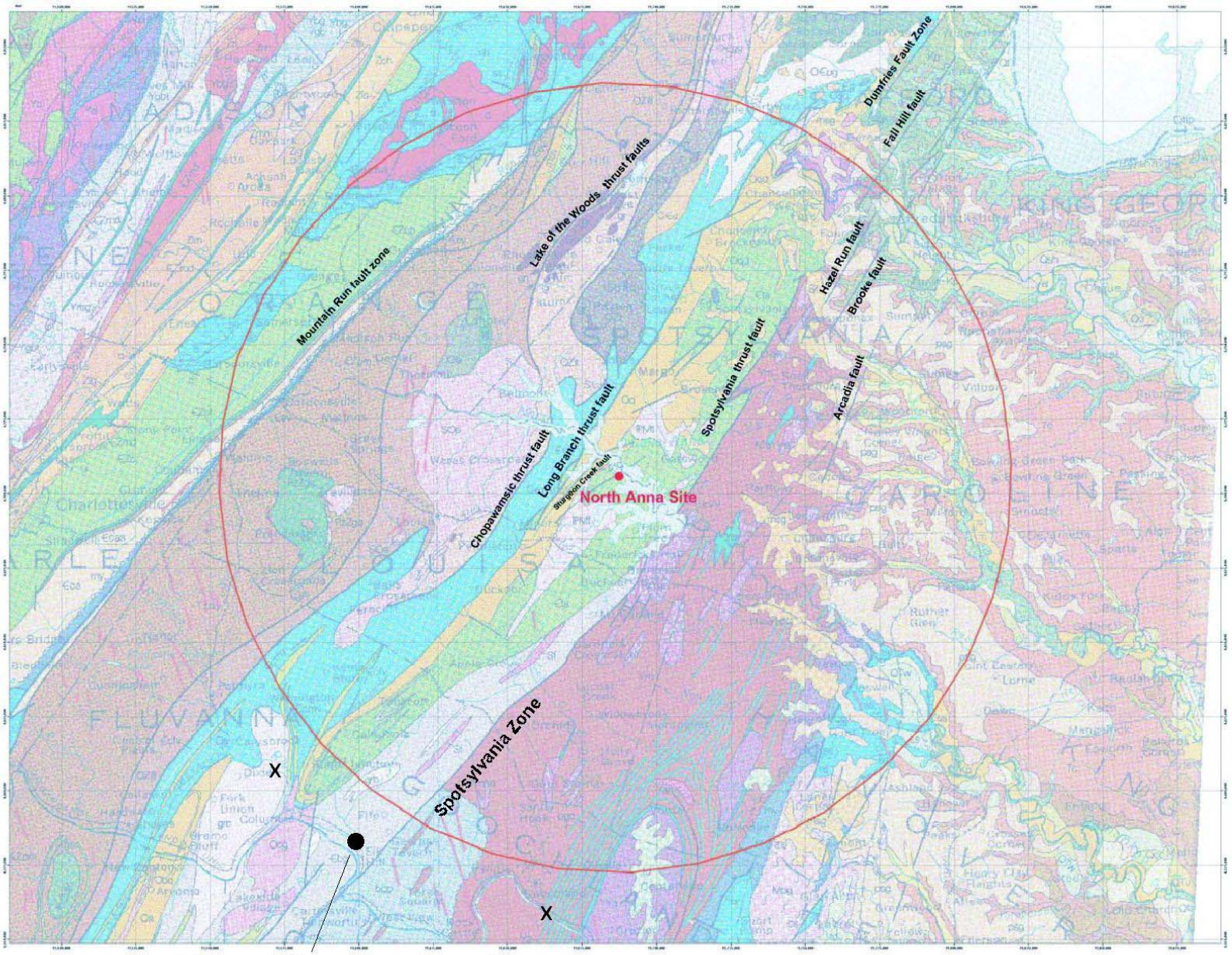


12/9/03 EQ

mb 4.5

2 locations

~45-50 km SSE of site

Site Vicinity Geologic Map
25-Mile Radius
North Anna Site

25-Mile Radius

N

0 2.5 5 7.5 10 Miles

Virginia Division of Mines and Geology, Geologic Map of Virginia, 1993, Scale 1:500,000

Virginia State Plane (North) coordinate system, Fipszone 4501, NAD 1927 Horizontal datum.

Kim and Chapman (2004) location

USGS location

x = paleoliquefaction feature

Parameters of Dec. 9, 2003 Earthquake (Kim and Chapman, 2004):

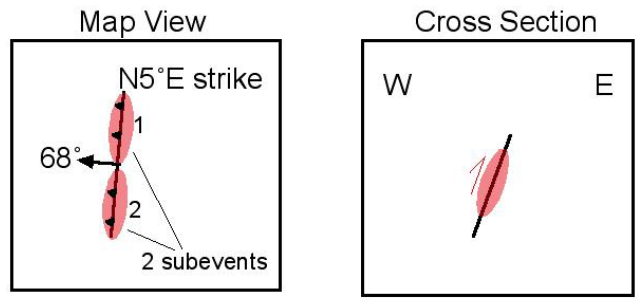
Magnitude: mb = 4.5; Mw = 4.3

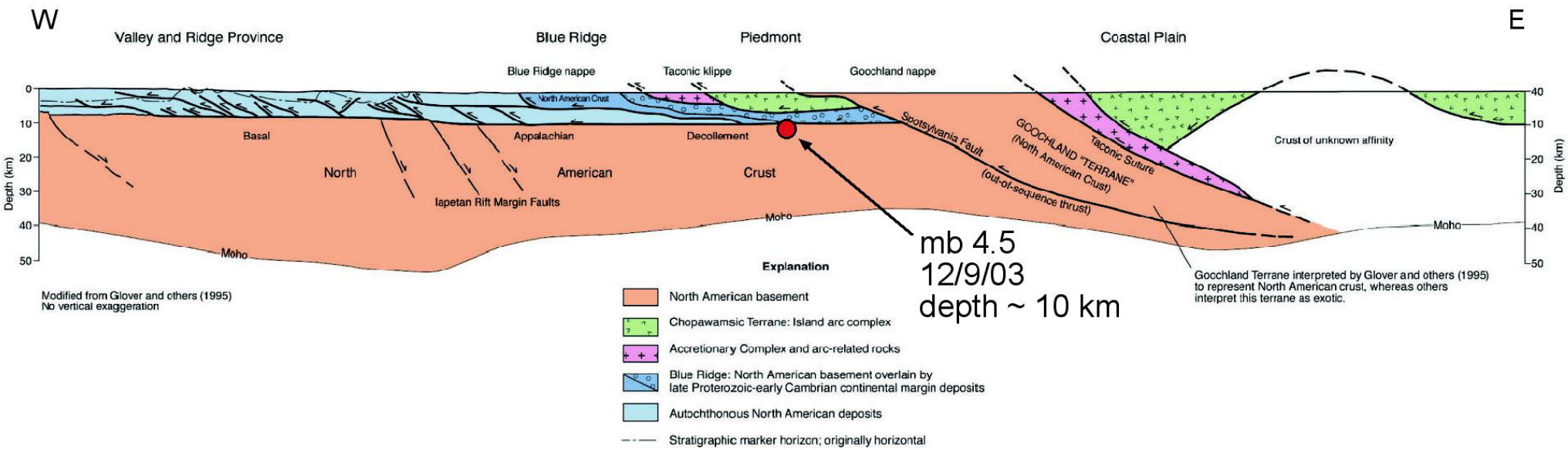
Depth: ~ 10 km

2 subevents separated by 12 seconds

P-axis: N60W, 18NW (plunge = 18˚, trend = 300˚)

possible fault plane: N5˚E (190˚), 68˚ NW; reverse faulting





December 9, 2003 mb 4.5 Central Virginia Earthquake *(continued)*

- Conclusion
  - Earthquake is an expected event in the CVSZ
  - No change to CVSZ source parameters is required

Dominion

Paleoliquefaction Features: Implications for CVSZ

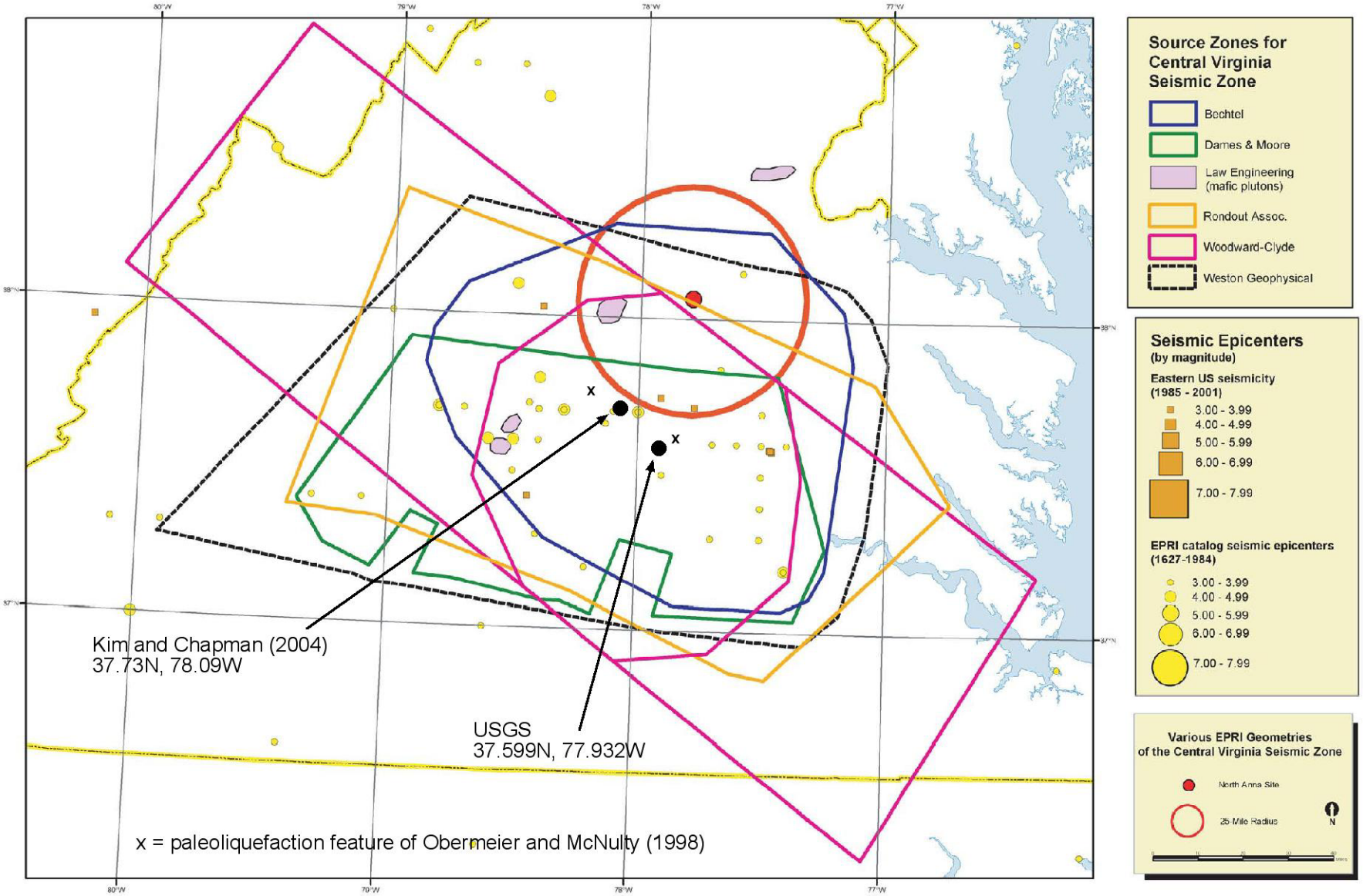
- Paleoliquefaction Features in CVSZ

Obermeier and McNulty (1998):

- Area searched: 100 x 100 km; >300 km of stream channels
- Deposits 2,000 to 5,000 years old commonplace
- Probable paleoseismic feature at one site on James River (< few hundred yards)
- Possible paleoseismic feature at one site on Rivanna River (early Holocene)
- Absence of widespread features indicate that large magnitude (M7) earthquakes are unlikely, and M6-7 earthquakes are not abundant

Dominion

Locations of Dec. 9, 2003 Earthquake (mb 4.5) and Paleoliquefaction Features



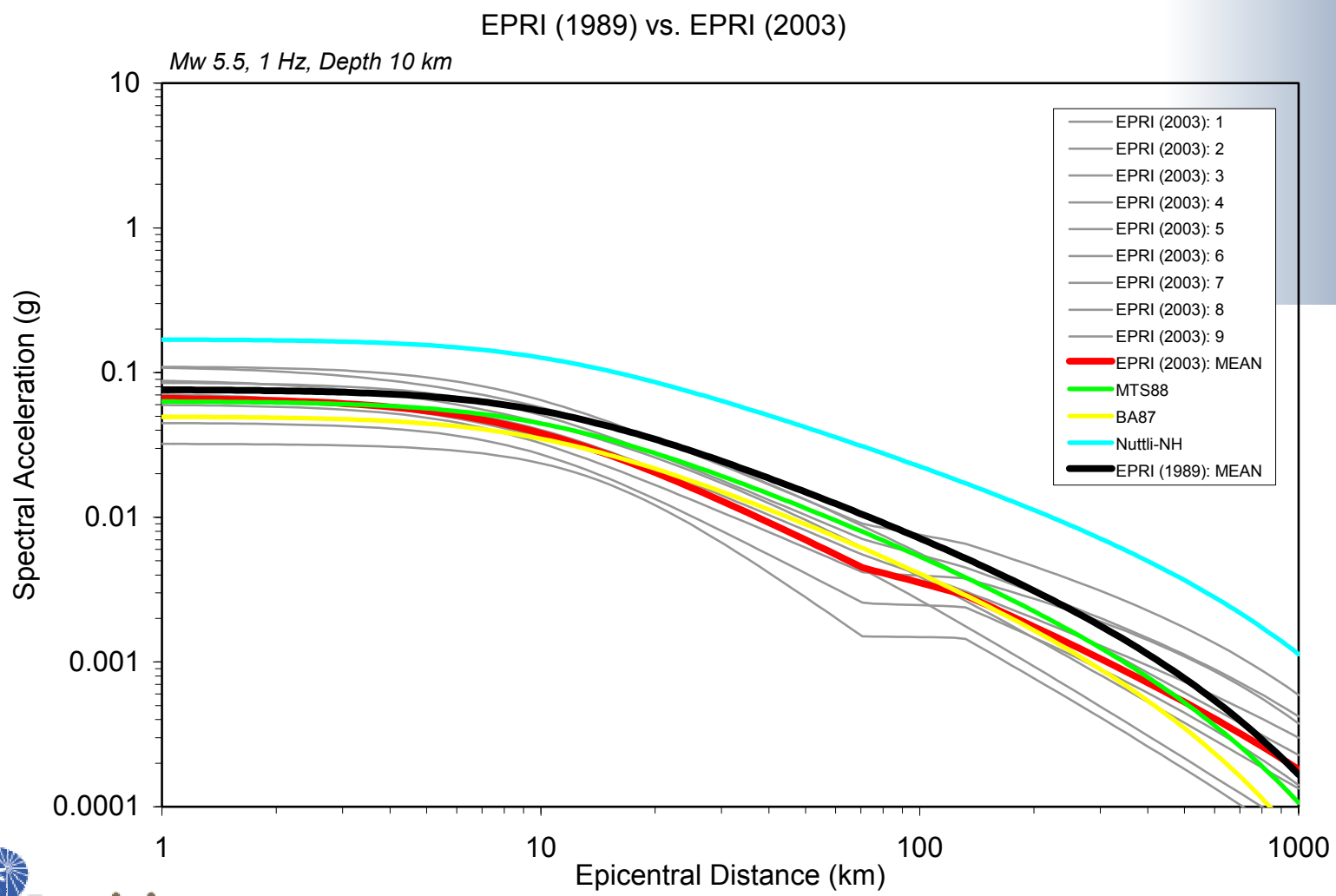
Paleoliquefaction Features: Implications for CVSZ *(continued)*

- Conclusion
  - Minor paleoliquefaction features are expected within CVSZ
  - Observed paleoliquefaction features support EPRI characterization of CVSZ
  - No change in CVSZ source parameters is required

3.1 Review and Update EPRI Seismic Source Models *(continued)*

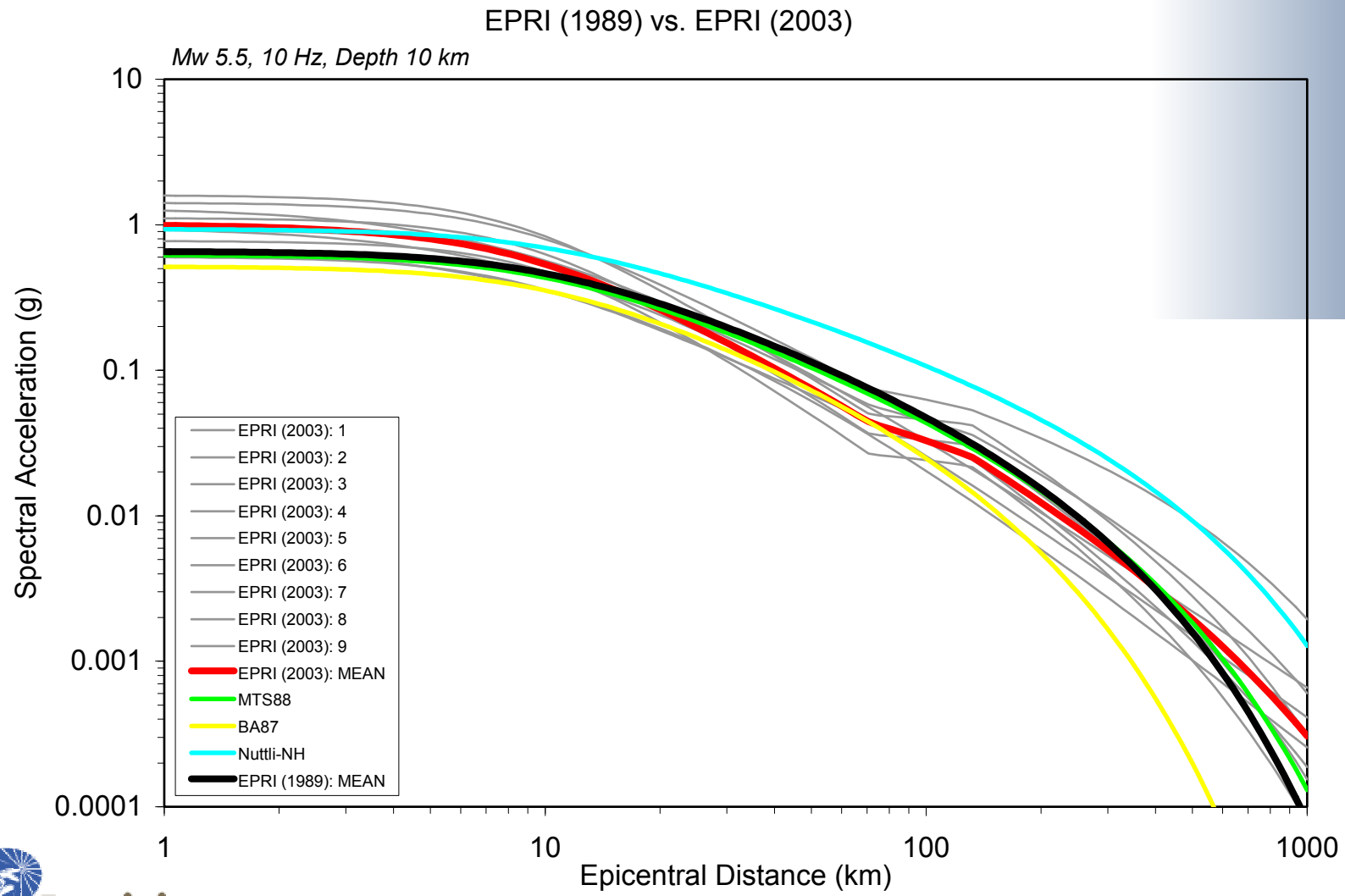
- Recurrence (Seismicity)
  - Central Virginia seismic zone is the dominant local source
  - Seismicity was updated from EPRI 1989 study (through 1984) to include more recent earthquakes (through 2001) from Virginia Tech and ANSS catalogs
  - EPRI 1989 procedure was repeated using the additional earthquakes
  - Analysis indicates that average seismicity has declined in more recent years

3.2 Review and Update EPRI Ground Motion Models



Dominion

3.2 Review and Update EPRI Ground Motion Models *(continued)*



Dominion

3.3 Perform Sensitivity Analyses or Updated PSHAs

- No new local sources
- No changes in parameters for 1989 EPRI sources (seismicity, Mmax)
- Additional East Coast Fault sources (ECFS) added
- ECFS-S source (Charleston) with **M**=7.5 (m_b=7.2) and 550-year return period indicates some additional hazard at 1 Hz
- ECFS-S source added to all six EPRI team interpretations

Dominion

3.4 Derive SSE Ground Motions

- Calculate hazard using 2003 EPRI ground motion models and additional ECFS-S source
- Base SSE on mean 10^{-5} annual frequency of unacceptable performance of components for all structural frequencies
- Account for slope of seismic hazard curves between 10^{-4} and 10^{-5}
- Procedure supported by DOE Standard 1020, Draft ASCE Standard XXX, and NUREG/CR-6728.
- Recommendation is for ***Performance-based spectrum***

Dominion

3.5 Additional Sensitivity Studies

- Recommended performance-based spectrum consistent with mean UHS calculated at 5×10^{-5}
- Recalculated seismic hazard using m_{min} of **M**=5.0, rather than m_b=5.0—this reduces ground motion amplitudes ~20% at high frequencies
- Recalculated seismic hazard using western US empirical ground motion σ's rather than EPRI 2003 σ's—this reduces ground motion amplitudes ~10% at all frequencies.
- The last two studies indicate about 30% overall conservatism in ground motions at high frequencies

Dominion

3.6 Performance-Based Spectrum Approach

- Risk based approach used to establish design basis response spectrum
  - Develops a risk-consistent design response spectrum (DRS) as opposed to a relative Uniform Hazard Response Spectrum (UHRS) based upon median exceedance frequency for 29 sites
  - Approach implements risk-consistent regulatory goals
  - Conservatively aimed at achieving a target performance goal for unacceptable seismic performance

3.6 Performance-Based Spectrum Approach *(continued)*

- Reference to ANS 2.26 on Mean $1x10^{-4}$/yr Uniform Hazard Response Spectrum
  - ANS 2.26, "Categorization of Nuclear Facility Structures, Systems and Components For Seismic Design"
  - Objective is "to achieve a risk consistent design that protects the public, workers and the environment from potential consequences of earthquakes"
  - Structures, systems, and components are divided into five Seismic Design Categories (SDCs)
  - For each SDC, four Limit States are recognized

3.6 Performance-Based Spectrum Approach *(continued)*

- Reference to ANS 2.26 on Mean $1x10^{-4}$/yr Uniform Hazard Response Spectrum *(continued)*
  - The most stringent criterion is for SDC 5 and Limit State D – elastic response. This criterion is considered applicable to commercial nuclear power plants.
  - Most stringent criterion leads to less than $1x10^{-5}$/yr exceedence probability of inelastic behavior.

Dominion

3.6 Performance-Based Spectrum Approach *(continued)*

- Risk Based Design Response Spectrum

DRS = Design Response Spectrum

DF = Design (Scale) Factor

$UHRS_{10^{-4}}$ = Mean 1×10^{-4}/yr Uniform Hazard Response Spectrum

$$DRS = DF * UHRS_{10^{-4}}$$

Dominion

3.6 Performance-Based Spectrum Approach *(continued)*

- DF is a Function of:
  1. Target Performance Goal P_F (Mean annual probability of unacceptable seismic performance)
  2. Ratio A_R between mean $1x10^{-5}$ and mean $1x10^{-4}$ spectral accelerations:

$$A_R = \frac{UHRS_{10^{-5}}}{UHRS_{10^{-4}}}$$

  3. Conservatism of seismic design criteria as defined by high confidence low probability of failure (HCLPF) seismic margin ratio:

(HCLPF/DRS)

Dominion

- References

1. Kennedy, R.P., *Establishing Seismic Design Criteria to Achieve an Acceptable Seismic Margin,* Plenary 5, Transaction of the 14th International Conference on Structural Mechanics in Reactor Technology (SMiRT), Lyon, France, August 1997.
2. Kennedy, R.P., *Development of Risk-Based Seismic Design Criterion,* Proceedings of the OECD-NEA Workshop on Seismic Risk, Tokyo, Japan, August 1999.
3. Draft ASCE Standard, *Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities,* December 2003.
4. DOE-STD-1020-2002, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities,* January 2002.
5. NUREG/CR-6728, *Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard and Risk Consistent Ground Motion Spectra Guidelines,* October 2001.

3.7 Additional Modification of Selected Spectrum

- Development of Engineering Design Spectrum
  - Studies show Seismological Design Spectrum "is an unrealistic design input for the analysis and design of structures"
    - SDS shows the response of single DOF oscillators mounted on small light pads on ground surface
    - Small mass would not modify the ground motion; thus these oscillators may experience the predicted high frequency motions
    - Structures with large masses would modify the free field motion
  - Observations have led to the conclusion that high frequency motions are less damaging except for situations such as relay chatter.

Dominion

3.7 Additional Modification of Selected Spectrum *(continued)*

- Development of Engineering Design Spectrum *(continued)*
  - SDS must be modified to obtain a realistic design spectrum
  - Two factors to consider:
    - Wave incoherence effects
    - Effects of high frequency ground motions

Dominion

3.7 Additional Modification of Selected Spectrum *(continued)*

- Wave Incoherence Effects
  - Observed response of the ground is different than response of a large basemat
  - Average response of a large basemat is significantly less than a small pad attached to the ground (i.e., supporting instruments that record the ground motion)
  - Reduction is greater at higher frequencies and for larger basemat sizes

3.7 Additional Modification of Selected Spectrum *(continued)*

- Effects of High Frequency Ground Motions
  - High frequency motions are accompanied by small displacements
  - Energy content is also less as shown by power spectral densities
  - Well-engineered structures have ample capacity to dissipate the corresponding limited energy
  - Structures are damaged only when the story drifts are relatively large. High frequency motions do not generate drifts approaching damaging levels.
  - Potential for damage reduces substantially at higher frequencies
  - Modification should be based on “equal risk” concept (i.e., equal factor of safety against failure)

Dominion

3.7 Additional Modification of Selected Spectrum *(continued)*

- Effects of High Frequency Ground Motions *(continued)*
  - Potential for damage reduces substantially at higher frequencies
  - Modification should be based on “equal risk” concept (i.e., equal factor of safety against failure)

4. NRC-Identified Topics in 2/20/04 E-Mail

- Performance-Based Approach (PBA)
  - a) Incorporating equipment performance into SSE determination at ESP stage
  - b) Documentation of PBA in ESPs or NUREG/CR 6728 (i.e., how is scale factor determined?)
  - c) Starting at mean 10^{-4} UHS
  - d) Deaggregation of hazard results for Controlling EQs
  - e) Enveloping site-specific response spectra for SSE
  - f) Updating reference probability on case-by-case basis

Dominion

4. NRC-Identified Topics in 2/20/04 E-Mail *(continued)*

- Updates for ESP PSHA
  - a) Updating 1989 EPRI results (ESTs)
  - b) Impact of Charleston EQ on hazard (i.e. low-frequency Controlling EQ)
  - c) Characterization of CVSZ (recurrence, maximum magnitudes)
  - d) 2003 EPRI update of ground motion attenuation models (grouping of 13 relationships, weighting criteria, handling of variability, large ground motions at high frequencies)

4. NRC-Identified Topics in 2/20/04 E-Mail *(continued)*

- Geotechnical Topics
  - a) Coverage of proposed site to characterize subsurface (borings,geophysical surveys)
  - b) Liquefaction analysis
  - c) Slope stability analysis

Dominion

4. NRC-Identified Topics in 2/20/04 E-Mail *(continued)*

- March 4 at North Anna
  - a) Characterization of Central Virginia Seismic Zone in view of paleoliquefaction
  - b) Basis for evaluating capability of regional faults
  - c) Details on assessment of local sources for ESP (aerial reconnaissance, literature search, ...)
  - d) Overview of site geology (soil/rock types, layering, variability)
  - e) Overview of geotechnical and geophysical surveys and results performed prior to submittal of application
  - f) Tour of proposed site

Dominion

Characterization of Regional Faults

Data Suggestive of Fault Activity

- Published and unpublished reports
- Geomorphic expression
- Alignment of seismicity
- Offset Cenozoic strata
- Paleoseismic features

Evaluation of Regional Faults

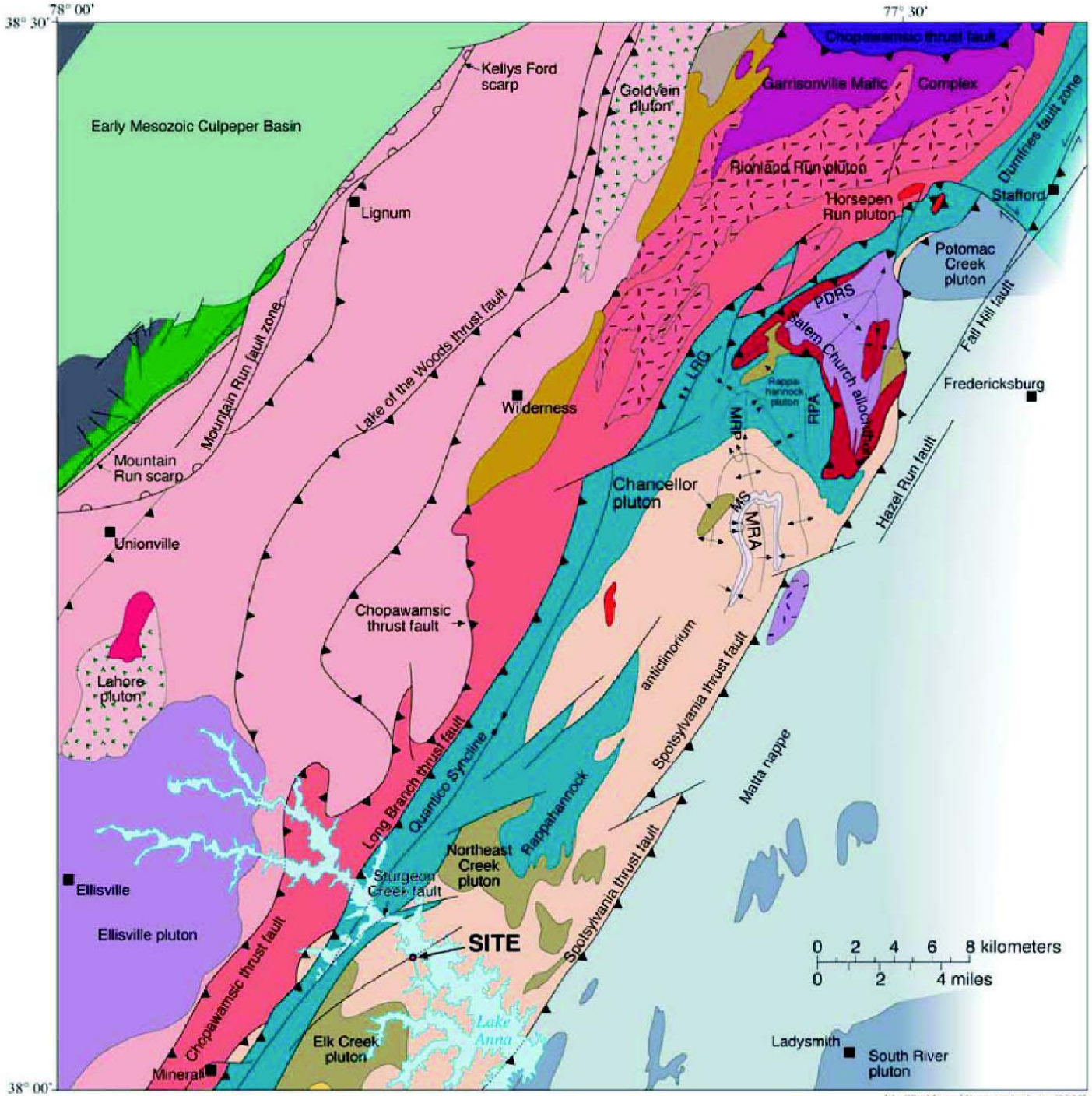
- Literature review
- Contact local researchers
- Aerial reconnaissance (Stafford, Mountain Run, Northern ECFS)
- Field reconnaissance (Stafford, Mountain Run)
- Seismicity analysis

Local Researchers Contacted

- James Spotila (VT)
- Robert Mixon (USGS, ret.)
- Bob Hatcher (U Tenn)
- John Marr (VDMR)
- Steven Obermeier (USGS, ret.)
- Mark Petersen (USGS)
- Robert Weems (USGS)
- Rus Wheeler (USGS)
- Art Frankel (USGS)
- Pradeep Talwani (USC)

Paleozoic Faults (25 mile radius)

- Hylas
- Spotsylvania (within 5 miles)
- Long Branch (within 5 miles)
- Chopawamsic (within 5 miles)
- Lake of the Woods
- Mountain Run



Modified from Mixon and others (2000)