Seismic Performance of a Critical Nuclear Facility

2020 DOE-NRC NPH Meeting

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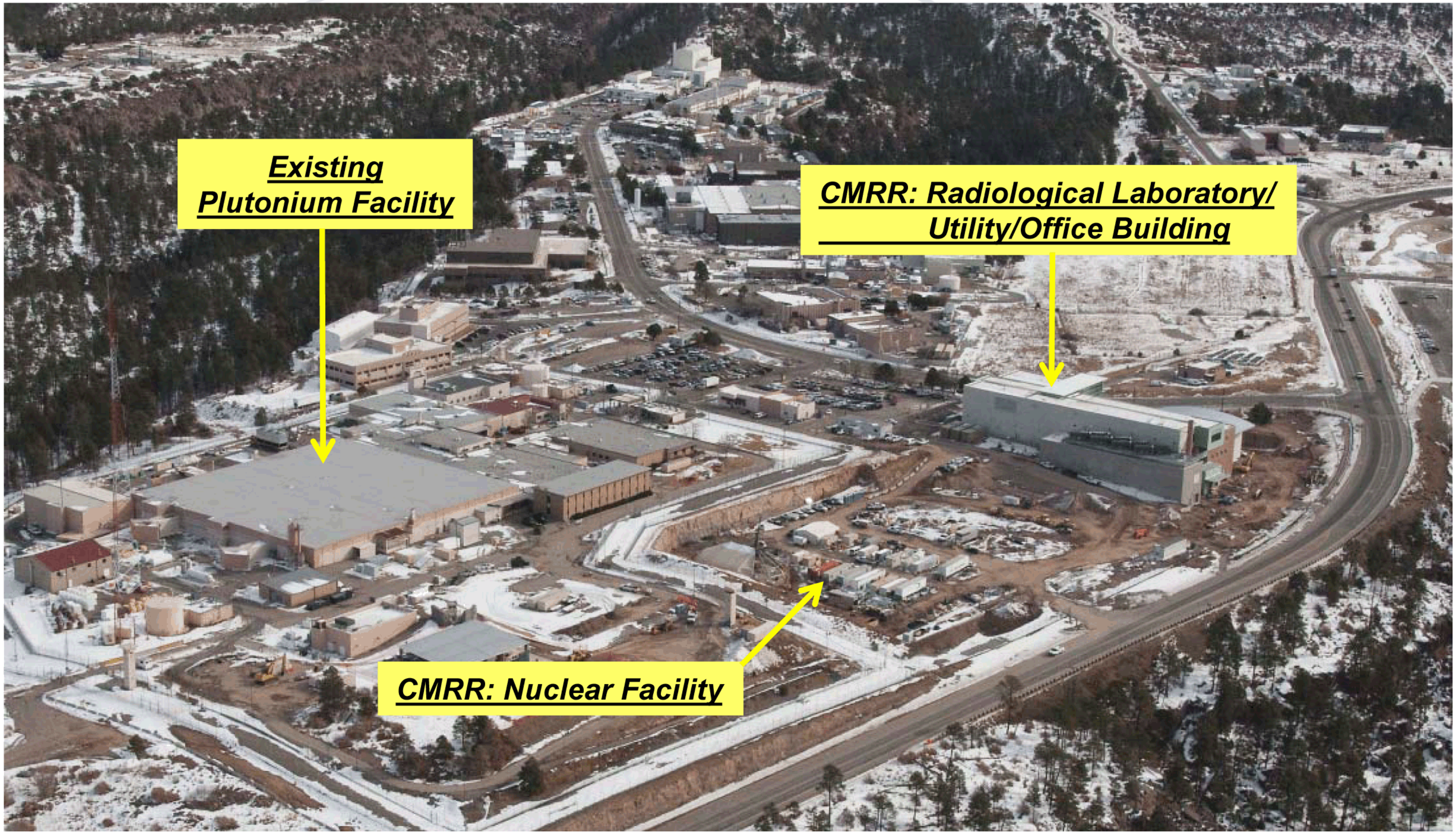
Presentation outline

- Background/Drivers
- Existing Analysis
- Existing Results
- New Framework
- Schedule

Background


Existing Plutonium Facility
CMRR: Radiological Laboratory/ Utility/Office Building
CMRR: Nuclear Facility

Previous Analyses

- **CJC & Associates (2013)**
  - Multiple Analyses
  - Development of nonlinear backbone curves based on static pushover analysis
  - Fragility parameters based on median models at DBE levels of loading
- **SGH (2014)**
  - Multiple analysis
  - Developed a multi-mode adaptive pushover model
  - Did not quantify failure rates

Table 2 – Results of PF-4 Nonlinear Analyses and Fragility Evaluation (Ref. 10)

No.	Component Failure Mode	DBE* (g)	Med. Cap. /DBE	Variability (β)	P_F (x 10^{-4})
1	Shear failure of interior roof girder on Gridline 8 leading to collapse	1.007	2.94	0.53	0.92
2	Tension-shear failure interior roof girders leading to collapse	1.007	3.07	0.50	0.80
3	Shear failure of exterior roof girder	0.805	3.80	0.53	0.54
4	Exceed captured Type V column rotation limit and possible collapse (Basement Columns Embedded in Vault Walls)	0.797	3.07	0.29	0.51
5	Tension-flexure yielding of Service Chase roof slab leading to large vertical displacements and possible collapse	1.160	3.99	0.43	0.38
6	Punching shear failure of laboratory floor slab leading to collapse	1.220	4.10	0.30	0.31
7	Loss of axial load capacity for captured Type V columns following a shear failure leading to collapse. (Basement Columns Embedded in Vault Walls)	0.797	4.05	0.37	0.29
8	Formulation of a yield line mechanism in the laboratory floor slab with large vertical displacements possibly leading to collapse.	1.220	4.34	0.35	0.29
9	Onset of shear wall strength degradation	0.797	3.94	0.32	0.28
10	Flexure yielding of exterior roof girder leading to large vertical displacements and possible collapse	0.805	4.75	0.45	0.28
11	Tension-Flexure yielding of interior roof girder leading to large vertical displacements and possible collapse	1.007	5.81	0.41	0.15
12	Probability of failure based on combined fragility of lateral and vertical failure modes.	1.007	2.33	0.37	1.21
13	Probability of failure based on combined fragility of vertical mechanisms	1.007	2.67	0.46	1.04
14	Probability of failure based on combined fragility of lateral mechanisms	0.797	3.07	0.29	0.53

*Design Basis Earthquake ground motion expressed as the spectral acceleration in terms of the acceleration due to gravity at the frequency that dominates the response of the element/system.

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Previous Analyses

- **Seismic Experts Panel**
  - Looked at “similarities and differences” in two sets of existing analysis
  - Published findings in 2015 report
- **Prudent Actions**
  - Increase shear capacity of all interior roof girders
  - Increase shear capacity of roof girder at line 8
  - Conduct limited physical test of slab-capital-column systems to simulate gravity and severe earthquake effects
- **Required Actions**
  - Inspect tops of columns for potential shear cracking under gravity loads
  - Inspect sliding joint detail in service chase
  - Understand rotational restraint provided by service chase corridor
  - Post live loads limits
- **Observations**
  - **Nonlinear response-history analysis should be used for future fragility or risk assessments for complex structures such as PF-4.**
  - We see no need to perform another vulnerability assessment of PF-4 at this time.

Independent Review of Seismic Performance Assessments for the Plutonium Facility PF-4

Los Alamos National Laboratory, Los Alamos, NM

Prepared for

Los Alamos National Laboratory
National Nuclear Security Administration
Department of Energy

Prepared by

Dr. Robert Kennedy
Dr. Brian McDonald
Dr. Troy Morgan
Dr. Andrew Whittaker (Chair)
Mr. Loring Wyllie
Mr. Lawrence Goen

Rev 1
October 2, 2015

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P-SPRaP

- NLDA – Non-Linear Dynamic Analysis
- SPR – Seismic Performance Reassessment
- Why do we need this?
  - 2015 NNSA directed LASO to conduct a nonlinear dynamic analysis of PF-4
  - NNSA made a commitment to DNFSB

Department of Energy
National Nuclear Security Administration
Washington, DC 20585
August 18, 2015

The Honorable Joyce L. Connery
Chairman
Defense Nuclear Facilities Safety Board
625 Indiana Avenue, NW, Suite 700
Washington, DC 20004

Dear Madam Chair:

This letter is to inform you of our next steps regarding improvements in PF-4's seismic performance following release of the Seismic Expert Panel's report, *Independent Review of Seismic Performance Assessments for the Plutonium Facility, PF-4*.

I transmitted the enclosed memorandum to the Los Alamos Field Office requesting it to direct Los Alamos National Lab to update their plan to address the remaining PF-4 seismic issues, considering the costs and benefits of additional design upgrades as well as addressing the schedule for a future safety basis update. In addition, I have asked that a team be formed to develop a Request for Proposal that NA-50 would use to solicit cost, scope, and schedule for a dynamic non-linear analysis of selected aspects of PF-4.

Our path forward to understand and ensure appropriate seismic margin for this vital, enduring facility will continue to mature as start dates and completion timelines are developed for follow-on actions. My office will continue to inform your staff of refinements and schedules associated with this path forward.

If there are any questions, please contact the Acting Deputy Associate Administrator for Safety, Jeffry Roberson, at 301-903-9228.

Sincerely,

James J. McConnell
Associate Administrator
for Safety, Infrastructure & Operations

Enclosure

cc: J. Olencz, AU-1.1
K. Lebak, NA-LA

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P-SPRaP = NLDA + SPR

- Objective – "*To obtain a state-of-the-art seismic performance analysis of PF-4 (as upgraded), with results that can be compared to the alternate criteria of ASCE/SEI 43-05 and the DOE STD 1020 Target Performance Goal. The analysis would build upon the four seismic performance analyses accomplished during the last five years to further improve understanding of and confidence in PF-4's long-term seismic performance.*"
- *Jim McConnell to Kimberly LeBak (Manager, NA-LA), 2015*

Drivers

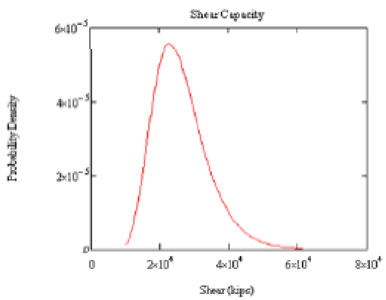
- DOE O 420.1c
- DOE STD 1020
- NNSA Commitment toward ongoing seismic safety improvements
- The Project consists of a number of subprojects
  - Nonlinear Dynamic Response History analysis of PF-4
  - Computation of Probabilistic Seismic Demand
  - Update of Seismic Fragilities
  - Performance Computation
  - Generation of Time Histories
- Seismic Performance is measured against Performance Goals in ASCE 43-05

TABLE 1-3. Target Performance Goals for SDCs

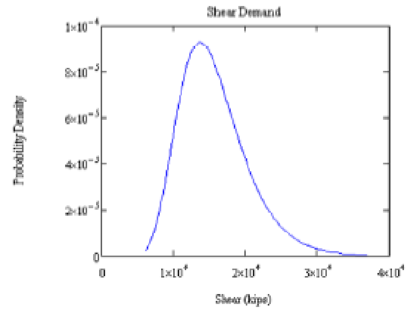
SDC	Target Performance Goal (P_F)
1	$(< 1 \times 10^{-3})$*
2	$(< 4 \times 10^{-4})$ *
3	$\sim 1 \times 10^{-4}$
4	$\sim 4 \times 10^{-5}$
5	$\sim 1 \times 10^{-5}$

Notes:
*Working Group's assessment of performance goals approximately achieved by building codes.
Shaded boxes, SDC 1 and 2, are not addressed in this Standard.

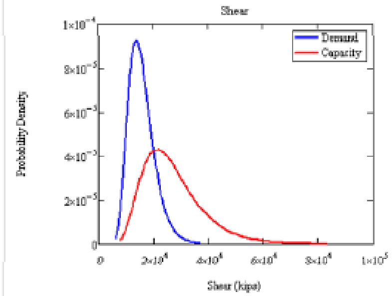
New Framework



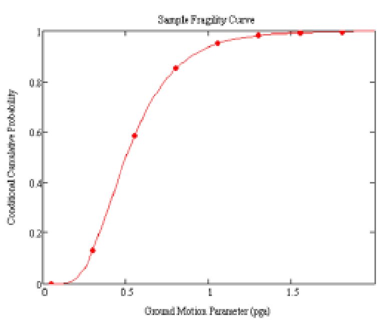
Step 1 – Assign PDF to Identified Failure Mode



Step 2 – Derive Distribution of Demand for Given APE Event



Step 3 – Compute Pf for Given APE Event



Step 4 – Construct Mean Fragility Curve

$$P_f = -\int_0^{\infty}\left(\frac{dH(a)}{da}\right)P_{F|a}(a)da$$

Or·¶

$$P_f = \int_0^{\infty} H(a)\left(\frac{dP_{F|a}(a)}{da}\right)da$$

Step 5 – Convolve Fragility with Hazard to Compute Performance

Note – Steps 1 -3 are repeated M times, for M ground motion levels

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NLDA + SPRaP

- Why are we confident in favorable results?
  - NLDA Phase 1 shows us that system nonlinearities significantly affect engineering demand parameters (EDPs) and reduce risk
  - Risk in the context of DOE O 420.1c, DOE STD-1020-2016, ASCE 43-05 is measured in terms of annual seismic induced failure

Seismic Hazard: how likely is ground motion at a particular site

Seismic Performance – Mean annual probability of failure (exceeding some limit state)

$$P_F = \sum_{i=1}^{\infty} P_{F|a_i}\left(P_{a_i}\right)$$

Seismic Fragility: what is the probability of failure for a given ground motion

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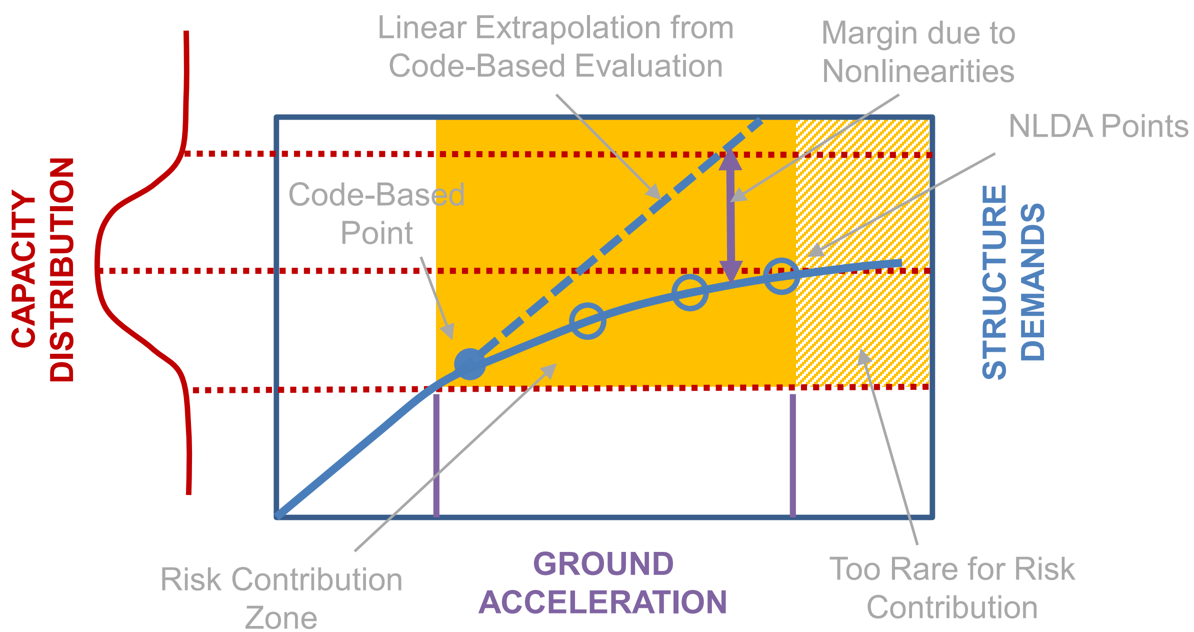
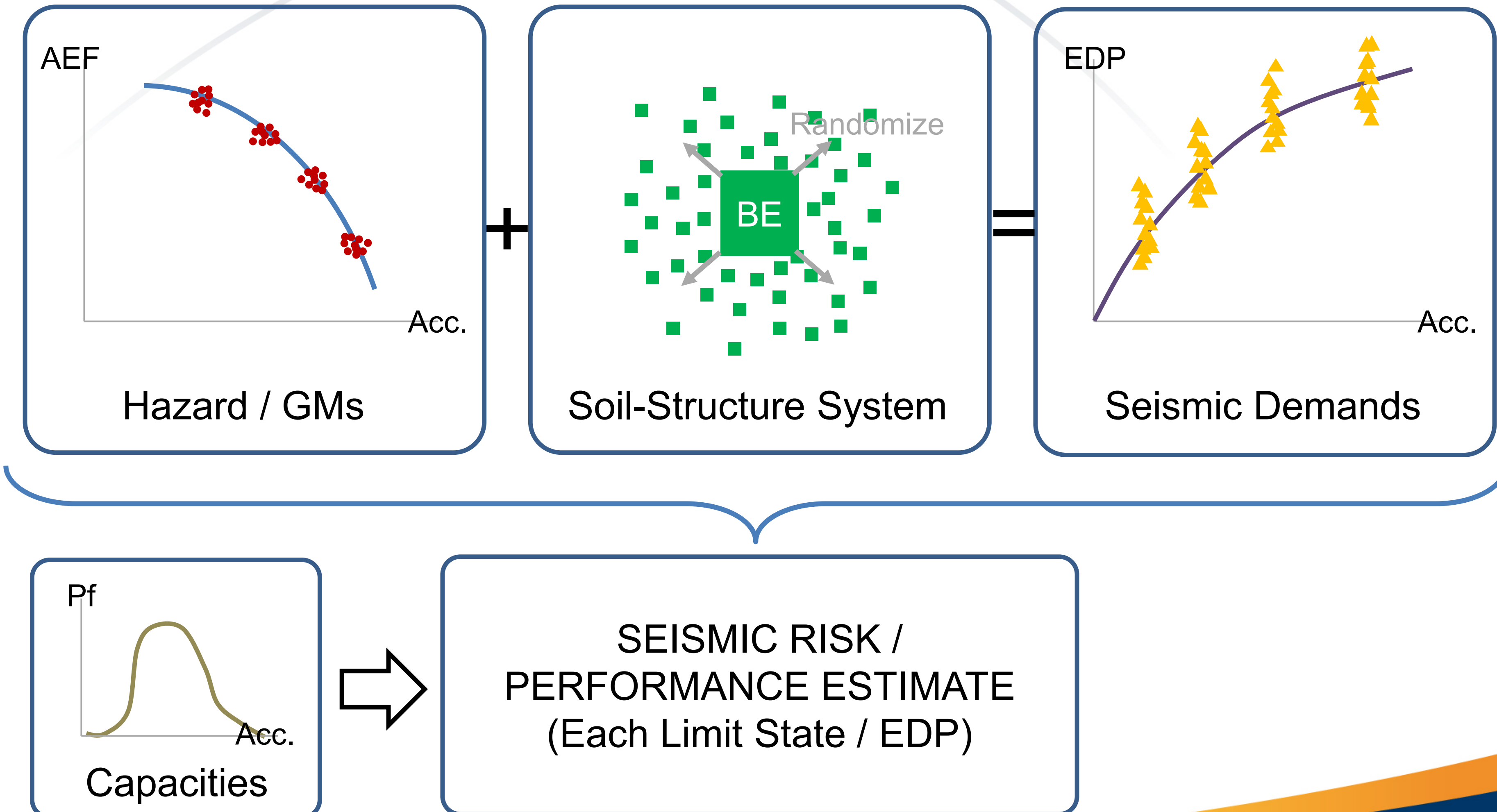
NLDA + SPRaP

- Why are we confident in favorable results?
  - NLDA Phase 1 shows us that system nonlinearities significantly affect engineering demand parameters (EDPs) and reduce risk:



Approach for Final Risk



Summary of Project: Integrated Approach NLDA and Performance Re-assessment

- Guiding Principles
  - Plan for necessary end-use of NLDA from beginning (think ahead)
  - Collaboration across LANL, INL, and sub-contractors (leverage expertise)
  - Build consensus across stakeholders with incremental milestones (transparency)
  - Leverage prior DOE/NNSA investments in modern techniques and knowledge (build upward)
- Phased Approach
  - *NLDA* Phase I (April 2020)
    - Finalize modeling details (technical studies – finished)
    - Build and debug baseline model (Finished)
    - Obtain agreement from technical project team on approach
  - *NLDA* Phase II (Q1, 2022)
    - Development of simulated cases at various ground motion levels
    - Execute analysis runs, extract seismic demands
  - *SPR* Phase III (Q4, 2023)
    - Update seismic fragilities corresponding to seismic demands
    - Convolve fragilities with hazard
    - Verify seismic performance achieved

NLDA + SPR

- How can NNSA use this at other facilities?
  - Majority of NNSA facilities were built coincident to maturation of seismology and earthquake engineering (60s-80s). Legacy methods can only go so far in evaluating beyond design capacity.
  - P-SPRaP methods allow one to quantify and credit performance margin that was previously recognized but had to be neglected.
  - P-SPRaP methods are a lifeline for widespread NNSA facilities: Avoid unnecessary and costly upgrades to facilities that can be shown to meet target performance goals.
  - DOE/NNSA have invested millions in R&D of the methods applied to P-SPRaP. Time to put it in practice to benefit the facilities.

Acknowledgments

Office of
ENVIRONMENT, HEALTH, SAFETY & SECURITY

Jim McConnell, Associate Administrator for Infrastructure and Operations

National Nuclear Security Administration

Theodore Wyka, Principal Deputy Associate Administrator for Safety, Infrastructure and Operations

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