteria to be included in the USGS Quaternary Fault and Fold Database. This will better inform DOE of the risk associated with these faults for the safety of PULSE, DAF, and other NNSS nuclear facilities.

Currently, neither DOE Order 420.1C, *Facility Safety* [25], nor DOE Standard 1020-2016 address the presence of active faults near defense nuclear facilities. The staff team is working with the responsible managers for the order and standard to include appropriate criteria.

Appendix B: Safety Issues Identified During the Review of the Safety Design Basis Documents for the Enhanced Capabilities for Subcritical Experiments (ECSE) Projects

Members of the Defense Nuclear Facilities Safety Board's (Board) staff reviewed the safety design basis documents [1, 2] for the ECSE projects at the Principal Underground Laboratory for Subcritical Experimentation (PULSE). The ECSE projects include the U1a Complex Enhancements Project (UCEP) and the Z-Pinch Experimental Underground System (ZEUS) test bed project, both of which are major modifications to the existing facility. The Board's staff team identified numerous safety issues in the safety design basis documents, which are discussed further below. The staff team is providing these findings so that Mission Support and Test Services, LLC (MSTS), can address them as it moves forward and develops the final documentation.

The staff team reviewed the preliminary documented safety analysis (PDSA) for UCEP. Based on the review interaction, MSTS agreed with several issues identified by the staff team and communicated its intent to address most of them in the next revision of the PDSA. Shortly after this interaction, MSTS completed the draft PDSA for ZEUS. Given the similarities between the two projects, the staff team performed a limited review of the draft PDSA for ZEUS that focused on how it differed from the UCEP PDSA. In the draft PDSA for ZEUS, MSTS had taken steps to ensure that some identified issues from the UCEP PDSA were not carried forward.

Improper Functional Classification for ZEUS Shield Walls. For the ZEUS test bed project, MSTS plans to construct two shield walls near the experiment operations area. In the draft ZEUS PDSA, MSTS analyzed a What-If scenario of one of these walls falling onto an experimental package during a seismic event. MSTS determined that this scenario needed further evaluation in the hazard analysis.

In the applicable hazard analysis scenario, MSTS credits the Zero Room structure and anchors that support overhead equipment to reduce the likelihood of this event. MSTS did not credit the walls for this scenario and stated that they were support structures, systems, and components (SSC), not safety SSCs. MSTS concluded that the walls only need to meet the same design requirements as the Zero Room structure (i.e., seismic design category [SDC]-2 criteria) but not the same functional classification. It is inappropriate to classify these walls as support SSCs because installing them creates a unique hazard in the Zero Room.

Crediting these walls as safety significant and designing them to SDC-2 criteria would adequately reduce the risk associated with these walls falling onto a subcritical experiment. Personnel from the National Nuclear Security Administration (NNSA) Nevada Field Office agreed with this concern and developed a condition of approval for the draft PDSA on this issue [26]. MSTS has since upgraded the walls to be safety significant in the PDSA and design documents.

Inappropriate Assumed Location of the Co-Located Worker. The UCEP and draft ZEUS PDSAs analyze unmitigated accident consequences for the co-located worker at the Area 6 construction facilities—i.e., 3,500 meters from PULSE—for all hazard scenarios. The NNSA Cognizant Secretarial Officer for Safety claimed in December 2020 [27] that moving the assumed location of the co-located worker was allowed per section 3.3.2 of Department of Energy (DOE) Standard 3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis*, which states:

> *For existing facilities, a situation could occur where no viable control strategy exists that could either prevent or mitigate one or more of the hazard/accident scenarios from exceeding the above onsite radiological or chemical consequence thresholds. In such a case, the DSA* [documented safety analysis] *may determine co-located worker consequences at receptor distances further than 100 meters, if it* [is] *consistent with the actual location of adjacent facilities.*

The Board communicated to the Secretary of Energy in a letter dated December 1, 2021 [13], that this approach is inappropriate for the ECSE projects, given that the allowance is for "existing facilities" and not a major modification project to an existing facility. After the Board issued its letter, the NNSA Cognizant Secretarial Officer for Safety at the time reaffirmed NNSA's position on the matter in a memorandum dated January 4, 2022 [28].

The staff team interacted with DOE's Office of Environment, Health, Safety, and Security (EHSS)[8] on May 24, 2023, to understand its perspective on the alternate co-located worker location NNSA had selected for the ECSE projects' safety design basis documents. EHSS staff confirmed that the quoted passage above is not applicable to the major modification projects at PULSE and communicated this position to NNSA. Additionally, in September 2022, DOE's Office of Enterprise Assessments published the results of its independent review of the UCEP PDSA [29]. The final report has a finding that states that the "PDSA does not meet the conditions for using an alternate dispersion factor based on a co-located worker receptor distance more than 100 meters from the point of release."

The current NNSA Cognizant Secretarial Officer for Safety has since re-evaluated their office's prior position on the matter and no longer plans to use this provision in DOE Standard 3009-2014. As a result, MSTS will move the co-located worker back to 100 meters, and the unmitigated co-located worker dose consequences for seismic accident scenarios will exceed 100 rem total effective dose (TED). DOE Standard 1020-2016, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*, requires credited seismic controls to be designed to SDC-3 requirements when the unmitigated dose consequences exceed 100 rem TED to the co-located worker. MSTS plans to seek an exemption to allow the seismic controls meet SDC-2 requirements instead of SDC-3 requirements.

Nonconservative Analysis for External Vehicle Impact Scenario. Both the UCEP and draft ZEUS PDSAs analyze external vehicle collision events and consider the events to be "beyond extremely unlikely." The PDSAs justify this likelihood by stating, "The time at risk is very small for the transport distance from the U1a Complex fence to the U1h Collar Area. The external vehicle's inability to obtain sufficient velocity to inflict significant damage to the Transfer Vehicle carrying the SCE [subcritical experiment] or HE [high explosive] Configuration is due to the lack of space for another vehicle to be within the U1h fence." MSTS also indicated that the on-site transportation safety basis precludes more than one transport

[8] EHSS is the Office of Primary Interest for DOE Standard 3009-2014.

vehicle at the U1h collar. However, the on-site transportation safety basis [30] does not identify an initial condition or specific administrative control (SAC) to implement this restriction. Furthermore, section 3.2.2 of DOE Standard 3009-2014 states that administrative controls shall not be assumed to be available for the unmitigated analysis. MSTS plans to re-evaluate the unmitigated frequency for this scenario in both PDSAs.

Regarding the PSDAs' discussions of potential vehicle velocity, external vehicles are allowed inside the PULSE boundary and can be parked outside the fence that surrounds the U1h collar area. Outside of this fence, there is sufficient space for a vehicle to obtain a velocity that could inflict significant damage to either the transfer vehicle or the experimental package. Additionally, there are no barriers surrounding the U1h collar area other than a chain-link fence. MSTS should consider adding a physical barrier around the collar area that will prevent vehicles from entering and a SAC that restricts the number of vehicles allowed during insertion activities (i.e., when the subcritical experiment package or high explosive configuration are being delivered and lowered underground).

Inadequate Controls for Seismic Hazard Scenarios. The UCEP PDSA has three scenarios in the hazard analysis with no identified safety controls to mitigate risk to the public, co-located worker, and facility worker. These scenarios note: "The operation will be conducted at risk as there are no controls to prevent or mitigate this accident." All three events analyze mechanical impacts to the subcritical experiment package due to a seismic event either at the U1h collar area, in the U1h shaft, or in the underground drifts that lead to the Zero Room. MSTS plans to re-evaluate these hazard scenarios in the next revision of the PDSA and indicated that it would consider crediting the U1h hoist structure and the subcritical experiment container as controls to reduce the risk to an acceptable level. MSTS credited these controls for similar scenarios in the draft ZEUS PDSA.

For the U1h hoist structure, the draft ZEUS PDSA states, "A seismic evaluation will need to be developed to demonstrate that the U1h hoist can withstand an SDC-2 seismic event." MSTS has developed an engineering work plan for this evaluation but has not established a timeline on when it will be completed. This evaluation is needed to justify the structural adequacy of the hoist.

MSTS has evaluated the insertion path to determine which overhead items could fall and impact the shipping container for the subcritical experiment package. MSTS will use the results from this evaluation to determine a bounding impact energy that the shipping container would need to withstand and develop applicable performance criteria for the shipping container.

Inappropriate Unmitigated Frequencies in the Hazard Analysis. The staff team identified several instances in which the UCEP and draft ZEUS PDSAs used an inappropriate unmitigated frequency for a scenario analyzed in the process hazard analysis. Using the appropriate frequency may result in the identification of the need for additional controls to reduce the risk to an acceptable level. Below are specific examples:

- In the UCEP PDSA, MSTS used an "unlikely" unmitigated frequency for fire scenarios when personnel are present. However, the PDSA states that these scenarios are considered “anticipated.” MSTS plans to update the unmitigated frequencies for these scenarios to “anticipated” in the next revision of the PDSA. For the draft ZEUS PDSA, almost all the unmitigated frequencies for the relevant scenarios are listed as “anticipated.”

- In the UCEP PDSA, MSTS used an “unlikely” unmitigated frequency for explosion scenarios caused by a drop event due to equipment failure or operator error. MSTS justified the unmitigated frequency in the PDSA based on the high explosive needing a significant mechanical insult for detonation. However, Section 3.2.2 of DOE Standard 3009-2014 states, “The likelihood of an unmitigated accident is generally the likelihood of the initiating event.” The initiating event for these scenarios is a drop due to human error or equipment failure, for which the PDSA states that the unmitigated frequency should be “anticipated.” MSTS plans to update the unmitigated frequencies for these scenarios to “anticipated” in the next revision of the PDSA. For the draft ZEUS PDSA, some of the unmitigated frequencies for the relevant scenarios are listed as “anticipated.”

- In the UCEP PDSA, MSTS used an “unlikely” unmitigated frequency for loss of confinement scenarios that result from the vessel confinement system failing. Table 2 in DOE Standard 3009-2014 defines “unlikely” as “[e]vents that are not anticipated to occur during the lifetime of the facility.” The vessel confinement system failed to perform its safety function during the Ediza experiment, which resulted in a small release of radiological material into the Zero Room. Therefore, an appropriately conservative unmitigated frequency for these scenarios would be “anticipated.” The applicable scenarios in the draft ZEUS PDSA also have an “unlikely” unmitigated frequency.

Vague Performance Criteria for Safety SSCs. In the draft ZEUS PDSA, the credited rockbolts and crane that will be used in the Zero Room have performance criteria that are the same as the applicable functional requirement. Specifically:

- The rockbolts have a functional requirement that states, “The anchoring for equipment will be capable of handling the attached loads.” The applicable performance criterion states, “SS [safety significant] structural supports in the Zero Point Operations Area for mounted equipment, equipment attached to the back (ceiling), ribs (walls), invert (floor) and utilities must support the attached loads as designed.” MSTS stated that a specific value could not be assigned for this performance criterion because the control may be applied to various components that will require different loads.

- The crane has a functional requirement that states, “Load handling equipment must support loads up to their rated capacity.” The applicable performance criterion states, “Crane must be able to hold at least 100% of their rated capacity by design specific controls.” The crane also has another functional requirement that states, “Speed control systems must limit the speeds that the crane and hoist travel.” The applicable performance criterion states, “Crane and hoist speed control systems are designed to

> limit the speed at which the hoist and crane travel." MSTS indicated that the design of the crane was not complete at the time it submitted the draft PDSA and that it will update the performance criteria to incorporate the relevant information.

MSTS also submitted requests to early procure these SSCs [31, 32]. Section 4.5.3 of DOE Standard 1189-2016, *Integration of Safety into the Design Process*, requires the performance criteria of safety SSCs be submitted as part of the safety documentation request. The performance criteria for each credited SSC must be well-defined before the contractor procures the control to ensure the SSC will be able to perform its safety function.

Inappropriately Analyzed Hazards Due to High Explosives Sensitivity. In the draft ZEUS PDSA, MSTS did not further analyze certain hazard scenarios or apply controls if the insult parameters—such as the impact energy—did not exceed the thresholds needed to initiate the high explosive, as established by the nuclear weapon laboratories (NWL). The staff team evaluated implementation of this approach but did not assess the technical basis for the device response thresholds used.

MSTS agreed that several hazard scenarios may have been inappropriately excluded from further consideration and additional analysis or clarification is needed. MSTS plans to identify safety controls or provide updated analyses to address these scenarios in an upcoming revision to the PDSA. Additionally, MSTS plans to better define performance criteria for various design features and SACs to ensure these controls preclude the various hazard scenarios for which they are credited. Selected examples include the fasteners in the shipping container for the subcritical experiment, as well as SACs related to use of high-energy initiators[9] (HEI) and approved electrical equipment. MSTS also plans to add a new SAC to ensure facility maintenance activities are not performed when a subcritical experiment is in the Zero Room. Finally, MSTS no longer credits the Qualified Explosives Handlers SAC in the draft ZEUS PDSA and will remove the SAC from the UCEP PDSA. The staff team agrees with removal of this SAC.

Inadequate Performance Criteria for Equipment Used to Implement SACs. The Use of High-Energy Initiators SAC and Approved Electrical Test Instruments SAC are intended to ensure that high explosive configurations use HEIs and that only approved electrical equipment is used when connecting to high explosive configurations. Neither the various pieces of electrical equipment (e.g., testers) nor the HEIs themselves are credited engineered controls. Section [4.5.X.4] of DOE Standard 3009-2014 states, "If equipment is required to implement the SAC and it is not designated as SC [safety class] or SS [safety significant] SSC, then this subsection provides performance criteria imposed on the SSC so it can meet functional requirement(s) and, thereby, satisfy the SAC safety function."

---

[9] Per DOE Standard 1212-2019, Change Notice 1, *Explosives Safety*, an electro-explosive device (EED) is a component "containing some reaction mixture (explosive or pyrotechnic) that is electrically initiated." Within subcritical experiments, EEDs—more commonly known as initiators—are used to detonate high explosive charges to evaluate special nuclear material responses for stockpile stewardship applications. DOE Standard 1212-2019 goes on to specify two types of initiators—low-energy initiators and HEIs—based on the electrical input necessary to result in their initiation. HEIs are defined as "[e]xploding bridgewire systems, slapper detonators, and EEDs with similar energy requirements for initiation."

Performance criteria for the SACs do not specify required levels of performance (e.g., initiation energies for HEIs or specific thresholds representing safe levels of electrical energy) against which to evaluate the HEIs and electrical equipment. The PDSAs instead refer to the explosives safety program or the NWL to ensure the items meet the functional requirements of the SACs. Without specified performance criteria, it is unclear how MSTS ensures that controls perform their credited safety functions. MSTS indicated that it would work with the NWLs to address this safety concern.

References

[1] Mission Support and Test Services, LLC, *U1a Enhanced Capabilities for Subcritical Experiments Preliminary Documented Safety Analysis*, U1a-ECSE-PDSA-001, Revision 1, September 2021.

[2] Mission Support and Test Services, LLC, *U1a Complex Z-Pinch Experimental Underground System (ZEUS) Testbed Draft Preliminary Documented Safety Analysis*, U1a-ZTB-PDSA-001, Revision 1, March 2023.

[3] National Nuclear Security Administration letter to the Nuclear Weapons Laboratories and National Security Technologies, LLC, *Approval of Mission Need for Enhanced Capabilities for Subcritical Experiments at the Nevada National Security Site, U1a Complex*, September 2014.

[4] Fenix and Scission, Inc., *Geology of the U1A.01 Horizontal Drift Complex, Southwest Yucca Flat, Nevada Test Site*, March 1989.

[5] U.S. Geological Survey, *Quaternary Fault Map of the Basin and Range and Rio Grande Rift Provinces, Western United States*. Open File Report 82-579, 1981.

[6] Bechtel Nevada, *Updated Structural Geology of the U1a Complex Project No. N/A*, June 2003.

[7] Mission Support and Test Services, LLC, Geoscience Operation Group, *Geology and Ground Monitoring in the U1a.104 and 108 Drifts during Mining for the U1a Complex Enhancements Project*, June 2021.

[8] Mission Support and Test Services, LLC, Geoscience Operation Group, *U1a Complex Enhancements Project Geology of the U1a.103 Drift Extension, U1a Complex*, October 2021.

[9] National Security Technologies LLC, Geology Group, *Predicted Geologic Conditions in the Planned U1a.103 Extension, the U1a.100 Extension, and Associated Drifts*, June 2014.

[10] Mission Support and Test Services, LLC, Geoscience Operation Group, U1a Complex Map, September 2023.

[11] Wells, D.L. and Coppersmith, K.J., *New Empirical Relationship among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement*, Bulletin of Seismological Society of America, 1994.

[12] Defense Nuclear Facilities Safety Board, *Letter to the Secretary of Energy James Richard Perry regarding U1a Complex Safety Basis Review*, December 19, 2018.

[13] Defense Nuclear Facilities Safety Board, *Letter to the Secretary of Energy Jennifer M. Granholm regarding Alternate Location for the Co-Located Worker at the U1a Complex*, December 1, 2021.

[14] Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Mission Support and Test Services, LLC, *Device Container Evaluation Project Analysis of Alternatives*, DEVCON-AOA-001, October 2019.

[15] Mission Support and Test Services, LLC, *VCS Qualification Issues*, U1a-SBE-2022-01, Revision 0, July 2022.

[16] National Nuclear Security Administration Nevada Field Office, *Vessel Confinement Systems (VCSs) In Service Inspections (ISIs) Do Not Meet ASME Boiler and Pressure Vessel Code Requirements*, OAA-22-AMOS-MJP-05-02-2022, June 2022.

[17] Los Alamos National Laboratory's Nevada Weapons Experiments Office memorandum to Los Alamos National Laboratory's Nevada Experimental Operations, *Postulated Loss of Confinement Failure Scenarios of a 6-foot Vessel Confinement System Used for Subcritical Experiments at the Nevada National Security Site U1a Facility Zero Rooms*, WP-2021-134, November 2021.

[18] Los Alamos National Laboratory's Nevada Experimental Operations memorandum to Los Alamos National Laboratory's Nevada Weapons Experiments Office, *Recommended Path Forward Regarding Loss of Confinement Scenarios of a 6-foot Vessel Confinement System Used for SCE at the NNSS U1a Facility Zero Rooms*, DDW-2022-005, January 2022.

[19] Los Alamos National Laboratory, *VCS and Zeus/Scorpius Zero-Room Quasi-Static Pressure Determination*, ENG-EC-SCE-1813, Revision A, March 2022.

[20] Mission Support and Test Services, LLC, *Nevada National Security Site (NNSS) Underground Facility Safety and Health Program Description*, PD-P200.002, Revision 5, April 7, 2022.

[21] Department of Energy, *Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities*, DOE Standard 1020, Washington, DC, 2016.

[22] International Code Council, *International Building Code*, Country Club Hills, IL, 2015.

[23] American Society of Civil Engineers, ASCE 43-19, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities*, 2019.

[24] Geomatrix Consultants, Inc., *Probabilistic Seismic Hazard Analysis and Design Ground Motions for Device Assembly Facility Site*, 2007.

[25] Department of Energy, *Facility Safety*, DOE Order 420.1C, Washington, D.C., 2012.

[26] National Nuclear Security Administration Nevada Field Office, *Safety Review Letter, Revision 0, for the U1a Complex Z-Pinch Experimental Underground System (ZEUS) Testbed Draft Preliminary Documented Safety Analysis (PDSA), Revision 1*, AMOS-SRL-2023-005, Revision 0, August 2023.

[27] Memorandum for David R. Bowman from the National Nuclear Security Administration Cognizant Secretarial Officer for Safety, *Use of an Alternative Location for the Co-located Worker for Safety Analysis and for Determination of Natural Phenomena Hazards Design Criteria*, December 8, 2020.

[28] Memorandum for Record from the National Nuclear Security Administration Cognizant Secretarial Officer for Safety, *Use of an Alternative Location for the Co-located Worker for Safety Analysis and for Determination of Natural Phenomena Hazards Design Criteria*, January 4, 2022.

[29] Department of Energy Office of Enterprise Assessments, *Independent Assessment of the Preliminary Documented Safety Analysis for the Nevada National Security Site U1a Enhanced Capabilities for Subcritical Experiments Project*, September 2022.

[30] Mission Support and Test Services, LLC, *Nuclear Onsite Transportation Safety Document for the Nevada National Security Site*, OTSD-NSAF.100, Revision 5, June 2023.

[31] Mission Support and Test Services, LLC, letter to National Nuclear Security Administration Nevada Field Office, *Contract DE-NA0003624, Request for Limited Procurement and Construction Activities Prior to Approval of the Z-Pinch Experimental Underground System (ZEUS) Test Bed Preliminary Documented Safety Analysis (PDSA), Submittal #3*, 1000-RR-22-0030, May 16, 2022.

[32] Mission Support and Test Services, LLC, letter to National Nuclear Security Administration Nevada Field Office, *Contract DE-NA0003624, Request for Limited Procurement and Construction Activities Prior to Approval of the Z-Pinch Experimental Underground System (ZEUS) Test Bed Preliminary Documented Safety Analysis (PDSA), Submittal #6*, 1000-RR-23-0015, April 11, 2023.