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Table of Contents

ABSTRACT.....	1
1.0 Overview.....	2
2.0 Meteorological Conditions Leading Up to the Las Conchas Fire.....	4
3.0 Nuclear Facility Structural Information.....	6
3.1 Roofing Fire Ratings.....	6
3.2 Roofs.....	6
3.3 Exterior Wall Construction.....	7
3.4 Area G.....	7
4.0 LANL Fire Protection and Emergency Operations Programs	10
5.0 Summary	12
6.0 References.....	14

ABSTRACT

As a result of the Las Conchas Fire, the Department of Energy in correspondence SO:32CK-372899 (DOE 2011) requested that LANS take the following action:

Evaluate the Las Conchas fire experience and other data on airborne projection of burning embers and the appropriate planning and controls for Los Alamos National Laboratory (LANL) facilities, including nuclear and high hazard facilities.

This paper addresses the DOE action by evaluating 1) the meteorology at the time of the accident and implications for new wild land fires; 2) the ability of LANL facilities to withstand fires as a result of burning embers, and 3) LANL programs in place to mitigate the effects of wild land fires.

The spread of fire as a result of burning embers is a known and important mechanism. Both empirical and computational studies have been performed, and it is recognized that these studies should continue (Kim 2009, Koo 2010, Sardoy 2007). Due to the locale and environs of LANL, burning brands or embers from forest fires are a credible risk at LANL. With the exception of the Area G TRU Waste Facility, LANL nuclear facilities have fire resistant exteriors with UL Class A roofs. Waste at Area G is stored in fire resistant containers. The laboratory has comprehensive Emergency Operations and Fire Protection Programs, which includes assessing wildland fire risk and mitigating the spread of fires, for example, by maintaining fire breaks and additional defensible buffer areas free of combustibles around LANL facilities and limits on combustible loading. Vegetation is cut-back to at least national consensus standards on a regular basis around nuclear facilities. Fire Department services are provided by Los Alamos County through an agreement with the Department of Energy. The interface between the Fire Department and LANL during emergencies is the Emergency Operations Division.

The ability of LANL facilities to withstand a wildland fire was tested by both the Cerro Grande fire in 2000 as well as the Las Conchas fire. No nuclear or high-hazard facilities were damaged even though the Cerro Grande fire burned around a number of the facilities. Since then, the laboratory has strengthened programs to protect against wildland fires.

1.0 Overview

Airborne transport of burning brands from wildland fires to LANL facilities, including nuclear and high hazard facilities, is a credible threat. This is substantiated by an evaluation of the meteorological conditions that preceded the Las Conchas Fire. Because LANL nuclear facilities are located in cleared areas, typically surrounded by pavement or gravel, direct propagation of flames to facilities is not likely. Secondary fires started by burning brands constitute a significant wildland fire risk to LANL facilities. Burning brands (Koo 2010) from large wildfires such as the Las Conchas fire can be transported up to several miles ahead of the main fire front igniting spot fires. Transport distances from smaller fires are more limited but still present a credible threat to a number of LANL facilities.

Because of successful firefighting efforts, and favorable wind direction, the Las Conchas fire did not get close enough to present a severe challenge to LANL facilities. The 2000 Cerro Grande fire did present a severe challenge to a number of laboratory facilities, burning around a large number of them, Figure 1 (LANL 2000). Many laboratory facilities were in close enough proximity to fires to expose these facilities to flames and brands. However, the 2000 Site-Wide Environmental Impact Statement (SWEIS) Yearbook (LANL 2000) gives the following summary.

Although the Cerro Grande fire burned more than 7500 acres of Laboratory land, and although the burned area contained many of the Laboratory's important facilities, no major buildings were significantly damaged, and no facilities with a nuclear hazard classification (DOE Order 5480.23) were affected. (LANL 2000)

Damage from this wildland fire was minimized largely because of LANL facility requirements, fire department response efforts, preparations performed as part of the LANL Fire Protection Program (FPP), and the LANL Emergency Operations programs. Even prior to the Cerro Grande fire, LANL had performed a significant amount of fuels mitigation.

Fire resistant building construction makes it unlikely that burning brands or small secondary fires can significantly damage a facility. LANL nuclear facilities with the exception of TA-54 Area G, all have roof coverings designed to meet Underwriters Laboratory Class A standards. Class A roof coverings are effective against severe fire test exposures (UL 2008 and ASTM 2010). Exterior walls and doors were designed and built to building codes in place at the time of design. Most LANL nuclear facilities have concrete exterior walls. The facilities without concrete walls have other types of fire resistant exteriors. Roof and exterior wall construction for LANL nuclear facilities will be discussed in Section 3.0. The LANL TRU Waste Facility (Area G) will also be discussed further.

The precepts of the LANL FPP (LANL 2011) provide protection of LANL facilities from fire related threats. The FPP is supplemented by the FPP Manual, which addresses all aspects of fire protection including wild land fires (LANL 2011a). Preventive components of the FPP dealing with wildland fires include utilizing fire danger assessment methods from the National Weather Service. LANL procedures control operations involving outdoor spark or flame producing operations including shutting these operations down depending on the Fire Danger Matrix. The Emergency Operations Division Wildland Fire Management Plan describes the performance of regular wildland fire risk assessments with subsequent Hazard Mitigation Plans. These plans

may include measures such as: establishment and maintenance of adequate defensible space around structures by thinning, clearing, and controlling vegetation around facilities; maintaining good housekeeping practices around structures; controlling outdoor man-made ignition sources; and taking additional measures in areas of higher risk mitigate damage from wildland fires

The County of Los Alamos provides fire department services to the Laboratory through a Cooperative Agreement managed by the National Nuclear Security Administration (NNSA) Los Alamos Field Office (FO). A Joint Powers Agreement allows the various governmental stakeholders (tribal, state, and federal) to cooperate on mitigation and suppression efforts on the various lands impacted by wildland fire. The LANL Fire Protection Division works closely with the Fire Department. The LANL Emergency Operations Division becomes the interface between the Laboratory and the county fire department (LANL 2011b) during emergencies.

Figure 1. Map of LANL Showing 2000 Cerro Grande Fire Extent on Laboratory Property (Ref. 1)

2.0 Meteorological Conditions Leading Up to the Las Conchas Fire

During a La Nina weather pattern, New Mexico typically receives less than average precipitation during the winter and spring (NOAA). This is caused by the jet stream and storm track being shifted poleward, leaving New Mexico under the influence of a stronger than normal high pressure system. The weather in Los Alamos fit this pattern during the winter of 2010-2011 and the spring of 2011. Los Alamos received only 33% of normal snowfall during the winter of 2010-2011 (19 inches versus 58 inches average). Dry weather continued during the spring; at the end of June, Los Alamos had received less than half of the precipitation recorded during the first 6 months of the driest year on record (Figure 2).

Figure 2. Cumulative Rainfall In Los Alamos For The Ten Driest Years On Record

The Laboratory measures the 10-hour fuel moistures at the TA-6 meteorological tower to provide one measure of fire potential. Ten-hour fuel moistures refer to the moisture contained in dead twigs and branches, between $\frac{1}{4}$ and 1 inch in diameter. These fuels, along with 1-hour fuels, or fuels that are less than $\frac{1}{4}$ inch in diameter, are important for the potential for fires to spread. The “10-hour” of the measurement refers to the amount of time that a fuel (or the dowel in this case) to reach $\frac{2}{3}$'s of the moisture equilibrium with its local environment. The measurement is made using a $\frac{1}{2}$ inch diameter 20-inch long ponderosa-pine dowel fabricated to US Forest Service specifications (Campbell). The electronic resistivity of the dowel changes with moisture content. The measurement of the change in resistivity is converted to percent moisture by weight (1%=1 g).

Weekly average 10-hour fuel moisture (Figure 3) typically range between 10% and 15%. In January 2011, 10-hour fuel moisture began to fall as winter snow and spring rains did not materialize. At the beginning of June, average weekly 10-hour fuel moisture fell below 5%.

Single 15 minute measurements of 10-hour fuel moisture reached 2-3% on June 19th and remained at these low levels until late July when monsoon rains began.

Figure 3. Weekly Average 10-Hour Fuel Moisture

In addition to very dry conditions in Los Alamos, the typical windy spring season (March, April, and May) lasted through the entire month of June. Figure 4 compares the 20 year long term average wind speeds at TA-6 level 1 and 3 (12 and 46 m height) with the daily average wind speeds recorded during June 2011. The average wind speeds in June 2011 at 12 and 46 m were 28 % and 21% higher, respectively than the long term average values. These winds contributed to the massive growth of the Las Conchas fire during its first days.

In summary, the meteorology precursors to the Las Conchas fire included record low precipitation during the winter and spring of 2011 and well above average wind speeds during June 2011.

Figure 4. TA-6 Daily Average Wind Speeds: For June 2011 and Long Term Average

3.0 Nuclear Facility Structural Information

This section applies to the nuclear facilities other than Area G, which is discussed below. Nuclear facilities at LANL were designed to building codes in place at the time of design. Because of differences in building classifications and codes it is difficult to generalize about the fire resistance of these facilities. Most LANL nuclear facilities have concrete exterior walls conferring a high degree of fire resistance. The facilities without concrete exterior walls have other types of fire resistant exteriors. These facilities have Class A rated roof coverings which will provide protection against fire brands from a wildland fire. All of these facilities have either noncombustible steel or concrete roof decking under the roof coverings.

Current LANL standards require that all new buildings and upgrades to buildings meet fire-resistant building guidelines. The LANL Engineering Standards Manual, *Guidelines for Architectural Design* (LANL Eng Std), includes the following general guideline:

All new structures should follow Laboratory and reference guidelines for fire-resistant building design. Existing building should incorporate these design measures when upgraded and renovated.

3.1 Roofing Fire Ratings

Both Underwriters Laboratories Inc. and ASTM International publish standards for test methods for fire tests of roof coverings (UL 2008 and ASM 2010). The test methods are nearly the same. The class A roof classification is defined in UL 2008 as follows:

- *Class A roof coverings are effective against severe fire test exposures. Under such exposures, roof covering of this class afford a high degree of fire protection to the roof deck, do not slip from position, and are not expected to produce flying brands.*

The tests for these classes include intermittent-flame, spread-of-flame, burning-brand, and flying-brand tests. The burner for the intermittent-flame, spread-of-flame, and burning brand tests consists of a 44 in (1.12 m) length of nominal 2 in [2.38 in (60.3 mm) OD] pipe having a ½ in (12.7 mm) wide, 36 in (0.91 m) long slot in the side toward the test deck. The burner is supplied with gas at both ends to provide a uniform gas pressure at the burner assembly. The gas supply is regulated so that the flame develops a temperature of $760 \pm 28^{\circ}\text{C}$ ($1400 \pm 50^{\circ}\text{F}$) for Class A tests. For the spread-of-flame tests the exposure time is 10 min for class A tests.

3.2 Roofs

Roofs consist of a roof deck topped with multiple layers of roof covering materials. Roof coverings are tested as multilayer systems. The LANL Master Specification – Membrane Roofing General Provisions lists Underwriters Laboratories, Inc., Class A Fire Hazard Classification as a performance requirement (LANL Eng Std). All of the LANL nuclear facilities (except Area G structures) have either a steel or concrete roof deck. All of the LANL nuclear facilities have Class A rated roof coverings.

3.3 Exterior Wall Construction

The exterior walls of LANL nuclear facilities were constructed to building codes in place at the time of design. This makes it difficult to generalize about the fire resistance of facility exteriors. All LANL facilities have exteriors that are inherently fire resistant. The larger facilities all have concrete exteriors providing a high degree of fire resistance. Likely, the least fire resistant is the Waste Characterization Reduction and Repackaging Facility (WCRRF) which is a steel frame building with sandwich walls with foam insulation between pieces of gypsum board and plaster over the outside. This configuration is considered fire resistant. Table 1 gives exterior wall descriptions for LANL nuclear facilities as taken from safety basis documentation.

Table 1. Exterior Wall Descriptions for LANL Nuclear Facilities

Facility	Document	Exterior Wall Descriptions
WETF	WETF-FSAR, R0 (LANL 2010)	TA-16-205 and 205 addition – concrete masonry unit (CMU) (block) walls TA-16-450 – 12” wide shear walls (reinforced concrete)
CMR	CMR-OSA-001 Rev 0.1 (LANL 2010a)	Original structure - reinforced concrete walls Wing 9 addition – concrete frames with lightly reinforced concrete masonry in-fill walls
PF-4	TA55-DSA-2008 Rev 1.7 (LANL 2009)	14” thick reinforced concrete
RLWTF	Final Safety Analysis Report for Radioactive Liquid Waste Treatment Facility at TA-50-01 (LANL 1995)	Reinforced concrete and hollow concrete masonry block walls
WCCRF	ABD-WFM-005, R.2.1 (LANL 2011c)	The exterior walls are constructed of 6-in.-deep, 14-gauge structural steel studs supporting ½-in thick gypsum board sheathing and 2-in. rigid insulation with a stucco finish on the outside and 5/8-in. gypsum board sheathing on the inside.
RANT	ABD-WFM-007, Rev. 1.1 (LANL 2011d)	External facility walls are 14 in thick, load-bearing, and constructed of precast concrete panels with exterior insulation finish.

3.4 Area G

Area G is addressed separately from other nuclear facilities because most structures at Area G are fabric dome structures, and were not intended to be permanent structures. These dome structures do not have Class A roof construction or non-combustible concrete or similar walls.

Area G is located on a cleared mesa top with large areas occupied by buildings, asphalt pads and graveled roads. There are pinion/juniper woodlands on the sides of the mesa that could burn and shower Area G structures with hot brands. Because of the cleared nature of Area G, a wildland fire is a reduced threat to burn directly across the mesa; secondary fires ignited by sparks are credible. However, nuclear material is stored within non-flammable waste containers, either steel containers or ignition-resistant fiberglass-reinforced plywood boxes. Most of these waste items are located inside fabric dome structures. The fiberglass-reinforced plywood boxes are stored either in transportainers or in a dome with a fire suppression system. A small amount of waste in

approved metal containers is staged outside in the yard area between structures at Area G. Waste repackaging activities that are underway at Area G can occur in several existing Area G structures, and involve opening up some of these waste containers to sort, segregate, and size-reduce larger items. Some of the waste material in these containers is combustible, therefore this activity results in exposed combustible material (i.e., not in noncombustible storage containers). This activity is performed within a fire resistant PermaCon® structure with sprinkler protection, or within a contamination control structure within a building equipped with sprinkler protection. Waste repackaging activities would not occur during a wildland fire.

The waste containers (steel drums, fiberglass reinforced plywood boxes, steel-clad plywood boxes, steel boxes) are designed and tested to survive moderate fire insults without failing. Waste drums have been subjected to a number of fire tests (WHC 1995 and WHC 1996). The most pertinent of these tests relative to a wildland fire was a test where 85 lbs of simulated waste was spread between two rows of instrumented drums and burned. Figure 5 from WHC 1995 shows the layout of this test. The simulated waste consisted of paper products, plastic, rubber, and cotton materials ignited with a flammable liquid. Drums 1 and 4 were instrumented. The heat flux on these drums was about 25 kW/m^2 , which is well below the 45 kW/m^2 minimum heat flux needed to cause lid failure. Both drums 1 and 4 did vent through the lid seals. Fiber reinforced boxes have also been tested (INEL 1979). In testing with flames from a pool fire impinging on the edges and lower corners it took about 40 min of direct flame impingement to produce sustained combustion.

Figure 5. Layout of trash fire exposure setup from Rhodes, et al.

The Area G storage domes have coated fire-resistant canvas exteriors. The Fire Hazards Analysis for Technical Area 54, Area G (LANL 2010b) gives the following information on the dome fabric.

Fabric used to cover the domes was tested under NFPA 701 and found to be fire resistant (ref. UST, 1991 [UST 1991]) during its recommended life. Flame Spread Index of no more than 25, Smoke Developed Index of no more than 450: Class A Interior Finish per NFPA 101 and NFPA 255. The fabric is conservatively considered to be combustible, reference Occurrence Report NALASO-LANL-WASTEMGT-2006-0005, but the amount of fabric used (18 ounces per square yard) is limited. When the dome fabric is new, it exhibits low flame spread. The fabric has aged considerably since original installation, so its originally documented fire performance is somewhat suspect. However, it is canvas-type material and so is not expected to drip flaming material onto storage below. Additionally, the presence of the steel structure, multiple attachment points on the steel structure, and the tension of the fabric on the outside of the structure mean that a breach of the fabric due to fire would not result in a significant quantity of the fabric dropping on storage below - the steel structure would hold the remaining fabric in place - therefore the fabric is not expected to significantly contribute to the building's combustible loading, nor is it expected to provide a propagation path for fire within the dome.

Figure 6 (LANL 2011e) shows the south-east corner of Area G. Defensible space exists between the domes and the surrounding pinion/juniper forest. The trees have been thinned to a relatively sparse state, with a clear area of approximately 50 feet between the trees and the domes.

Figure 6. Photo of South-East Corner of Area G Showing Domes and Surrounding Vegetation

4.0 LANL Fire Protection and Emergency Operations Programs

From the Fire Protection Program Description, PD1220 (LANL 2011): *The objectives of the LANL FPP are to minimize the potential for*

- *the occurrence of a fire or related event;*
- *injury or loss of life from fire or related event;*
- *fires that cause an unacceptable on-site or off-site release of hazardous or radiological material that could impact the safety and health of employees, the public, or the environment;*
- *unacceptable interruption of a Department of Energy (DOE) and/or National Nuclear Security Administration (NNSA) designated “vital” program or loss of a LANL-designated “mission critical” program or activity as a result of a fire or related event;*
- *property loss from a fire or related event exceeding the defined limits established by LANL, and*
- *fire damage to critical process safety controls and Safety Class (SC) Structures, Systems, and Components (SSCs) as established by safety analyses.*

The laboratory undertook a major initiative to reduce wild land fuels beginning in 2008. This was done due to increasing fire dangers that have been present in the past several years. The mitigation created fire breaks at the perimeter of the DOE owned property with additional buffer areas within the perimeter at strategic locations. This mitigation is intended to prevent a fire outside of the LANL boundaries from propagating onto DOE owned property, and for preventing a fire within the LANL boundaries from propagating outside of DOE owned property. The breaks also prevent a fire originating within the LANL boundaries from spreading to other laboratory areas. To date a total of 1806 acres have been treated with further work to be conducted through FY13 and beyond, Figure 7.

The FPP is administered by the LANL Fire Protection Division. The complete list of responsibilities is included in PD1220. This includes programmatic, management and implementation responsibilities. The link between Fire Protection and facilities flows through the Facility Operations Directors (FODs). One of the responsibilities from PD1220, as implemented through Emergency Operations on a regular basis, which is most pertinent to wildland fire protection, is to:

Provide and maintain required defensible space surrounding buildings, structures, and facilities to minimize the threat of wildland fire exposure, and to allow the safe execution of outdoor experimental activities such as explosives testing, hydrodynamic shots, etc.

Figure 7. Map showing areas of fire mitigation areas.

The FPP Manual (LANL 2011a) consists of approximately 80 sections and is available from the Fire Protection Division website (FP website). The wildland fire module is the most relevant to the issue at hand, though other modules also contain pertinent material. Introductory material from the wildland fire module includes the following statement:

Due to the Laboratory's geographical location bounded by canyons, wild lands and forests, the single largest threat to life and property is wild land fire. This has been the cause of the only major fire loss in the Laboratory's history. LANL therefore takes measures to reduce the risk of starting wildland fires and to mitigate damage from wildland fire should one occur.

The Laboratory addresses the risk of starting wildland fires through the use of the Fire Danger Matrix and the concurrent Fire Danger Rating (displayed on the laboratory home page) and through procedures for controlling spark- or flame-producing operations. Damage from wildland fires is mitigated by performing regular wildland fire risk

assessments, establishing clear structure ignition zones and/or defensible space, and taking additional measures in areas of higher risk.

As part of the FPP, the Fire Protection Division also performs Fire Hazard Analyses (FHAs) for nuclear and high hazard laboratory facilities. For facilities at risk of wildfire, these FHAs include a Wildfire Hazard Analysis typically based on NFPA 1144, *Standard for Reducing Structure Ignition Hazards from Wild land Fire* (NFPA 2008) or the techniques contained within the *International Wildland-Urban Interface Code*.

Facilities are expected to maintain a minimum 30 ft defensible (cleared of combustibles) space around buildings. Additional mitigation has been performed where needed in “Structural Ignition Zones” of up to 200 ft from facilities.

Through the Wildland Fire Management Plan and ISSM, LANL activities are controlled through regular risk assessment and evaluation of hazardous operational activities which could ignite a fire. The Fire Danger Rating (low through extreme and red flag) is one axis of the Fire Danger Matrix. The Fire Danger Matrix prohibits certain types of outdoor activities under Red Flag conditions and sets conditions for outdoor activities that become more restrictive with increasing fire danger. The Fire Protection Division also reviews and can restrict spark or flame producing outdoor operations upon issuance of wildland fire restrictions.

A February 24, 2003, memorandum from the Secretary of Energy to the Under Secretary for Energy directed all sites subject to wildland fires to develop wildland fire management plans consistent with the *Review and Update of the 1995 Federal Wildland Fire Management Policy* from the National Interagency Fire Center. This policy emphasizes the need for wildfire management plans to support existing land and resource management plans, hence the LANL Wildland Fire Management Plan.

5.0 Summary

Burning brands from forest fires are a credible risk at LANL. With the exception of the TRU Waste Facility (Area G), LANL nuclear facilities have fire resistant exteriors with UL Class A roofs. Waste at Area G is stored in fire resistant containers. The laboratory has comprehensive programs through the Fire Protection and Emergency Operations divisions to assess wildland fire risk and to mitigate fuels. The Wildland Fire Management Plan is implemented through the Emergency Operations Division. Vegetation is cut-back to at least national consensus standards on a regular basis around nuclear facilities. Fire Department services are provided by Los Alamos County through an agreement with the Department of Energy. The interface between the Fire Department and LANL during emergencies is the Emergency Operations Division.

The ability of LANL facilities to withstand a wildland fire was tested by both the Cerro Grande fire in 2000 as well as the Las Conchas fire. No nuclear or high-hazard facilities were damaged even though the Cerro Grande fire burned around a number of the facilities. Since then, the Laboratory has strengthened programs to protect against wildland fires.

The LANL Wildland Fire Management Plan describes the program to manage risk associated with wildland fires. In addition to the Cerro Grande and Las Conchas fires, the La Mesa Fire

(1977), Dome Fire (1996), and the Oso Fire (1998) clearly demonstrate that forests on and surrounding Los Alamos National Laboratory (LANL) are susceptible to destructive crown fires. In addition to the general public and local residents, there are over 12,000 people employed at LANL whose safety could be at risk in the event of a wildfire. The replacement value of facilities and infrastructure at LANL is estimated at 6.5 billion dollars. In addition to the threat to lives and property, wildfires could cause the release of radiological or other hazardous materials from LANL operations and facilities. They also pose a significant risk to cultural and natural resources. The combined goals of Fire Protection Division, Emergency Operations Division, and the LANL Wildland Fire Management Plan address these threats. In particular, the LANL Wildland Fire Management Plan responds directly to requirements set forth in the Los Alamos National Security, LLC Contract Appendix G and Department of Energy (DOE)/National Nuclear Security Administration (NNSA) policy regarding wildland fire management.

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