ELECTRIC POWER RESEARCH INSTITUTE

Task G1.1
ASCE 43-05 Performance-Based Method for Determining Site Ground Motion

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Task G1.1 Scope:

•Computed updated PSHA for 28 NPP sites, compute design basis response spectra using ASCE 43-05 approach, and evaluate ASCE 43-05 approach

Updates:

Seismic sources:	Charleston source New Madrid source Illinois sources Saline River sources Gulf Coast sources
Ground motion	EPRI 2003
Sources of Information:	Clinton ESP application (2003) Grand Gulf ESP application (2003) North Anna ESP application (2003) TVA seismic hazard study (2004)

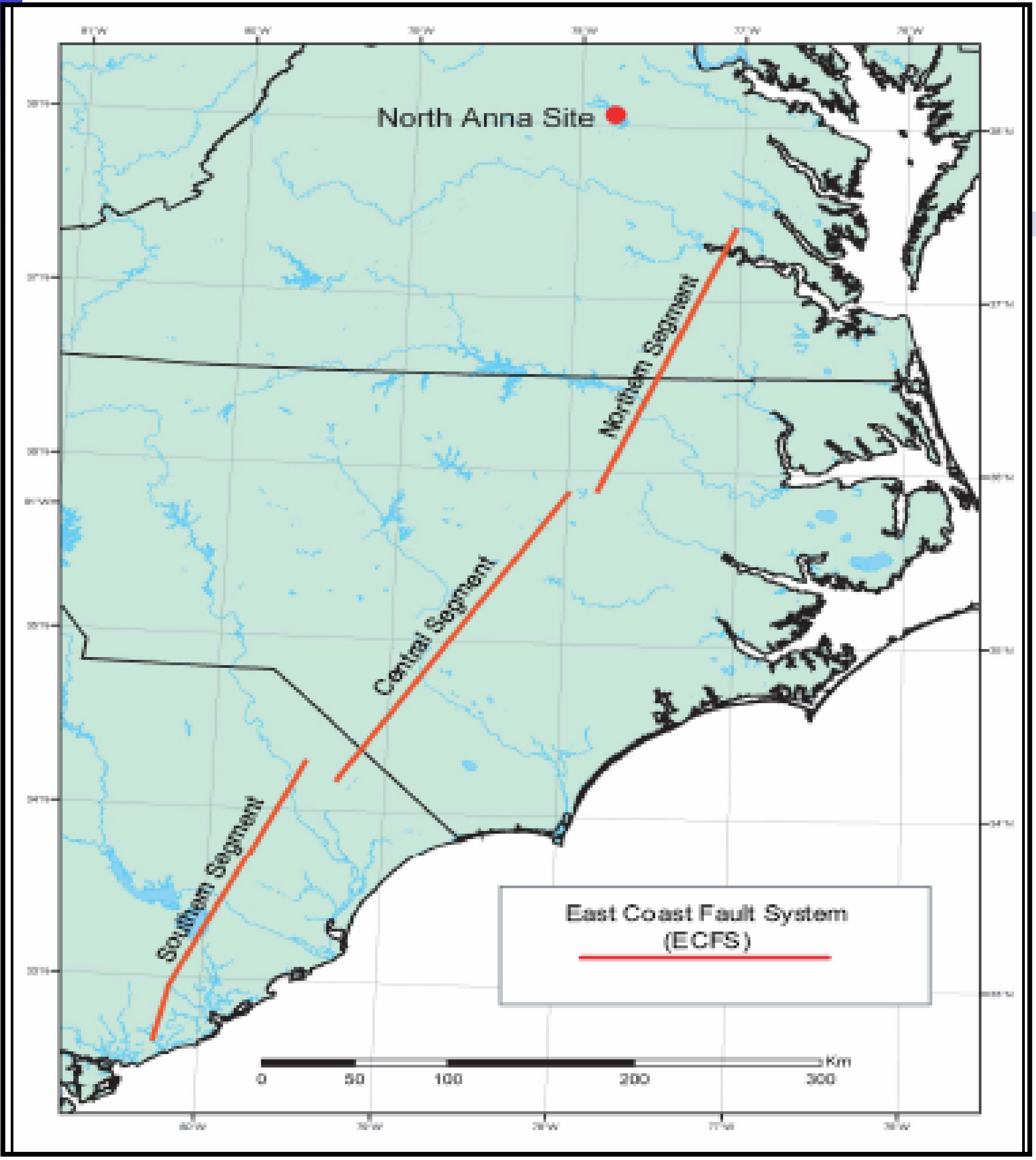


Figure 3.5-13 Northern, Central, and Southern Segments of the East Coast Fault System

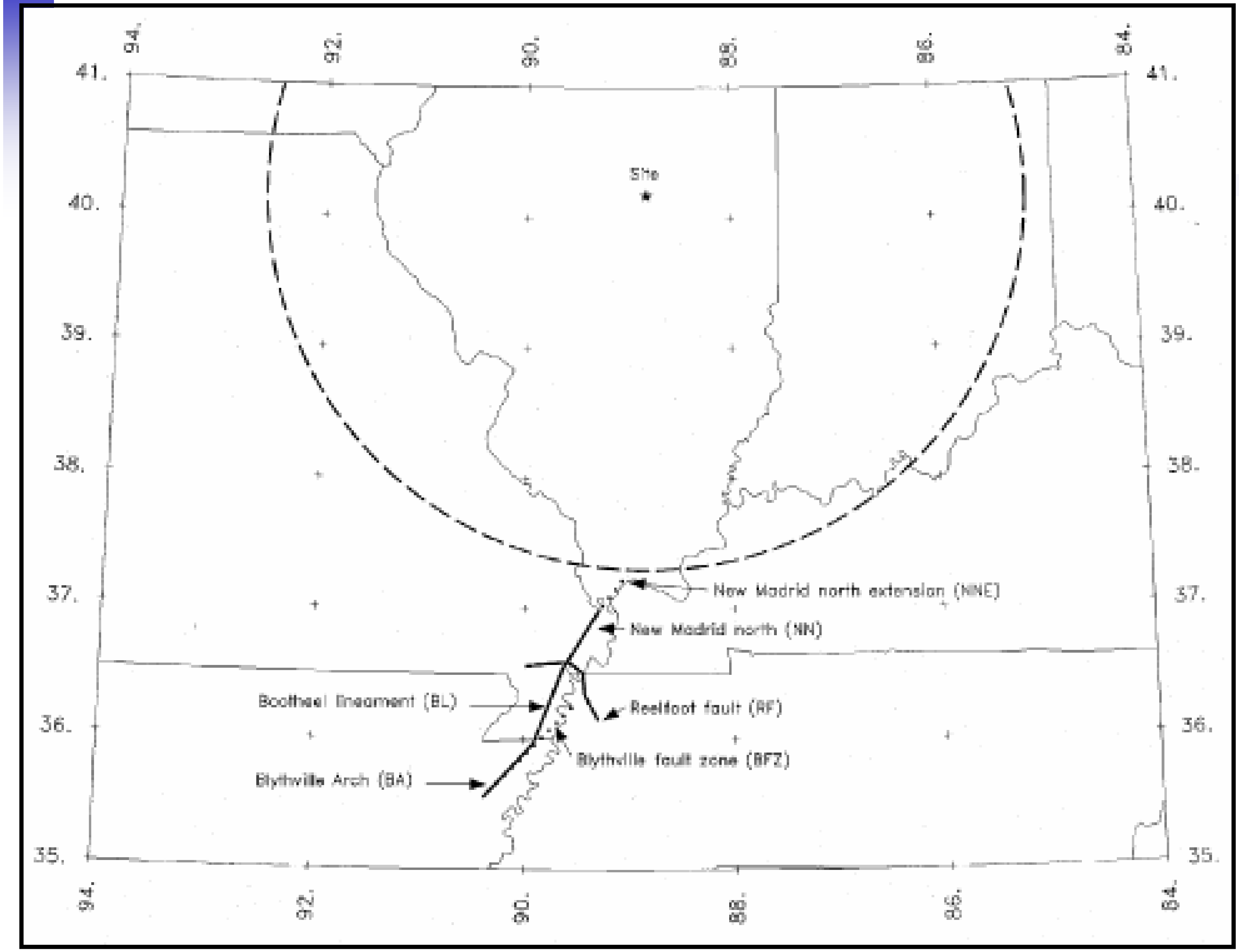


Figure 4.1-2 Seismic Hazards Report for the EGC ESP Site: Locations of Fault Sources for Characteristic New Madrid Earthquakes

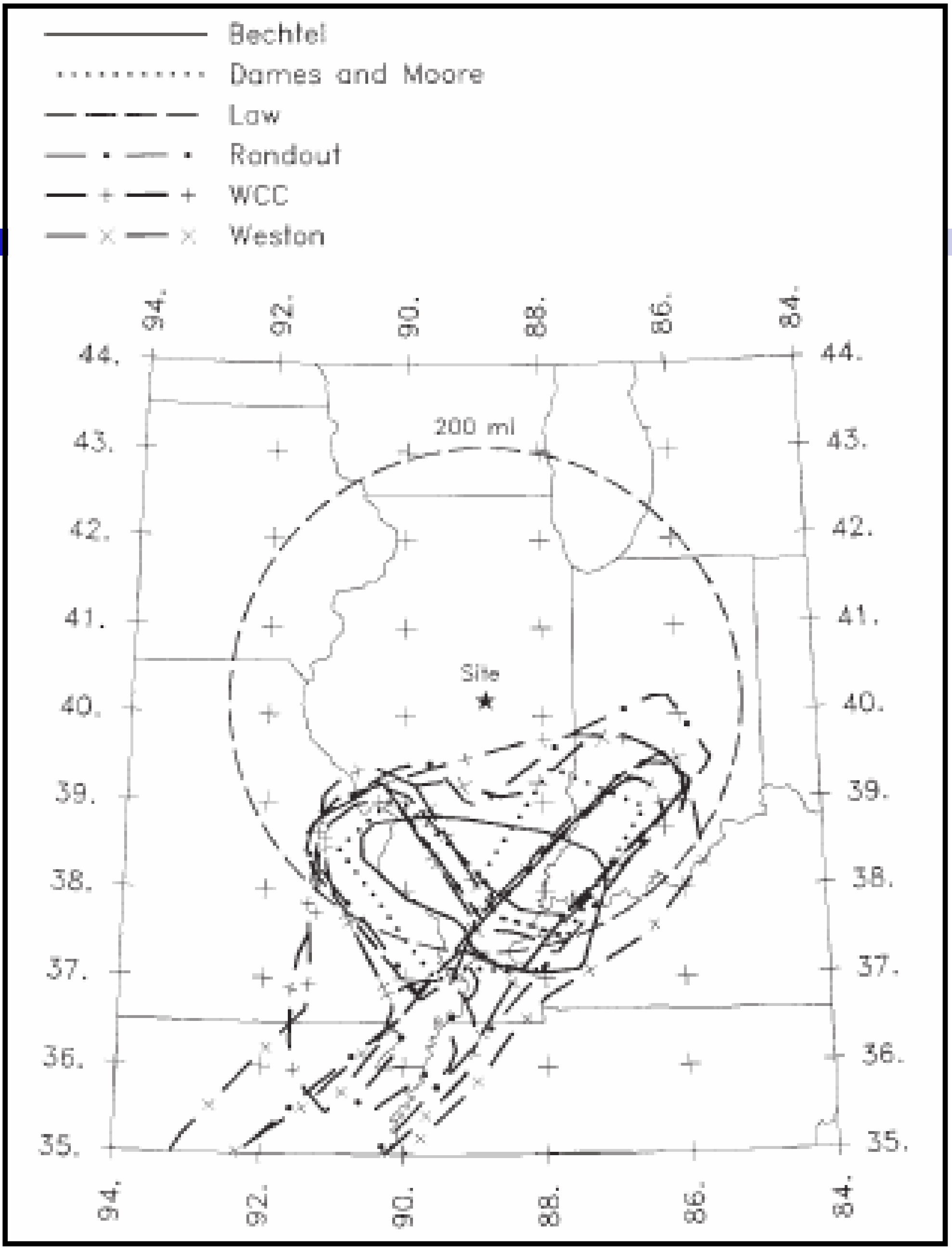
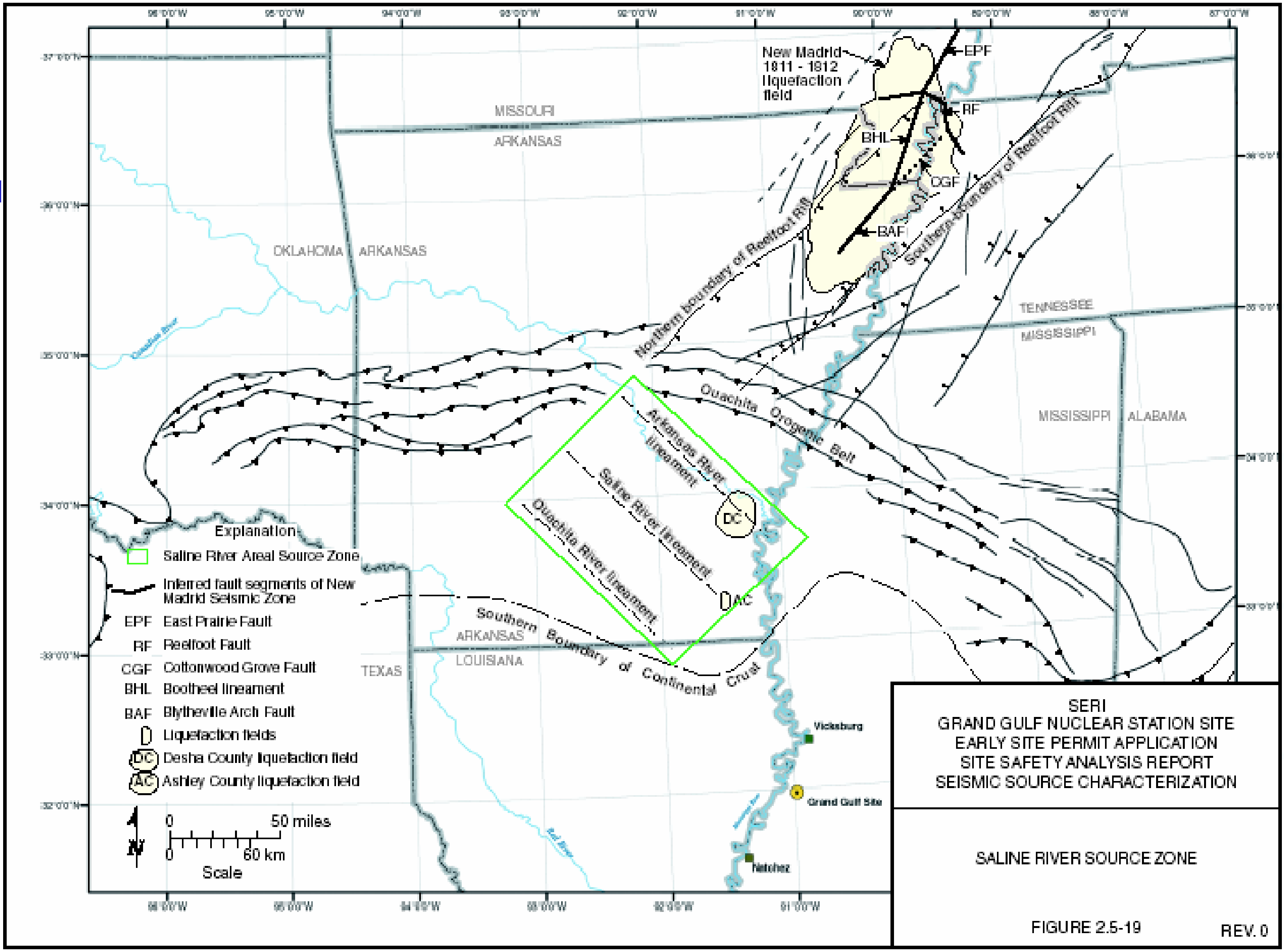


Figure 3.1-1 Alternative Southern Illinois-Wabash Valley Source Configurations used in EPRI-SOG


New Madrid 1811 - 1812 liquefaction field
EPF
RF
BHL
CGF
BAF
MISSOURI
ARKANSAS
OKLAHOMA
ARKANSAS
TENNESSEE
MISSISSIPPI
MISSISSIPPI
ALABAMA
TEXAS
ARKANSAS
LOUISIANA
Northern boundary of Reelfoot Rift
Southern boundary of Reelfoot Rift
Ouachita Orogenic Belt
Arkansas River lineament
Saline River lineament
Ouachita River lineament
Southern Boundary of Continental Crust
DC
AC
Vicksburg
Grand Gulf Site
Natchez
Explanation
Saline River Areal Source Zone
Inferred fault segments of New Madrid Seismic Zone
EPF East Prairie Fault
RF Reelfoot Fault
CGF Cottonwood Grove Fault
BHL Bootheel lineament
BAF Blytheville Arch Fault
Liquefaction fields
DC Desha County liquefaction field
AC Ashley County liquefaction field
0 50 miles
0 60 km
Scale
SERI
GRAND GULF NUCLEAR STATION SITE
EARLY SITE PERMIT APPLICATION
SITE SAFETY ANALYSIS REPORT
SEISMIC SOURCE CHARACTERIZATION
SALINE RIVER SOURCE ZONE
FIGURE 2.5-19
REV. 0

Changes in seismic sources:

Charleston:

- mean recurrence interval ~ 550 years for large earthquakes (**M** • 6.8 to 7.3)

New Madrid:

- mean recurrence interval ~ 500 years for large earthquakes (**M** • 7.5 to 8.2)
- cluster model used for earthquake occurrence

Wabash Valley/ Illinois sources:

- Wabash Valley/Southern Illinois: **M** • 7.3 to 7.5
- Central Illinois: **M** • 6.3 to 7.0

Saline River source: (new source)

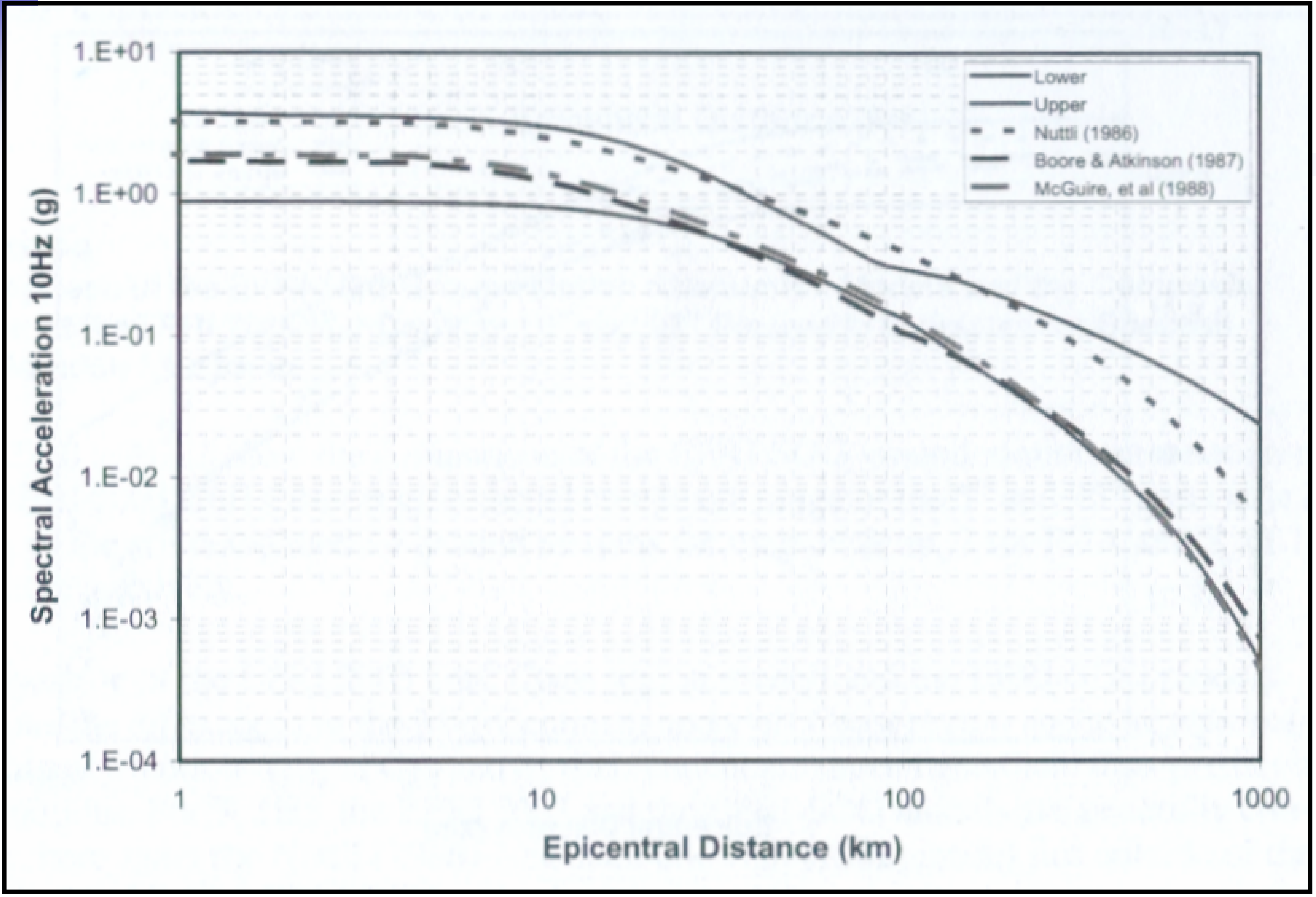
- **M** • 6 to 7
- recurrence interval 1,000 to 125,000 years

Gulf Coast sources:

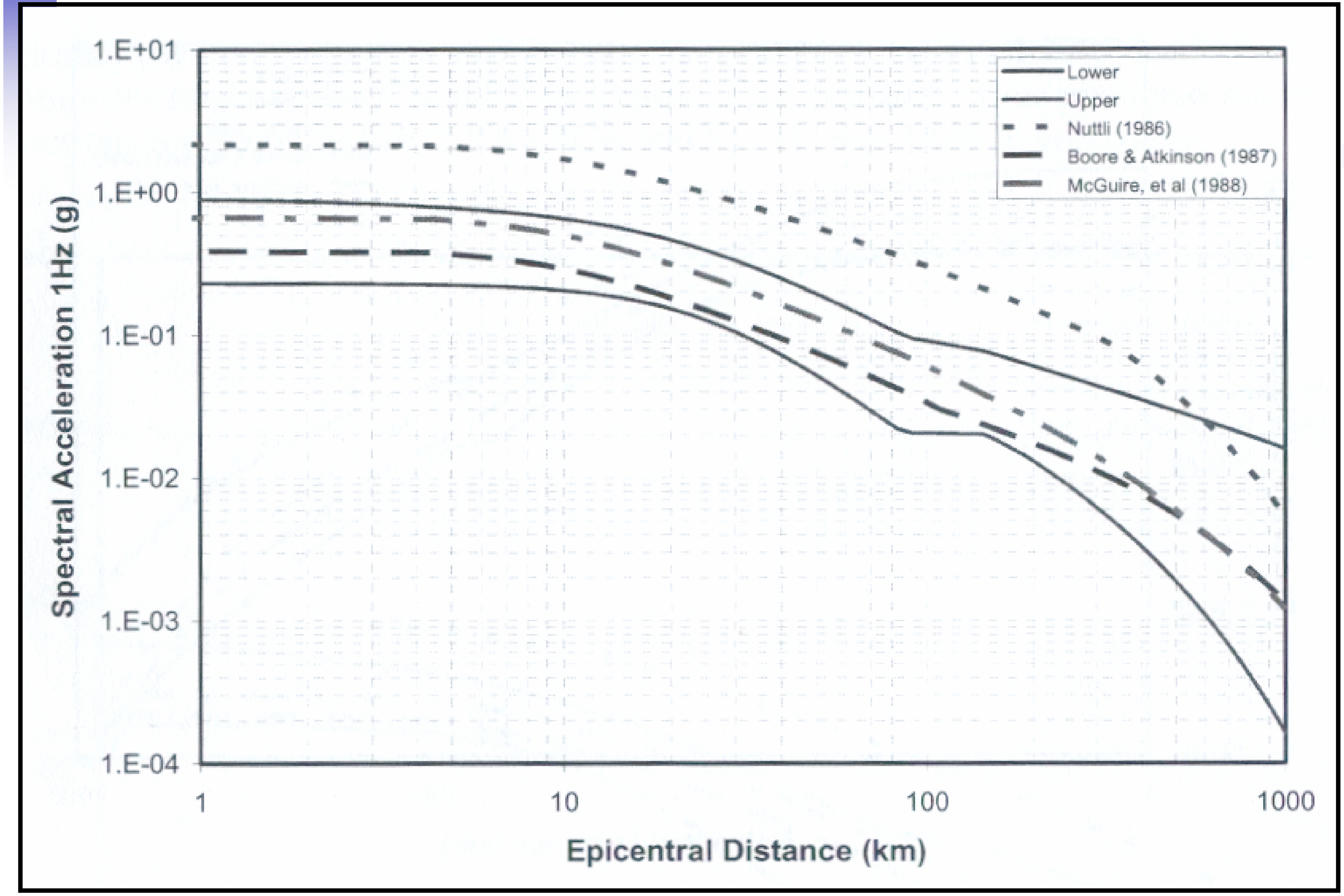
- raised minimum m_{max} to m_b 5.4 (**M** 5.0)

Changes in ground motion models:

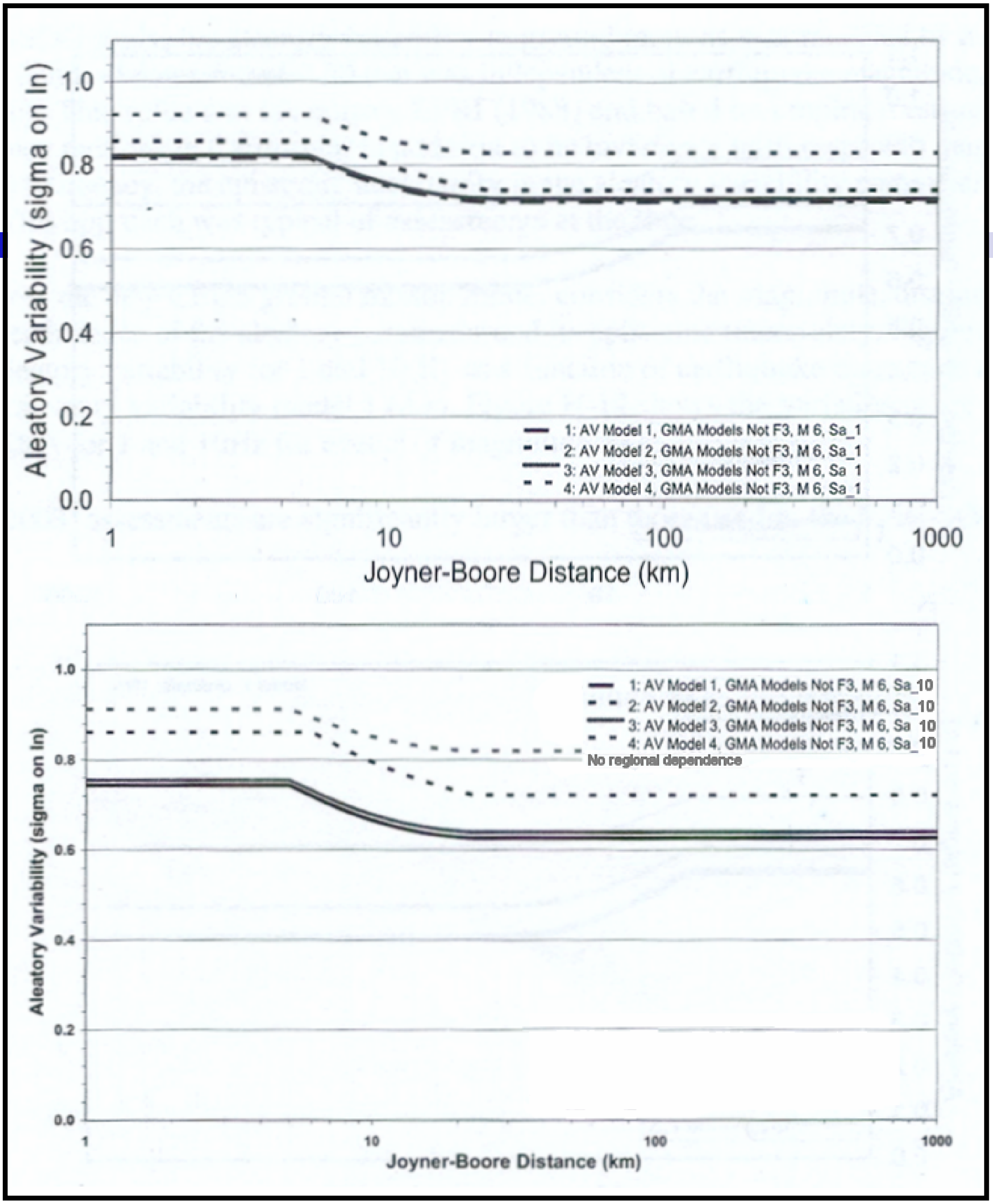
- High frequencies: EPRI 2003 similar to EPRI 1989 in mean, σ larger
- Low frequencies: EPRI 2003 lower than EPRI 1989, σ larger



EPRI 2003 10 Hz SA for m_b 7, compared to EPRI-SOG equations



EPRI 2003 1 Hz SA for m_b 7, compared to EPRI-SOG equations



EPRI σ for M 6, 1 Hz (top) and 10 Hz (bottom)

Figure 1.1 Map Showing 28 Plant Sites Where Hazard Curves were Calculated

Verification Studies:

- Replicated EPRI 1989 rock hazard calculations at 4 test sites (verifies FRISK88 software, EPRI-SOG sources)
- Replicated ESP application rock hazard calculations at 3 ESP sites (verifies updates to seismic sources, EPRI 2003 ground motion model)

Assumptions for seismic hazard analysis:

- Minimum magnitude = m_b 5.0 (follows EPRI-SOG and 2 of 3 ESP applications)
- Cluster model used for New Madrid earthquakes (follows Clinton ESP application)

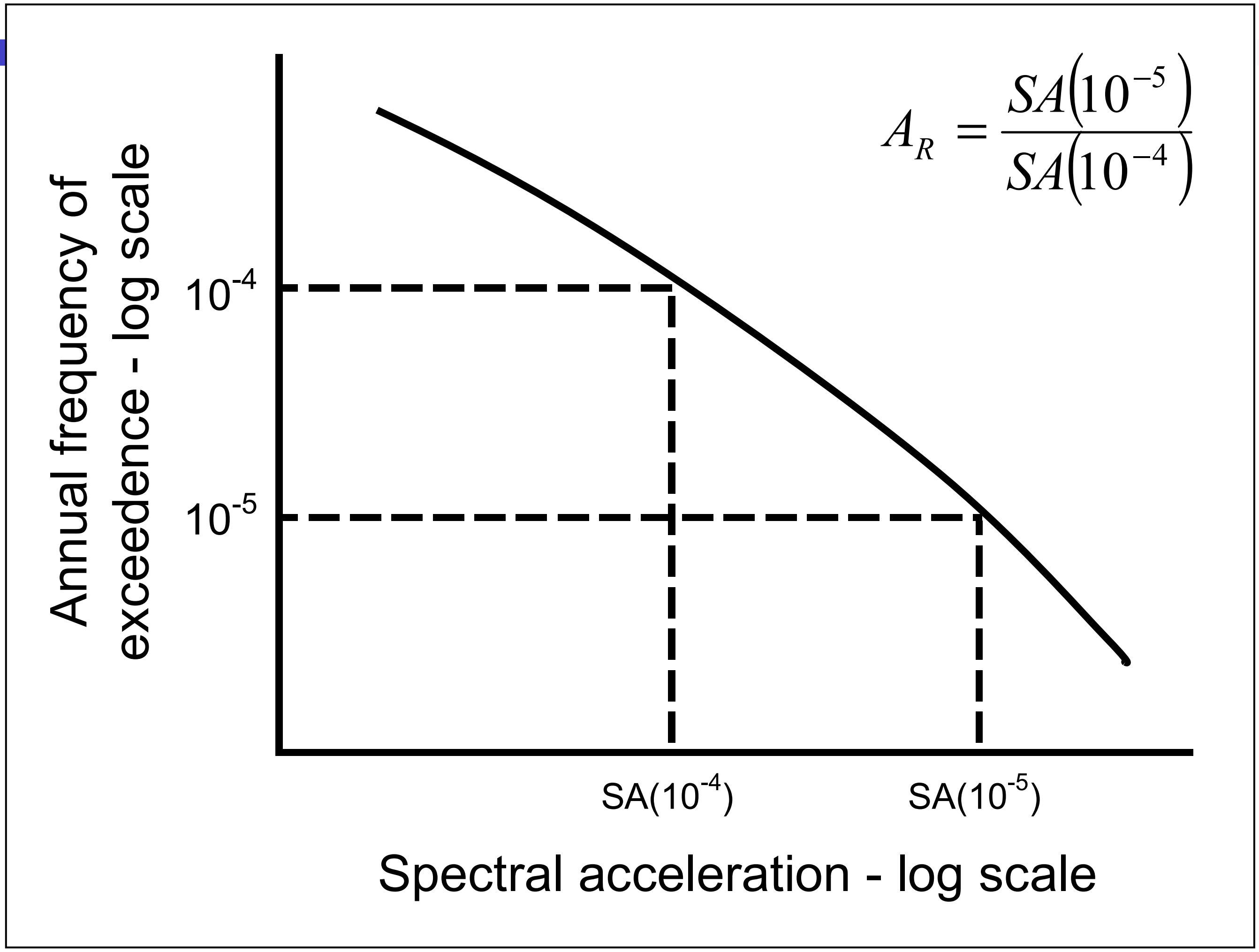
Site specific amplification model for soil and soft-rock sites:

- equivalent linear vertically propagating shear-wave model
- site properties (shear-wave velocity, K, G/G_{max}, hysteretic damping) modeled to basement rock (Vs = 9200 ft/s)
- site properties and depth to basement were randomized using correlation model
- site information taken from FSAR publications
- rock hazard curves were integrated with amplification factors to calculate site-specific hazard curves, accounting for epistemic uncertainties

Calculations:

- Focus on 5 and 10 Hz spectral response (following Reg. Guide 1.165)
- Develop recommended design response spectra following ASCE (2005):
  - DRS = DF • UHRS

1 Calculate ground motion ratio A_R



② Establish design basis earthquake response spectrum DRS:

$$UHRS = \text{mean } 10^{-4} \text{ spectrum}$$

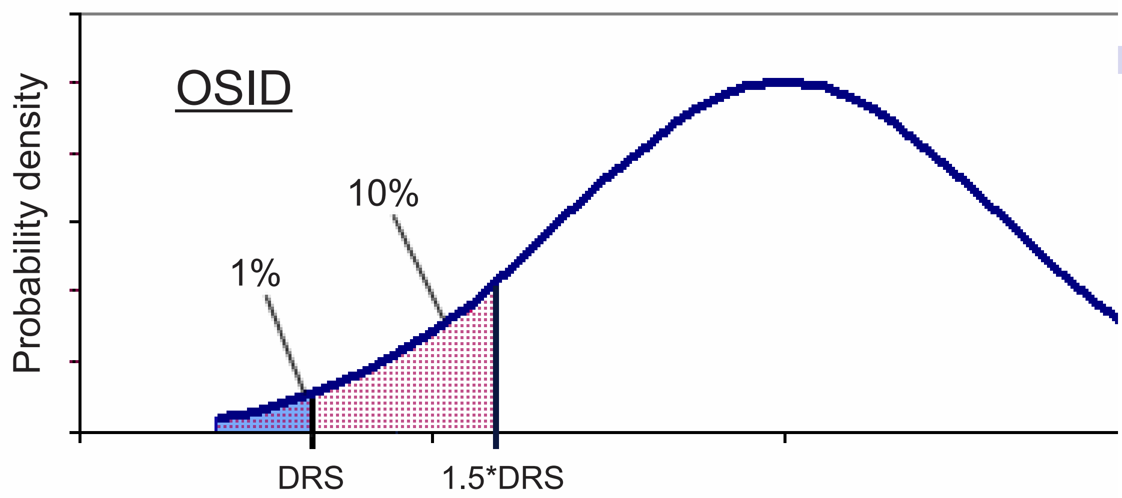
$$DF = \max\left(1.0,\ 0.6A_R^{0.8}\right)$$

$$DRS = DF * UHRS$$

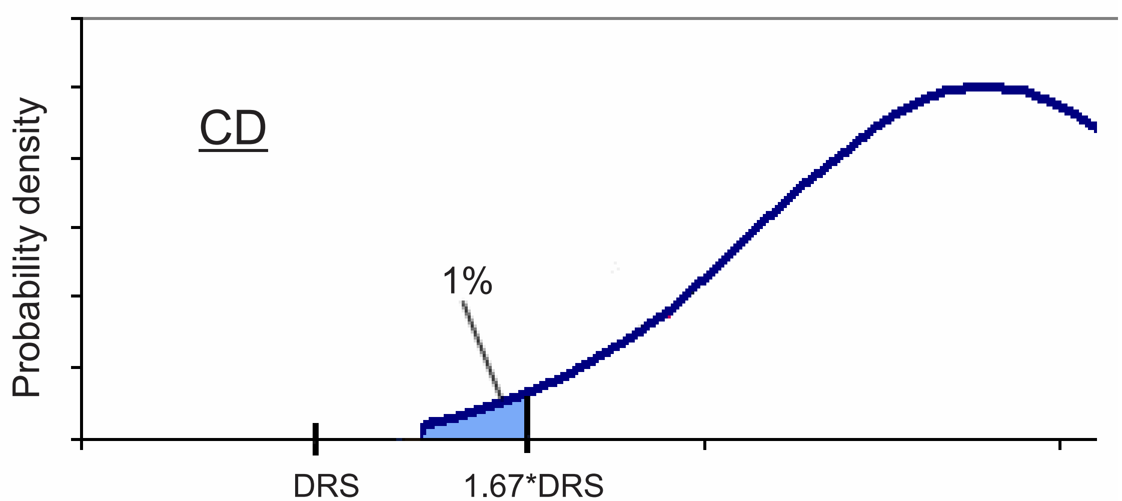
Range of AR, DF, and P[exceedance] for 28 sites in study

	Min	16th	50th	84th	Max
10 Hz, AR	1.50	2.26	3.01	3.67	4.36
10 Hz, DF	1	1.15	1.45	1.70	1.95
10 Hz, PE/1E-4	0.37	0.40	0.48	0.68	1
5 Hz, AR	1.64	2.17	2.63	3.33	4.05
5 Hz, DF	1	1.11	1.30	1.57	1.84
5 Hz, PE/1E-4	0.38	0.43	0.54	0.75	1
2.5 Hz, AR	1.54	2.19	2.42	3.23	3.81
2.5 Hz, DF	1	1.13	1.22	1.53	1.75
2.5 Hz, PE/1E-4	0.4	0.45	0.62	0.76	1
1 Hz, AR	1.58	2.24	2.49	3.40	3.77
1 Hz, DF	1	1.14	1.24	1.60	1.74
1 Hz, PE/1E-4	0.39	0.44	0.61	0.73	1

3 Estimate plant resistance to:

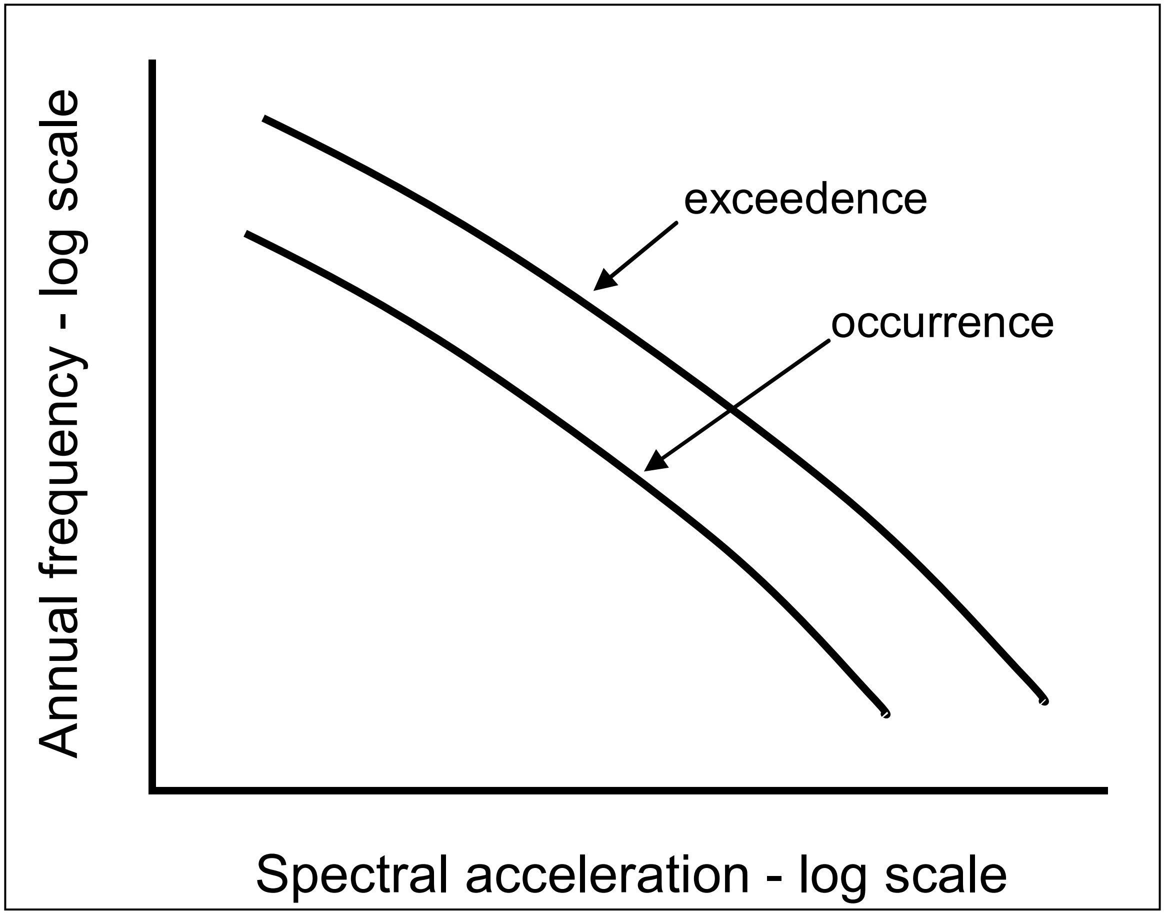


A. Onset of significant inelastic deformation

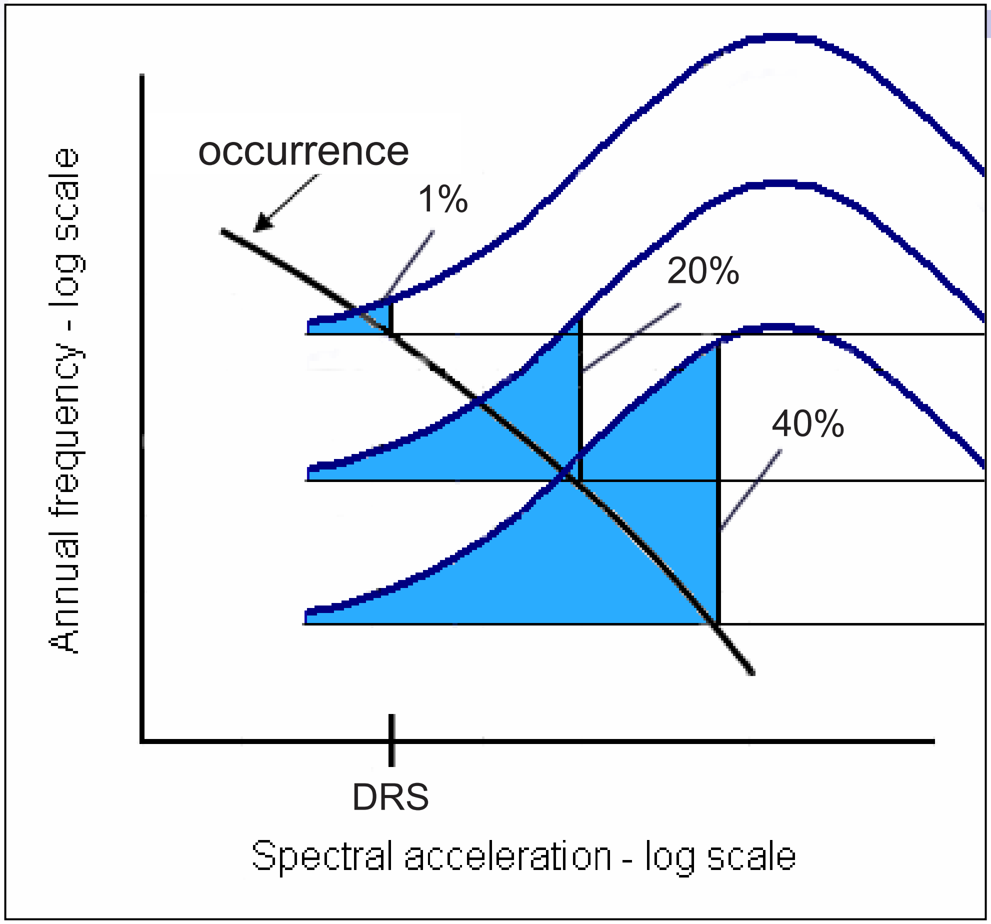


B. Core damage

4 Derive P[occurrence] from P[exceedence]



5 Convolution



$$FOSID = \sum_{SA} f(SA) * P[OSID|SA]$$

$$SCDF = \sum_{SA} f(SA) * P[CD|SA]$$

Calculations:

- Comparison 1: Recommended design response spectra vs. SSE spectra used for existing plants:
  - average of DRS/SSE at 5 and 10 Hz
  - minimum DRS is RG 1.60 spectrum anchored to 0.1g (ASCE, 2005)

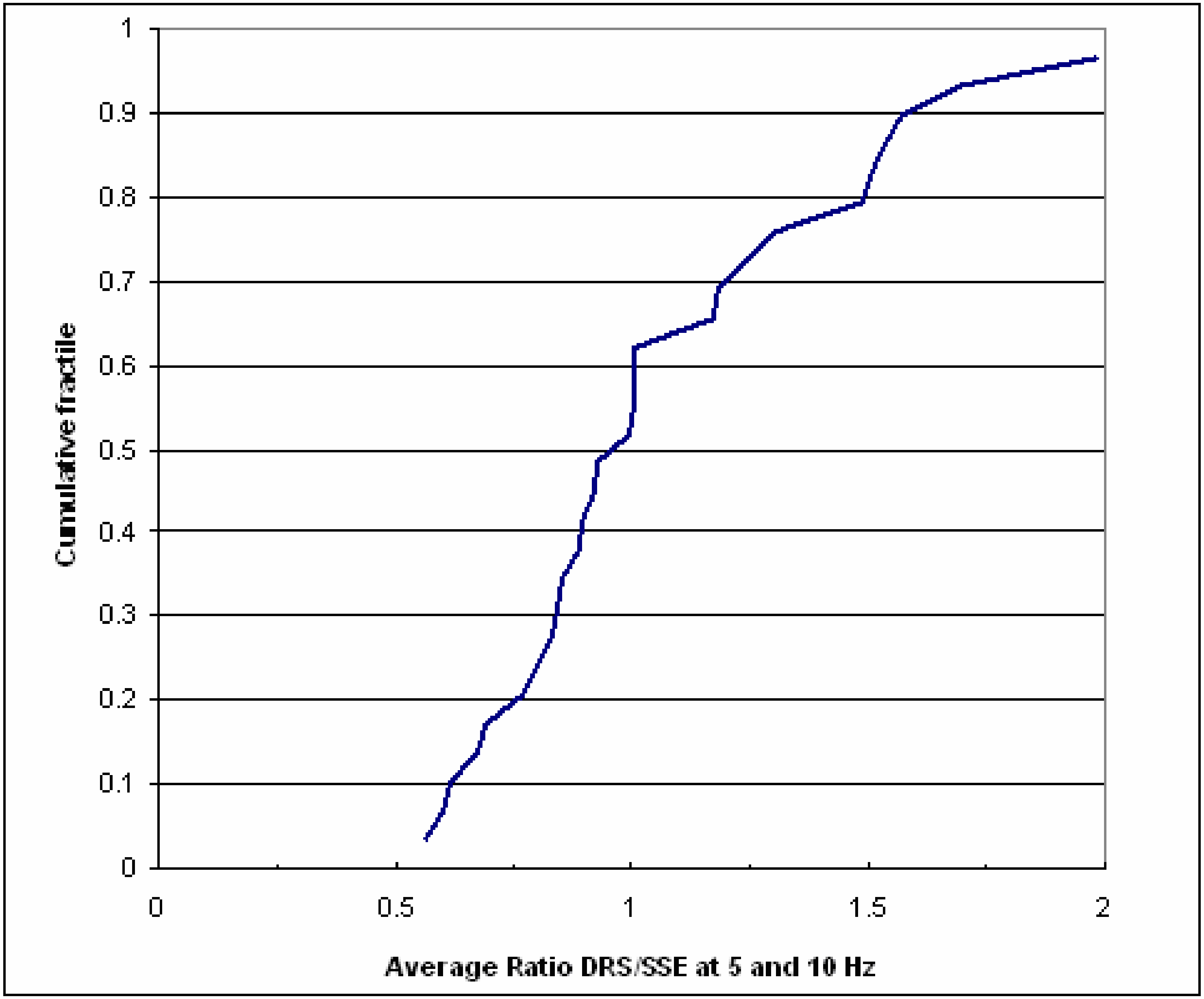
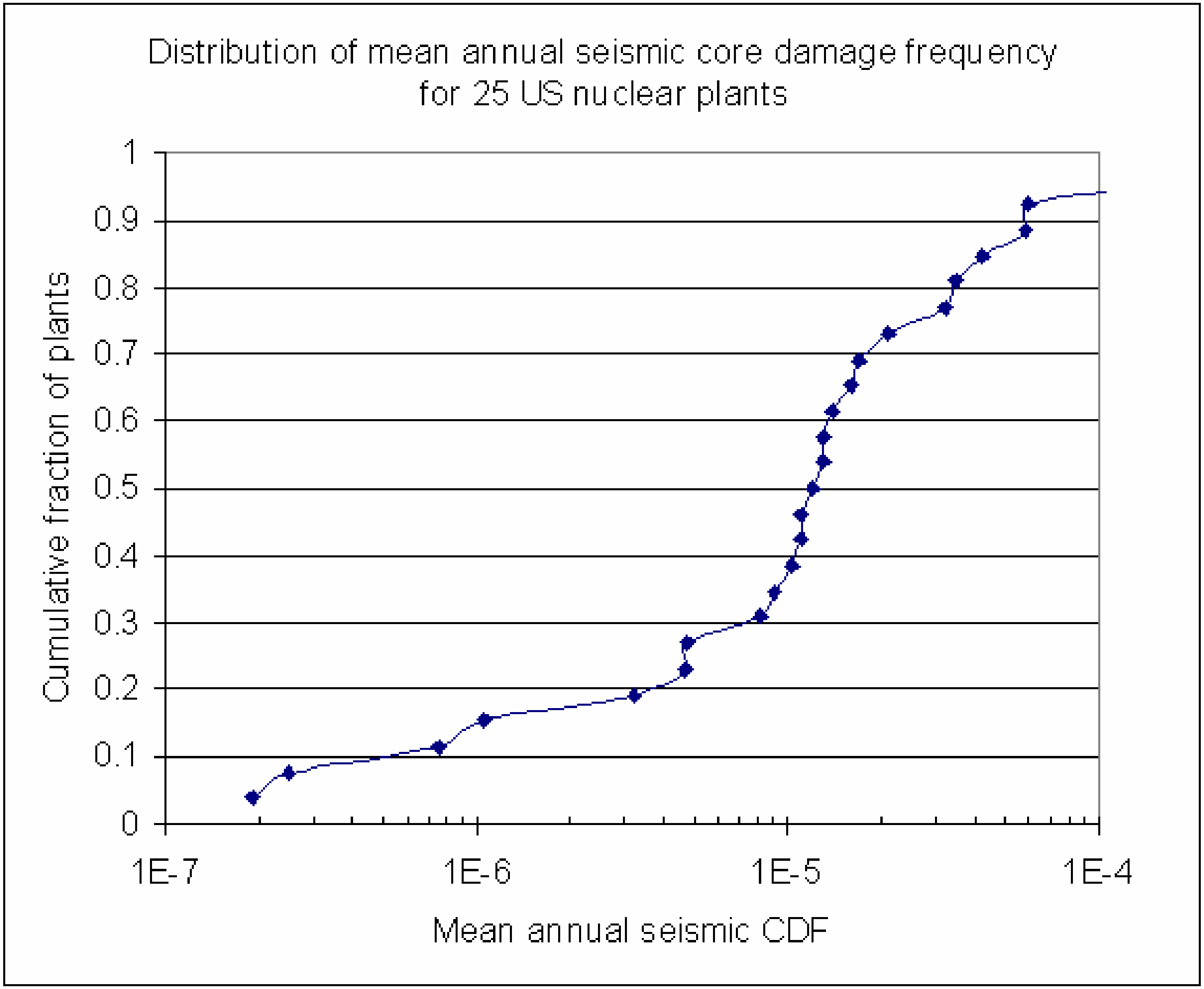
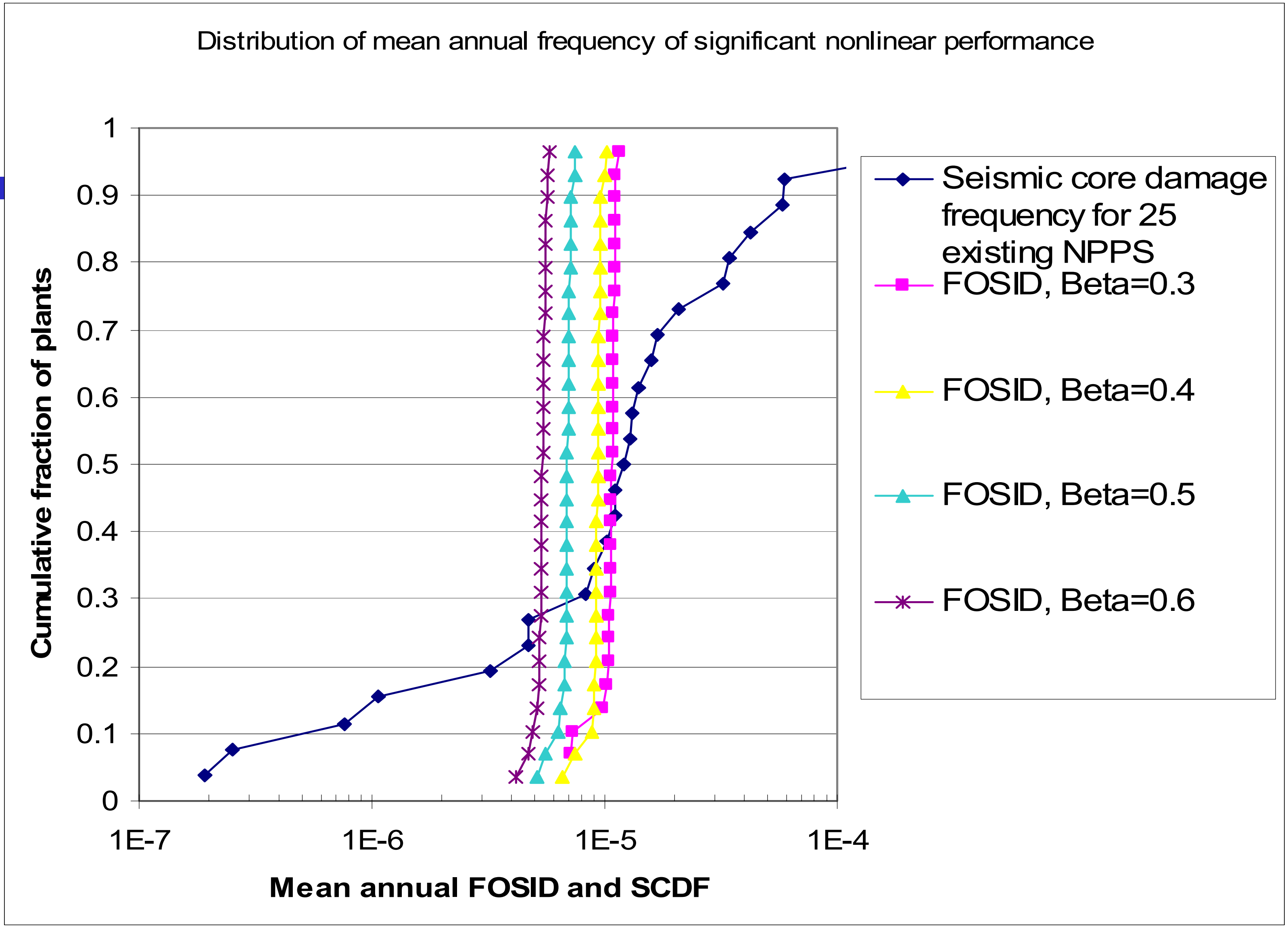


Figure 3.1 Cumulative Distribution of DRS/SSE Ratio at 5 and 10 Hz

Calculations:

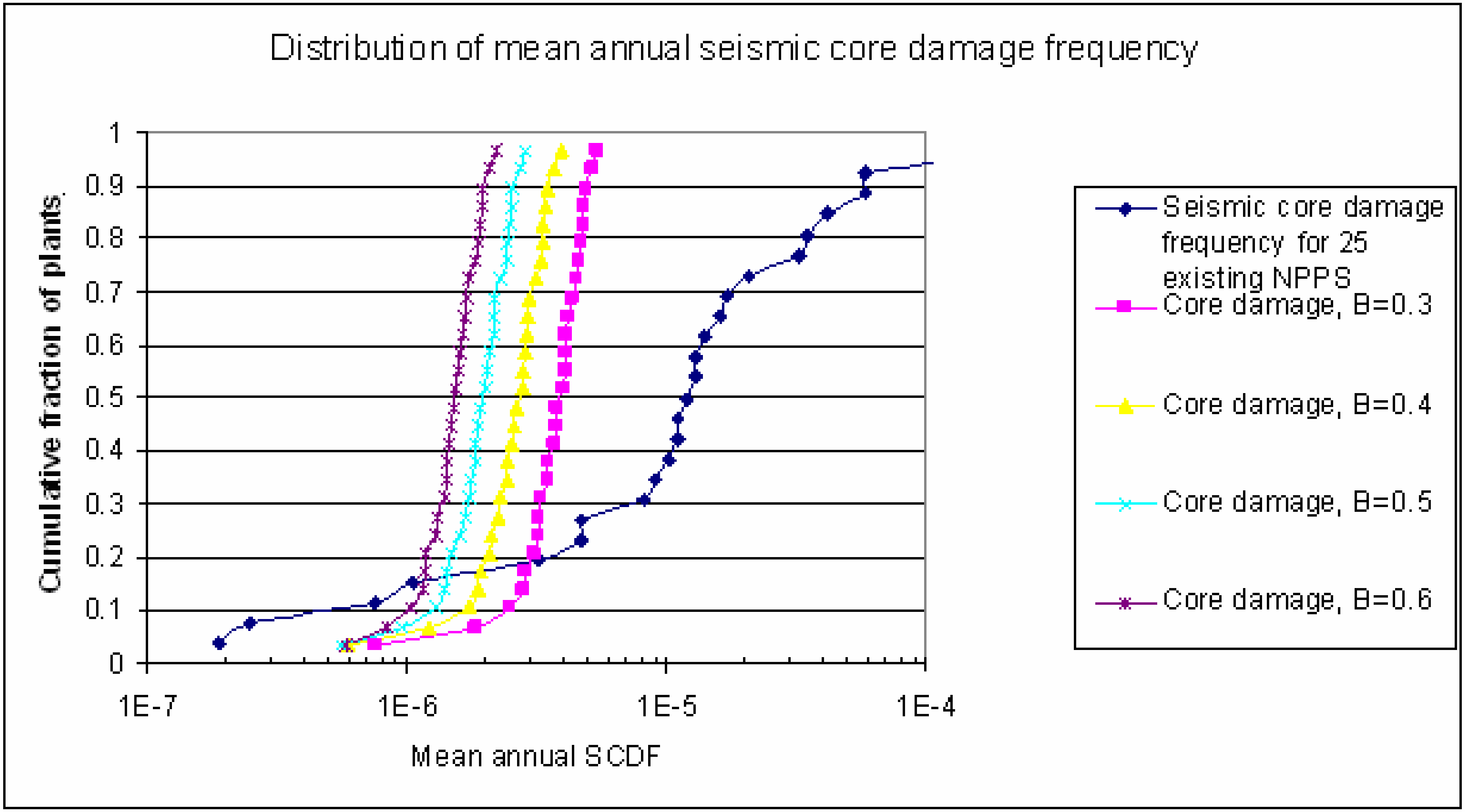
- Comparison 2: Component-level behavior:
  - calculate Frequency of Onset of Significant Inelastic Deformation (FOSID), compare to distribution of Seismic Core Damage Frequency (SCDF) from 25 seismic PRAs


Distribution of mean annual seismic core damage frequency for 25 US nuclear plants
Cumulative fraction of plants
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1E-7
1E-6
1E-5
1E-4
Mean annual seismic CDF


Distribution of mean annual frequency of significant nonlinear performance
Cumulative fraction of plants
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1E-7
1E-6
1E-5
1E-4
Mean annual FOSID and SCDF
Seismic core damage frequency for 25 existing NPPS
FOSID, Beta=0.3
FOSID, Beta=0.4
FOSID, Beta=0.5
FOSID, Beta=0.6

Calculations:

- Comparison 3: Plant-level behavior:
  - calculate frequency of plant-level damage, compare to distribution of Seismic Core Damage Frequency (SCDF) from 25 seismic PRAs


Distribution of mean annual seismic core damage frequency
Cumulative fraction of plants
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1E-7
1E-6
1E-5
1E-4
Mean annual SCDF
Seismic core damage frequency for 25 existing NPPS
Core damage, B=0.3
Core damage, B=0.4
Core damage, B=0.5
Core damage, B=0.6

Conclusions:

- ASCE DRS method leads to recommended design response spectra at 5 and 10 Hz that, as a whole, are equivalent to those used at 28 existing NPPs
- ASCE DRS method leads to recommended site-specific design response spectra that achieve a performance goal of 1×10^{-5} per year, for individual components at 5 and 10 Hz
- ASCE DRS method leads to plant-level performance estimates that are safer against seismic initiated core damage than 80% of existing nuclear plants (based on 5 and 10 Hz)