Los Alamos National Laboratory
Plutonium Facility (PF-4) Seismic Safety

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Los Alamos NATIONAL LABORATORY EST. 1943

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Overview

- Challenges
  - PF-4 seismic demand has increased x3 horizontally and x6 vertically
  - PF-4 is susceptible to non-ductile failures during a large rare earthquake:
  - Est. failure probability: ~20 % greater than 1 $x10^{-4}$ /yr DOE Performance Goal
- Path-forward
  - Modifications within two years appear straight-forward. New est. failure probability is ~20 % below the DOE Performance Goal
  - An alternate analysis has been conducted to improve confidence but may also identify potential new concerns
  - By February 2015, a Seismic Expert Panel will advise on path-forward
- Outline of Talk
  - Background on PF-4 and LANL seismic hazard
  - Linear dynamic analysis (2011) & non-linear pushover analyses (2012, 2013)
  - Modifications completed and those underway

Background on the LANL Plutonium Facility (PF-4)

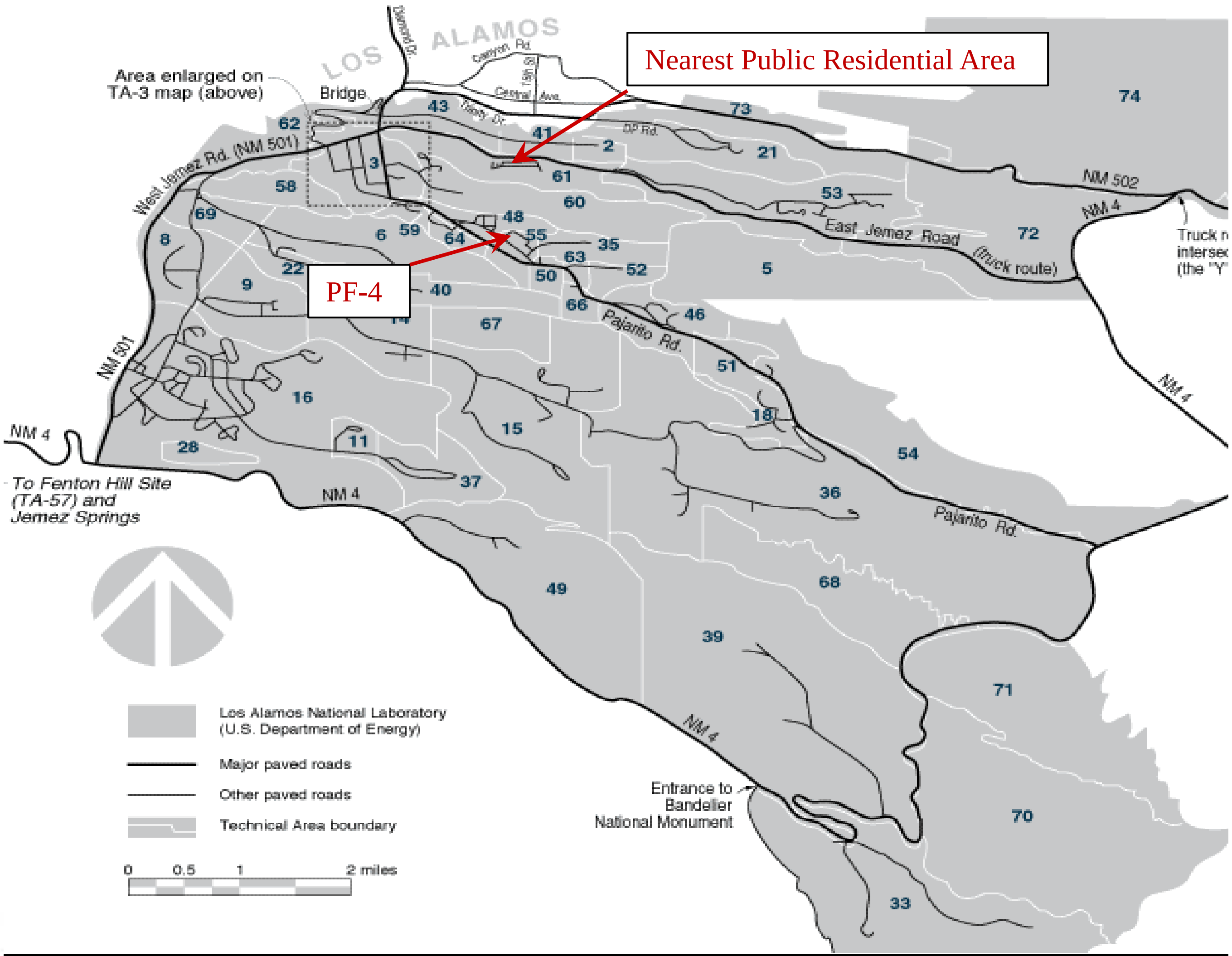
- PF-4 is the nation's enduring Pu R&D and production capability
- Designed to early 1970's requirements and a less demanding earthquake
- Operational since 1978
- Two-story shear-wall structure, partially embedded on 3 sides
- ~233,000 ft^2 overall

- PF-4 lacks modern ductile detailing: there is little additional margin between an earthquake that initiates failures and a slightly larger one that induces collapse
- PF-4 lacks redundant load-carrying path-ways; failure of one component (e.g., a roof girder) could lead to a progressing failures of adjacent components

PF-4 Structural Configuration

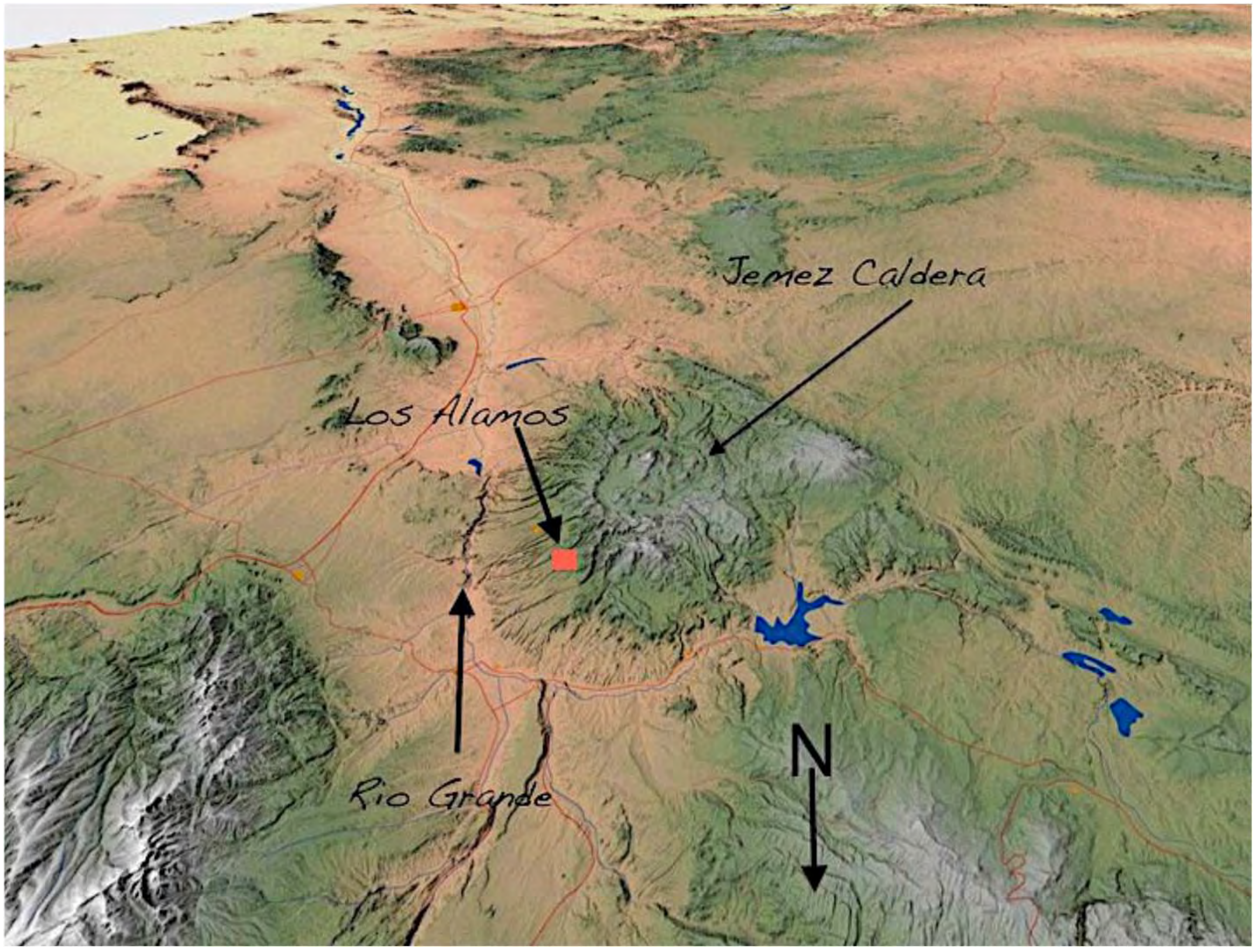
- Two-story concrete structure
- Interior shear walls divide the basement into quarters
- On the main floor, one interior shear walls does not extend to roof (i.e., incomplete lateral load-path)
- Columns and shear walls support the main-floor and roof
- Some columns extend up through the main floor and connect to roof girders
- Reinforcement in girders, columns, and their connections do not meet post-1970's-era requirements
- Loss of a column or girder would increase loads on adjacent members, leading to a progressive failure

PF-4 is close to the public



A Seismic Hazard Perspective

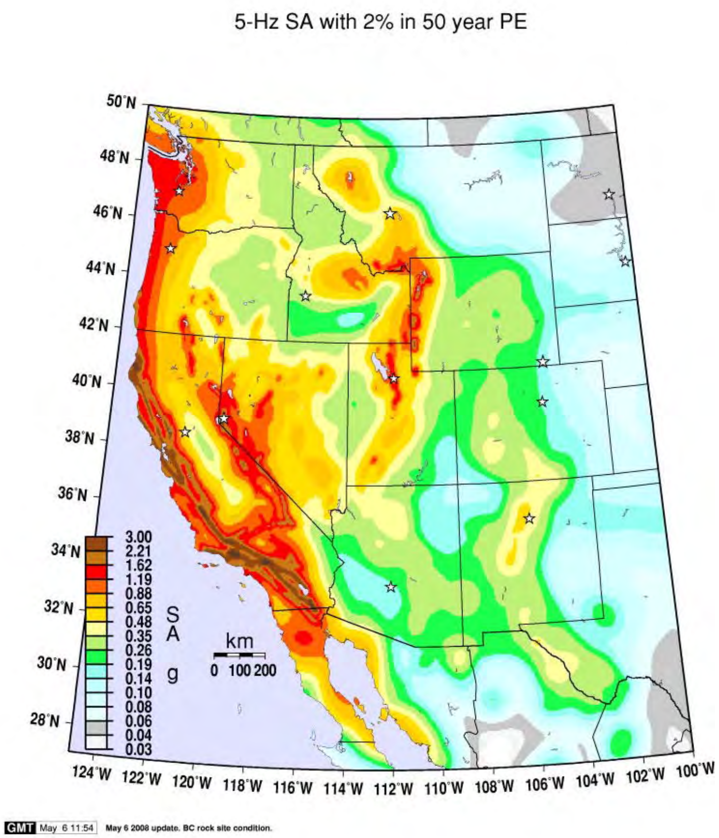
- Los Alamos is between an ancient super-volcano and the Rio Grande Rift

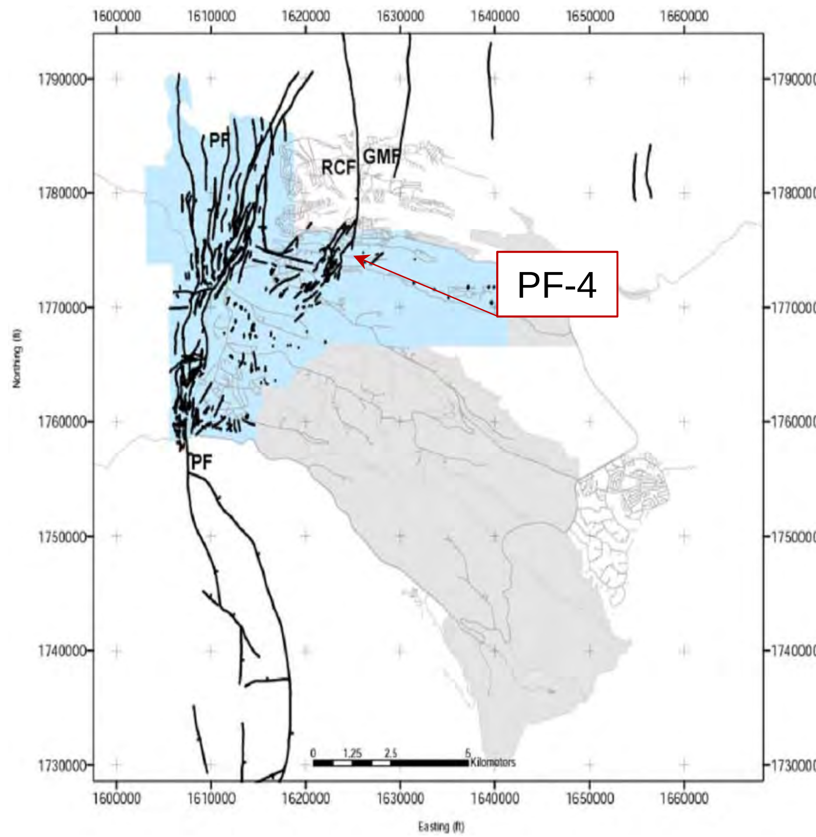


From LA-UR-22775, T. Wallace, *The Seismic Hazard of New Mexico: Earthquakes and Building Codes*

A Seismic Hazard Perspective

- Los Alamos seismic hazard is higher than some western US regions and lower than others; it is driven by the Pajarito Fault System to the west



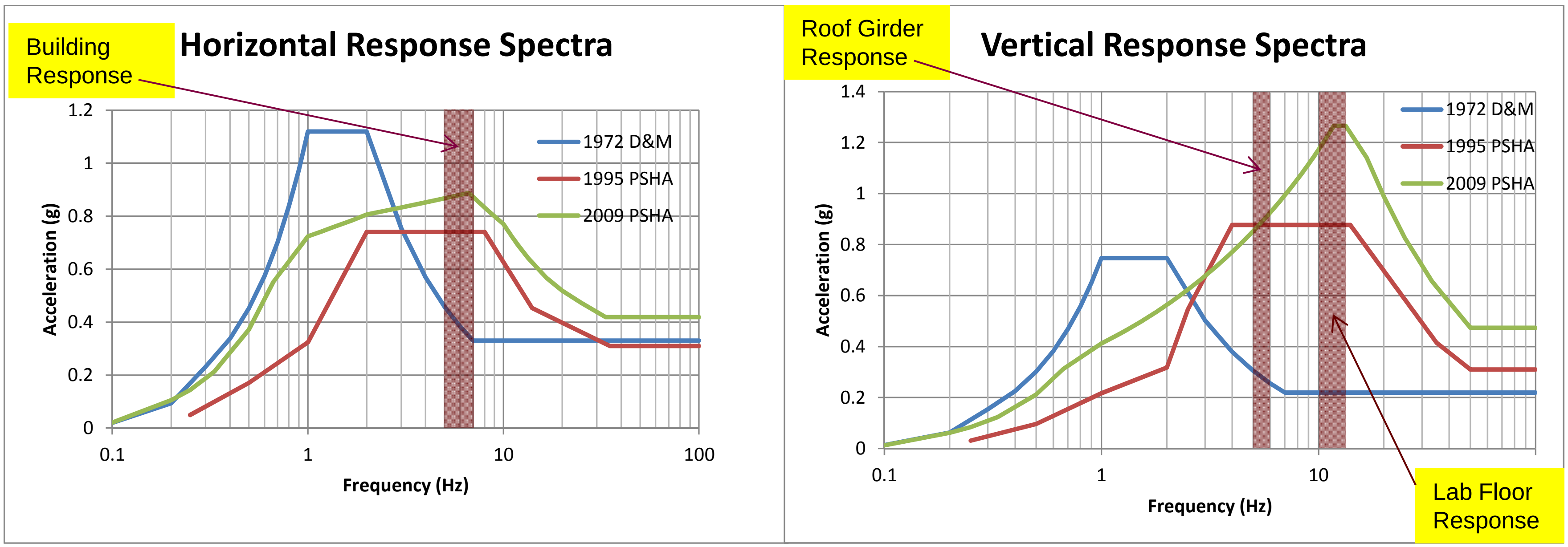


ref: USGS 2008 Seismic Hazard Maps
2% probability of exceedance in 50 years
for a 5 Hz system

ref: LA-UR-13-22775
PF: Pajarito Fault
RCF: Rendija Canyon Fault
GMF:Guaje Mountain Fault

LANL's evaluated seismic hazard has increased

- 2007 and 2009 updates to the site's Probabilistic Seismic Hazard Analysis (PSHA) resulted in higher design basis ground motion
- Because of the higher ground motion, a structural evaluation of PF-4 was required to determine whether or not there was a degradation in nuclear safety



Timeline

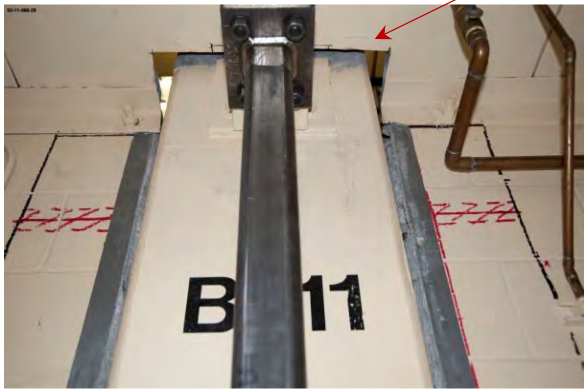
- 2007 – Update to the 1995 Probabilistic Seismic Hazard Analysis (PSHA)
- 2009 – Focused PSHA on the PF-4 location
- May 2011 – Completed linear dynamic analysis
- Oct 2011 – Completed roof (drag strut) reinforcement
- Feb 2012 – Completed remaining mod's; launched pushover analysis
- Oct 2012 – Completed first pushover analysis and fragility analysis; began alternate independent analysis
- Mar 2013 – Cleared path-forward with DOE/NNSA senior management; began design additional modifications (e.g., roof girders) with targeted completion in 2016
- Oct 2013 – Completed revision to pushover analysis
- Oct 2014 – Completed Phase 1 of the alternate analysis chartered Seismic Expert Panel to review analyses to date.

2011 – Linear dynamic analysis led to modifications

- Determined performance against national consensus codes
- Indicated need for structural modifications
- At the start, predicted failure modes had estimated probabilities of once within hundreds of years, with calculated off-site consequences of hundreds of rem
- About 3 dozen actions taken. Structural modifications included:
  - strengthening of the roof structure to resist horizontal loads (drag strut),
  - ventilation fan bases,
  - ceiling supports,
  - shield wall supports,
  - plenum structures,
  - mezzanines
- Results also indicated that nonlinear analysis was needed to understand column performance and to estimate failure probabilities

2011 modifications addressed confinement weak-links

- Mezzanines above the main floor were strengthened
- Ventilation component pads were reinforced
- Over-constrained basement columns were released
- Ceilings of basement ventilation plenum rooms were reinforced

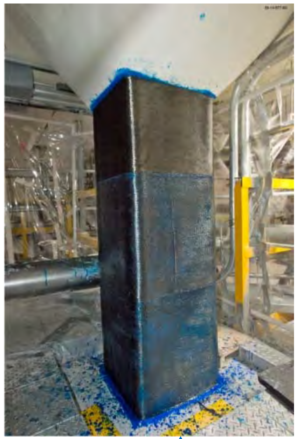


Roof modification reduced probability of collapse

- Oct 2011 roof (drag strut) reinforcement compensated for incomplete shear wall on the main floor; collects and transfers in-plane roof loads

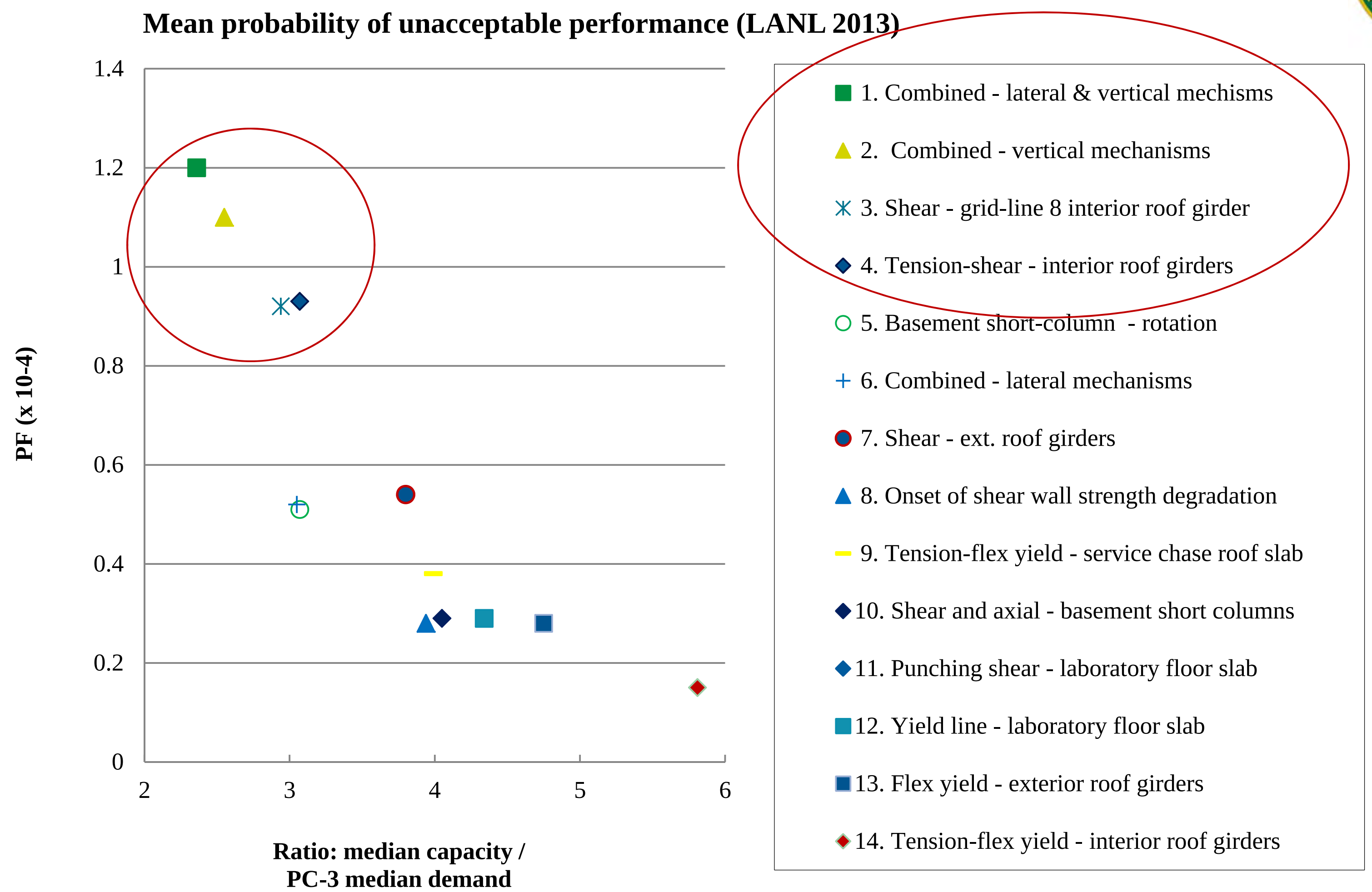
2012 – Non-linear pushover analysis identified additional modifications are needed

- The 2011 analysis identified columns and an interior shear wall as marginal.
- The Oct 2012 nonlinear pushover analysis better estimated probabilistic performance and identified other “weak links”
- Results indicated additional structural modifications were needed to meet performance requirements
  - Short columns in the basement (modification complete)
  - Interior roof girders (modification design complete)
- Probabilistic performance (probability of failure):
  - Before identified modifications: 1.2x10-4 (1 in 8,300 years)
  - With modifications complete: 0.8x10-4 (1 in 12,500 years)
  - Target Performance Goal: 1x10-4 (1 in 10,000 years)



Installation of carbon fiber wraps on short columns

2013 Update – girders are the dominant failure mode

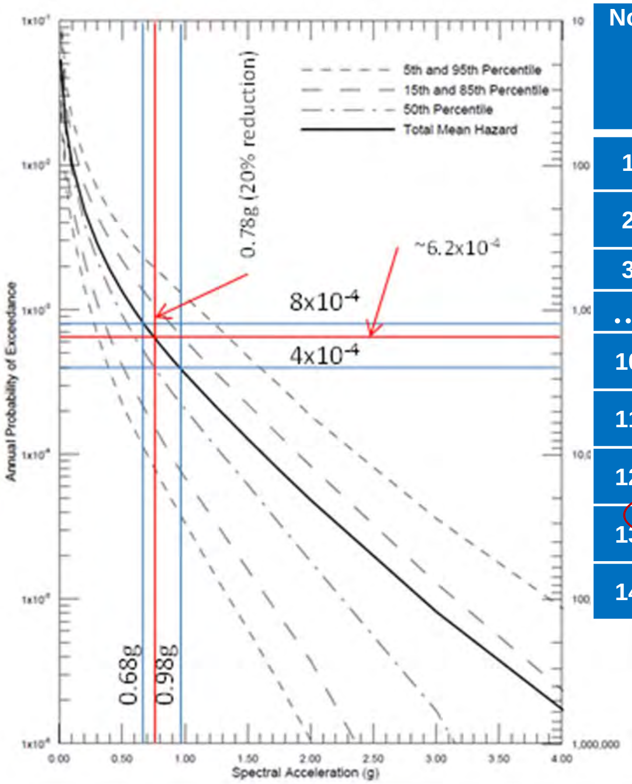


DOE permits some relief for existing facilities

- DOE Order 420.1C and DOE Standard 1020-2012 provide guidance for the evaluation of existing facilities that are close to meeting requirements:
  - *For SSCs [structures, systems, and components] which are within 10 percent of meeting the criteria in this Standard, the risk from non-compliance is likely to be small and it may not be cost effective to strengthen the SSC in order to obtain a small reduction in risk… It is permissible to perform such evaluations using natural phenomena hazard exceedance probability of twice the value (i.e., half the return period) specified for new design, provided that the resulting reduction in the hazard level is less than, or equal to, 20 percent.*
- Based on the results of the pushover analysis, LANL checked the performance of PF-4 using the allowable hazard reduction
- Check is based on alternative acceptance criteria (ASCE 43-05, Section 1.3)
  - Conditional probability of failure for the design basis ground motion (DBE) is less than or equal to 1%: and,
  - Conditional probability of failure for 1.5x the design basis ground motion is less than or equal to 10%

LANL evaluated PF-4 under DOE relief provisions

- The LANL seismic hazard curves limited the hazard-level reduction to 80%
- With this relief, as-is, PF-4 meets the alternate acceptance criteria



TA-55 Seismic Hazard Curve (Spectral Accelerations @ 5Hz)

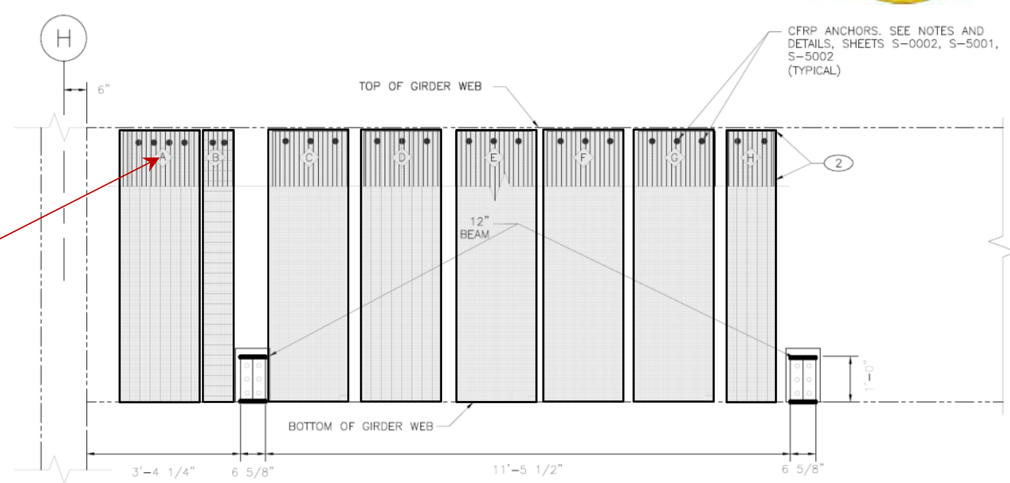
No.	Component Failure Mode	0.8xDBE*	Cond P_F** @0.8xDBE	1.2xDBE*	Cond P_F** @1.2xDBE
1	Shear failure of interior roof girder on Gridline 8 leading to collapse	0.8056	0.7%	1.2084	4.5%
2	Tension-shear failure interior roof girders leading to collapse	0.8056	0.4%	1.2084	3.0%
3	Shear failure of exterior roof girder	0.644	0.2%	0.966	1.5%
…					
10	Flexure yielding of exterior roof girder leading to large vertical displacements and possible collapse	0.644	<0.1%	0.966	0.1%
11	Tension-Flexure yielding of interior roof girder leading to large vertical displacements and possible collapse	0.8056	<0.1%	1.208	<0.1%
12	~~Probability of failure based on combined fragility of lateral and vertical failure modes.~~	0.8056	~~0.8%~~	1.2084	~~4.8%~~
13	Probability of failure based on combined fragility of vertical mechanisms	0.8056	0.8%	1.2084	4.8%
14	Probability of failure based on combined fragility of lateral mechanisms	0.6376	<0.1%	0.9564	0.7%

HOWEVER….

- PF-4 has a unique, enduring national security mission
- Controlling failure modes are non-ductile
- Collapse scenarios have high calculated off-site consequences
- Modifications within two years appear straight-forward

Design of girder modification is complete

- The modification consists of layers of carbon-fiber reinforced polymer (CFRP) where the girder meets the central wall (the H-wall)
- In addition to surface adhesion, the layers will be anchored at the top
- Minimal space for wrapping under girder
- Difficult access and interferences complicate work in the attic



Typical Elevation – Roof Girder Upgrade

An alternate analysis may identify new concerns

- In 2012, DOE/NNSA initiated a modal loading pushover analysis, by an independently engineering firm
- Reports issued in recent weeks are being evaluated; there may be new concerns (e.g., unreinforced capitals at top of basement columns)
- Preliminarily:
  - Roof girders – results appear consistent with LANL analyses but may include additional girders
  - Column capitals – vertical rebar across a construction joint may de-bond from concrete and propagate
  - Others… To Be Determined…

- By February 2015, a Seismic Expert Panel will advise on path-forward

Summary and Conclusions

- PF-4 has a unique, enduring national security mission
- Update to the Probabilistic Seismic Hazard Analysis increased seismic demand
- 2011 linear dynamic analysis indicated areas that needed to be strengthened; completed in 2012
- Nonlinear pushover analysis indicated additional improvements needed
  - Controlling failure modes are non-ductile
  - Collapse scenarios have high calculated off-site consequences
  - Short-column modifications are complete.
  - Roof girder modifications are in progress.
- An alternate analysis is underway; reports issued in recent weeks may identify a need for additional modifications
- A Seismic Expert Panel will review both sets of analyses and advise on path-forward