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memorandum

Earth and Environmental Sciences Division

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Evaluation of potential seismic hazards from surface-rupturing faults at Building 185, Technical Area 55, Los Alamos National Laboratory

This memorandum summarizes geologic investigations at and around Technical Area 55 (TA-55) of the Los Alamos National Laboratory (LANL) in Los Alamos County, New Mexico.

Standards and compliance for permitting of Building 185 fall under the auspices of the Resource Conservation and Recovery Act (RCRA). Seismic considerations for RCRA-permitted facility location standards are presented in the Code of Federal Regulations, Title 40 (40 CFR) Part 270.

40 CFR 270, 14(b)(11) states:

> If the facility is proposed to be located in an area listed in Appendix VI of Part 264 [e.g., Los Alamos County], the owner or operator shall demonstrate compliance with the seismic standard. This demonstration may be made using either published geologic data or data obtained from field investigations carried out by the applicant. The information provided must be of such quality to be acceptable to geologists experienced in identifying and evaluating seismic activity. The information submitted must show that either:
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> (A) No faults which have had displacement in Holocene time are present, or no lineations which suggest the presence of a fault (which have displacement in Holocene time) within 3,000 feet of a facility are present, based on data from:
> (*1*) Published geologic studies,
> (*2*) Aerial reconnaissance of the area within a five-mile radius from the facility,
> (*3*) An analysis of aerial photographs covering a 3,000 foot [0.59 mile] radius of the facility, and
> (*4*) If needed to clarify the above data, a reconnaissance based on walking portions of the area within 3,000 feet [0.59 miles] of the facility,
> or
>
> (B) If faults (to include lineations) which have had displacement in Holocene time are present within 3,000 feet [0.59 miles] of a facility, no faults pass within 200 feet of the portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted, based on data from a comprehensive geologic analysis of the site. Unless a site analysis is otherwise conclusive concerning the absence of faults within 200 feet of such portions of the facility data shall be obtained from a subsurface exploration (trenching) of the area within a distance no less than 200 feet from portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted. Such trenching shall be performed in a direction that is perpendicular to known faults (which have had displacement in Holocene time) passing within 3,000 feet of the portions of the facility where treatment, storage, or disposal of hazardous waste will be conducted. Such

investigation shall document with supporting maps and other analyses, the location of faults found.

Through this document, we provide a summarization of published geologic studies completed in and around TA-55, with specific focus on one facility within the boundary of TA-55 (Building 185) for purposes of evaluating seismic hazards to this portion of LANL. Additionally, we present an analysis of aerial photography of the greater TA-55 area, and a detailed discussion of mapping efforts to determine the presence or absence of geologic faults at LANL with the potential for surface rupture (this includes an area of field reconnaissance greater than a five-mile radius of the proposed facility as mandated by RCRA standards). We begin the geologic discussions from a broad view of the Pajarito Plateau and will end by focusing on the specific area of interest, Building 185.

Full citations for references are included at the end of this memorandum. For non-LANL recipients of this memorandum, electronic copies of any cited internal LANL reports are included as a compact disc attachment to this document. Cited non-LANL reports are available via publicly-accessible professional journals or other refereed publications. Copies of unpublished consulting reports can be provided upon request.

Definitions

The following technical terms are used frequently throughout this document. Definitions are taken from The Dictionary of Geological Terms (Bates and Jackson, eds., 1984).

Holocene: an epoch of the Quaternary period, from the end of the Pleistocene, approximately 8 thousand years ago [*sic*; Ogg et al. (2008) have updated the beginning of the Holocene to 11,700 years ago] to the present time.

Lineament: a linear topographic feature of regional extent that is believed to reflect crustal structure. Examples are fault lines, aligned volcanoes, and straight stream courses.

Fracture: a crack, joint, fault, or other break in rocks.

Fault: a fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.

It should be noted that the definition of "lineament" does not imply that such an identified feature is actually a surficial manifestation of crustal structure with recent tectonic activity until the local geology is carefully considered. Additionally, unless otherwise clarified through reports or other means, the definition of "fault" does not imply a tectonic mechanism for genesis and/or growth. The definition also does not imply that each "fault" is independently seismogenic. Features defined as faults through geologic mapping must be considered in the context of the surrounding geology before their mechanism of formation is determined.

General Geologic Setting

TA-55 and Building 185 sit atop an unnamed mesa in the north-central part of LANL (Figure 1). The local bedrock is the Tshirege Member of the Bandelier Tuff, dated at 1.256 Ma (Phillips et al., 2007). The older member, or Otowi Member, of the Bandelier Tuff has been dated at 1.61 Ma (Izett and Obradovich, 1994). The Bandelier Tuff is sourced from nearby Valles caldera, located approximately 10 miles west of TA-55, Building 185. Several discrete subunits comprise the Tshirege Member of the Bandelier Tuff, and are variably interbedded with pyroclastic surge deposits. Commonly accepted stratigraphic nomenclature for the Bandelier Tuff is described in detail by Broxton and Reneau (1995). The subunits of the Tshirege Member and the nature of the contacts between Tshirege Member subunits provide the critical data to identify fault-generated displacements around the Pajarito Plateau. The Pajarito Plateau is bounded on its western edge by the Pajarito fault system, a 50-km-long system locally comprised of the down-to-the-east Pajarito fault (PF; the master fault) and the subsidiary, antithetic down-to-the-west Rendija Canyon (RCF), Guaje Mountain (GMF), and Sawyer Canyon (SCF) faults (Figure 1). This fault system forms the local active western margin of the Rio Grande rift near Los Alamos.

Before the completion of detailed geologic mapping in the northern portions of LANL, some previous studies had inferred the surface traces of the southern tips of the Rendija Canyon and Guaje Mountain faults to continue southward through TA-55 and TA-63, respectively (Dransfield and Gardner, 1985). Studies by Gardner et al. (1998, 1999), Lewis et al. (2002), Lavine et al. (2003), Lavine et al. (2005), Gardner et al. (2008), and Lewis et al. (2009) show through careful investigation of local geology and aerial reconnaissance of the entire LANL campus that while there is minor faulting in the greater TA-55 area, the surface trace of the Rendija Canyon fault bends southwesterly and splays into TA-3 instead of continuing directly through TA-55, and the surface expression of the Guaje Mountain fault is not visible south of Pueblo Canyon.

Published geologic studies of relevance to seismic hazards issues at TA-55

Several geologic investigations have taken place specifically at TA-55, given the sensitive nature of some facilities at that site and the significance of TA-55 operations to the LANL mission. This memorandum summarizes some key geologic studies in the TA-55 area in chronological order by publication date.

Reports

- Dames and Moore, 1972, Report of geologic, foundation, hydrologic and seismic investigation, Plutonium Processing Facility, Los Alamos Scientific Laboratory, Los Alamos, New Mexico [unpublished consulting report for the US Atomic Energy Commission]

The engineering firm Dames and Moore completed a detailed geologic study for the site of the then-planned Plutonium Facility at TA-55. The study included an evaluation of geologic features within a 200-mile radius of the site and a detailed investigation of the immediate site area. In geologic reconnaissance of the site, the report notes that the main Pajarito fault trace is located approximately 2.7 miles west of the site, no tectonic fracture system associated with faulting or volcanism passes through the immediate facility footprint, and a fracture zone trending 340° to 345° (N20W to N15W) was identified 1,000 ft to the east of the facility footprint. A trench 1,000 ft long, 3 ft wide, and 8 ft deep was excavated diagonally (WNW-ESE) across the site and noted that no evidence of tectonic faulting was found. The log for this trench, however, is inconclusive because no coherent stratigraphic markers could be carried across the trench.

- Dransfield and Gardner, 1985, Subsurface Geology of the Pajarito Plateau, Española Basin, New Mexico [report number LA-10455-MS]

This report provides a description of pre- and post-Bandelier Tuff geologic structure based upon findings from drill cores and geophysical surveys across the Pajarito Plateau. The authors note prominent aerial photographic lineaments projecting southward from Pueblo Canyon, and correlate these lineaments to subsurface projections of the Rendija Canyon and Guaje Mountain faults as far south as Water Canyon. The study attributes the lineaments to surficial manifestations of eroded fracture zones propagating upward from the subsurface trace of the faults. Both the Rendija Canyon and Guaje Mountain faults appear in seismic reflection transects south of their mapped surficial traces. A detailed surficial mapping campaign for the antithetic structures of the Pajarito fault system (Rendija Canyon and Guaje Mountain) had not yet been undertaken by the Laboratory.

- Reneau et al., 1995, Surficial Materials and Structure at Pajarito Mesa [from Reneau and Raymond, eds., report number LA-13089-MS]

A proposed mixed waste disposal facility at Pajarito Mesa prompted geologic surface mapping and exploratory trenching at TA-67. Previous studies had shown southern projections of the Rendija Canyon and Guaje Mountain faults through Pajarito Mesa. The geological mapping and trenching showed that faulting had affected Pajarito Mesa in the past, but the faulting is more complicated than previously inferred by Dransfield and Gardner (1985). Both down-to-the-east and down-to-the-west faulting is suggested at Pajarito Mesa. These small faults were identified through conventional geologic mapping and mesa-edge investigations. Their lateral continuity could not be constrained, so these small faults are identified on maps as point-locations of offset on the Bandelier Tuff Tshirege Member subunits (cf. Plate 1). A full paleoseismic history was not determined through trenching investigations, but it was found that faults did not affect geologic units younger than 50-60 ka. No increase in fracture density across the projections of the Rendija Canyon or Guaje Mountain faults was seen, and a detailed survey of pyroclastic surge beds showed no displacement of the Bandelier Tuff along the Rendija Canyon fault projection.

- Gardner et al., 1998, High-Precision Geologic Mapping to Evaluate the Potential for Seismic Surface Rupture at TA-55, Los Alamos National Laboratory [report number LA-13456-MS]

Because sensitive facilities at TA-55 lie south of the mapped trace of the Rendija Canyon fault, there was concern that the fault could pass through TA-55 if it were to continue surficially on its roughly north-south strike. This study used high-precision total station mapping of Bandelier Tuff Tshirege Member subunits to recognize vertical fault displacement so small that they would be overlooked and unmapped by conventional geologic mapping techniques. Similar to Reneau et al. (1995), point-locations of offset were identified on geologic maps, often because the fracture along which displacement of the Tshirege Member subunits occurred could not be traced vertically (into lower Tshirege subunits) or laterally (across mesas).

The study found that 1,500 ft west of the Plutonium Facility at TA-55, a single location was identified as having a 2-ft down-to-the-southeast offset of the unit 3–unit 4 contact (cf. Broxton and Reneau, 1995). Similar offset could not be found on the unit 2–unit 3 contact in Twomile Canyon in the same location, and the fault could not be traced laterally into and across Twomile Canyon. The high-precision geologic mapping also identified a small number of single-point location contact offsets at TA-48 and in Twomile Canyon, an increase in down-to-the-west faulting to the west of TA-48, and a zone of intense faulting at the Los Alamos County Landfill that merited further investigation to determine its relationship to the Rendija Canyon fault.

- Gardner et al., 1999, Structural Geology of the Northwestern Portion of Los Alamos National Laboratory, Rio Grande Rift, New Mexico: Implications for Seismic Surface Rupture Potential from TA-3 to TA-55 [report number LA-13589-MS]

Sparked by the findings of Gardner et al. (1998), Gardner et al. (1999) gathered structural geologic data for a region of LANL stretching from TA-3 to TA-55 through high-precision geologic mapping, conventional geologic mapping, stratigraphic studies, drilling, petrologic studies, and stereographic aerial photograph analysis. This study found that the Rendija Canyon fault, which is a single, simple down-to-the-west structure north of the Los Alamos townsite, splays to the southwest in a broad zone of deformation south of Los Alamos Canyon, through the Los Alamos County Landfill and TA-3, and likely dies out just south of Twomile Canyon. The potential for seismic surface rupture at TA-55 was estimated as extremely low because virtually no identifiable or mappable deformation in the last 1.2 million years (the rough age of the Bandelier Tuff Tshirege Member) could be documented at TA-55.

Additionally, this study evaluated and synthesized the findings of prior fracture investigations in areas to the north (Los Alamos Canyon) and to the south (Pajarito Mesa) of TA-55. Along the north edge of Los Alamos Canyon, Wohletz (1995) identified zones of abundant fractures by walking the mesa edge and measuring fracture orientation, aperture, and density. Wohletz (1995) could not determine whether tectonic movement produced the increased number of fractures seen east of Omega Site, or further opened fractures which originated as cooling joints. Detailed studies involving trenching, however, at sites on Pajarito Mesa have shown no correlation between higher-density zones of fractures and surficial faults (Kolbe et al., 1994; Reneau et al., 1995).

- Lavine et al., 2005, Evaluation of Faulting at the Chemistry and Metallurgy Research Facility Replacement (CMRR) Site Based on Examination of Core from Geotechnical Drilling Studies, TA-55, Los Alamos National Laboratory [report number LA-14170]

A team of LANL geologists was tasked with reviewing the findings of a geotechnical study by an outside contractor at the site of the proposed Chemistry and Metallurgy Research Facility Replacement (CMRR) site at TA-55. The northwestern corner of the CMRR site is located approximately 360 ft SSE of Building 185. The outside contractor completed a thorough drilling campaign of the proposed footprint of the facility. Preliminary examination by LANL geologists of the contact elevations from the drillholes, as identified by the outside contractor's site geologists, revealed many anomalies in the elevation of the Tshirege Member unit 3–unit 4 contact across the site. After careful re-examination of the core, the authors determined that a combination of poor core recovery across the critical contact area, human error (e.g., inconsistent contact calls, mislabeled core boxes, unlabeled run blocks, cores boxed upside-down) and unfamiliarity with the Bandelier Tuff Tshirege Member subunits on the part of the outside contractor's site geologists made for uncertain depth determinations of the unit 3–unit 4 contact. The re-evaluation of the cores found no evidence of large-scale (> 3 ft of vertical displacement) faulting at the site, but some anomalies from the contact elevations of the boreholes could not be resolved with the core data alone.

- Gardner et al., 2008, Geology and Structure of the Chemistry and Metallurgy Research Facility Replacement Site, Los Alamos National Laboratory, New Mexico [report number LA-14378]

As a follow-up from the work of Lavine et al. (2005), discussions began among the CMRR project staff and LANL's Seismic Hazards Geology Team to develop an appropriate approach to excavations for seismic surface rupture studies at the proposed CMRR site. A solution was reached to excavate a "seismic pit", allowing the Seismic Hazards Geology Team unobstructed access to the pit walls to evaluate the geology exposed there, while also providing a lay-down yard and staging area for construction of the neighboring Radiological Laboratory / Utility / Office Building (RLUOB). Detailed geologic investigations at the site of the proposed CMRR at TA-55 mapped in detail the Bandelier Tuff Tshirege Member subunits 3-4 contact (cf. Broxton and Reneau, 1995) and the variably-interbedded pyroclastic surge deposit, and identified and measured over 1,200 accessible and well-exposed fractures for the purpose of determining the potential seismic surface rupture hazard at the site. The northwestern edge of the CMRR excavation is located approximately 360 ft SSE of Building 185.

Many fractures exposed in the excavation had near-vertical dips, narrow apertures, and curvilinear trends. One fault at the CMRR site had a curving failure surface; updip, it had a reverse sense of relative movement, while showing a normal sense of movement downdip. These fracture characteristics are similar to those seen further east along Mesita del Buey and identified by Purtymun and Kennedy (1971) as indicative features of cooling joints. One category of structures found in the CMRR seismic pit is a suite of fractures that displace only the unit 4–surge contact or the surge–unit 3 contact. These fractures either do not displace both contacts or do not exhibit vertical continuity through both contacts. This suite of structures is a clear example of cooling features. Similar offset variability was identified by Gardner et al. (1998) at a location 1,500 ft west of the Plutonium Facility. Overall, the fractures identified at the CMRR site also had a wide range of orientations, with a slightly dominant pattern of west-northwest and north-northwest fracture strikes. The orientation data show no convincing relationship between the structures at the proposed CMRR site and the Pajarito fault system or the Rio Grande rift.

Analyses of the fractures at the proposed CMRR facility showed that only a very small percentage (2%) could be classified as faults. These identified faults commonly formed the bounding edge of areas identified as fossil fumaroles, which are volcanogenic features. The fossil fumaroles are interpreted to be regions of active degassing of the hot tuff very shortly after emplacement (on the order of one to ten years after deposition; cf. Dunne et al., 2003). Only one fault could be correlated between two of the excavation walls, but could not be found along-strike on another excavation wall. Additionally, Gardner et al. (1999) did not map this fault where its along-strike continuation would intersect natural exposures of the unit 3–unit 4 contact about 250 ft west of the CMRR pit's western edge.

This study concluded that fractures and faults at the proposed CMRR site formed very shortly after emplacement of the tuff at 1.256 Ma as a result of cooling and compaction, and the structures identified at the proposed CMRR site pose no independent seismic surface rupture hazard.

Geologic quadrangle mapping

Goff et al. (2001) completed geologic and structural mapping of the Frijoles (Los Alamos area) quadrangle at 1:24,000 scale. This study did not identify surficial geologic faults that disrupt the Bandelier Tuff or younger units in the vicinity of Building 185 at TA-55.

Lineament mapping from aerial photographs

This memo includes a lineament map (Plate 1) of the area surrounding TA-55. This plate includes the 3,000 ft RCRA buffer for the technical area and shows additional area beyond the buffer. Serving as the base for the lineament mapping is aerial photography shot by Bohannan-Huston, Inc. in the fall of 2008 during leaf-off conditions. Accuracy of the imagery is 1 in = 200 ft.

We identify a few north-northwesterly trending lineaments and a lesser number of northeasterly trending lineaments, mainly in the southern half of the map area. One northeasterly-trending lineament, near the northern edge of the 3,000 ft RCRA buffer, may likely be some sort of pipeline cut as it is quite straight and abruptly devoid of vegetation. The lineament trending towards the southwestern corner of TA-55 is roughly aligned with the inferred subsurface projection of the Rendija Canyon fault mapped by Dransfield and Gardner (1985). Beyond a possible correlation between the north-northwesterly trending lineament that projects into the southwest corner of the 3,000 ft RCRA buffer and two point-locations of identified offset from Reneau et al. (1995; Plate 1), other lineaments identified in this mapping do not correlate to known surficial geologic faults or have not been found to displace the Bandelier Tuff or younger units (where present) in the previous studies summarized above.

Discussion

Figure 2 is a map of the entire TA-55 area with a 3,000-ft (blue) buffer for RCRA seismic considerations. Several small northeast-trending splays of the Rendija Canyon fault, mapped by Gardner et al. (1999) fall within the northwest quadrant of the buffer. Identified offsets on Bandelier Tuff Tshirege Member subunits from studies by Reneau et al. (1995), Gardner et al. (1999), Lewis et al. (2002), and Lavine et al. (2003) fall within the eastern and southern portions of the 3,000 ft buffer. These identified offsets are shown as points because the lateral continuity of the fault at that location could not be traced. The faults have various senses of displacement (both down-to-the-east and down-to-the-west), but the majority of faults within the 3,000-ft buffer have down-to-the-west displacement. The greatest amount of displacement (in any sense) within the 3,000-ft buffer is 3 ft.

Figure 3 is a map of the Building 185 area, with 200-ft (red) and 3,000-ft (blue) buffers for RCRA seismic considerations. This map shows no mapped faults within the 200-ft buffer. Four identified points of offset on the Bandelier Tuff Tshirege Member subunits fall on or within the 3,000 ft buffer. The three point-locations wholly within the 3,000 ft buffer were mapped by Reneau et al. (1995) and the point-location along the buffer in the northeastern quadrant was mapped by Lavine et al. (2003). These points of offset were found to have no greater than 3 ft of displacement and their lateral continuity could not be identified.

Figure 1 shows that Building 185 is approximately 2.6 miles from the main trace of the potentially seismogenic Pajarito fault. This closest point to Building 185 along the Pajarito fault is located near the LANL Emergency Operations Center on West Jemez Road. Figures 1 and 2 also show that with respect to Building 185, the closest mapped fault (with lateral continuity) is approximately 0.59 miles (~ 3,055 ft) WNW from Building 185, exhibiting 3 ft of subsidiary down-to-the-west deformation (Gardner et al., 1999). Figure 3 shows that with respect to Building 185, the closest identified offset is 1,170 ft WNW in the eastern part of TA-48. Mapped by Gardner et al. (1999), this offset between Tshirege Member subunits 3 and 4 could not be traced vertically or laterally.

Conclusions

Small faults have been identified at TA-55 by previous geologic studies. Some of these small faults fall within the 3,000 ft RCRA buffer around Building 185; none project into the 200-ft buffer. These faults show modest displacements of a few feet on contacts of Tshirege Member subunits along the mesa edges. These faults have been attributed to (1) secondary deformation on subsidiary faults within the Pajarito fault system, and (2) cooling and compaction of the tuff shortly after emplacement. General fracture and fault characteristics include subvertical to vertical dips, curvilinear trends, narrow apertures, and wide ranges of orientations, as identified in numerous studies. Aerial reconnaissance and detailed geologic mapping of the entire LANL campus shows that the focus of potential Holocene faulting is concentrated closer to the Pajarito fault system, the main trace of which is approximately 2.6 miles west of Building 185. Lineament mapping identifies four lineaments that project into the 3,000 ft buffer around TA-55, and one lineament roughly correlates with two locations of mapped offset from a previous study.

Anthropogenic disturbance affects the area within the 200-ft buffer of Building 185. Nearly all post-Bandelier Tuff sediments have been stripped from the mesa-top within the technical area in exchange for construction fill. Without undisturbed post-Bandelier Tuff sediments, conducting future geologic field studies with the purpose of identifying potential Holocene movement(s) across geologic structures (including paleoseismic trenching or borehole investigations) would be extremely challenging, if not impossible, in the vicinity of Building 185. Without the presence of post-Bandelier Tuff sediments, future studies would not be able to determine the age of the most recent activity on such faults beyond the constraint of the age of the tuff. A recent, large-scale geologic investigation within the 3,000-ft buffer around Building 185 confirms the paucity of post-Bandelier sediments in the area and also attributes faulting in that area to cooling and compaction of the tuff shortly after emplacement. Detailed geologic studies of the greater TA-55 area over the last 20 years have identified faults that are small, both in displacement and in lateral continuity. The studies have broad interpretations of genesis of the TA-55 area faults, but those that delve into the faults' potential for future activity agree they are likely too small to be individually seismogenic.

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Attachments