# Los Alamos Study Group

**PRESS RELEASE**
January 29, 1997
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# EARTHQUAKE POTENTIAL PUTS LANL PLUTONIUM FACILITIES AT RISK

A review of seismic investigations at Los Alamos National Laboratory (LANL) has revealed that an inferred fault runs directly beneath LANL's plutonium processing and storage facilities, now slated to take over the manufacturing role of the defunct Rocky Flats Plant near Denver.

According to research funded by LANL, earthquake potential at the New Mexico site is "higher than might be indicated by the historical record and therefore higher than is commonly believed possible." Earthquakes centered at LANL up to Richter magnitude of 7.0 are possible.

Most of LANL's nuclear facilities were built decades ago and were not designed to withstand large earthquakes. A major program of upgrades is underway. Of special concern is the emergency fire suppression system at the plutonium facility, which is not adequate to prevent a catastrophic plutonium fire in the event of a major earthquake. Rocky Flats experienced more than 615 fires in its 37-year operating history, even without earthquakes.

Overall, seismic hazards at LANL are not fully understood, and current investigations cannot discover all faults--let alone the hazard each poses. In spite of these uncertainties, the Department of Energy (DOE) maintains in environmental impact statements (EISs) that LANL operations are safe from significant seismic hazard. Yet LANL scientists and consultants admit that they cannot make a realistic estimate of earthquake recurrence interval, and hence of seismic risk. The estimated recurrence interval of 55,000 years used by DOE in its recent Stockpile Stewardship and Management Programmatic EIS appears to be too large by a factor of ten. Even this correction would hardly be a conservative estimate.

Screening of LANL buildings for seismic vulnerability began late in the game, in 1994, using a unique methodology developed by LANL. Some structures passed, but most LANL nuclear facilities failed that analysis. Following these evaluations, LANL's testing methodology was peer reviewed by Degenkolb Engineers of San Francisco, who expressed little confidence in LANL's method. Degenkolb urged LANL to use a more detailed analysis and stated that some sort of external peer review should be included in future evaluations. While LANL spokespersons claim that changes have been made in evaluation methods, the nature of these changes has not been made public nor have they been, to our knowledge, submitted for truly independent peer review.

The seismic hazard at LANL, juxtaposed with DOE plans to build some $800 million in nuclear weapons facility upgrades, warrants sharp public and congressional concern. Seismic risks only add to the risks posed by LANL's managerial deficiencies, which have been highlighted in recent LANL and DOE accident reports.

Greg Mello, co-author of Study Group's review, concludes: "Concerns about seismic hazard at LANL must be answered by geologists, engineers and policy-makers ***prior*** to decisions that will increase risk to workers and the public--not afterward. The DOE, in its rush to begin making plutonium weapons components, is exhibiting the same production-dominated mentality that led to disastrous accidents at Rocky Flats. Such accidents can never be allowed to happen again."

One page (Figure 3) from the report is attached; the full report (12 pp.) is available upon request.

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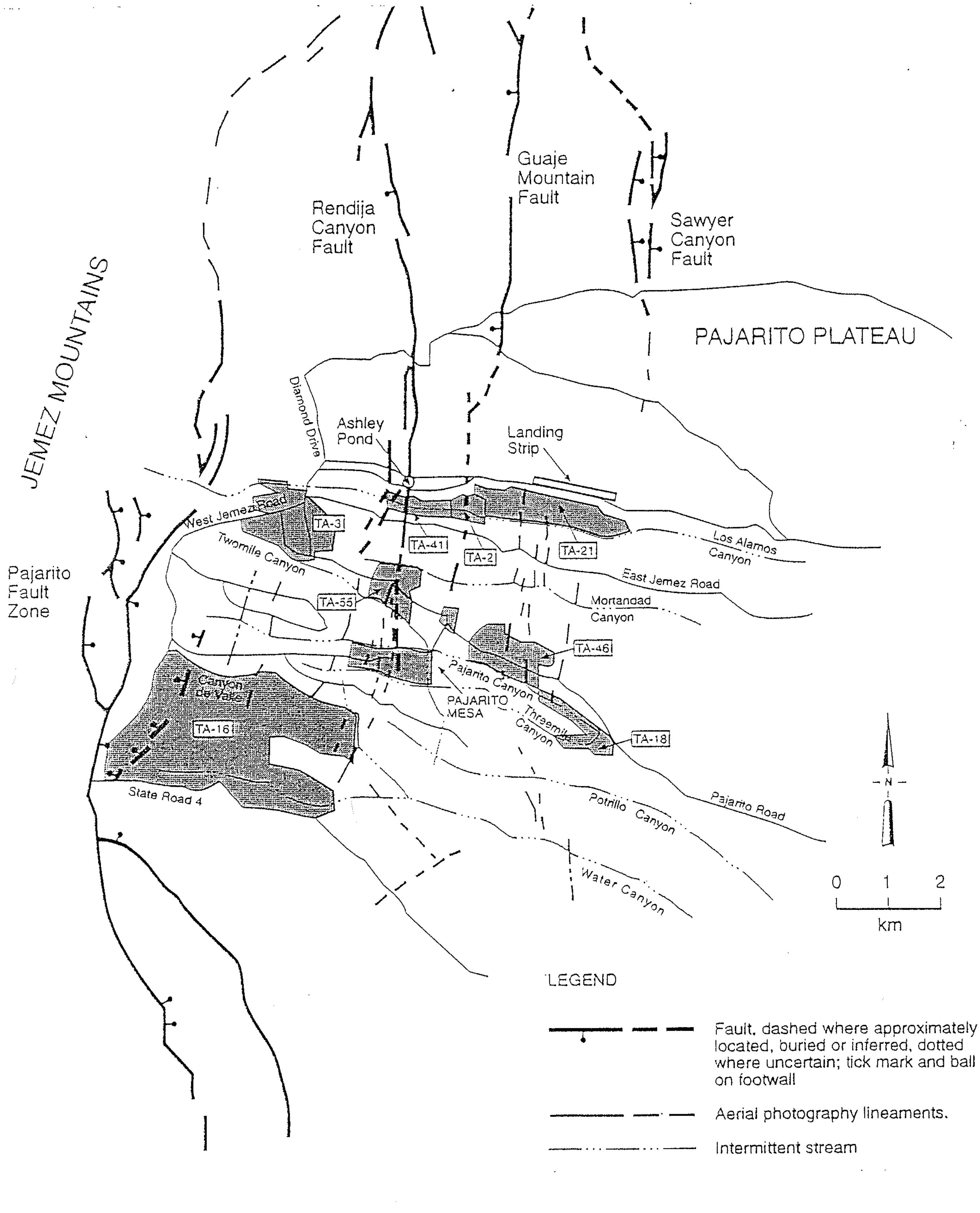


**Figure 3**
From: Wong et. al., p. 137

# Los Alamos Study Group

## Memorandum

Todd Macon and Greg Mello
January 23, 1997

# Seismic Hazards at Los Alamos National Laboratory with Emphasis on the Plutonium Facilities at TA-55

**Summary**

- Los Alamos National Laboratory (LANL) is located astride the Pajarito Fault System (PFS), an active and capable fault system containing 25 faults that have been identified as "potential seismic sources capable of generating significant ground shaking at the LANL."[1]
- Ground shaking hazard at LANL is "higher than might be indicated by the historical record and therefore higher than is commonly believed possible."[2] Earthquakes centered at LANL up to Richter magnitude of 7.0 are possible.
- The plutonium facilities at TA-55 may sit *directly* over an active and little-understood fault believed capable of a 6.5 magnitude earthquake.
- Overall, the seismic hazard at LANL is not fully understood, and the surface investigations now being done cannot discover all faults.
- Despite the known hazard and uncertainty, LANL maintains in environmental impact statements that its operations are completely safe from significant seismic hazard.
- Contradicting LANL's claim of little or no risk, at least nine and possibly a great many more major LANL buildings, including its principal nuclear materials facilities, have failed seismic evaluations. For example, the Nuclear Materials Storage Facility has failed a detailed dynamic evaluation, and while the Plutonium Facility (PF-4) *structure* has "passed" some sort of evaluation, PF-4's current *fire suppression system* would definitely not withstand a quake.
- Building evaluations conducted by the Lab for earthquake vulnerability have been criticized by external reviewers.
- The effects of seismic activity at LANL could include building collapse, fires, release of significant quantities of nuclear materials, blockage of emergency routes, loss of life, and environmental contamination.

## Introduction

Despite a common perception that New Mexico is relatively unaffected by seismic activity, the state--including the LANL region--has a history of seismicity and a potential for large earthquakes. This fact was not taken into consideration when LANL was founded and its facilities built. The seismic hazard is greatly increased by the fact that LANL's nuclear weapons research and proposed production facilities are proximate to and, in important cases, directly

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over inferred faults capable of producing substantial ground acceleration and building damage.

## Active Faults in Relation to LANL and TA-55

Los Alamos lies on the western margin of the Rio Grande Rift, about four miles east of the Jemez Caldera. The Caldera is underlain by approximately three large magma bodies, the long-term stability of which is unknown.[3] LANL itself is underlain by a series of connected faults called the Pajarito Fault System (PFS; see Figure 1). Three of the faults running through or adjacent to LANL--the Rendija Canyon, Guaje Mountain, and the Pajarito Fault Zone--are capable of large earthquakes. The largest of these, the 41 kilometer-long Pajarito Fault Zone, is believed capable of up to a 7.0 Richter magnitude earthquake.[4] It lies about one kilometer away from many vulnerable facilities, including the Chemistry and Metallurgy Research (CMR) building. The CMR building is by far the largest building at LANL and plays a major role in radioactive materials research, development, and component production. The Rendija and Guaje faults have a maximum magnitude around 6.5 (Figure 2) and run directly through LANL.

Significantly, the Rendija Fault is inferred to run beneath Building PF-4, the plutonium processing facility, and the Nuclear Materials Storage Facility (NMSF) at TA-55 (Figure 3).[5] Trenching on Pajarito Mesa, south of TA-55, has revealed a zone of abundant fracturing and noticeable displacement consistent with the presence of the Rendija Canyon Fault.[6] The best available information thus shows the presence of this fault both north and south of, and hence under, TA-55.

## Seismic Events Within the LANL Region

Since 1873 there have been 6 earthquakes with a Richter magnitude greater than 5.0 occurring "within the LANL region."[7] The largest of these, the 1918 Cerrillos earthquake, had a 5.5-6.0 magnitude with a Mercalli Intensity scale of VII (general fright and alarm, slight structural damage). In addition to these larger quakes, some 672 minor quakes in the region have been measured by the Lab's monitoring network between 1973 (the date measurements began) and 1994. The largest of these quakes measured around a 3.0 Richter magnitude.[8]

It is important to note that seismographs were not put in place at the Lab until 1973--and indeed anywhere in New Mexico until 1960. Current interpretations thus rest on a short historical record and may underestimate larger events. According to Wong et. al.:

> Despite the lack of large magnitude historical earthquakes, the geologic record indicates that many faults in the region have generated surface-faulting earthquakes [magnitude greater than 6.5] during the late Quaternary [i.e., since 1.6 million years ago].[9]

Indeed, according to this same source, there is evidence that significant seismic activity has occurred in the PFS in recent geological time; the Guaje Fault has been active in the Holocene (past 10,000 years) and the Pajarito may have been active in this period as well.[10] The Rendija

Fault exhibits evidence consistent with early Holocene or late Pleistocene activity.[11]

**Seismicity and Seismic Hazards Investigations at LANL**

The first seismic hazards study at LANL was conducted in 1972 specifically for PF-4 at TA-55 by Dames and Moore. This study was subsequently described by Woodward-Clyde as being "purely deterministic" and "based purely on the 100-year historical earthquake record."[12]

Following this early study, an in-house preliminary report was written in 1987 by Gardner and House of LANL. They conclude, "Some limited, inferential field data imply the fault system generates characteristic earthquakes in the magnitude (Richter) range 6.5 to 7.8." It was noted that these estimates might be high.[13] This report also stated, significantly:

> At present we cannot make a realistic estimate of recurrence interval for the characteristic earthquake and cannot, therefore, estimate probabilities so as to address the question of seismic risk at Los Alamos. (p. 54)

In evaluating seismic hazard, Gardner and House also concluded that "...the Laboratory and Los Alamos County will be isolated by road in the event of a large earthquake due to mass wasting and/or surface rupture."[14] Such isolation would prevent emergency crews (e.g. fire, medical, and hazardous materials teams) from entering Los Alamos should local resources be damaged or insufficient. It should be added that the seismic vulnerability of the Los Alamos Medical Center, a fact of great significance in impact analysis, has not been discussed in any public Department of Energy (DOE) or LANL report.

The clear need for more site-specific data in the TA-55 area led to a 1990 LANL fracture studies report. The conclusions of this report were not put in terms of seismic risk but did demonstrate fracturing, believed to represent faulting, around TA-55.[15] This report also mentioned the possibility of mass-wasting (i.e. cliff failure) hazards at LANL, specifically mentioning a 50,000+ ton block poised above TA-2.

The continuing lack of information--and a need to comply with DOE Order 5480.28 on "Natural Phenomena Hazards Mitigation"--led to a comprehensive "Seismic Hazards Evaluation" conducted for LANL by Woodward-Clyde Inc. of Oakland, CA. Their final report was released in February of 1995. This report reviewed seismic history, potential seismic sources, and geologic characteristics of particular technical areas, including TA-55. Woodward-Clyde identified 25 faults "as potential seismic sources capable of generating significant ground shaking at the LANL."[16]

Building on the Woodward-Clyde report, LANL geologist Jamie Gardner is conducting further studies under the title "Potential Faulting and Surface Rupture in the Vicinity of TA-55." Due for completion September 1997, these investigations will provide greater detail than the Woodward-Clyde report--which is strangely deficient regarding the area around TA-55. Dr. Gardner has expressed his concern to us that this project could be terminated before its completion.

In an important peer-reviewed independent paper by Ivan Wong and nine other authors, most or all of which are employed by LANL and its contractors, research to date on the seismicity of the LANL region is re-interpreted with greater detail. In this paper the authors infer the presence of the Rendija Canyon Fault directly beneath TA-55. In addition, faults of the Pajarito Fault Zone are shown converging at or near the Tritium Processing Facility at TA-16. These authors conclude:

> The results of the probabilistic seismic hazard analysis indicate that the ground shaking hazard at the LANL is higher than might be indicated by the historical record and therefore higher than is commonly believed possible.[17]

The situation is summed up by Fraser Goff, a LANL geologist, in his introduction to the New Mexico Geological Society Guidebook The Jemez Mountains Region. Goff writes:

> Los Alamos National Laboratory lies astride the Pajarito fault zone, one of the biggest and most active fault systems in the state of New Mexico. Since the Laboratory still has a mission to develop and maintain national security, shouldn't we be certain that Laboratory buildings are safe from future earthquakes?

The studies cited above, and several related works published in the Guidebook, were supported by LANL employment and contracts.

## Seismic Screenings and Evaluations of LANL Buildings

Finally, in November of 1994, LANL began to screen its 1,482 permanent buildings for seismic vulnerability. The preliminary "sidewalk screening" included some 479 buildings. Of these, a "Non-Exempt Priority List" was developed which included 169 of the "highest priority buildings" (e.g. those with potential nuclear hazards or large worker populations). Of these 169 buildings, three, including PF-4, were subsequently given "detailed" seismic analysis. All three buildings "passed," although documents describing this analysis have not been released.[18]

Although the PF-4 *building* apparently "passed" some sort of seismic evaluation, the critically-important *fire suppression system* that is meant to prevent a catastrophic fire involving pyrophoric plutonium metal would fail in the event of a major earthquake.[19] Such a fire would consume the High-Efficiency Particulate Arrestor (HEPA) filters at PF-4, probably resulting in a major release of airborne plutonium into the environment.[20] For this reason, operational funds are now being used for design and reconstruction of the fire suppression system at PF-4.[21]

The remaining 166 buildings were then assessed by a unique testing methodology developed for this occasion by LANL and its subcontractor Johnson World Controls Systems (JWCS). Some of these buildings--the total number is unknown to us--failed these screenings and evaluations. Buildings which failed include the NMSF, the Tritium Processing Facility

(TPF; an alias for the Weapons Engineering Tritium Facility, or WETF?) at TA-16, the Tritium Science and Technology Building at TA-21, the Sigma and other nuclear buildings at TA-3, TRU Waste Incinerator Building at TA-50, the CMR Building, and the Administration Building.[22]

After the bulk of these evaluations were completed, the LANL/JWCS evaluation method was peer reviewed by Degenkolb Engineers of San Francisco. This review compared the LANL method with the well-established Federal Energy Management (FEMA) 178 method on six example buildings. Though the two methods were described as having "reasonably good agreement" in these cases, the peer reviewers expressed a severe lack in confidence of both the LANL method and the process used to implement it:

> Based on the potential for structural details to control the behavior of a building, and on the potential to over estimate the shear strength, it is our recommendation that the LANL/JCWS method be revised to somewhat reflect flexural and connection performance. It can then possibly be used as a tool for prioritizing more detailed evaluations, but not as a means for determining the adequacy of a structure without further review. The seismic performance of details as reflected in the FEMA 178 checklists is an important aspect of rapid screening which is so far overlooked by the LANL/JCWS method.
>
> Due to obvious judgment required in such rapid evaluations, some form of peer review, possibly in-house, should be included in all future evaluation programs.[23] (emphasis added)

According to Doug Volkman, LANL Seismic Coordinator, the suggested changes have been implemented. Subsequent building evaluations have been done, including the NMSF, the CMR Building, and the TPF. These buildings have "passed" these evaluations, although the nature of the evaluations have not been released and have not been submitted for peer review, contrary to the suggestions of the Degenkolb review.[24] It should be noted that, despite "passing" this evaluation, seismic upgrades are now being done on these facilities.[25]

We do not know whether the LANL evaluations considered buildings to be constructed of ideal, or of real and as-built, materials. For example, the concrete in the NMSF has reinforcing steel placed considerably out of specification, weakening the stiffness of the walls. In one area, inspectors found "degraded" concrete with numerous hairline cracks, discoloration, and water seepage, all indicative of poor concrete quality.[26] Given that this facility is being upgraded to store up to 6,600 kg of plutonium--this *without any kind of environmental analysis*--these are non-trivial problems which warranted the cited letter from Defense Nuclear Facilities Safety Board Chairman John Conway to Assistant Secretary Vic Reis of DOE.

**Site Planning Considerations**

The most recent site plan for LANL was done in 1990. The authors of that plan understood, in theory at least, the dangers posed by earthquakes.

> Planning and development considerations with respect to the placement of facilities within fault zones focus primarily on the question of maintaining integrity of containment systems. This question is of greatest importance regarding certain special nuclear materials and waste management facilities...
>
> In the event of large earthquakes within the local fault systems, one must conservatively anticipate surface rupture along the fault traces. Thus, any building built within a fault zone could be seriously damaged or destroyed by surface rupture, depending on the magnitude of the rupture. This damage could result in destruction of containment structures...
>
> Given these considerations, the siting of some kinds of facilities must be constrained by the location of major faults within the Laboratory.[27] (emphasis added)

This Plan maps the "concealed" Rendija and Guaje faults as extending completely across LANL from north to south, conservatively inferring their presence regardless of surface expression.

Contrary to its practice at LANL, the DOE is required to conduct a "comprehensive land-use planning process with stakeholder involvement" prior to building new facilities. This requirement is found in DOE Order 430.1, promulgated on August 24, 1995, which replaced thirteen previous orders with a single set of comprehensive "life-cycle asset management" requirements. Although the University of California has formally accepted the requirements of this order in its contract,[28] the local DOE office adamantly maintains that this Order is not "yet" applicable to LANL.[29]

## Implications for LANL's Mission

DOE has recently chosen LANL as the site for plutonium processing and manufacturing for the nuclear weapons complex. This choice was in part based on risk analyses that assumed, for example, that the maximum release of plutonium from an earthquake at LANL would be less than 610 *milligrams*, and such an event was expected only about once every 100,000 years.[30]

This choice was also based on the extensive use of old buildings, conspicuously the CMR building and the NMSF, that have failed seismic evaluations and require extensive and very expensive upgrades.

In the final analysis, even this investment will not assure that LANL facilities, and the surrounding community, are safe from earthquake hazard. The history of the nuclear industry is replete with unexpected events thought impossible until they happened.

## Conclusions

The seismic hazard in and around LANL is not fully understood. Both what is known and what is not could have serious site planning and public health repercussions. Critical information about the location and extent of a number of faults (especially the Rendija), their recurrence intervals, and their potential affect on the safety of high-risk buildings has either not been fully researched, developed, or published. Should on-going seismic research be terminated, especially regarding the hazard at TA-55, the full extent of the hazard may not be known. Conservative planning and design practices, as well as the requirements of specific DOE orders, are being abandoned in the rush to build nuclear facilities and produce plutonium components for nuclear weapons.

The seismic hazard in the Los Alamos area is serious enough to warrant sharp public and congressional concern over the proposed increase in storage, processing, and manufacturing of nuclear materials and the components made from them. The safety measures in place could not confidently prevent large releases of nuclear materials in the event of earthquake and fire. The risk analyses in the recent Stockpile Stewardship and Management Programmatic Environmental Impact Statement are inadequate. The seismic hazards at Los Alamos should be more fully understood by geologists and engineers--and even more so by policy-makers and the public--*prior to* decisions that will increase risk to the public.

**Sources**


Degenkolb Engineers, "Peer Review LANL Seismic Screening Assessment Method [Degenkolb Job No. 94144.06]" San Francisco, CA: October 1995

Department of Energy, Final Programmatic Environmental Impact Statement for Stockpile Stewardship and Management, September 1996.

Easthouse, Keith "Study: Three large magma zones under Jemez range" The New Mexican, December 16, 1996.

Gardner, Jamie and Leigh House, "Seismic Hazards Investigations at Los Alamos National Laboratory, 1984 to 1985." LANL report: October 1997.

House, Leigh and Hans Hartse, 1995 "Seismicity and Faults in Northern New Mexico." New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, 1995.

Olig, Susan S. et. al., "The Earthquake Potential of the Pajarito Fault System, New Mexico." The New Mexico Geological Society, The Jemez Mountains Region pg. 143-151: 1996.

Todd, Tom, DOE Memorandum May 14, 1996, "Galvanic Corrosion of TA-55 Plutonium Facility Fire Suppression Supply Water Piping."

Todd, Tom, DOE Memorandum June 20, 1996,"Unreviewed Safety Question Determination

(USQD-95-006) for the Operations Center Upgrade at the Plutonium Handling Facility (PF-4), TA-55, LANL."

United States Department of Energy, Final Programmatic Environmental Impact Statement for Stockpile Stewardship and Management: September 1996.

Vaniman, D. and K. Wohletz, LANL Memorandum November 14, 1990, "Results of Geological Mapping/Fracture Studies: TA-55 Area."

Volkman, Doug, LANL Memorandum February 15, 1996, "LANL Seismic Path Forward Database."

Wong, Ivan, et. al. 1996, "Earthquake Potential and Ground Shaking Hazard at the Los Alamos National Laboratory, New Mexico." The New Mexico Geological Society, The Jemez Mountains Region pg. 135-151: 1996.

Woodward-Clyde, "Final Report: Seismic Hazards Evaluation of the Los Alamos National Laboratory". Los Alamos National Laboratory, University of California, Los Alamos, NM: February 1995.

Notes

1. Woodward-Clyde, p. 7-1.
2. Wong et. al., p. 41.
3. Keith Easthouse, 12/16/96.
4. Woodward-Clyde, p. ES-4.
5. Wong et. al., p. 137.
6. Woodward-Clyde, p. 4-54.
7. Wong et. al., p. 135.
8. Leigh House and Hans Hartse, p. 135.
9. Wong et. al., p. 135.
10. Wong et. al., p. 135; Woodward-Clyde, p. 2-19.
11. Woodward-Clyde, p. 2-19.
12. Woodward-Clyde, p. 1-18.

13. Gardner, p. ix.

14. Gardner 1987, p. 54.

15. Vaniman 1990.

16. Woodward Clyde p. 7-1.

17. Wong et. al., p. 141.

18. Volkman, p. 2.

19. Joe Vozella, DOE/LAAO, personal communication 1/21/97. See also Tom Todd, 5/14/96, p. 2.

20. Tom Todd, 6/20/96, Attachment 1, p. 1.

21. Joe Vozella, personal communication, 1/21/97.

22. Volkman, p. 2.

23. Degenkolb Engineers, p. 13.

24. Doug Volkman, phone conversation January 16, 1995.

25. Volkman, p. 2.

26. Conway, p. 1, and Attachment, p. 1 and 4.

27. Site Plan, pp. 254-255.

28. Letter from Sandra Vinson, Assistant Director, University of California Contracts Management, to DOE, March 20, 1996.

29. Tom Todd, DOE/LAAO, personal communication.

30. DOE, p. F-20.

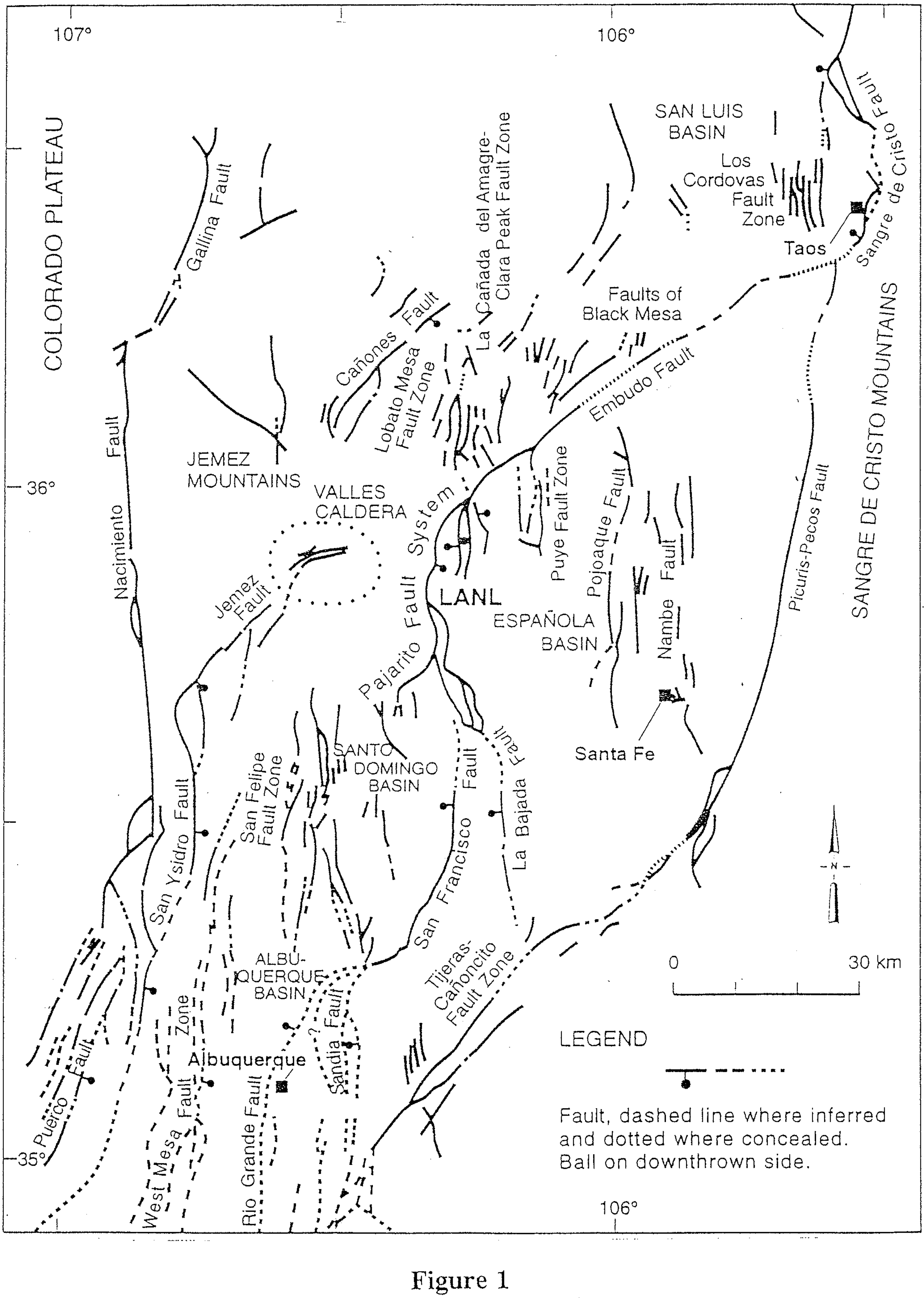


**Figure 1**
From: Olig et. al., p. 144

| Fault | Probability of Activity | Rupture Length (km) | Best Estimate Maximum Magnitude ($M_w$) | Slip Rate Best Estimate (Range) (mm/yr) | Style of Faulting |
|---|---|---|---|---|---|
| Pajarito | 1.0 | 41 | 6.9 ± 0.3 | 0.09 (0.01-0.95) | Normal |
| Rendija Canyon | 1.0 | 14 | 6.5 ± 0.3 | 0.02 (0.01-0.25) | Normal |
| Guaje Mountain | 1.0 | 12 | 6.5 ± 0.3 | 0.01 (0.01-0.14) | Normal |
| Sawyer Canyon | 1.0 | 14? | 6.5 ± 0.3 | 0.03 (0.01-0.3) | Normal |
| Puye | 1.0 | 20 | 6.3 ± 0.3 | 0.03 (0.01-0.3) | Normal |
| Lobato Mesa | 1.0 | 22 | 6.6 ± 0.3 | 0.05 (0.01-0.45) | Normal |
| La Bajada | 1.0 | 40 | 6.9 ± 0.3 | 0.07 (0.01-0.58) | Normal |
| Embudo | 1.0 | 64 | 7.0 ± 0.3 | 0.09 (0.02-0.72) | Oblique |
| Southwest Segment | 1.0 | 31 | 6.7 ± 0.3 | 0.09 (0.02-0.72) | Oblique |
| Northeast Segment | 1.0 | 30 | 6.7 ± 0.3 | 0.09 (0.02-0.72) | Oblique |
| La Cañada del Amagre/Clark Peak | 0.5 | 12 | 6.2 ± 0.3 | 0.10 (0.02-0.9) | Strike-Slip |
| San Francisco | 1.0 | 42 | 6.9 ± 0.3 | 0.07 (0.01-0.58) | Normal |
| Pojoaque | 0.5 | 49 | 7.0 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| San Felipe | 0.5 | 47 | 6.8 ± 0.3 | 0.05 (0.01-0.4) | Normal |
| Santa Ana | 0.5 | 21 | 6.5 ± 0.3 | 0.05 (0.01-0.4) | Normal |
| Algodones | 0.5 | 16 | 6.4 ± 0.3 | 0.05 (0.01-0.4) | Normal |
| Jemez-San Ysidro | 1.0 | 50 | 6.9 ± 0.3 | 0.06 (0.01-0.52) | Normal |
| Jemez | 1.0 | 26 | 6.7 ± 0.3 | 0.06 (0.01-0.52) | Normal |
| San Ysidro | 1.0 | 24 | 6.6 ± 0.3 | 0.06 (0.01-0.52) | Normal |
| Cañones | 0.5 | 30 | 6.7 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| Nambe | 0.1 | 50 | 7.0 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| Black Mesa | 0.5 | 15 | 6.5 ± 0.3 | 0.02 (0.01-0.21) | Normal(?) |
| Tijeras Cañoncito | | | | | |
| Lamy | 0.5 | 25 | 6.6 ± 0.3 | 0.09 (0.02-0.72) | Oblique |
| San Pedro/Ortiz/Monte Largo | 0.5 | 29 | 6.7 ± 0.3 | 0.09 (0.02-0.72) | Oblique |
| Tijeras/Four Hills | 1.0 | 31 | 6.7 ± 0.3 | 0.09 (0.02-0.72) | Oblique |
| Nacimiento | 0.5 | 78 | 7.2 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| Northern Segment | 0.5 | 34 | 6.8 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| Southern Segment | 0.5 | 44 | 6.9 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| Picuris-Pecos | 0.5 | 96 | 7.3 ± 0.3 | 0.05 (0.01-0.45) | Oblique |
| West Mesa | 1.0 | 52 | 7.0 ± 0.3 | 0.03 (0.01-0.17) | Normal |
| Puerco | 0.5 | 80 | 7.1 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| Gallina | 0.5 | 40 | 6.8 ± 0.3 | 0.02 (0.01-0.23) | Normal |
| Sandia-Rio Grande | 1.0 | 45 | 6.9 ± 0.3 | 0.18 (0.03-1.91) | Normal |
| Sangre de Cristo | | | | | |
| Segments 3 + 4 | 1.0 | 32 | 6.8 ± 0.3 | 0.12 (0.06-0.29) | Normal |
| Segments 2 + 3 + 4 | 1.0 | 60 | 7.1 ± 0.3 | 0.12 (0.06-0.29) | Normal |
| Los Cordovas | 0.5 | 12 | 6.2 ± 0.3 | 0.02 (0.06-0.29) | Normal(?) |

**Figure 2**

From: Wong et. al., p. 138

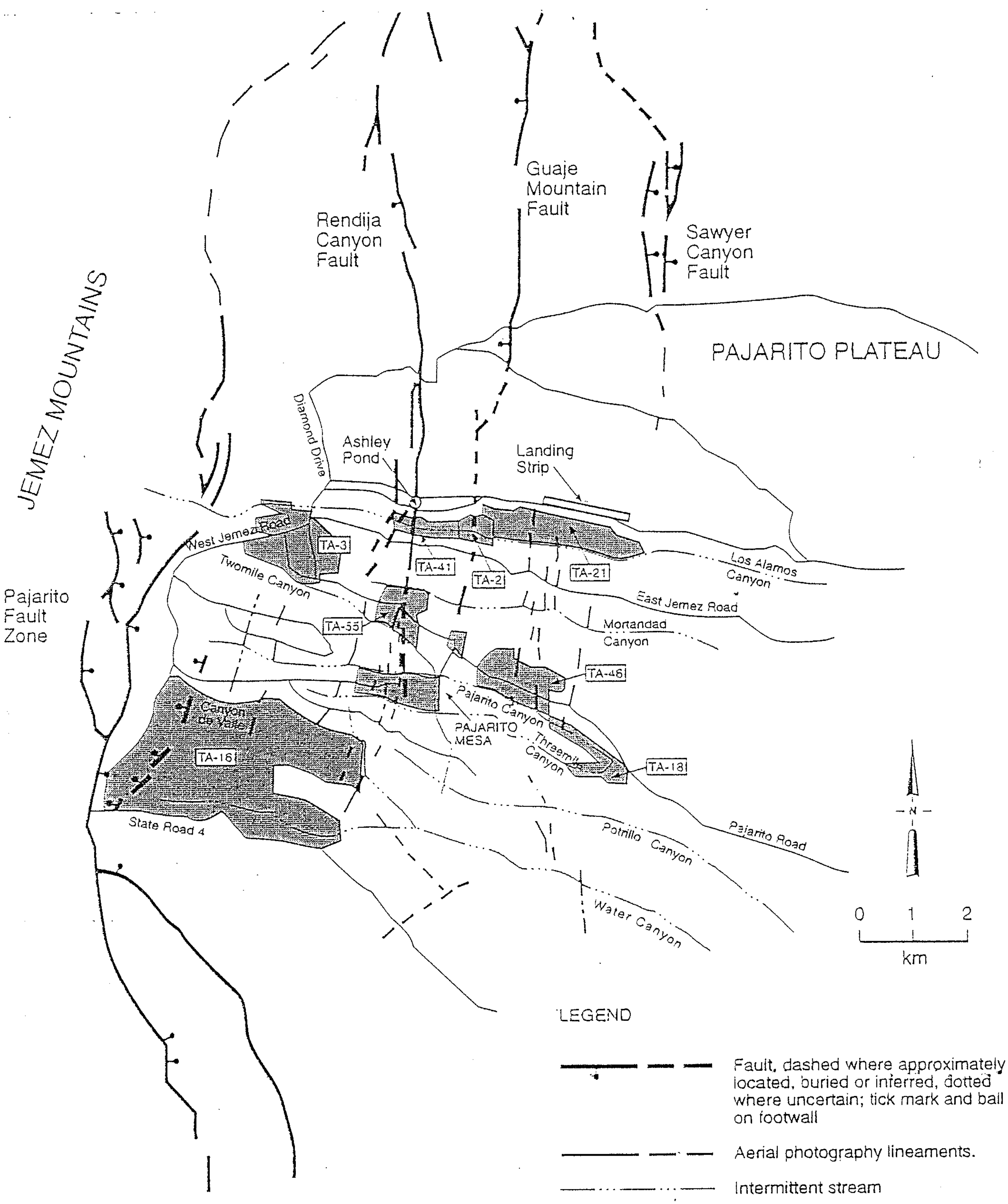


**Figure 3**
From: Wong et. al., p. 137