Causal Analysis Report for
Thunder Range, Block VIII Test - Management Concern

Date: September 20, 2018

1. Report Number: **NA-SS-SNL-6000-2018-0004**

2. Subject/Title of Report: **Thunder Range Block VIII Test Management Concern**

3. Responsible Manager (RM): **T. Mike Skaggs, Org 6640**

4. Causal Analysis Info

4(a). Causal Analyst: **Emily D. Wright, Senior Causal Analyst**

4(b). Type of Analysis Performed: **Cause and Effect Mapping**

5. Location: **Thunder Range**

6. Short Description of Event:

From July 24th -27th, 2018, Sandia National Laboratories (SNL) was conducting a series of explosive tests (referred to as Block VIII Tests) at Thunder Range. Thunder Range is an explosive testing range located on Kirtland Air Force Base and operated by SNL. The testing occurred on Range 7, a fragmentation range that is authorized for activities up to a maximum of 2,000 pounds net explosive weight (NEW). The maximum NEW for the Block VIII tests was 114 lbs. The specific management concern is that although the Thunder Range team identified controls to provide protection for essential personnel, those controls were not adequately evaluated before testing occurred.

7. Problem Statement:

The controls to protect essential personnel against testing hazards were not adequately evaluated before testing occurred.

8. Executive Summary:

Protection of essential personnel during explosives testing is of paramount importance. The Department of Energy (DOE) standard DOE STD-1212-2012 Explosives Safety, chapter 7 section 4.2.1 e. requires:

> *"Class 0: Areas used to conduct Class 0 (intentional initiation) activities shall protect all personnel from injury due to blast, fragments, and structural collapse of buildings. This protection may be achieved by measures (or combination of measures) to include control of fragments and overpressure by suppression, containment, or distance (location) as follows:*
>
> *(1) Impulse Sound Pressure Level (SPL) less than 140dB for operators. If impulse SPL exceeds 140dB hearing protection must be provided as specified in MIL-STD-1474D, Table 4-I, based on SPL or overpressure measurements made in the occupied environment.*
>
> *(2) No structural damage to any facility due to overpressure, fragments, or debris.*
>
> *(3) No fragment or debris impact to operators.*
>
> *(4) Operator protection from any injurious thermal flux.*

(5) Overpressure, fragment, and debris impact to surrounding areas limited to approved site plans and DoD 6055.09 M for intentional detonation of explosives criteria."

There were several controls in place at Thunder Range when the block VIII test was executed. Engineered controls including Fire Control Point (FCP) placement, FCP structure design, and administrative controls involving communications. These controls were in place but not thoroughly evaluated for adequacy in meeting requirements related to sound pressure and fragments before the test was executed. Compliance with the remaining requirements was achieved. The lack of evaluation did not result in harm to personnel, equipment, or structures but was deemed as an opportunity to further understand how compliance with DOE-STD-1212-2012 could be better achieved with defensible evidence. The information provided in the remainder of this report discusses these controls and the deficiencies that contributed to this management concern.

9. Description of the Event

9(a). Event Narrative:

Fire Control Point Placement- One of the controls associated with protecting essential personnel from testing hazards was the placement of the FCP away from the detonation point of the tests. Distance provides a reduction in the exposure to the amount of overpressure, noise, fragmentation, and thermal flux produced during an explosive test. There are several calculations related to selecting the placement of the FCP to ensure all requirements for essential personnel protection are met. These calculations result in several "K values" and distance measurements. The K values relate to the level of risk at a given distance from the detonation point, the smaller the K number the higher the risk. Placement of the FCP is, as common practice for Thunder Range, located within the K328 perimeter. The calculated K value associated with over pressure at .25 psi is K120. Placement of the FCP within the K328 perimeter but outside of the K120 is acceptable if adequate protection is provided. The essential personnel located in the FCP during tests were:

- Rudy Navarro, SNL Lead Explosive Operator
- Matthew Heine, SNL Explosive Safety for this event
- Phillip Rae, LANL diagnostics
- Allan Novak, LANL diagnostics

The FCP was placed behind a 1-inch steel wall thickness 18-ft. diameter shock tube with the intent to provide protection against impulse sound pressure, and fragment impacts. Calculations and/or measurements to quantify the level of protection provided by the shock tube were not completed before tests occurred.

Issue 1:

One portion of the FCP's northwest corner was not guarded by the shock tube.

Although the shock tube was intended to provide the FCP with an additional layer of protection, incomplete coverage of all areas could partially compromise the level of protection provided.

Cause 1 (contributing): Complete coverage of the FCP by the shock tube was not verified before the test series was started.

Issue 2:

Controls related to hearing protection were not adequately implemented.

The ESH100.2.IH.8 requirement for maximum allowed decibels (dB) allowed by an impact noise is 140dB. An industrial hygienist calculated this distance to be at K635 (unmitigated) for a .03 pound per square inch (psi) produced as an impulse or impact noise at the origination point. The IH assessment report dated June 2018 states;

"Exposure to impact noise is acceptable using the interim PPE requirement (ear plugs/muffs with NRR of23 or greater) for detonation operations; however further evaluation is required. Management shall contact Industrial Hygiene to collect area noise measurements prior to performing the detonation activities."

Cause 2 (contributing): The use of required hearing protection was not enforced.

Issue 3:

Technical requirements for determining essential personnel to allow within the zone were not formally described.

While there were technical reasons for each of the four people in the fire control point to be in that location, those reasons are not qualified through requirements within procedure or test documents.

Cause 3 (root): Reliance on experience in lieu of conducting calculations to determine adequacy of protections.

Design Controls- MN471001 "Explosives Safety Manual", Section 2.13.2.1.a, states;

> *"Proposed testing programs shall be examined for all foreseeable hazards involved in the test and be based upon the maximum credible event. This shall be done with knowledge of the construction and operation of all standard and nonstandard equipment to be used, as well as the type of explosives involved."*

The Failure Mode Analysis (FMA) activities performed at Thunder Range covered the following activities that contain hazards.

- Daily Operations
- Storage of Explosives
- Weighing of Explosives
- Transportation of Explosives
- Assembly and Disassembly of Test Items and Devices in Cage Facility (9963) and Tomography Building (9967)
- Explosive Testing / Arming and Firing
- RGD Use
- Hoisting & Rigging

Hazards that arose to unacceptable consequences were evaluated. There are two steps in the HA process: 1) Hazard Identification (HI), and 2) Hazard Evaluation (HE).

The primary objective of the HI is the identification of hazards from the Primary Hazard Screening (PHS). The screening process identifies, and carries forward for further evaluation, only those hazards posing potential threats to the safety and health of workers, the general public, or the environment. The HI also includes the consideration of potential hazards located adjacent to the selected site. The preliminary hazard identification (HI) begins by screening on the list of hazards from the appropriate PHS. These hazards will be evaluated to determine which (if any) represent the potential to rise up to an event that cannot be tolerated (e.g., Worker Death). This type of event is called an "Unacceptable Consequence". Hazards that do not meet the definition of an Unacceptable Consequence but that are still undesirable (i.e., we really don't want them to happen) are considered "Undesirable Consequences". Hazards with undesirable consequences represent those hazards that are adequately controlled by Corporate Safety Management Programs, Administrative Controls and Training. Hazards with only the potential for undesirable consequences do not require a formal in-depth analysis and may be addressed using the 6640 Checklist Analysis for Routine, Commonly Encountered Hazards. The requisite HI Team members were present: facilitator, scribe, Environmental Safety and Health (ES&H) representative, and several SMEs, Explosives, Industrial Hygiene, Internal and Safety Engineering SME's). The HI defined the scope of operations (as described above) to bound

the analysis. A screening effort was conducted to determine which hazards from the HI would carry forward for additional analysis in the Hazard Evaluation (HE).

Table 1—Hazards Identified for Analysis based on the HI Screening

Hazard / Energy Source	Hazard Description	Location
Explosives	• HC/D: 1.1, 1.2, 1.3, 1.4, 1.4S (up to approved Site Plan NEW) • Storage, Weighing, Transport, Assembly/Disassembly, A&F • Unexpended Explosives • Primary or Secondary Fragments	TR Storage Bunker TR Assembly Bunkers (9967 and Cage 9963) Approved Test Ranges
Electrical	• High Voltage - Hi-Potting • High Voltage – Fireset • Electrical Equipment	TR Storage Bunker TR Assembly Bunkers (9967 and Cage 9963) Approved Test Ranges
Radiation (RGDs)	• Exposure to Radiation above PEL	Approved Test Ranges Cage Facility (9963) Tomography Bldg. (9967)
Thermal Hazards Thermal Stressors	• Welding, Cutting & Brazing, • Working outdoors in inclement weather	Approved Test Ranges
Kinetic or Stored Energy Falling Objects (Pinch / Crush)	• Overhead lifts with Cranes • Movement of Materials with Forklifts	Approved Test Ranges Cage Facility (9963)
Fire	• Foam could catch fire, test units could catch fire, or a wildland fire could occur from testing • Fragments could start a fire	Approved Test Ranges
Toxic Fumes	• Cyanide By-Products from Foam	Approved Test Ranges

The HE used the hazards carried forward from the HI to identify potentially hazardous conditions/scenarios, as well as the corresponding preventive and mitigative controls. The What-If/Checklist method was the technique chosen by the 6640 Work Planning Team for this analysis, which is a combination of the “What-If” and the “Checklist” techniques. The What-If technique is a brainstorming approach, in which Subject Matter Experts (SMEs) ask questions or voice concerns about possible undesired event scenarios. The What-If/Checklist technique combines the creative brainstorming features of the What-If approach with the systematic features of the Checklist method. Further information on the What-If, Checklist, and What-If/Checklist Hazard Evaluation techniques can be found in Guidelines for Hazard Evaluation Procedures 3rd Edition, (i.e., “the Red Book”) published by the Center for Chemical Process Safety. In the Hazard Evaluation Workshop, unmitigated

scenarios were postulated unmitigated scenarios based on the hazards identified. In the Arming & Firing Section we analyze overpressure >1/4 psi was evaluated in a scenario whereby personnel inadvertently entire into the Hazard Zone. The worst-case consequence was worker death. Next, we identified the Engineered and Administrative controls to prevent or mitigate the severity of the occurrence and confirmed with team that the controls are adequate. This is the same process for fragments and projectiles.

One control, implemented to protect essential personnel, involved the use of an armored FCP. One of the unique capabilities of Thunder Range is the flexibility in experimental set-up. To achieve this flexibility the mobile FCP is employed instead of fixed bunkers. The front of the FCP was armored with ¼" steel layer, corrugated container skin, 2 layers of ¾" plywood, and another ¼" steel layer on one side of the FCP.

Issue 5

Calculations to understand the protection provided by the structure were done post-test.

Cause 3 (root): Reliance on experience in lieu of conducting calculations to determine adequacy of protections.

Issue 6

The consequences related to the hazardous effects of shock or fragment impact to areas of the FCP without additional armor were not evaluated before the test occurred.

Cause 4 (contributing): An impact of fragment or shock to unarmored portion of the structure was not evaluated in the failure modes analysis (FMA).

Communication Controls- Administrative communications controls were also in place to ensure that personnel were aware of the hazards associated with test activities as well as the controls in place to mitigate those hazards. It is the responsibility of Sandia to flow down requirements and operational safety to non-Sandia personnel. There were several opportunities to communicate operational practices including a management review of readiness conducted the week before the tests and daily briefings held all four days of the test series. However, these opportunities did not calibrate the expectations of non-Sandia personnel to operating practices specific to Thunder Range.

Following the tests discussions occurred where concerns from LANL support personnel were raised. The concerns centered on a difference in Thunder Range operations and the expectations they had concerning operating conditions. These expectations included:

- A more formal means of providing personnel accountability of location
- Either a fixed bunker or other structure such as a Hesco House
- The directionality of fragments to be less random
- Audible sirens would be used not hand-held radios.
- FCP would not be located within the fragment zone.

Issue 8

Methods of communicating were not effective in ensuring all personnel supporting testing were aware of operational practices.

Cause 5 (contributing): Content included in the daily briefings was perceived as having a disproportionate focus on safety as compared to what went well the previous day and discussion regarding the test objectives for the day.

Cause 6 (contributing): Attendance of the daily briefing in its entirety was not mandatory.

9(b). Operating Conditions of Facility at Time of Event:

The activities associated with the Block VIII test are normal operations within the approved explosives site located on Kirtland Airforce base. Activities supporting the tests were conducted both outdoors on explosives ranges and within mobile equipment and essential personnel Conex type structures. The week of the test there was heavy rainfall creating areas with significant pooled water.

9(c). Immediate Actions:

1. Senior manager requested calculations following discussion with site manager regarding the projectile path and its proximity to control box.

   T. Michael Skaggs July 26, 2018

2. Calculations regarding the probability of a projectile impacting the top of the FCP were completed.

   Robert Miner July 26, 2018

3. FCP sent for modifications to add armored reinforcements to the top and sides.

   David Veitch July 30, 2018

9(d). Extent of Condition Review:

Conditions related to the issues and causes identified in the causal analysis report for NA-SS-SNL-6000-2018-0003 "Electrical Shock at Thunder Range" were similar to causes identified by this causal analysis. The implementation of actions for the electrical shock event, which occurred in June of 2018, are not yet complete but would have likely prevented this management concern. For that reason, several of the actions associated with this concern are directly tied to the corrective actions identified from the electrical event.

10. Cause Analysis

10(a). Date Critique meeting was performed: **9/05/18**

10(b). Personnel Interviewed, and Documents Reviewed:

Personnel Interviewed:

Rudolfo Navarro	Lead Explosives Operator	Date of inquiry 9/13/18
Lorenzo Villareal	Industrial Hygienist	Date of inquiry 9/13/18
LANL Support Personnel		Date of interview 9/17/18

- Allan Novak,
- Brian Glover,
- Jake
- Phillip Rae

Documents Reviewed:

- DOE STD-1212-2012 Explosives Safety
- MN4710022 ES&H Manual Chapter "Physical hazards: Noise, Nonionizing Radiation, Thermal Stress"
- MN471001 "Explosives Safety Manual"
- Explosives Site Plan
- Block VIII Shot 3 Hazards Arc Map
- Block VIII Shot 3 Projected Distances
- Block VIII Shot 3 OUO Presentation Dated 7/26/2018
- Block VIII Distance Calculations
- Block VIII Shot Plan

- Block VIII Test Plan
- Minimum Safe Distance Data Excel Workbook
- Block VIII heat flux calculations and distance chart
- Exposure Assessment Survey Report SNLNM10702 Dated June 4, 2018
- Causal Analysis Report for NA-SS-SNL-6000-2018-0003 Electrical Shock at Thunder Range
- Thunder Range Expectations Memo Dated August 24, 2018

10(c). Corrective Action Development and Documentation:

Table 1: Corrective Action Plan for NA-SS-SNL-6000-2018-0004

Note: Greyed out boxes are actions developed during the electrical shock event causal analysis.

Fact(s)	Issue	(C#) Cause and Cause Code	(CM#) Compensatory Measure Action	Action Owner – Due Date	(LT#) Long Term Corrective Action	Action Owner – Due Date
1. According to IH Surveys and calculations, to reduce impact noise to 140dB at .03 psi a K635 distance was needed (unmitigated). 2. The viewing box was placed within the K328 zone, as is common Thunder Range practice. 3. The front of the FCP was armored with ¼" steel layer, corrugated container skin, 2 layers of ¾" plywood, another ¼" steel layer on one side of the viewing box. 4. The placement was believed to be acceptable based on the other protections provided (shock tube and FCP frontal armor) but not confirmed as adequate through calculations. 5. The FCP was placed behind an 18-ft diameter shock tube that has a 1-inch steel wall thickness. 6. IH assessment states that NRR 23 hearing protection is both adequate and required until further evaluation can be conducted when container is placed at a distance closer than K635. 7. LANL personnel were in the FCP.	1. Top portion of the FCP's northwest corner was not guarded by the shock tube.	1. Complete coverage of the FCP by the shock tube was not verified before the test series was started. **A2B3C02 – Inspection / testing LTA**			**CA 1**- Prior to use in testing, execute a series of tests to determine the protection provided by the modified FCP structure for both decibel and pressure reduction for a series of pre-established distances.	David Veitch 4/1/19
					CA2- Develop a procedure, based on the data from CA 1, for determining structure placement during the execution of tests.	David Veitch 5/1/19
					LT2.1: From Electrical Event Incorporate changes to clearly identify what is intended on each step in the Department 6647 standard explosive operating procedures and associated checklists.	David Veitch 12/21/18
					LT2.3: From Electrical Event Develop a controlled document which includes the Thunder Range expectations for writing, reviewing, approving, using, and routinely reviewing procedures.	David Veitch 12/21/18
	2. Controls related to hearing protection were not adequately implemented.	2. The use of required hearing protection was not enforced. **A4B1C01** – Management policy guidance / expectations not well-defined, understood or enforced	**CA 3-** Update OP, pre-job brief (PJB), and test plan templates to clearly state the requirement to wear hearing protection.	David Veitch 10/15/18	See CA1 and 2 (above) and LT1.1 (Below)	
	4. Technical requirements for determining essential personnel to allow within the zone were not formally described.	3. Reliance on experience in lieu of conducting calculations to determine adequacy of protections. **A5B2C08** – Incomplete / situation not covered	**CM1.1 from Electrical Event**: Draft and issue a memo of expectations/requirements including at a minimum the roles and responsibility for the team members, expectations for conduct of operations and utilizations of checklists.	David Veitch 8/24/18	**LT1.1 From Electrical Event**: Review and rewrite the OP-6647-001, including roles and responsibility definition, expectations for conduct of operations and utilizations of checklists, and implementation of improvements in the checklists while maintaining compliance with the ESM and Corporate policies. See also CA1 and 2	David Veitch 10/15/18

Causal Analysis Report for Thunder Range, Block VIII Test - Management Concern

Fact(s)	Issue	(C#) Cause and Cause Code	(CM#) Compensatory Measure Action	Action Owner – Due Date	(LT#) Long Term Corrective Action	Action Owner – Due Date
3. The front of the viewing box was armored with ¼" steel layer, corrugated container skin, 2 layers of ¾" plywood, another ¼" steel layer on one side of the viewing box. 8. 7. The FCP did not have additional armor on ends, top, or back side.	5. Calculations to understand the protection provided by the structure were not performed pre-test.	See cause 3			**LT1.2 From Electrical Event**: Develop and implement the training program on the new OP from LT1.1.	David Veitch 11/15/18
					LT1.3 From Electrical Event: Train the Thunder Range team on the new procedures.	David Veitch 11/15/18
					LT2.2 From Electrical Event: Using a cross-organizational team of explosive operators identify the best approaches to writing and developing operational procedures and document in a controlled and approved document. See also LT2.1 and LT 2.3	T. Mike Skaggs 12/1/18
	6. The consequences related to the hazardous effects of shock or fragment impact to areas of the FCP without additional armor was not evaluated before the test occurred.	4. An impact of fragment or shock to unarmored portion of the structure was not evaluated in the failure modes analysis (FMA). **A5B2C08** – Incomplete / situation not covered	**CA 4-** Clearly define "most likely credible events" in the FMA process and address them. Additionally, capture which scenarios that were discussed but deemed not credible and rationale why.	Christopher Hall 10/31/18	See CA1 and 2	
9. Testing was accomplished over a 4-day period and the beginning of each day started with a review of the previous day's activity as well as general discussion concerning the tests for that day. 10. Site operational safety and flow down of requirements to non-Sandia personnel is the responsibility of site management. Post-shot discussion revealed that LANL personnel involved in the tests had the following concerns: • A formal means of providing personnel accountability of location seemed to be lacking • The absence of either a fixed bunker or other structure such as a Hesco House	8. Methods of communication, including management review of readiness, daily safety briefings, and daily test discussions, were not effective in making all personnel aware of operational practices.	5. Content included in the daily briefings was perceived as having a disproportionate focus on safety as compared to what went well the previous day and discussion regarding the test objectives for the day. **A3B3C01** – Attention was given to wrong issues	**CA5-** Update PJB and related documents to include a section that outlines the hazards, the controls, and clearly communicates our expectations and mechanisms for voicing concerns.	David Veitch 12/19/18		
		6. Attendance of the daily briefing in its entirety was not mandatory. **A4B1C02** – Job performance standards not adequately defined	**CA 6**- Develop a process to provide positive verification of attendance at the daily safety meeting for all essential personnel.	David Veitch 12/19/2018		

Causal Analysis Report for Thunder Range, Block VIII Test - Management Concern

Fact(s)	Issue	(C#) Cause and Cause Code	(CM#) Compensatory Measure Action	Action Owner – Due Date	(LT#) Long Term Corrective Action	Action Owner – Due Date
• The directionality of fragments seemed to be random. • Audible sirens were replaced by hand-held radios. • The FCP was located within the fragment zone. 11. Management review to evaluate readiness for test series was conducted the week before the test.						

11. Supporting Documentation:

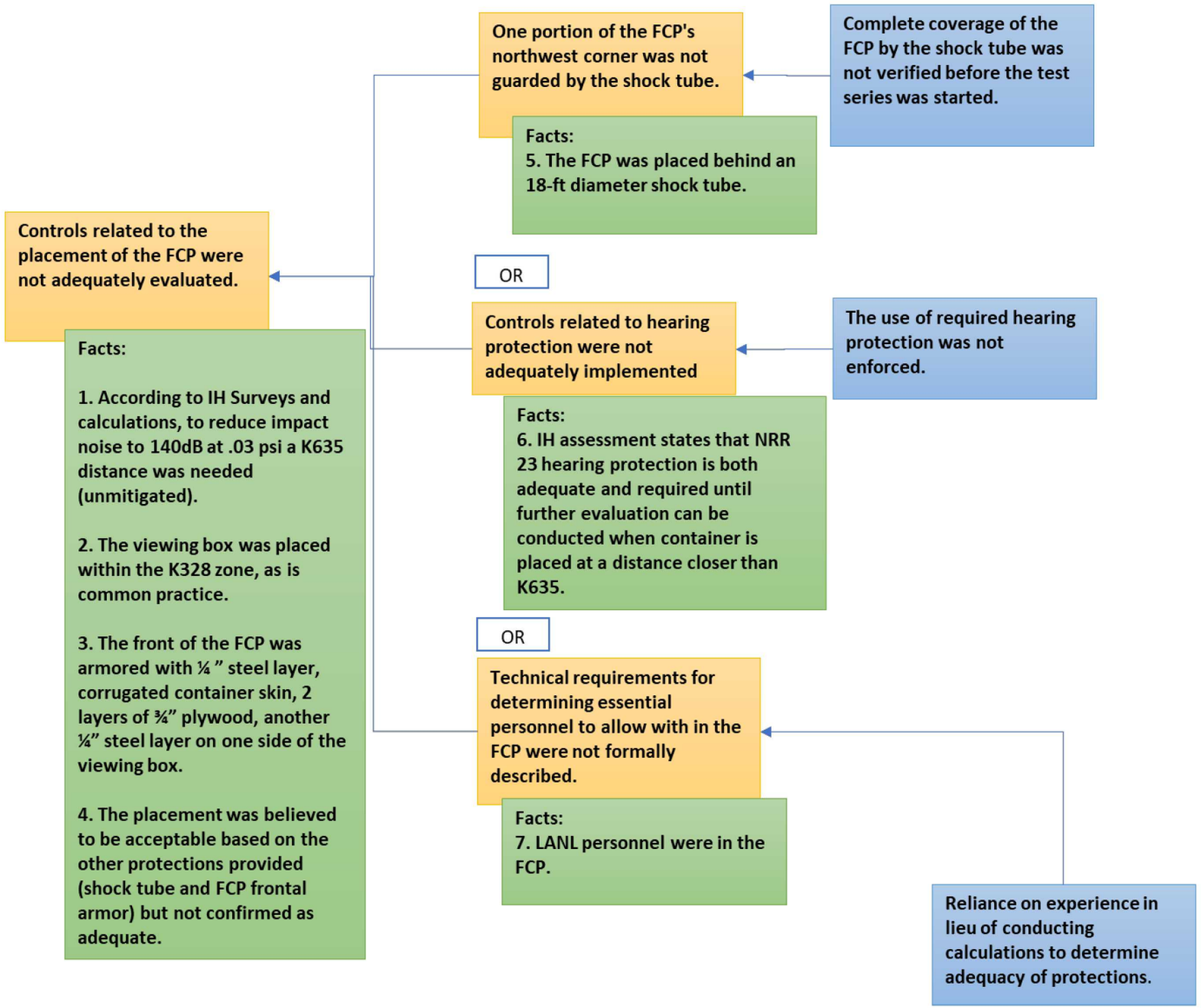

Figure 1- Partial Cause Map- Top Branch

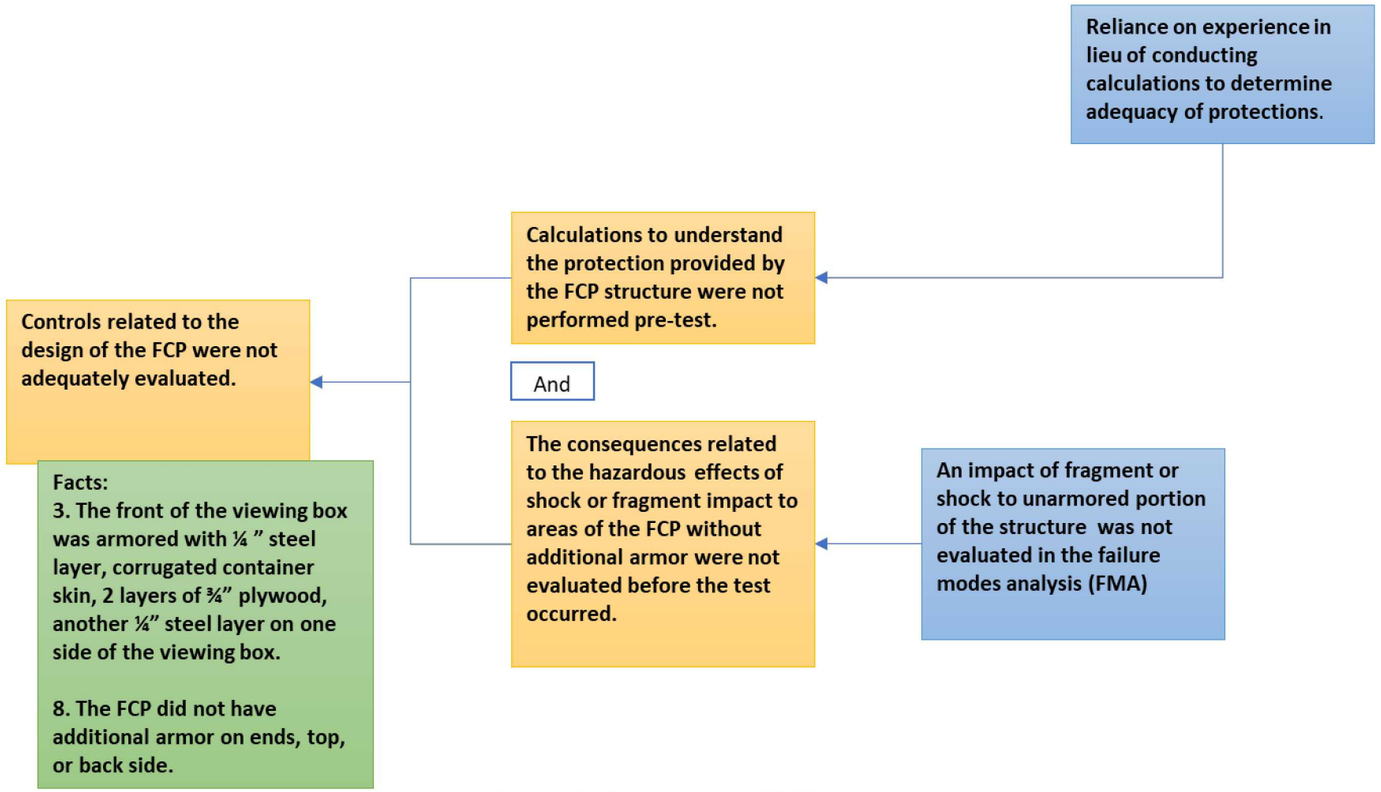

Figure 2- Partial Cause Map- Middle Branch

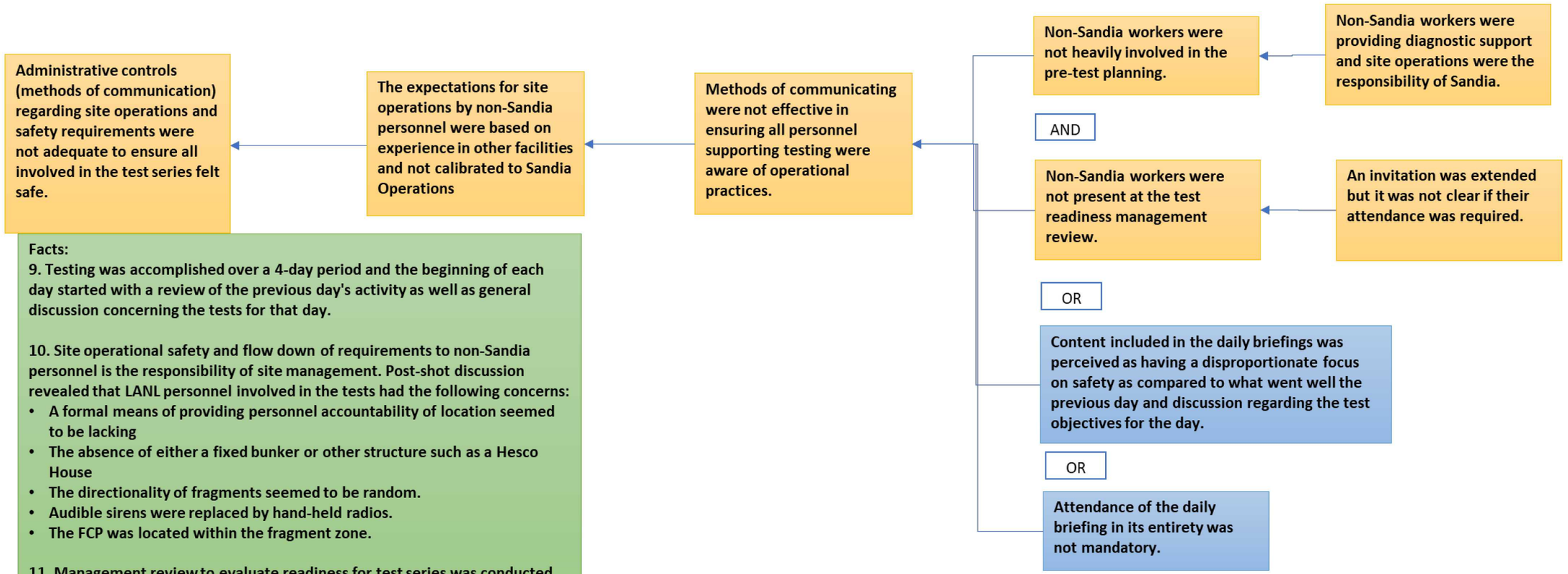

Figure 3- Partial Cause Map- Bottom Branch

Causal Analysis Report for Thunder Range, Block VIII Test - Management Concern

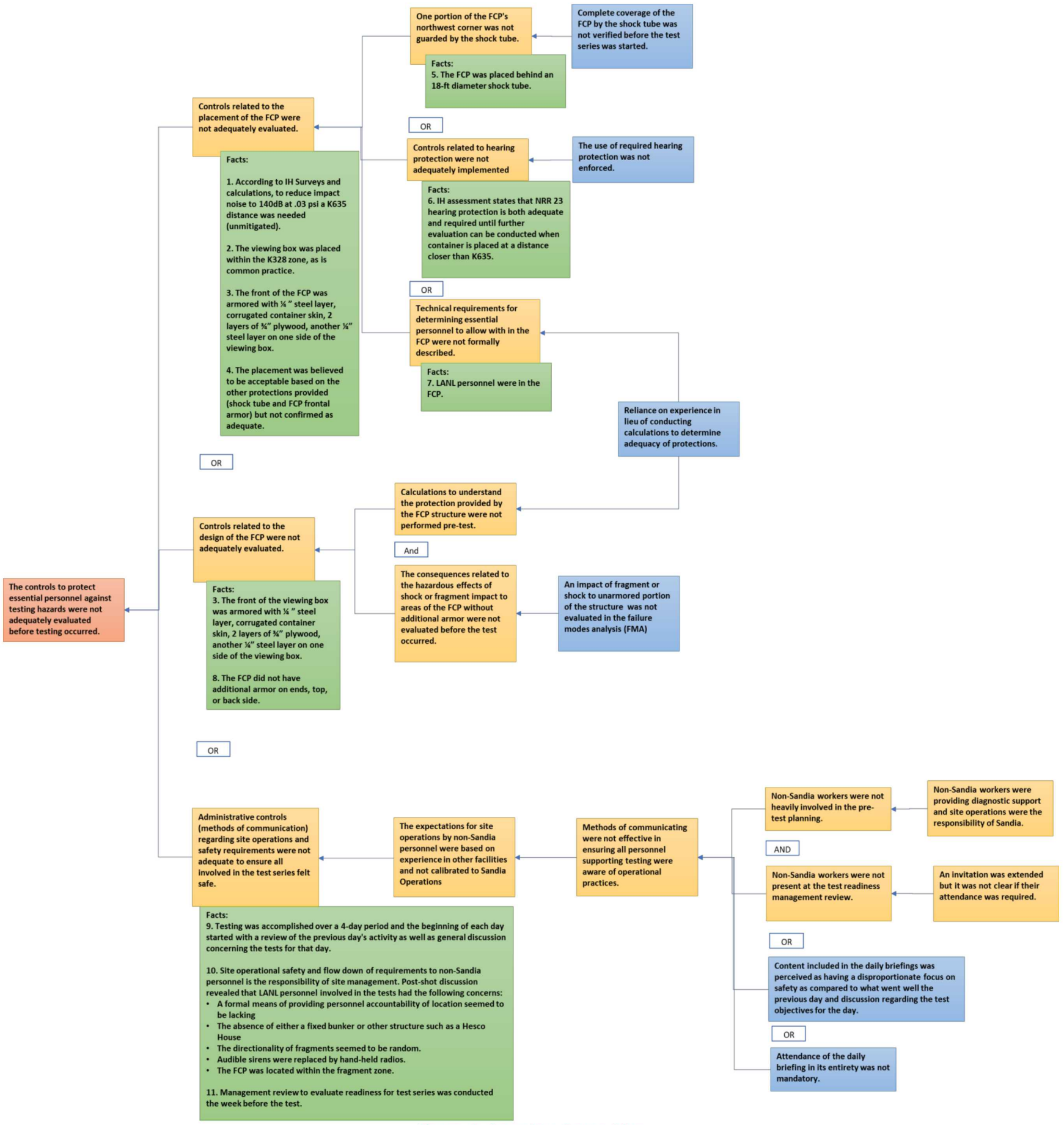

Figure 4- Complete Cause Map

Table 2: Corrective Action Verification and Validation Plan

Corrective Action (CM# or LT#)	Required evidence of completion (Verification)	Required evidence of effectiveness (Validation)
The validation activities associated with the Thunder Range Electrical Shock Event will be used to validate the effectiveness of actions linked to this management concern, but developed for that event.		
CA 1- Prior to use in testing, execute a series of tests to determine the protection provided by the modified FCP structure for both decibel and pressure reduction for a series of pre-established distances.	Test report that documents the decibel and pressure reduction for each distance tested.	Validation assessment will review the placement of the FCP for several tests to evaluate if the placement met the requirements outlined in the approved procedure.
CA2- Develop a procedure, based on the data from CA 1, for determining structure placement during the execution of tests.	Documented and approved procedure (or procedural steps added to an existing procedure) which provides direction for selecting placement of the FCP.	
CA 4- Clearly define "most likely credible events" in the FMA process and address them. This should help generate conversation about which hazards are primary and capture which were discussed but deemed not credible and why.	Approved revision of the FMA which includes evaluation of deficiencies identified in this management concern as well as justifications for additional scenarios that were further evaluation was deemed unnecessary.	Validation assessment will review the FMA revisions for several tests to evaluate if additional scenarios are evaluated based on lessons learned prom previous tests and that justifications for no further evaluation continue to be documented.
CA5- Update PJB and related documents to include a section that outlines the hazards, the controls, and clearly communicates our expectations and mechanisms for voicing concerns.	Documented pre-job briefing which includes test specific information for hazards and hazard controls as well as standard expectations for voicing concerns and the mechanisms available to do so.	Validation will review briefing content and positive attendance verification for several tests to evaluate if test specific safety information was covered and all essential personnel were in attendance.
CA6- Develop a process to provide positive verification of essential personnel attendance at the daily safety meeting.	Documented and approved process (or procedural steps added to an existing procedure) which describes how positive verification of essential personnel attendance at the daily safety briefing will be achieved.	

12. Causal Analysis Team:

Role	Org
Responsible Manager (RM)	6640
Range Department Manager	6647
Principle Investigator for Block VIII Test Series	6647
Work Planner and ES&H Coordinator	6142
Sandia Explosives Subject Matter Expert	0622
Sandia Explosives Subject Matter Expert	0622
Occurrence Management	0635
ES&H Performance Assurance Manager	0635
Safeguards and Security Regulatory Support	9114
Los Alamos Division Leader Explosive Science and Shock Physics	LANL
Los Alamos Deputy Division Leader Explosive Science and Shock Physics	LANL
Los Alamos Explosives Safety Subject Matter Expert	LANL
Los Alamos NA Program	LANL
Sandia Field Office Manager	SFO
Sandia Field Office	SFO
Sandia Field Office	SFO
Sandia NA Program	NA-513

13. RM Approval:

Responsible Manager: T Michael Skaggs 7/28/18 **(Sign and Date)**

Name of RM: T. Michael Skaggs **Organization: 06640**