Natural Phenomena Hazards (NPH) Implications for DOE Nuclear Facilities

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Overview

- Step through five lessons learned as related to natural hazard analysis
- Lessons track with IAEA preliminary findings
- Will show examples to illustrate approaches to addressing the lessons
- Goal is to provide a basis for path forward: subject of tomorrow's break-out session

Context for Lessons Learned

- Not based on a detailed knowledge of Japan's practices regarding NPH and specific application at Fukushima-Daiichi
- Some conclusions come from IAEA review, others from personal observation
- Not a statement that "Japan did it wrong"
- Not a statement that "DOE does it right"
- Lessons reinforce observations made previously from other events
- Goal: enhance our practices and safety

IAEA Preliminary Conclusions

IAEA

International Atomic Energy Agency

IAEA INTERNATIONAL FACT FINDING EXPERT MISSION OF THE NUCLEAR ACCIDENT FOLLOWING THE GREAT EAST JAPAN EARTHQUAKE AND TSUNAMI

Tokyo, Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and Tokai NPP, Japan

24 May- 1 June 2011

Preliminary Summary

NPH Lessons Learned

- Lesson #1: Probabilistic hazard criteria should be explicit and risk-informed
  - Risk definition
  - Performance goals provide foundation for design hazard levels

Hazard

–Rate of ground motions, expressed as annual frequency

X

Consequence

–Response or loss given a certain level of hazard

=

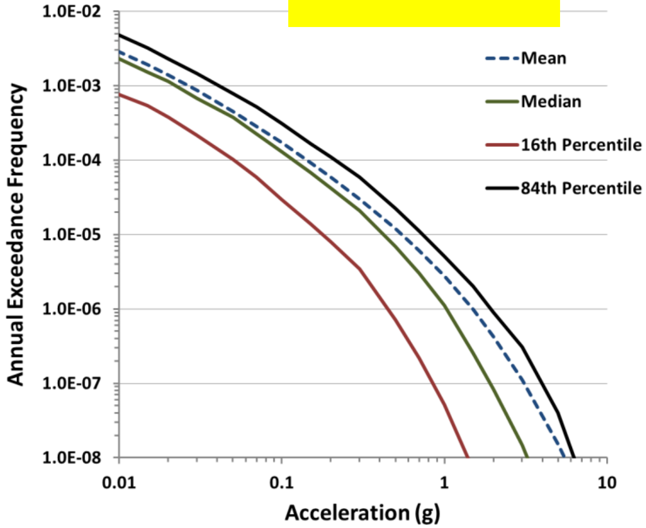
Risk

–Rate of loss, expressed as annual frequency

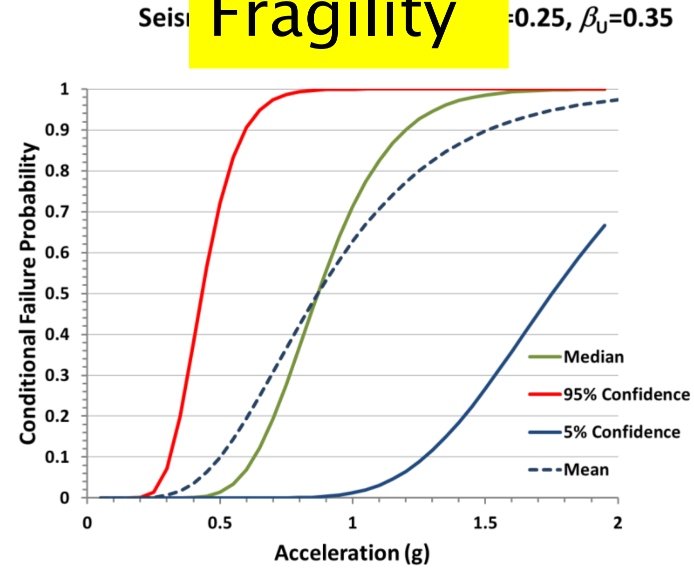
Risk Definition

- Risk is expressed as *rate* of loss, which comes from the probabilistic treatment of the hazard
- Rate (annual frequency, probability, chances) is essential to meaningful expression of risk
- Otherwise, consequence is not qualified by its chances of occurring

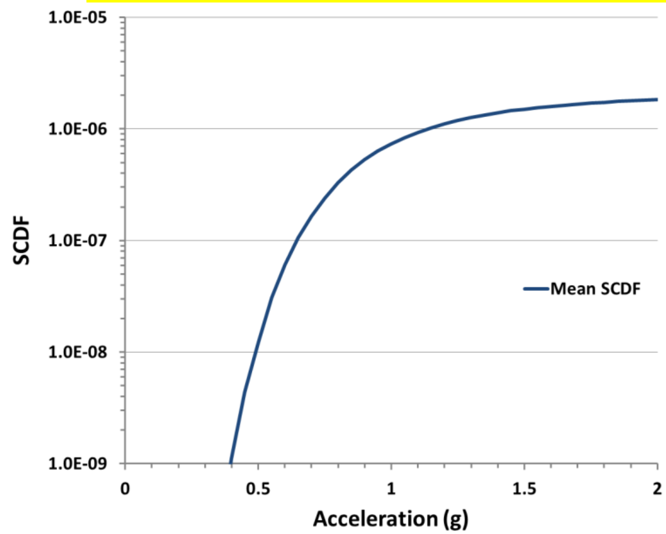
Hazard



Fragility



Mean Seismic CDF



Probabilistic Seismic Hazard Analysis (PSHA)

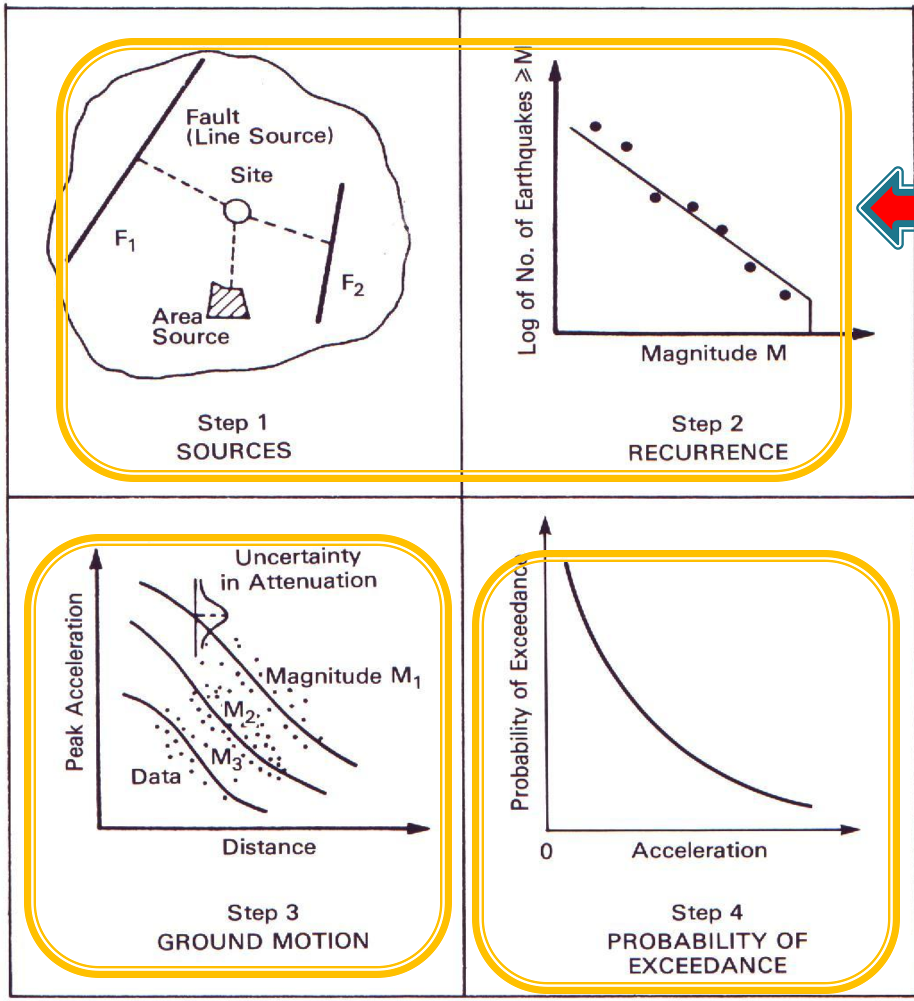
Seismic Source Characterization: SSC Model

Source Geometry

Earthquake Recurrence

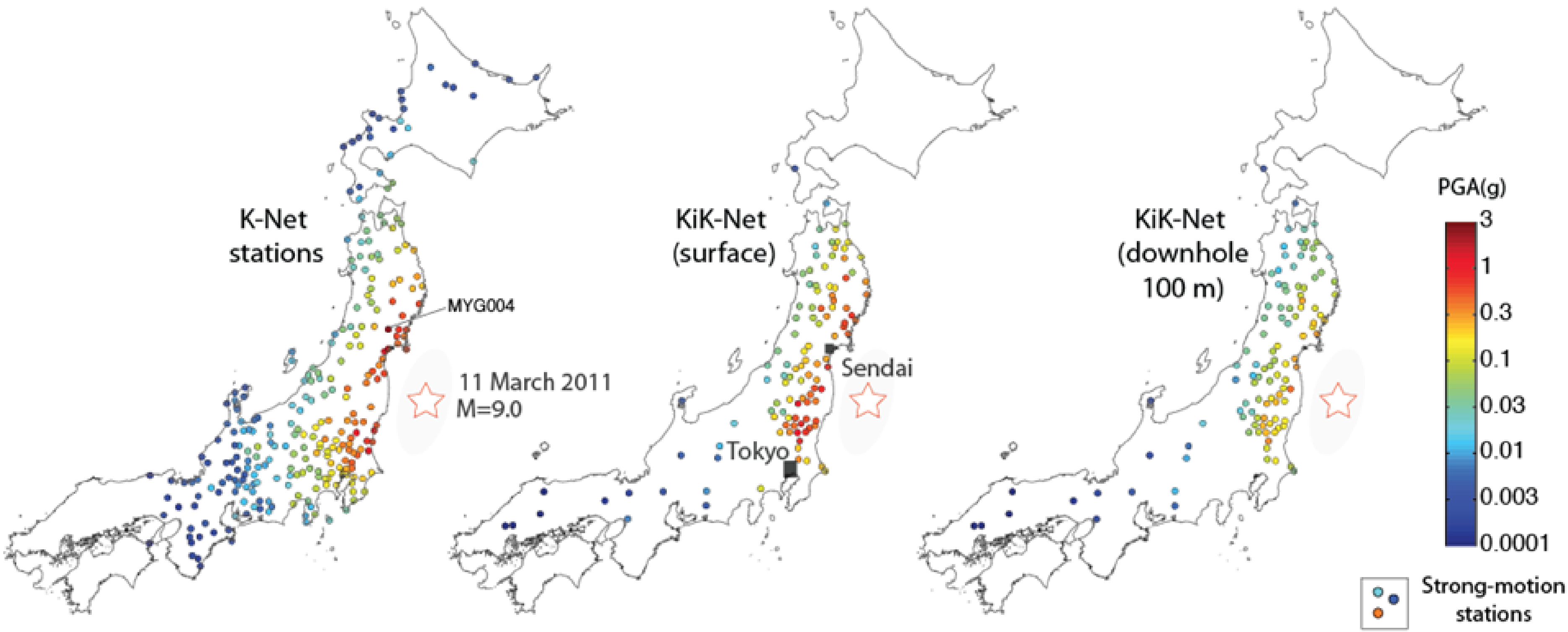
Ground Motion Characterization: GMC Model

Seismic Hazard Curve

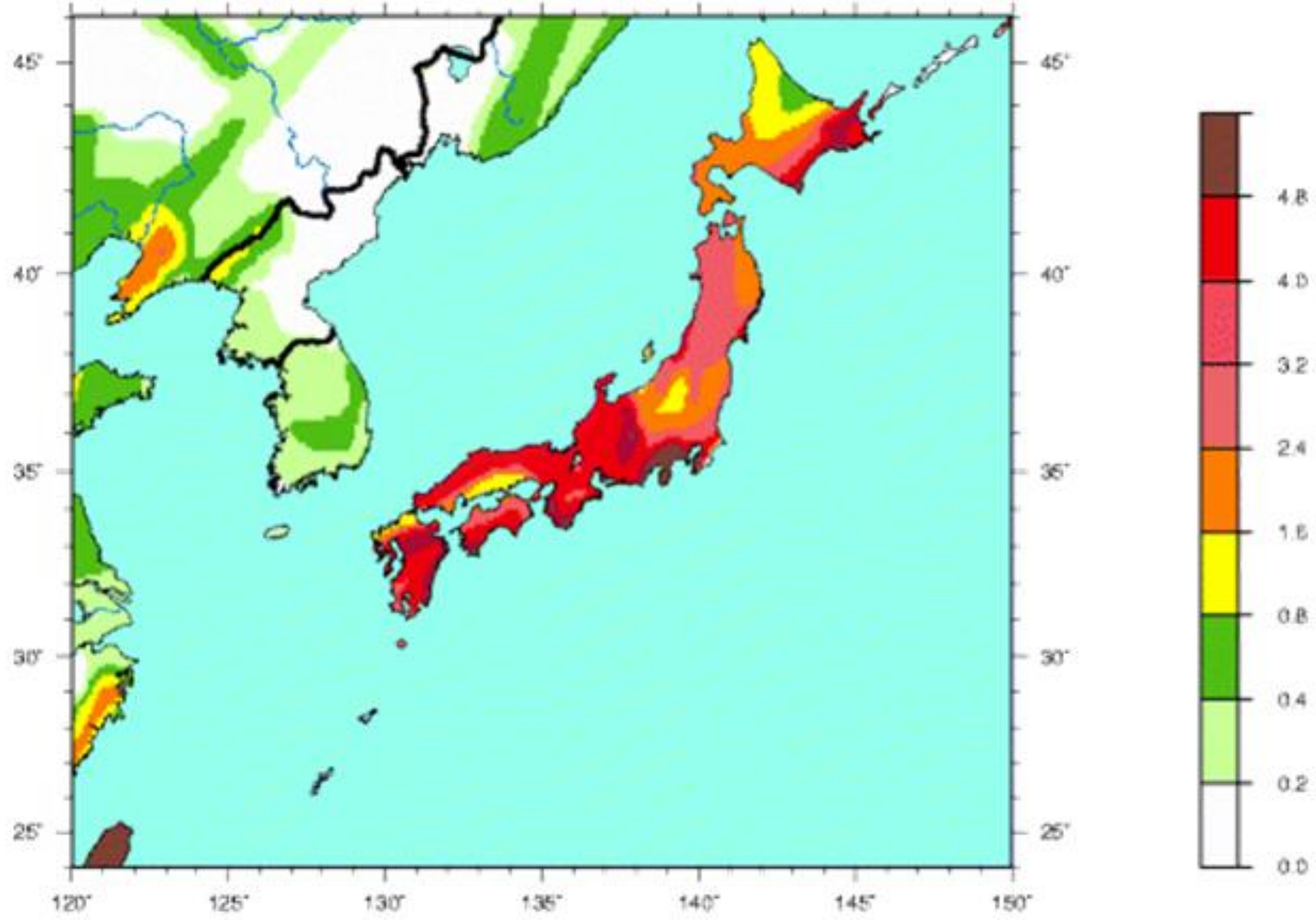


Reiter (1990)

Peak Ground Motion Acceleration (PGA) of the 11 March 2011 Tohoku M=9.0 earthquake



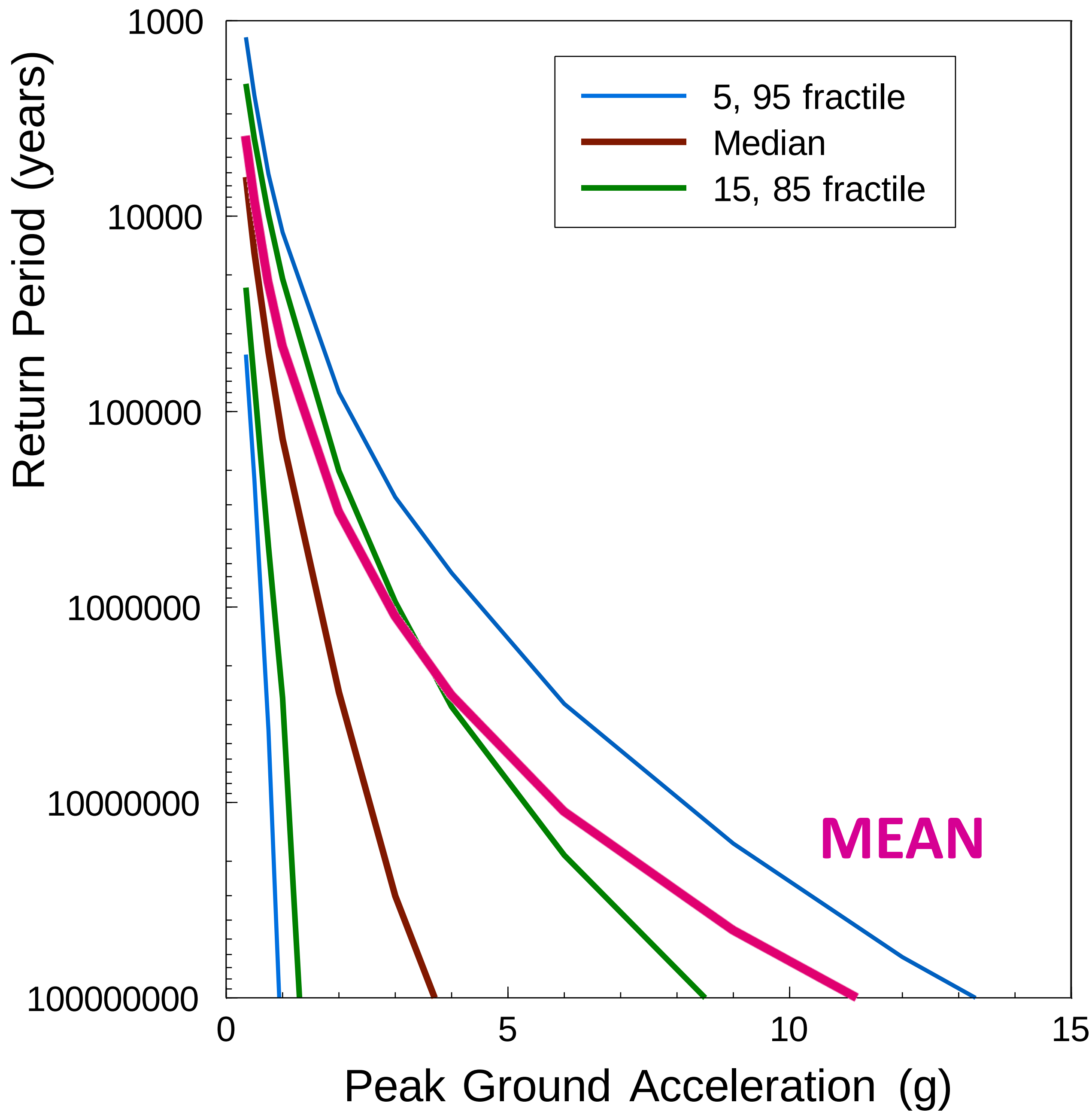
Maximum PGA of 2.7g was recorded at Miyagi Prefecture



Peak Ground Acceleration (m/s²) with 10% Probability of Exceedance in 50 Years

Probabilistic Hazard Approach

- Explicitly incorporates the rate of occurrence
- Provides for the incorporation of uncertainties
- Mean hazard has become the metric of interest
- Lognormal distribution of seismic hazard is skewed, thus mean is usually well above the median



Where do we enter the mean hazard curve for design?

DOE

Variety of nuclear facilities

- **DOE Order (O) 420.1C,** *Facility Safety*
- **DOE-STD-1020-2002:** *NPH Analysis and Design Criteria*
- **ANSI/ANS-2.26-2004,** *Categorization of Nuclear Facility Structures, Systems, and Components for Seismic Design.*
- **ANSI/ANS-2.27-2008,** *Criteria for Investigation of Nuclear Facility Sites for Seismic Hazard Assessment*
- **ANSI/ANS-2.29-2008,** *Probabilistic Seismic Hazards Analysis*

NRC

Nuclear power plants

- **10 CFR 100.23** *Geologic and Seismic Siting Criteria*
- **10 CFR Part 50**, App. S, *Design Bases for Protection Against Natural Phenomena*
- **RG 1.208** *A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*
- **NUREG/CR-6728:** *Risk Consistent Design Spectra*
- **NUREG/CR-6372**: *PSHA: Guidance on Uncertainty and Use of Experts*

ASCE/SEI Standard-43-05

Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities

ASCE/SEI Standard 43-05

- Performance-based approach to ensure facility achieves desired performance
- Tells us where to enter the mean hazard curve to achieve a desired performance objective and, in turn, to mitigate defined dose consequence

ASCE/SEI Standard 43-05 (cont'd.)

Table 2-1 Seismic Design Basis (SDB)

SDC	Limit State			
	A Large Permanent Distortion (Short of Collapse)	B Moderate Permanent Distortion	C Limited Permanent Distortion	D Essentially Elastic
1	SDB-1A	SDB-1B	SDB-1C	SDB-1D
2	SDB-2A	SDB-2B	SDB-2C	SDB-2D
3	SDB-3A	SDB-3B	SDB-3C	SDB-3D
4	SDB-4A	SDB-4B	SDB-4C	SDB-4D
5	SDB-5A	SDB-5B	SDB-5C	SDB-5D

SDC is the Seismic Design Category

Nuclear Power Plants

ASCE/SEI Standard 43-05 (cont'd.)

Table 2-2 Earthquake Design Parameters for SDC 3, 4 & 5

	SDC		
	3	4	5
Target Performance Goal (P_F)	1×10^{-4}	4×10^{-5}	1×10^{-5}
Probability Ratio (R_P)	4	10	10
Hazard Exceedance Probability (H_D) $H_D = R_P \times P_F$	4×10^{-4}	4×10^{-4}	1×10^{-4}

FOSID Criterion in RG 1.208 Achieves SCDF of ~10^{-6}

IAEA: Regulatory Process

- *Nuclear regulatory systems …should ensure that regulatory independence and clarity of roles are preserved in all circumstances in line with IAEA Safety Standards.*
  - –IAEA, 2011

NPH Lessons Learned

- Lesson #2. An explicit, open process should be used in conducting hazard analyses and defining design bases
  - The public is represented by regulators and review groups
  - Regulatory confidence is essential to public trust
  - DOE, NRC, and utilities have developed guidance for conducting hazard analyses:
    - NUREG/CR-6372: Senior Seismic Hazard Analysis Committee (SSHAC)
    - ANSI/ANS-2.29-2008: Probabilistic Seismic Hazard Analysis

What is a SSHAC process?

A structured framework and procedure for conducting multiple-expert assessments of input to PSHA

NUREG/CR-6372
UCRL-ID-122160
Vol. 1

Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts

Main Report

Prepared by
Senior Seismic Hazard Analysis Committee (SSHAC)
R. J. Budnitz (Chairman), G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, P. A. Morris

Lawrence Livermore National Laboratory

Identical process given in ANSI/ANS-2.29-2008

Procedures defined by the Senior Seismic Hazard Analysis Committee (SSHAC)

Prepared for
U.S. Nuclear Regulatory Commission
U.S. Department of Energy
Electric Power Research Institute

Key Features of a SSHAC Process

Goals:

1. Systematic consideration of all data, models, and methods within the larger technical community
2. Represent the center, body, and range of technically defensible interpretations

SSHAC Provides an Accepted Assessment Process

- SSHAC formed to deal with issues of common concern to multiple users of PSHA: NRC, DOE, and EPRI
- Four Study Levels: Levels 3 and 4 for nuclear facilities
- Regulatory Guide 1.208
- ANSI/ANS-2.29-2008
- Detailed implementation guidance for SSHAC Level 3 and 4 projects being developed by NRC

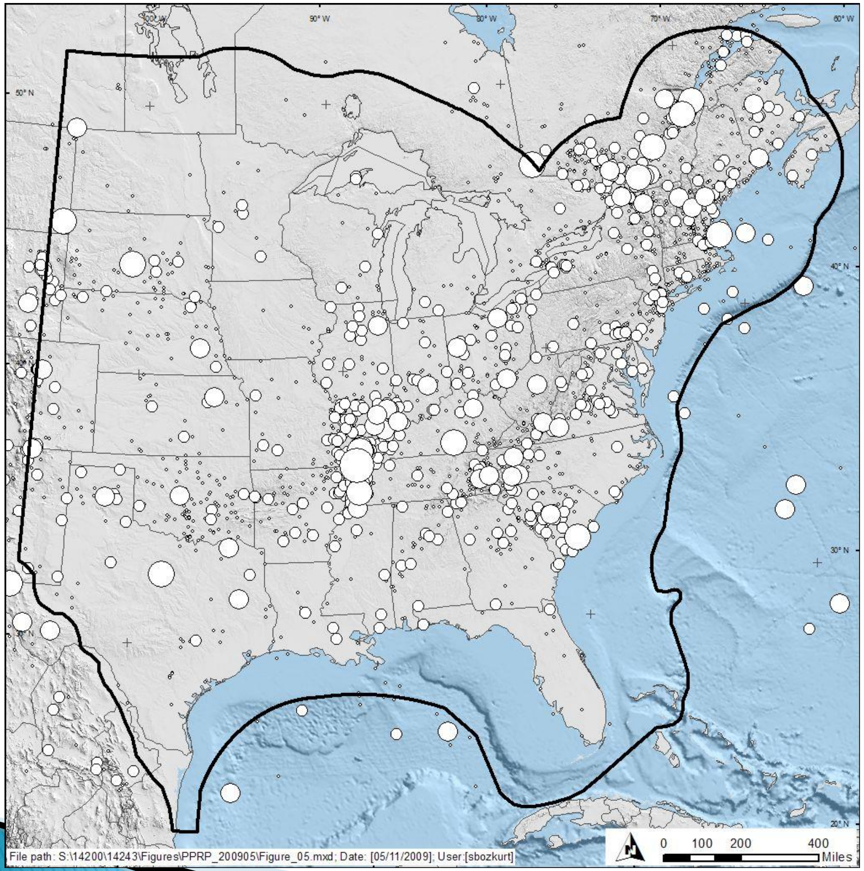
NUREG-XXXX

Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies

Draft for Comment

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

Central and Eastern United States Seismic Source Characterization for Nuclear Facilities Project



U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

U.S. DEPARTMENT OF ENERGY

EPRI

CEUS SSC for Nuclear Facilities (2008-2011)

- Purpose: to provide a ***regional seismic source model*** for use in PSHA for nuclear facilities
- Replaces previous regional seismic source models developed by industry and NRC
- SSHAC Level 3 methodology: high confidence that uncertainties have been properly addressed and that the views of the technical community have been considered.

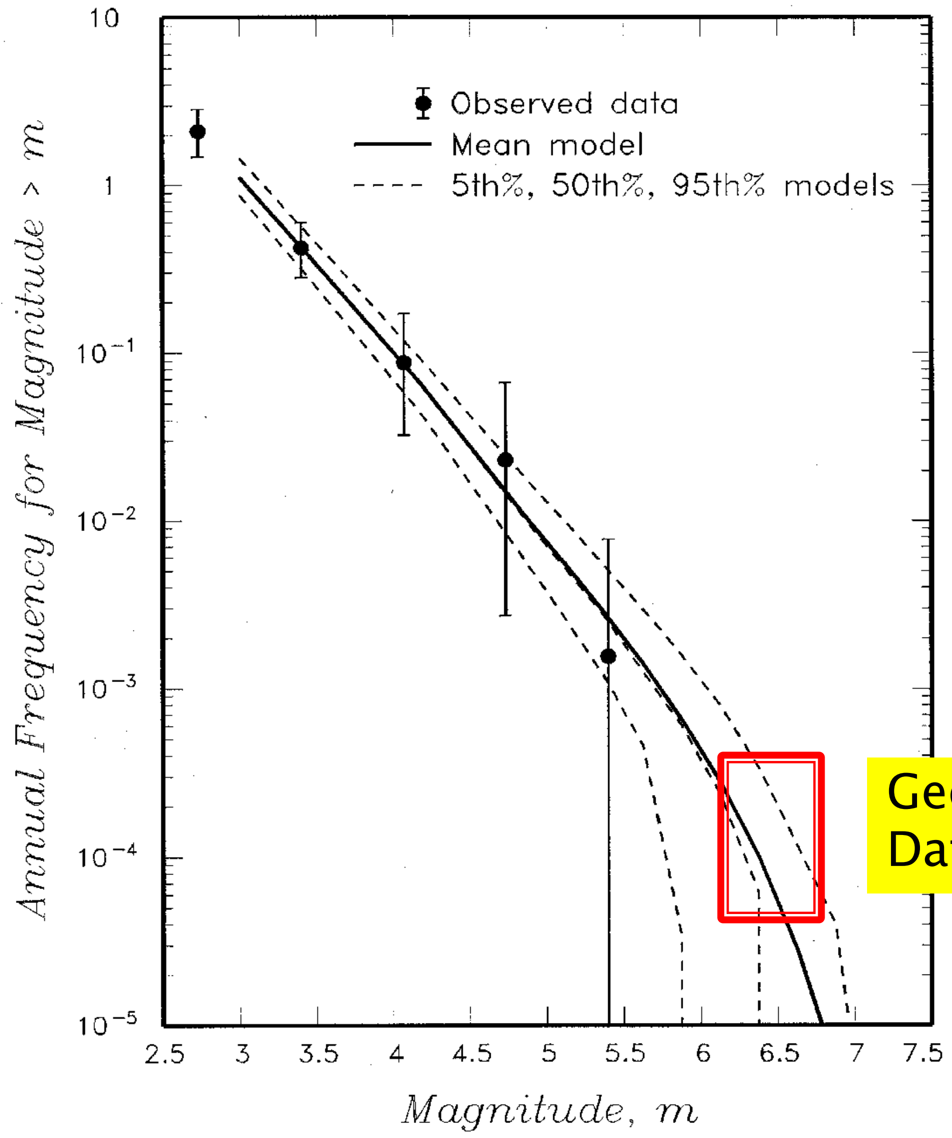
IAEA: Rare Events

- *Nuclear regulatory systems should address extreme external events adequately, including their periodic review…in line with IAEA Safety Standards.*
  - –IAEA, 2011

NPH Lessons Learned

- Lesson #3. The full suite of historical and prehistorical occurrences should be considered in the hazard analysis; uncertainties should be incorporated

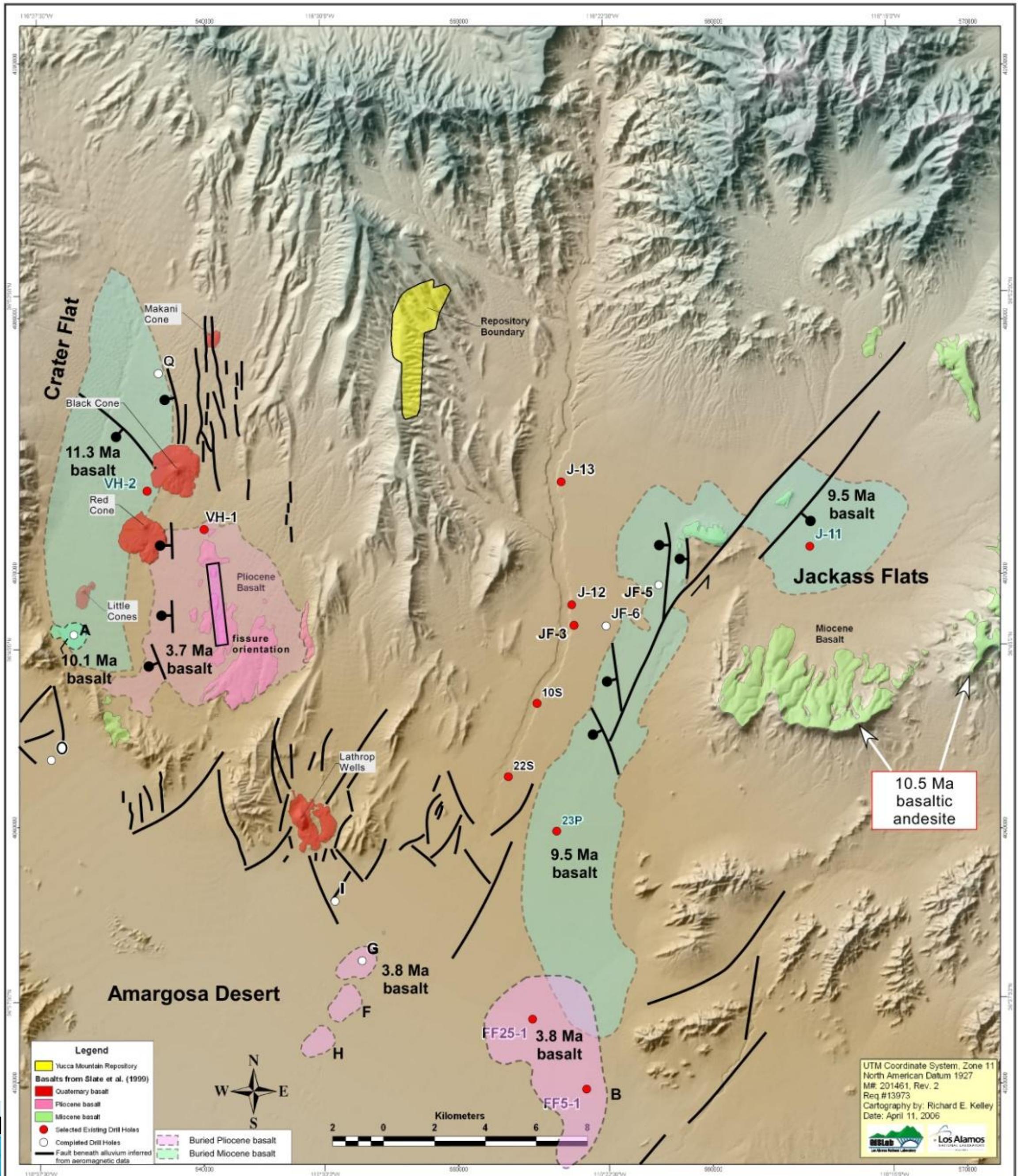
Comparison of observed earthquake frequency with predicted recurrence rates



Geologic Data

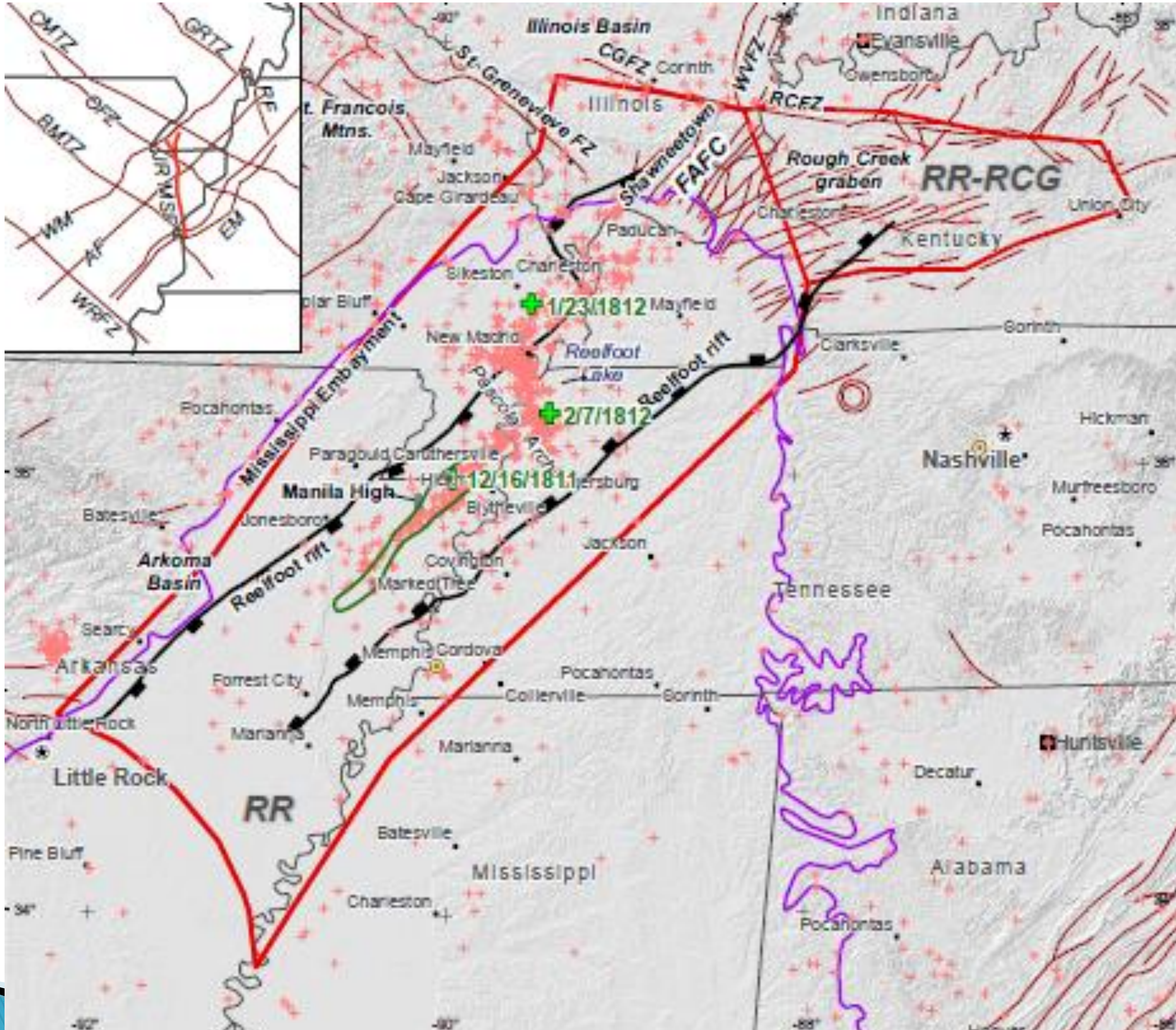
Implications for US

- Most of US has short historical record (<250 yrs)
- Most is low activity
- Probability that have seen extreme, rare events is low
- Increasing reliance on geologic record and physical models

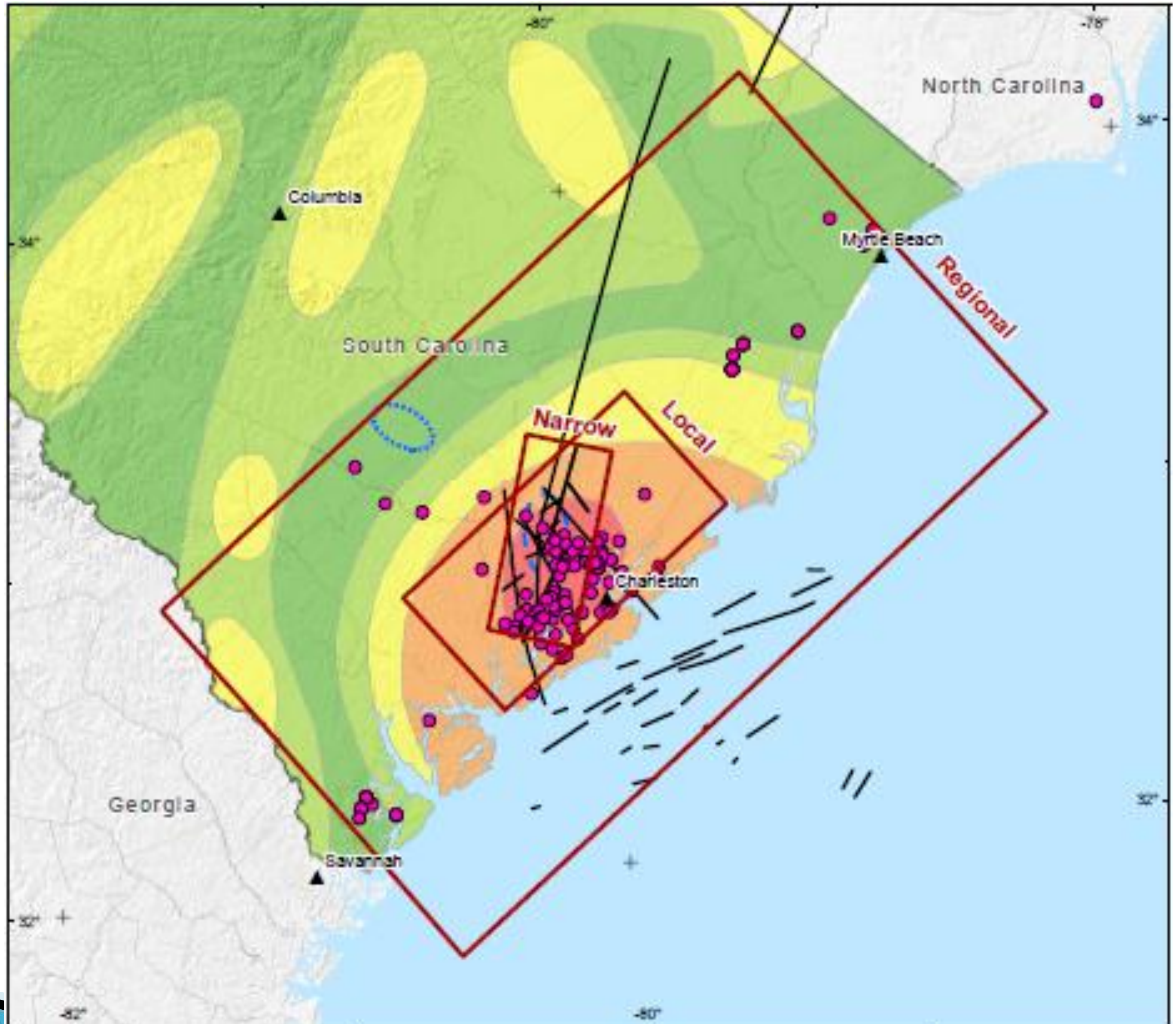


Crater Flat
Makani Cone
Q
Black Cone
11.3 Ma basalt
VH-2
Red Cone
VH-1
Pliocene Basalt
Little Cones
A
10.1 Ma basalt
3.7 Ma basalt
fissure orientation
Repository Boundary
J-13
J-12
JF-5
JF-6
JF-3
10S
22S
23P
9.5 Ma basalt
9.5 Ma basalt
J-11
Jackass Flats
Miocene Basalt
10.5 Ma basaltic andesite
O
Lathrop Wells
I
G
3.8 Ma basalt
F
H
Amargosa Desert
FF25-1
3.8 Ma basalt
FF5-1
B
Legend
Yucca Mountain Repository
Basalts from Slate et al. (1999)
Quaternary basalt
Pliocene basalt
Miocene basalt
Selected Existing Drill Holes
Completed Drill Holes
Fault beneath alluvium inferred from aeromagnetic data
Buried Pliocene basalt
Buried Miocene basalt
N
W
E
S
Kilometers
2 0 2 4 6 8
UTM Coordinate System, Zone 11
North American Datum 1927
M# 201461, Rev. 2
Req #13973
Cartography by: Richard E. Kelley
Date: April 11, 2006
Los Alamos

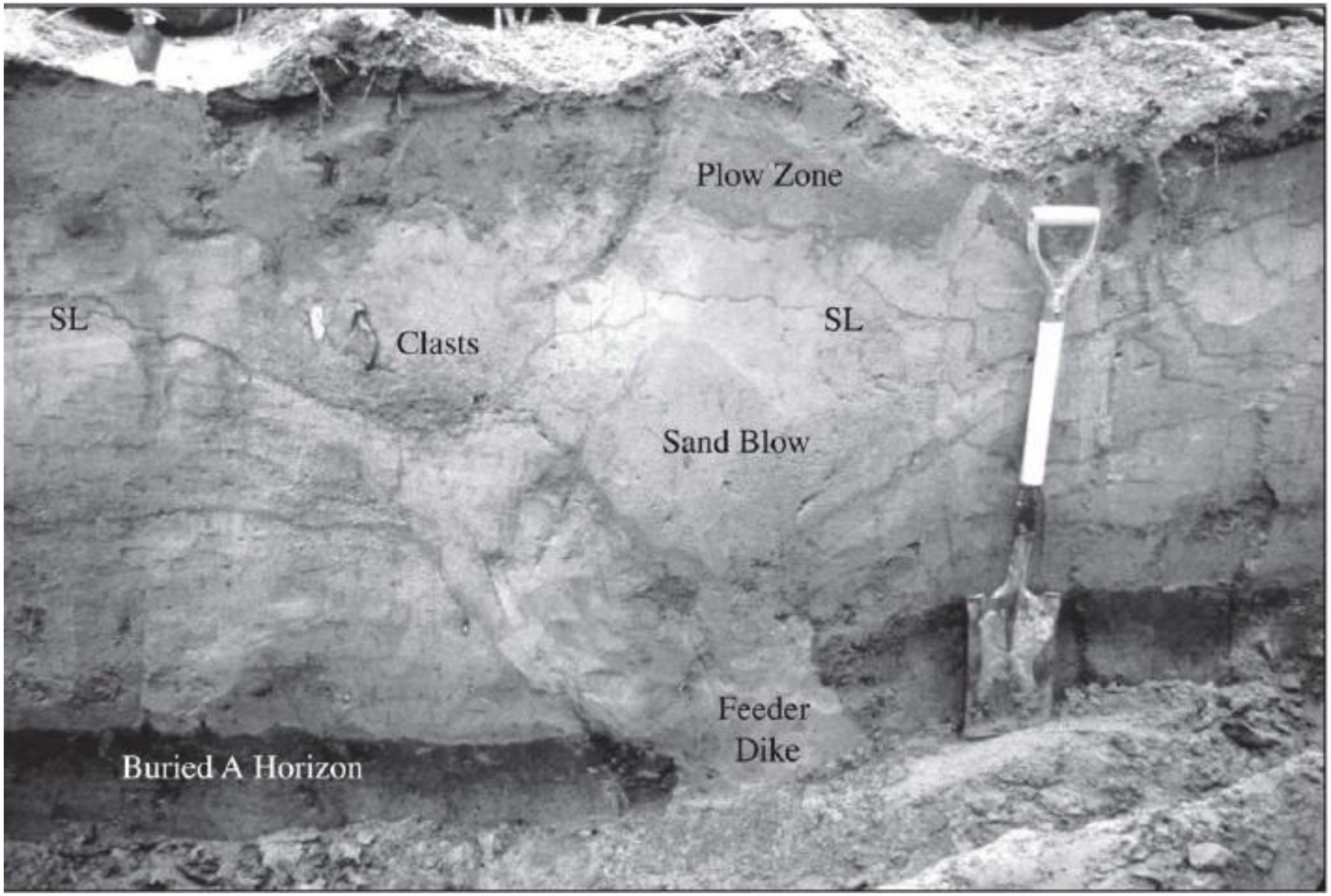
Charlevoix
Wabash Valley
Cheraw
New Madrid/
Reelfoot Rift
Meers
Charleston

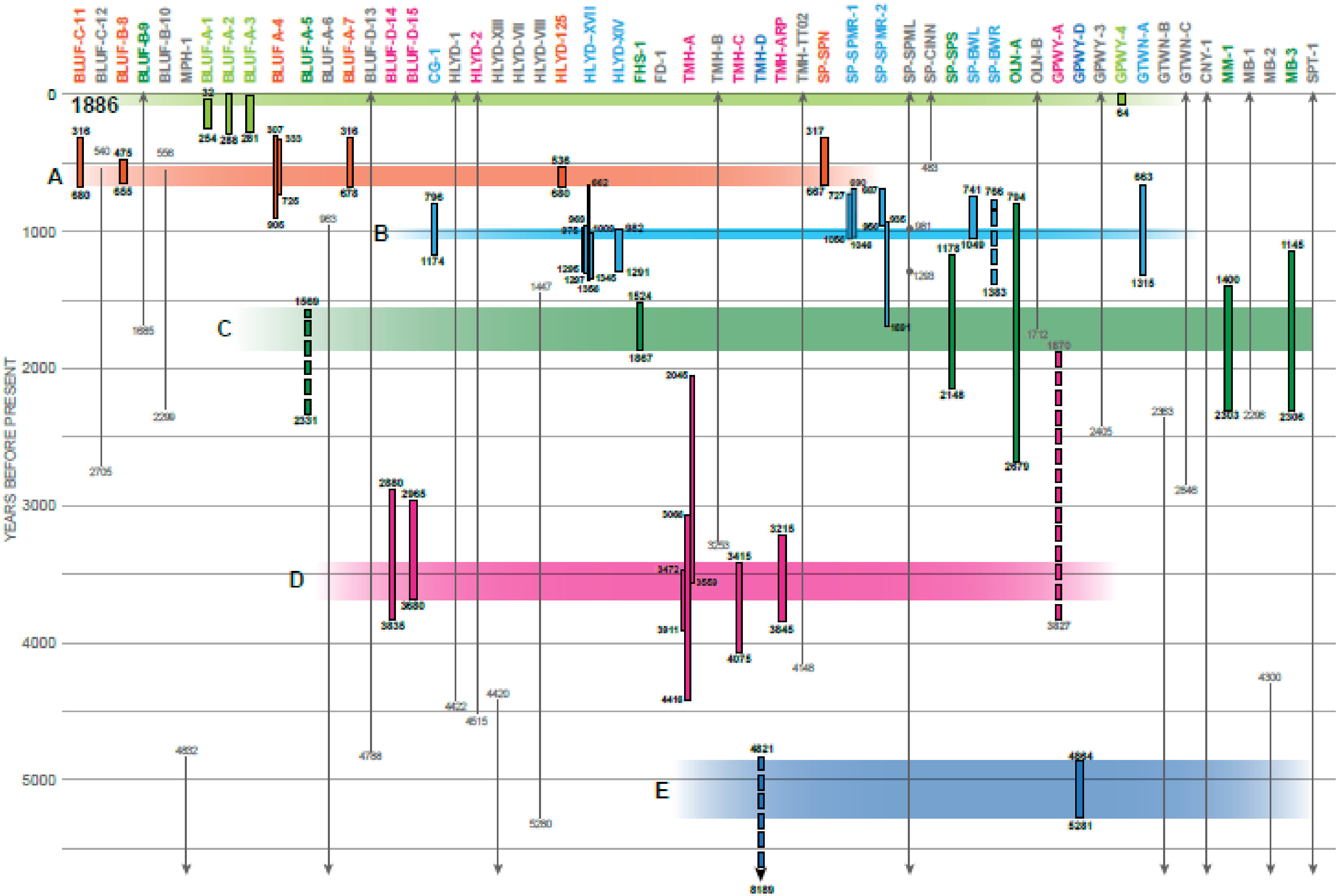


CMTZ
GRTZ
OFZ
RF
BMTZ
RMSP
WM
AF
EM
WRFZ
Illinois Basin
St. Genevieve FZ
CGFZ
WVFZ
RCFZ
Indiana
Evansville
Owensboro
Illinois
Corinth
St. Francois Mtns.
Mayfield
Jackson
Cape Girardeau
Shawneetown
FAFC
Rough Creek graben
RR-RCG
Union City
Charleston
Paducah
Kentucky
Sikeston
Charleston
1/23/1812
Mayfield
New Madrid
Reelfoot Lake
Reelfoot rift
Clarksville
Corinth
Mississippi Embayment
Pocahontas
Pascola Arch
2/7/1812
Hickman
Nashville
Paragould
Caruthersville
12/16/1811
Manila High
Blytheville
Murfreesboro
Batesville
Jonesboro
Pocahontas
Jackson
Arkoma Basin
Reelfoot rift
Covington
Marked Tree
Tennessee
Searcy
Memphis
Cordova
Arkansas
Forrest City
Pocahontas
Collierville
Corinth
Memphis
North Little Rock
Marianna
Marianna
Huntsville
Little Rock
Decatur
RR
Batesville
Pine Bluff
Mississippi
Alabama
Charleston
Pocahontas
Hoover

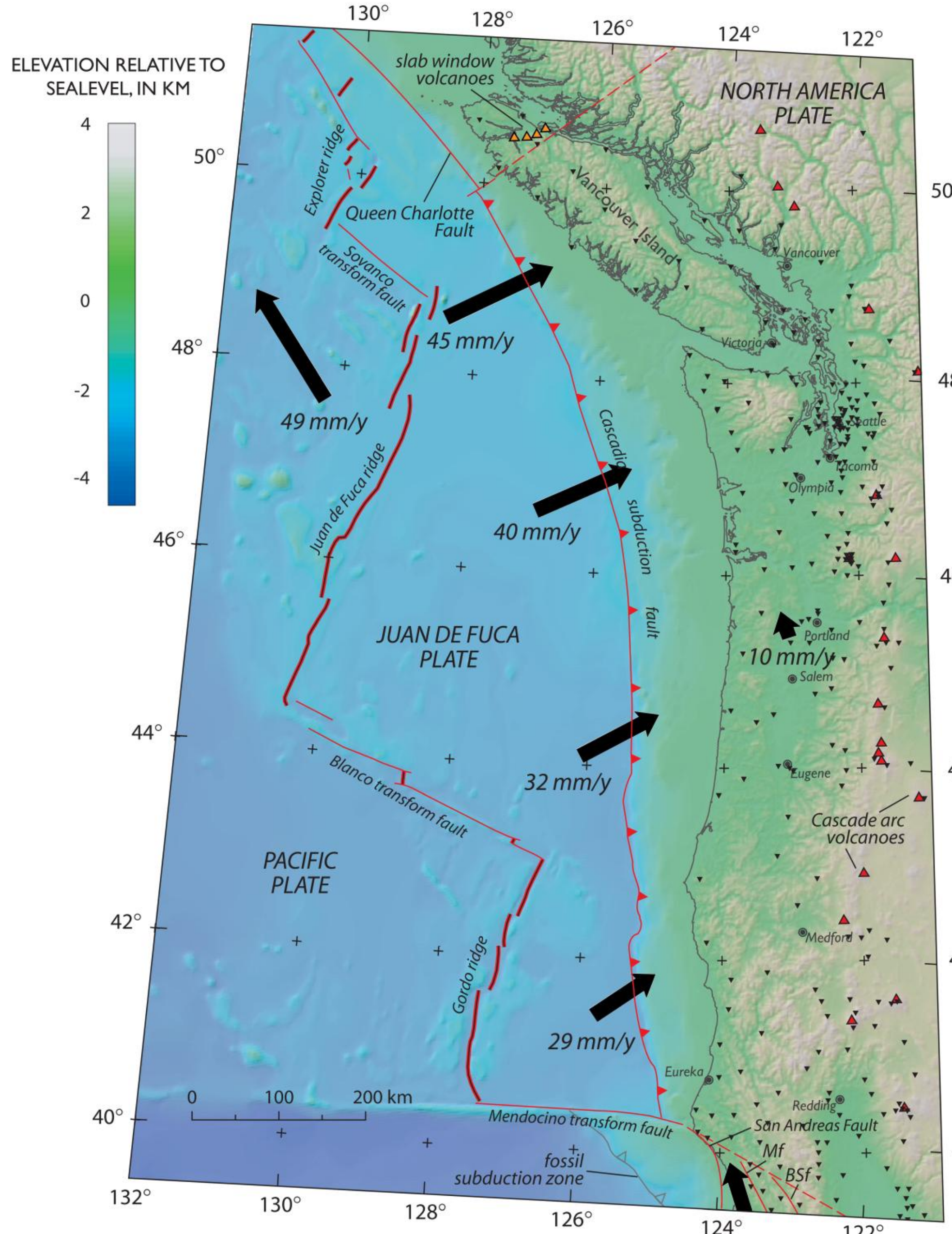


North Carolina
South Carolina
Georgia
Columbia
Myrtle Beach
Charleston
Savannah
Regional
Local
Narrow
-80°
-78°
-82°
34°
32°


Plow Zone
SL
Clasts
SL
Sand Blow
Feeder
Dike
Buried A Horizon



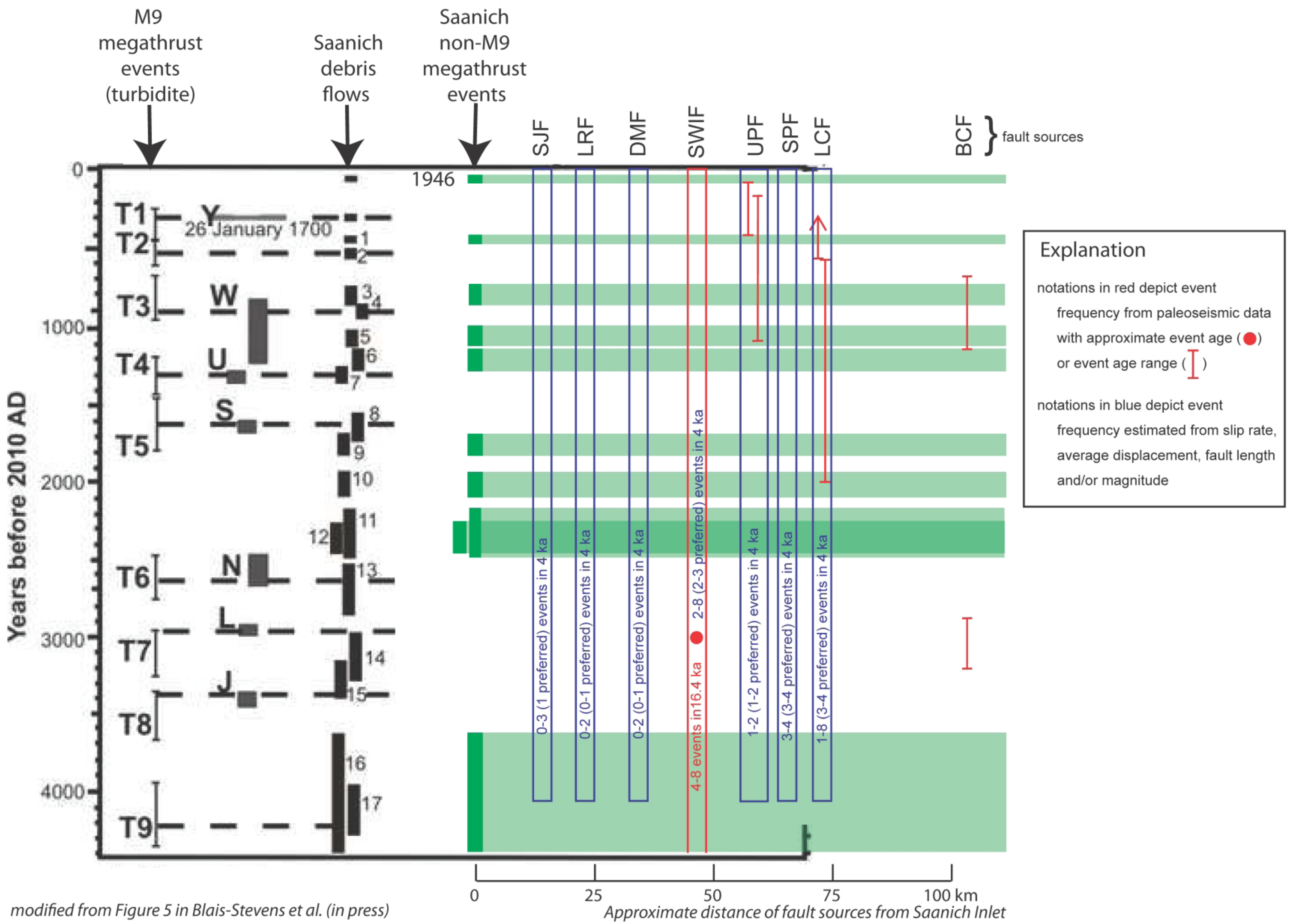
BLUF-C-11
BLUF-C-12
BLUF-B-8
BLUF-B-9
BLUF-B-10
MPH-1
BLUF-A-1
BLUF-A-2
BLUF-A-3
BLUF A-4
BLUF-A-5
BLUF-A-6
BLUF-A-7
BLUF-D-13
BLUF-D-14
BLUF-D-15
CG-1
HLYD-1
HLYD-2
HLYD-XIII
HLYD-VII
HLYD-VIII
HLYD-125
HLYD-XVII
HLYD-XIV
FHS-1
FD-1
TMH-A
TMH-B
TMH-C
TMH-D
TMH-ARP
TMH-TT02
SP-SPN
SP-SPMR-1
SP-SPMR-2
SP-SPML
SP-CINN
SP-SPS
SP-BWL
SP-BWR
OLN-A
OLN-B
GPWY-A
GPWY-D
GPWY-3
GPWY-4
GTWN-A
GTWN-B
GTWN-C
CNY-1
MM-1
MB-1
MB-2
MB-3
SPT-1
1886
A
B
C
D
E
YEARS BEFORE PRESENT
0
1000
2000
3000
4000
5000



Transverse Mercator projection,
standard parallel -128E, centered at 46.8N, -128E,
with standard parallel rotated 3.5° clockwise of vertical
[from Wilson, 2002, USGS OFR 02-328]
Shaded relief DEM from GEBCO [see text]

McCrory, Blair, Oppenheimer, and Walter, 2004,
Depth to the Juan de Fuca slab beneath the Cascadia subduction margin—
A 3-D model for sorting earthquakes: U.S. Geological Survey Data Series 91

FIGURE 1



modified from Figure 5 in Blais-Stevens et al. (in press)

Fault source abbreviations: SJF - Skipjack fault; LRF - Leech River fault; DMF - Devils Mountain fault; SWIF - South Whidbey Island fault; UPF - Utsalady Point fault; SPF - Strawberry Point fault; LCF - Lake Creek-Boundary Creek-Little River fault; BCF - Boulder Creek fault

IAEA: Updating Hazard Assessments

- *The tsunami hazard for several sites was underestimated. Nuclear designers and operators should appropriately evaluate and provide protection against the risks of all natural hazards, and should periodically update these assessments and assessment methodologies in light of new information, experience and understanding.*
  - –IAEA, 2011

NPH Lessons Learned

- Lesson #4. A process for updating hazard analyses in light of new data, models, and methods must be implemented
  - DOE Order 420.1B
  - ANSI/ANS-2.29-2008
  - NRC approach

Fixed Term Review of Need to Update

- DOE Order 420.1B
  - *3. REQUIREMENTS.*
    - *c. NPH Assessment.*
    - *(4) An NPH assessment review must be conducted at least every 10 years and must include recommendations to DOE for updating the existing assessments based on significant changes found in methods or data. If no change is warranted from the earlier assessment, then this only needs to be documented.*
- Note:
  - Review is required, not reassessment
  - “Significant change” is not defined

ANSI/ANS- 2.29-2008 on Updating Existing study

- 4.1 High Level Requirements
- "…the PSHA analyst may have the option to use an existing seismic study as a starting point for a site-specific assessment."
- HLR-A: Scope
  - "The assessment of the frequency of earthquake ground motions at a site shall be based on a PSHA that considers the epistemic uncertainty in the analysis inputs and that reflects the composite distribution of the informed technical community. The level of the analysis shall be determined based on the intended application of the PSHA results and on site-specific complexity (see Sec. 4.3). For PSHA levels 3 and 4, the analysis shall include a site-specific detailed analysis."
- HLR-B: Data collection
  - [develop a comprehensive up-to-date database per ANSI/ANS-2.27-2008]

ANSI/ANS- 2.29-2008 on Updating Existing study (cont'd.)

- HLR-C: Seismic source characterization
- HLR-D: Ground motion characterization
- HLR-E: Local site effects
- HLR-F: Quantification
  - [Epistemic and aleatory uncertainties included in each element of PSHA]
- HLR-G: Use of existing studies
  - "When use is made of an existing study for PSHA purposes, it shall be confirmed that the basic data and scientific interpretations in the original analysis are still valid in light of current information, the study meets the requirements outlined in HLR-A through HLR-F above, and the study is suitable for the intended application."

Tracks well with IAEA recommendation

NRC Approach to Updating

- In the past, relied on updates related to new licensing, regional studies (e.g., EPRI-SOG, LLNL) conducted in the 1980s
- Recent COLAs have highlighted the need for updating
- CEUS SSC project and NGA-East projects will update Eastern US using SSHAC Level 3
- GI-199 may lead to updates of western site seismic hazard assessments (DCPP)
- Guidance being developed: defines when to replace, revise, refine, accept existing study

Draft NRC Recommendations Regarding Updating Hazard Assessments for Nuclear Facilities

Existing Study	Condition of Existing Study	Hazard Assessment Needed	Recommendation	SSHAC Level for New Study
No study, or previous studies conducted at lower SSHAC Levels (2 or 1), or non-SSHAC studies	Not adequate for nuclear/critical facilities	Regional and/or site-specific	Conduct new study	3 or 4
Regional or site-specific	Not viable and hazard results expected to be significantly different	Regional and/or site-specific	Replace existing study	3 or 4
Regional or site-specific	Not viable but hazard results not expected to be significantly different	Regional and/or site-specific	Revise existing study	2, 3, or 4
Regional, no site-specific	Viable	Site-specific	Refine regional study locally consistent with RG 1.208 and ANSI/ANC-2.27-2008	2, 3, or 4

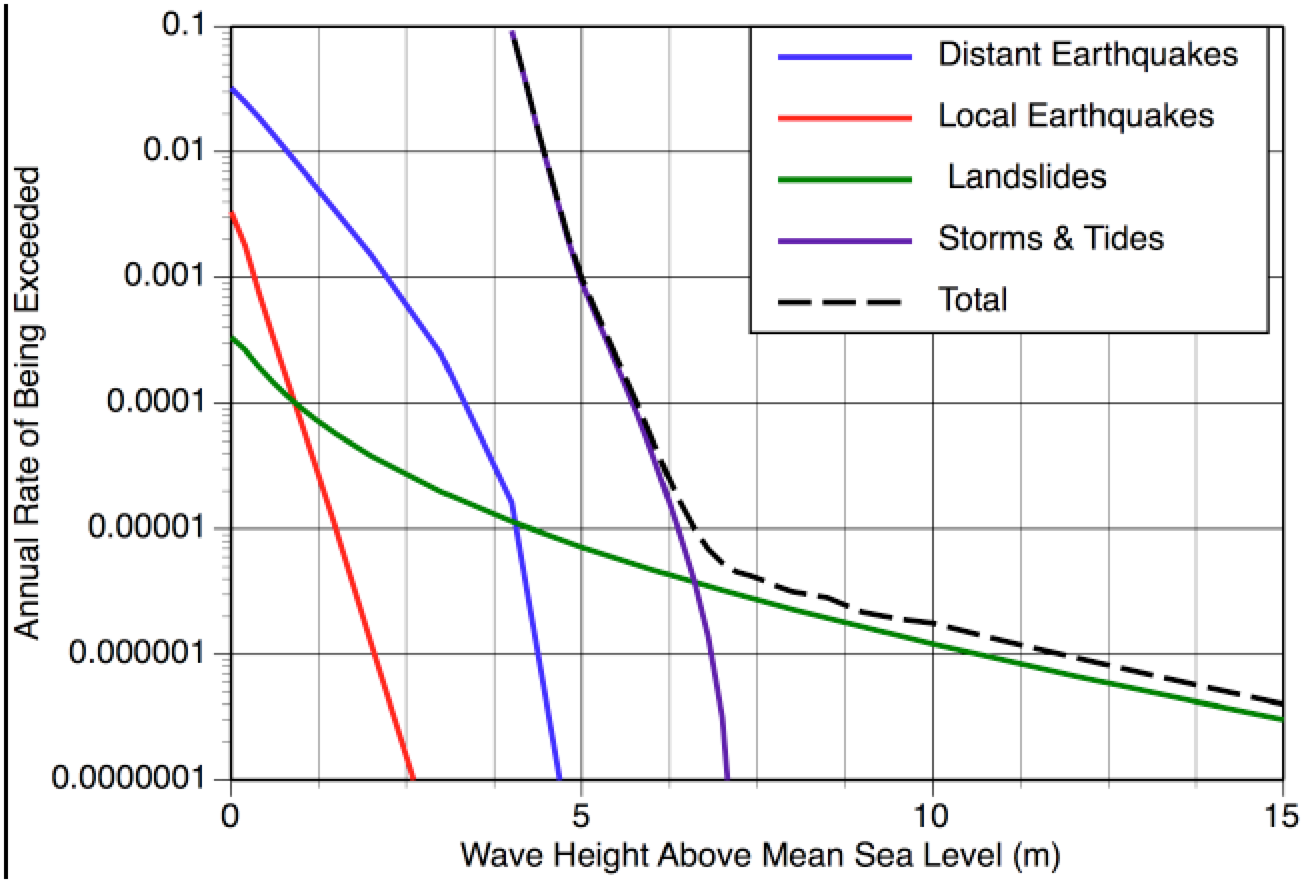
[1] "Viable" is defined as: (1) based on a consideration of data, models, and methods in the larger technical community, and (2) representative of the center, body, and range of technically defensible interpretations.

IAEA: Combinations of Hazards

- *Severe long term combinations of external events should be adequately covered in design, operations, resourcing and emergency arrangements.*
  - –IAEA, 2011

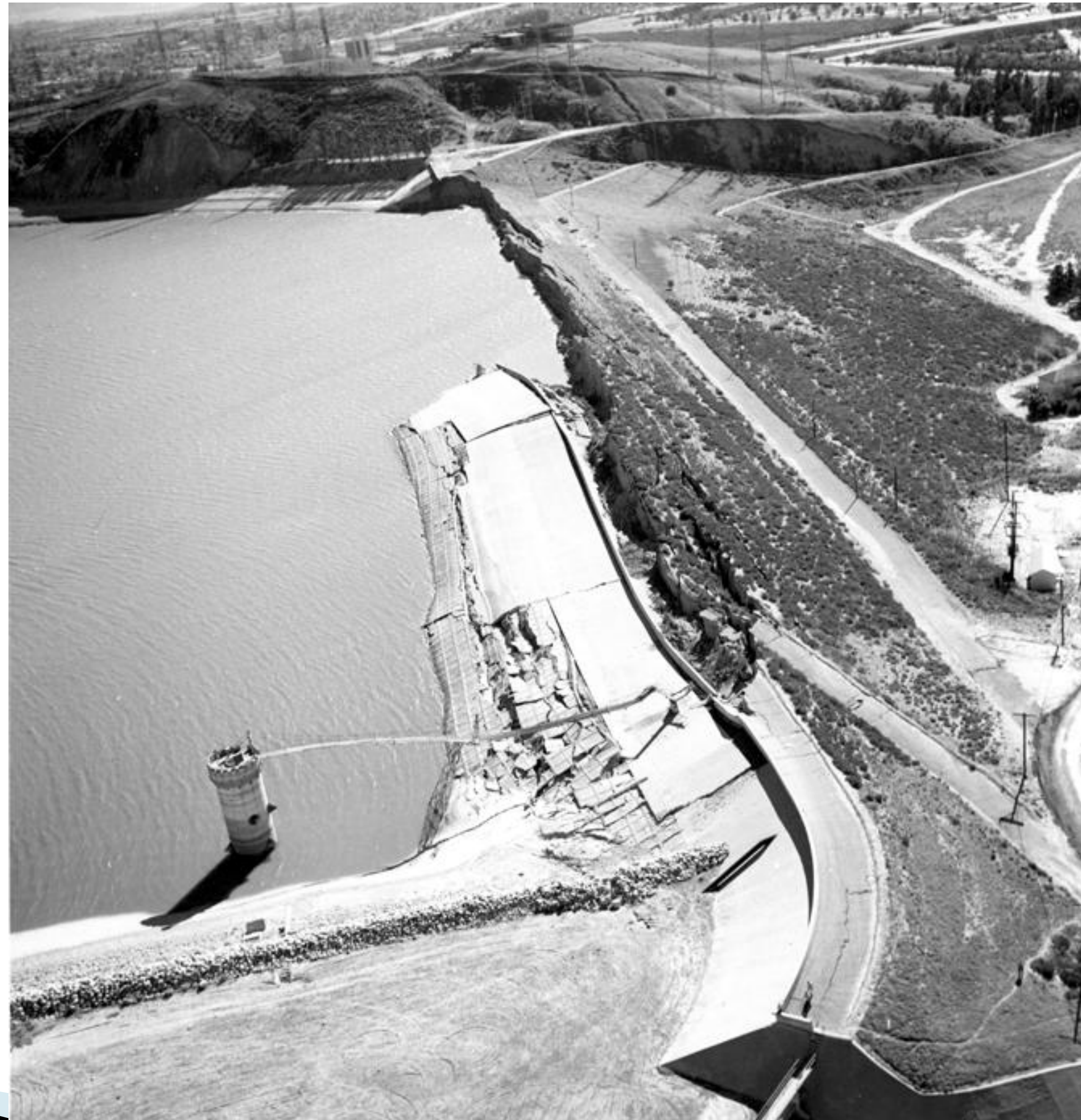
NPH Lessons Learned

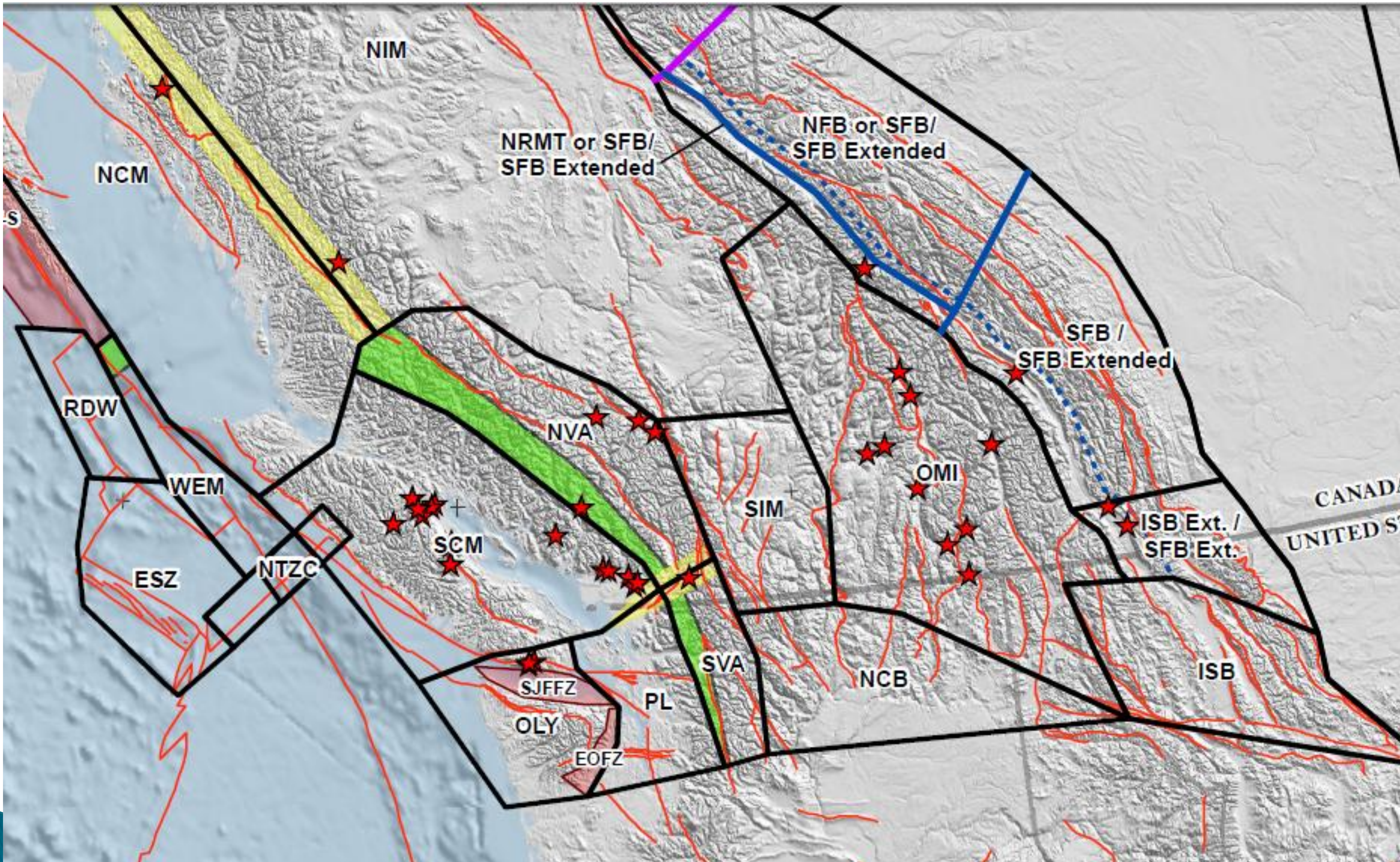
- Lesson #5. Combinations of hazards must be considered, along with their joint probabilities of occurrence
  - Examples
    - Earthquakes and tsunami (subduction-related)
    - Earthquakes and tsunami (landslide-related)
    - Earthquakes and flooding
    - Wind, flooding, and storm surge
  - Dependencies raise their joint probability



Distant Earthquakes
Local Earthquakes
Landslides
Storms & Tides
Total
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
Annual Rate of Being Exceeded
0
5
10
15
Wave Height Above Mean Sea Level (m)

San Fernando, California, Earthquake February 1971. Lower Van Norman Dam




NIM
NCM
NRMT or SFB/
SFB Extended
NFB or SFB/
SFB Extended
SFB /
SFB Extended
RDW
WEM
NVA
OMI
SIM
SCM
ESZ
NTZC
ISB Ext. /
SFB Ext.
CANADA
SJFFZ
SVA
NCB
ISB
PL
OLY
EOFZ


Fraser River Drainage Basin
Saskatchewan River Drainage Basin
Missouri River Drainage Basin
Colorado River Drainage Basin
Great Basin
Great Salt Lake
Kinbasket Lake
Columbia
Revelstoke
Ivermere
Okanagan Lake
Kelowna
Nelson
Kootenay
Okanogan
Puget Sound
Seattle
Tacoma
Pend Oreille
Spokane
Flathead
Flathead Lake
Missoula
Cowlitz
Yakima
Astoria
Lewis
Snake
Clearwater
Lewiston
Kennewick
Columbia
Portland
The Dalles
Salem
Willamette
Deschutes
John Day
Salmon
Eugene
Payette
Boise
Boise
Idaho Falls
Snake
Twin Falls
Owyhee
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76

Conclusions

- Lessons learned regarding NPH hazard assessments reinforce good practice
  - Risk-informed probabilistic design criteria
  - Open process for hazard analysis
  - Use all data to characterize rare events
  - Define and implement process for updating
  - Consider hazard combinations
- DOE, NRC, and Industry have made strides in these areas
- Fukushima-Daiichi lessons provide focus and urgency to ongoing efforts