Report to the U.S. Nuclear Regulatory Commission on Evaluation and Application of 2002 USGS National Seismic Hazard Assessment

November 30, 2004

This report is a series of software verification documents of the Monte Carlo seismic hazard codes that we have developed for the CEUS.

USGS PSHA Software Verification

Program: ceusruns.f
Module: nmadrupt.f
Version number:
Technical Contact: Steve Harmsen
Email: harmsen@usgs.gov
Verification Date: November 10, 2004

Purpose of Code:
This code determines seismic hazard Monte Carlo (MC) model parameter settings from the sources and attenuation models used in the USGS 2002 Update probabilistic seismic hazard assessment. It writes files for these parameter settings and runs PSHA codes to generate seismic hazard curves.

Code Alternate Branches:

- Use precomputed model input files, including gridded rate file (agrid) for resampled seismicity catalogs.
- Compute input files, include resampling of catalogs to recompute sample agrids.

Test 2:
Find the sample distribution of New Madrid fault location alternatives and compare with expected numbers for sample size = 200.

Result:

The model coded in *ceusruns.f* and in *nmadrupt.f* for sample fault locations uses a two-step uniform-variate generator. Attachment 1 shows the parts of the *ceusruns* code and explanations. The result is an integer, imod, that can take on values 1 through 9. Ceusruns calls the Fortran subroutine, *nmadrupt.f*, which gets the fault parameters from pre-existing files located in a subdirectory named "data/". Attachment 2 is a listing of *nmadrupt.f*. *Nmadrupt* also has fault-location options associated with imod=11 through 16, but these are not used in the NRC work.

A-8

We determine the actual numbers of the nine NMSZ fault location options that are written to the files nmad.inV3*k*, where *k*=001 through 200, during a run of ceusruns. Attachment 3 shows the actual lines of the 200 nmad.inV3*k* files that indicate which of the nine NMSZ fault-location models is chosen in that file. These counts are tabulated below. We compare these with expected numbers, given the model coded up in ceusruns.f. The following table shows the results.

	West+	West	West-	Center+	Center	Center-	East+	East	East-
Obs	8	30	16	16	55	18	13	35	9
Exp	12.5	25	12.5	25	50	25	12.5	25	12.5

In this table, the top row indicates the nine alternatives. The second row indicates the samples that fall in each alternative, and the third row indicates the expected sample. The 2002 USGS PSHA gives the central fault location 50% epistemic weight, and 25% to the two extremal or bounding locations. The Monte Carlo sampling keeps this scheme, and uses a 60%/20%/20% weight scheme for choosing original, minus, and plus location options, respectively. Random sampling can explain the differences between the observed and expected values.

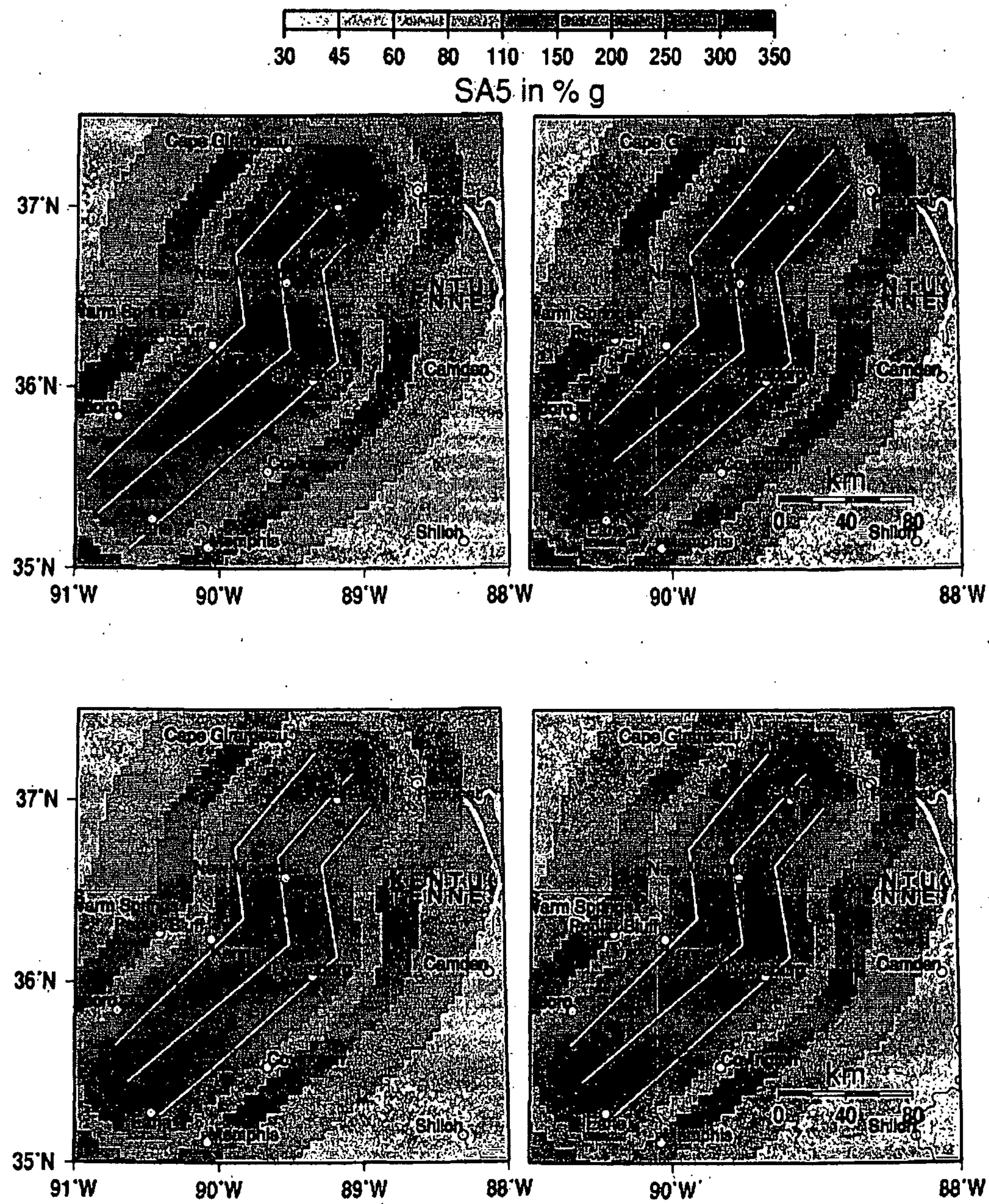
We next verify that the locations of the sample NMSZ fault locations are what they are claimed to be by randomly selecting nmad.inV3* files that correspond to the above nine locations and by plotting the fault-location information contained in these.

In the following figure, the lower left map shows the USGS 2002 west, central, and east fault-location options, for comparison with these QA test fault locations. The lower right map shows three fault locations taken from three "central" nmad.inV3 files. These fault traces are the same as those in the lower-left map. The fault information overlays 5-Hz spectral amplitudes for the 2% in 50 year Probability of Exceedance. The PSHA information is not needed but it helps indicate the potential influence that the fault-location changes could have for sites in the vicinity of the New Madrid seismic zone.

The upper left map shows three locations taken from three minus (-) nmad.inV3 files, where minus is an indicator that means extend the faults southwest and remove corresponding lengths from the northeast. Note that this extension moves the south endpoint of one of the faults well south of Earle, AR.

The upper right map shows three locations taken from three plus (+)nmad.inV3 files, where plus is an indicator that means extend the faults northeast and remove a corresponding lengths from the southwest. Note that this extension moves one of the faults into the vicinity of Paducah, KY. This extension moves the northern endpoint of the western fault well north of Cape Girardeau, Missouri.

Conclusion: The module nmadrupt.f writes the New Madrid fault-location alternatives correctly, and ceusruns assigns these with the correct frequency, within statistical-sampling fluctuation limits.



GMT Nov 10 10:25 OA causruns. Background 5hz SA. NMSZ 2002 faults lower left; Monte Carlo originals lower rt; extend sw upper left; extend ne upper rt.

Attachment 1:

In ceusruns.f, randomization of position of New Madrid fault is performed in two steps. First, a uniform random variable v is generated, then its amplitude is used to determine the choice. The part of ceusruns code for choosing west, central, or east New Madrid fault location:

```
c   Choose rupture model for NMSZ
c   2002 National Maps section
      v = 0.0
      if(lrup) v = ran1(idum,iy,iv)
      irup = 1
      if(v .lt. .50) imod = 1  !NMSZ02c
      if(v .ge. .50 .and. v .lt. .75) imod = 2 !NMSZ02e
      if(v .ge. .75) imod = 3 !NMSZ02w
```

These lines are at about line number 200 of the ceusruns.f code.

The part of code for determining whether to use original fault, or to extend it sw and truncate ne, or to extend ne and truncate sw:

```
c   Choose length uncertainty for NMSZ
c   2002 National Maps section
      v = 0.
      if(llsd .and. irup .eq. 1) v = ran1(idum,iy,iv)
      if(v .ge. .6 .and. v .lt. .8) imod = imod + 3 ! South -sd
endpoints
      if(v .ge. .8) imod = imod + 6 ! North +sd endpoints
```

Although the comment line above says length uncertainty, the alternatives are really position uncertainty, as the lengths remain reasonably constant.

The lines above are at about line number 260.

Some other constants are established and at about line 340, the new Madrid source specification information is fed to subroutine nmadrupt:

```
        call nmadrupt(2,imod,rinm,fmnm,nmwc,wnm,wtnm)
```

The next attachment is a listing of nmadrupt.f

USGS PSHA Software Verification

Program: ceusruns.f
Module: main, lines 464 to 476
Version number:
Technical Contact: Steve Harmsen
Email: harmsen@usgs.gov
Verification Date: November 29, 2004

Purpose of Code:

This code determines seismic hazard Monte Carlo (MC) model parameter settings from the sources and attenuation models used in the USGS 2002 Update probabilistic seismic hazard assessment. It writes files for these parameter settings and runs PSHA codes to generate seismic hazard curves.

Code Alternate Branches:

- Use precomputed model input files, including gridded rate file (agrid) for resampled seismicity catalogs.
- Compute input files, include resampling of catalogs to recompute sample agrids.

Current Test:

Compute areal rates for Charleston, South Carolina mainshocks from input files *amake.agridXXX*.
Find the sample areal rate distribution of Charleston, South Carolina mainshocks and compare with expected areal rate distribution. Use sample size = 200.

Narrative:

The Charleston, South Carolina mainshock is modeled as a fixed-strike source whose overall mean rate in the 2002 USGS update of the national seismic hazard maps is 1/550 (Frankel *et al.*, 2002). In the Monte Carlo runs, the mean rate parameter is a random variable. It is modeled using the following Fortran code, extracted from ceusruns.f.:

```
Lines 464 to 476:

c   Choose recurrence interval for CSZ
c   2002 National Maps section
        vv = 0.25 ! gives mean in this case
        if(lri .and. jrup .gt. 0) vv = gasdev(idum,iset,gset,iy,iv)
c         rich = log(485.) + vv*.5 ! 550y mean recurrence interval
c-----changed by ADF  11/16/04
c        rinm = log(440.) + vv*.5 ! 500y mean recurrence interval
      rmed= (1./550.)/exp(0.5**2/2.)
      rich= alog(rmed) + vv*0.5
      rich = exp(rich)
c---- convert to recurrence interval
      rich= 1./rich
c   Cramer, 2001 (Eng. Geol.) section


The randomized rate is then written to amake.agrid at line 596:

          write(3,'(f7.5,f4.1,f5.2/''amake.agrid'')') 1./rich,fmch,1.0
a

The randomized rate is 1 over the randomized recurrence interval, rich.
```

In the above, the distribution of mean rates is log-normal. The median rate is given above in the variable *rmed*, the median that corresponds to a mean of 1/550 and a variance of 0.5. The sample recurrence interval, *rich*, is computed as 1/(sample rate), and finally the sample rate is written into a file that is used to compute areal rates as 1/(sample recurrence interval). This occurs at line 596 of the code, *ceusruns.f*.

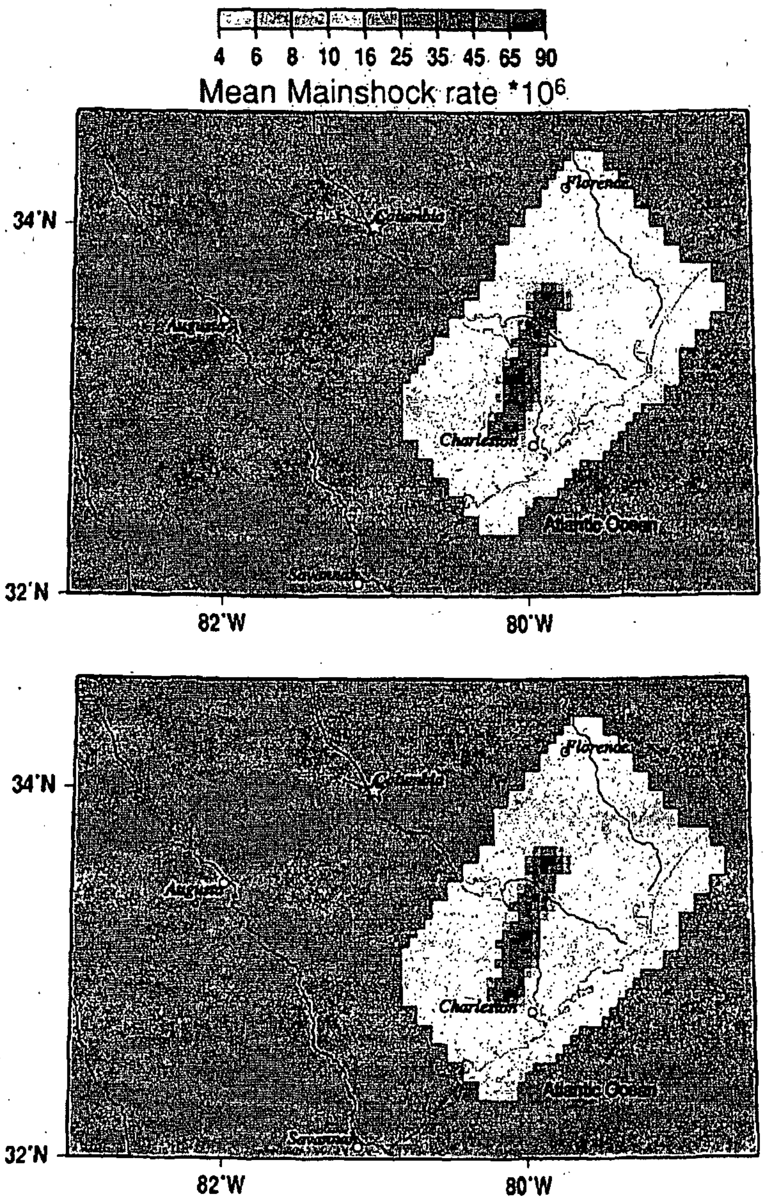
Result:

The model coded in *ceusruns.f* for generating areal grids of earthquake rates writes output files named amake.agrid*j*, where *j*=001 through 200 for the current test. The program *hazgridsum.f*, attachment 1 below, determines the source-cell a-values and related information from input files char.inV3*j*. It then computes rates of earthquakes of specified magnitudes, at the spatial grid of points, and finds the average rates at these grid points. An example input file, char.inV3001, is attachment 2 below. The ascii output file of rates computed by *hazgridsum.f* is examined in this test.

For this test and for the "production runs" we determine the mean rate of Charleston mainshocks by summing the source rates at grid points that sample the source region at 0.1 degree intervals in latitude and longitude. The sample mean is this sum divided by the number of MC runs, which for this test, is 200. The Charleston mainshock areal source has two epistemic branches, a broad region in eastern South Carolina and a narrow region, corresponding to the southern zone of river anomalies (S-ZRA) of Marple and Talwani (2000). Each of these branches has weight 0.5.

To test the modeled rates in these regions, we compare the mean rate of Charleston mainshocks from 200 MC runs with the mean of the two epistemic branches in the National Seismic Hazard maps. The following figure shows the comparison. The top map is the rate of Charleston mainshocks, as a function of spatial position, from the national maps, and the bottom map is the mean rate of Charleston mainshocks, computed from the files amake.agrid001 through amake.agrid200, from the November, 2004, revisions of ceusruns.f. Note that the rate of earthquakes in the narrow zone is on average more than ten times the rate in the broad zone. This rate difference follows from the fact that the narrow zone has less than 1/10 the area of the broad zone.

The close similarity of the top and bottom maps at all locations indicates that the mean of the sample rates closely approximates the expected rate at all locations where Charleston mainshock hazard is non-zero. (Zero-hazard space is colored dark gray in this figure.)



GMT Nov 29 09:51 Mean areal rate Charleston main. Bottom, 200 Sims of revised amako.agrid (Nov 2004). Top, avg(narrow,broad) 2002 PSHA map. Rivers blue.

In addition to the above visual comparison, we compute the overall mean rate of Charleston mainshocks from the 200 MC runs. This mean is $1.903 \cdot 10^{-3}$. The expected mean is $1.818 \cdot 10^{-3}$. The former mean is very close to the latter, well within fluctuation expected by sampling the log-normal distribution on earthquake rates. Note that the latter mean is 1/550, where 550 years is the mean recurrence interval used in the 2002 USGS PSHA for the Charleston mainshock (Frankel *et al*, 2002).

Conclusions:

- The code *ceusruns.f* randomizes the rate of Charleston mainshocks both spatially and temporally with the expected frequency, within statistical-sampling fluctuation limits. The overall rate of Charleston mainshocks is very close to the expected annual rate, namely 1/550.

- Previous versions of *ceusruns.f* based the model of variation of rate of mainshocks on a log-normal distribution in which the mean recurrence interval was 550 years. These previous versions produced significantly higher rates of the Charleston mainshock than the model used by Frankel *et al.* (2002). The current revision of *ceusruns.f*, therefore, more faithfully conforms to the USGS published model.

- We note here that there is probably not enough empirical (mostly paleoseismic) data to choose between the model in which the mean rate is 1/550 and the model in which the mean recurrence interval is 550 years. We assume that the sample mean is distributed as a log-normal variable with variance 0.5.

Reference:

Frankel, Arthur D., Mark D. Petersen, Charles S. Mueller, Kathleen M. Haller, Russell L. Wheeler, E.V. Leyendecker, Robert L. Wesson, Stephen C. Harmsen, Chris H. Cramer, David M. Perkins, and Kenneth S. Rukstales (2002). Documentation for the 2002 Update of the National Seismic Hazard Maps, U.S. Geological Survey Open-File Report 02-420.

Marple, R. T. and P. Talwani, 2000. Evidence for a buried fault system in the Coastal Plain of the Carolinas and Virginia - Implication for neotectonics in the southeastern United States, *Geol. Soc. Am. Bull.*,**112**, p. 200-220.

USGS PSHA Software Verification

Program: ceusruns.f
Module: all
Version number:
Technical Contact: Steve Harmsen
Email: harmsen@usgs.gov
Verification Date: December 7, 2004

Purpose of Code:
This code determines seismic hazard Monte Carlo (MC) model parameter settings from the sources and attenuation models used in the USGS 2002 Update probabilistic seismic hazard assessment. It writes files for these parameter settings and runs PSHA codes to generate seismic hazard curves.

Code Alternate Branches:

- Use precomputed model input files, including gridded rate file (agrid) for resampled seismicity catalogs.
- Compute input files, include resampling of catalogs to recompute sample agrids.

Current Test:

Compute mean, median, and fractile seismic hazard curves for 29 nuclear power plants in the CEUS.
Compare the mean rates for 1-s and 0.1-s SA with the USGS 2002 PSHA hard-rock model update (Frankel et al, 2002). Explain differences.
Make spot-check comparisons for other SA periods at random subset of these 29 sites.
Use sample size = 200.

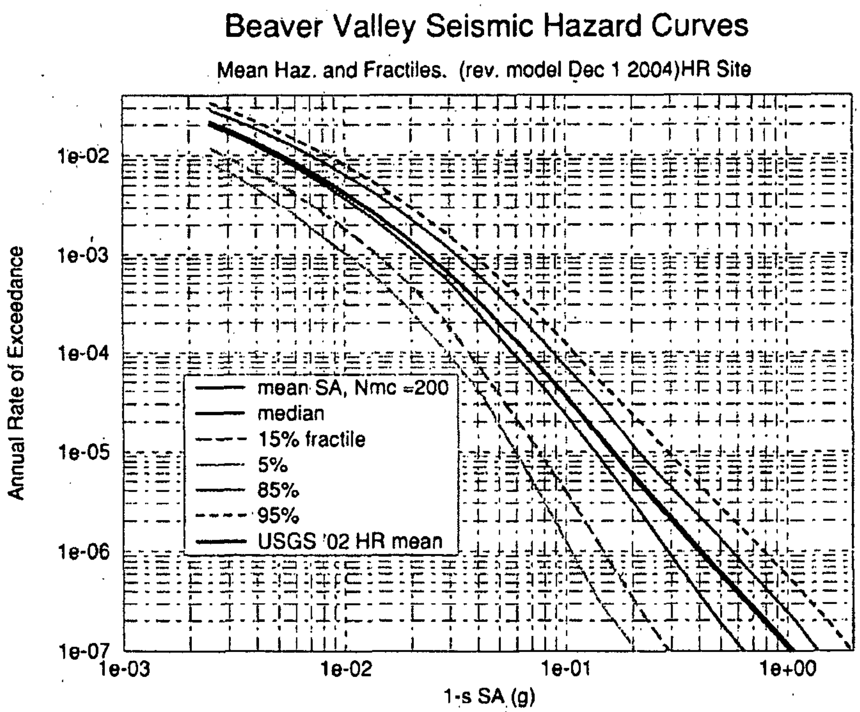
Narrative:

The November 2004 revisions to the code that prepares gridded seismicity *a*-grid matrices resulted in new estimates of seismic hazard. The primary reason for the new estimates is that the earlier version of the code did not sample the *a*-grids that correspond to random seismicity extrapolated from magnitude □ 4 historical earthquakes. The intended model was to give these *a*-grid models an epistemic weight of 0.2 (i.e., 20% of the Monte Carlo samples should use the m □ 4 based estimates of background rates). The current revision of the *ceusruns* code now gives this model the 0.2 weight that was intended.
A second modification gives the identified earthquake sources the same mean rates as the USGS 2002 model. The identified sources are (1) Cheraw, Colorado (2) Meers, Oklahoma (3) New Madrid Seismic Zone, and (4) Charleston seismic zone. The original code gives these sources the same mean recurrence interval as the USGS 2002 model. However, including a log-normal sampling distribution yielded mean rates that were □ 30% higher than those of the USGS 2002 model, when sampling was performed on mean recurrence interval.

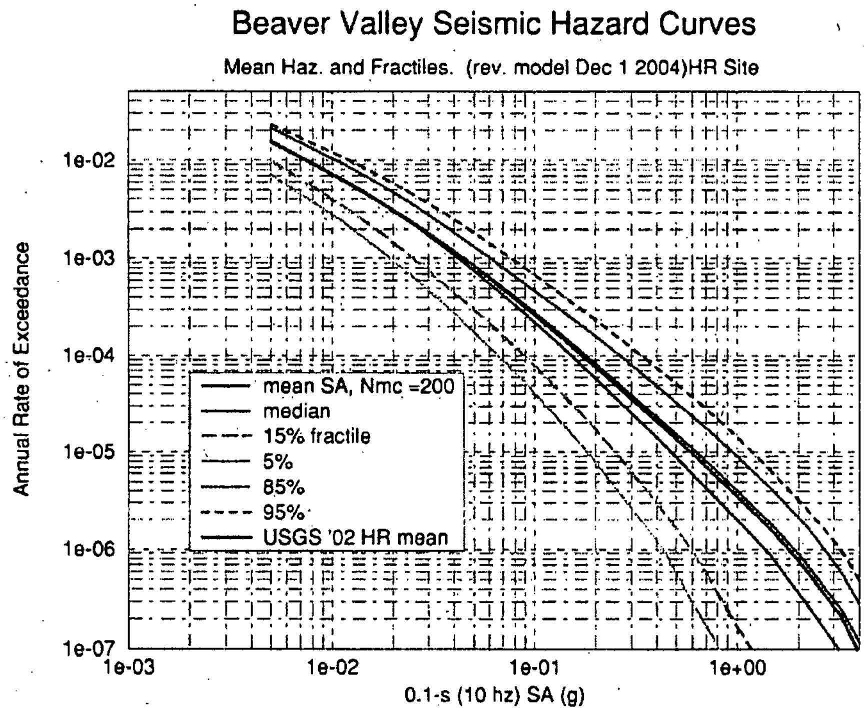
Result:

Graphs of the 29 sites 1- and 10-hz SA seismic-hazard curves are presented in alphabetic order. For some sites, additional frequency hazard curves are also presented.

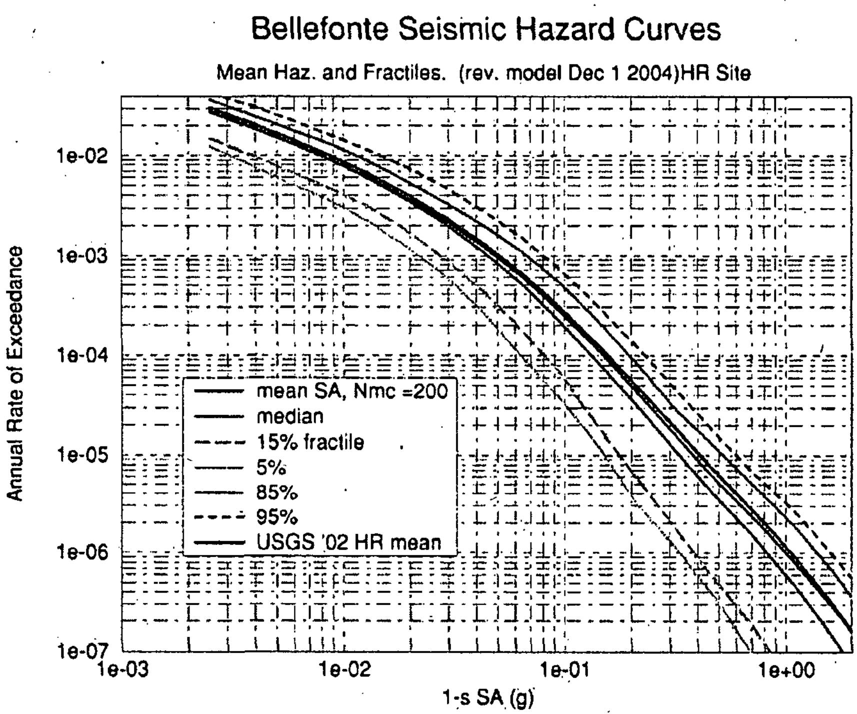
(1) Beaver Valley

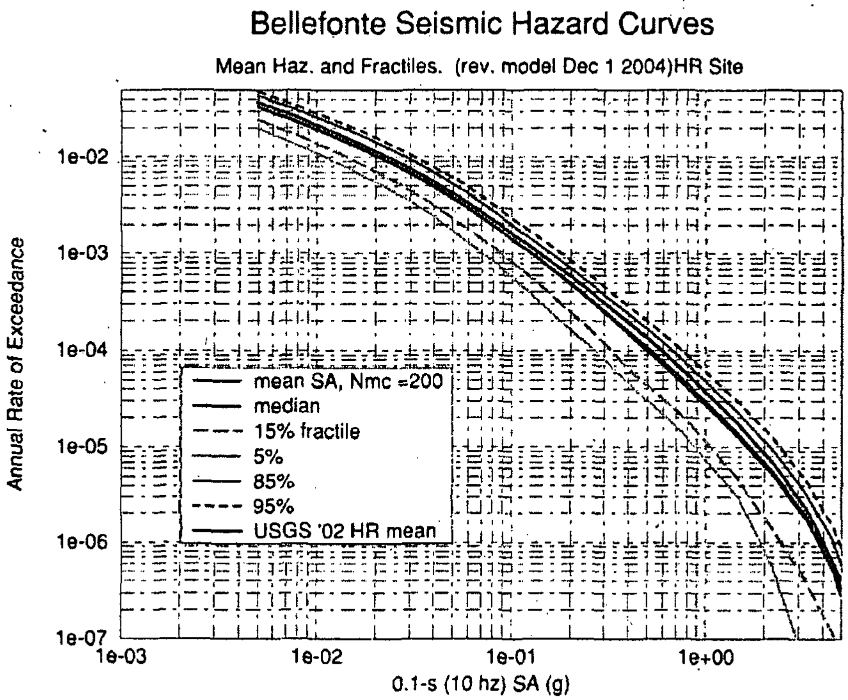


Beaver Valley Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



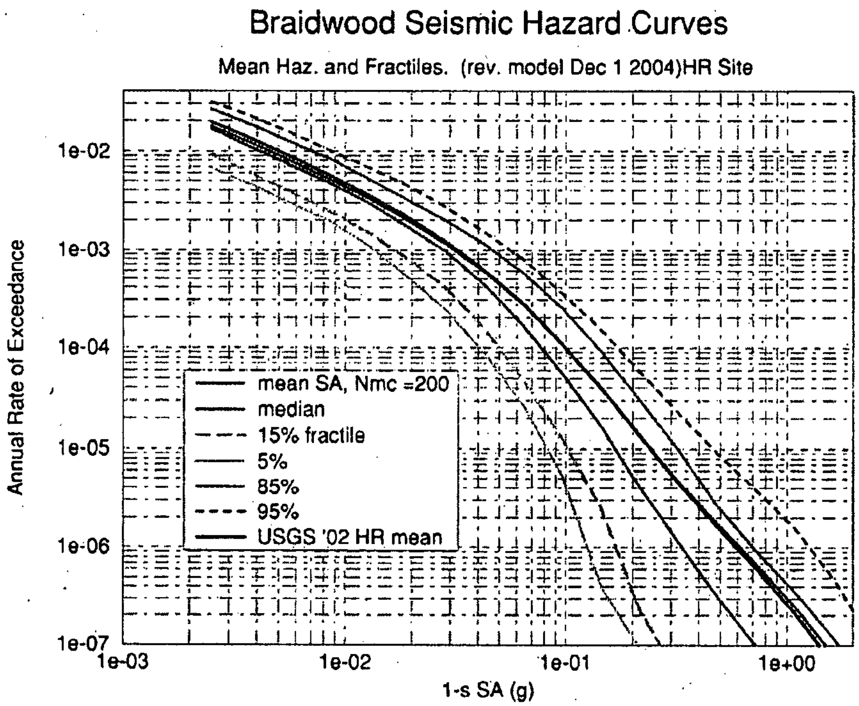
(2) Bellefonte

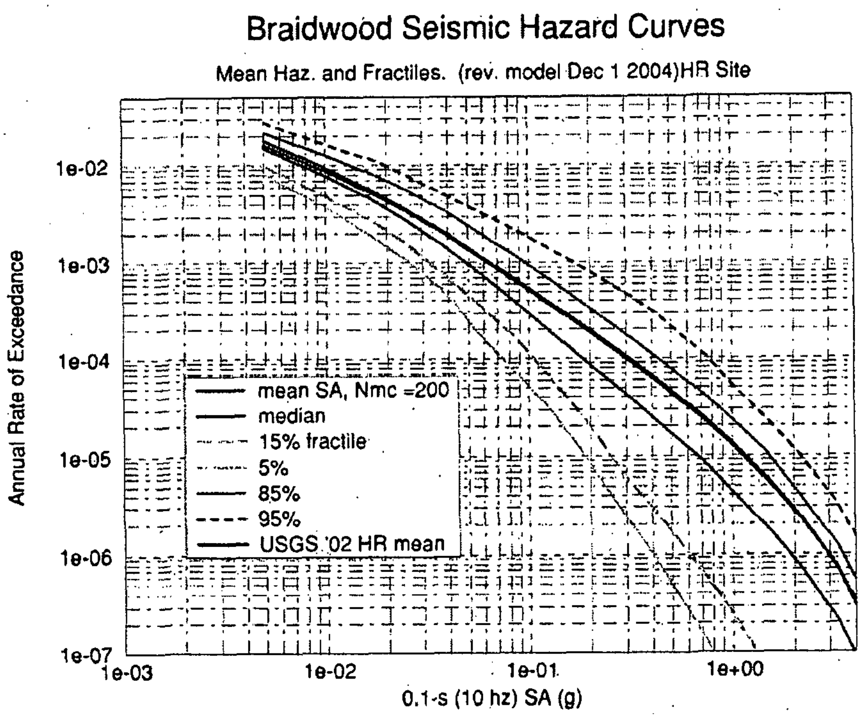

Bellefonte Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



Bellefonte Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

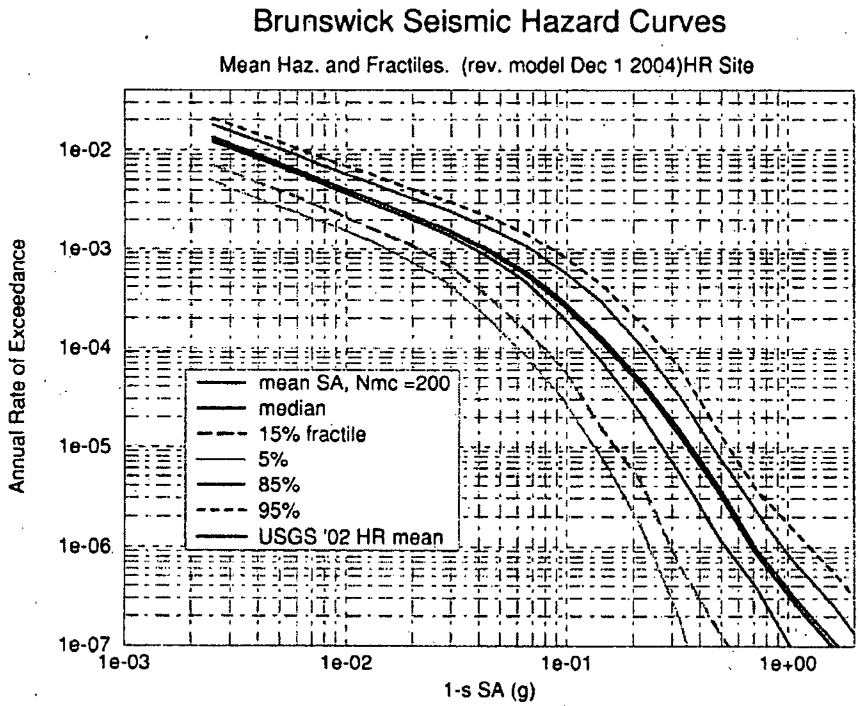
(3) Braidwood

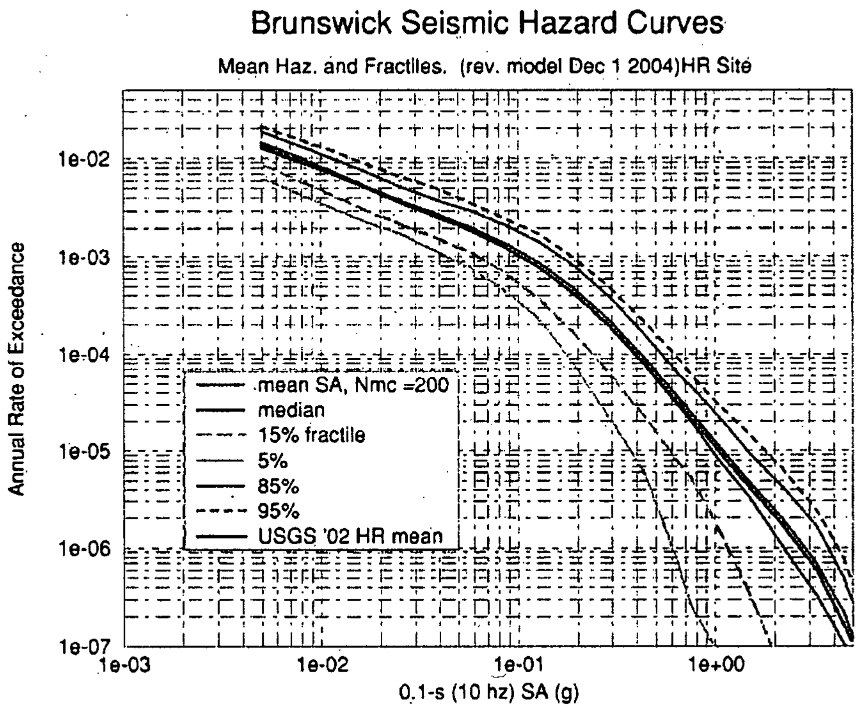

Braidwood Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



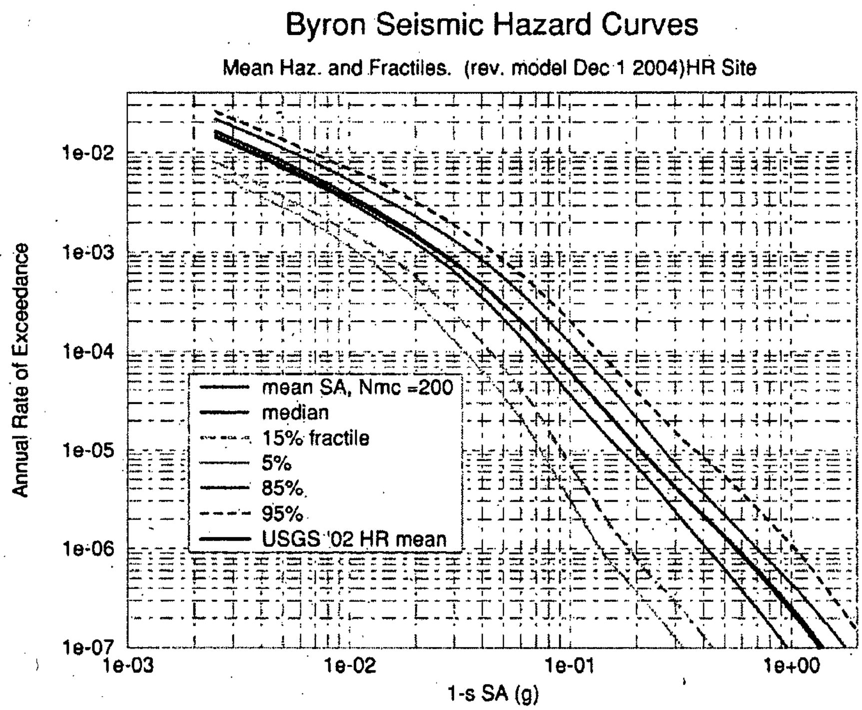
Braidwood Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

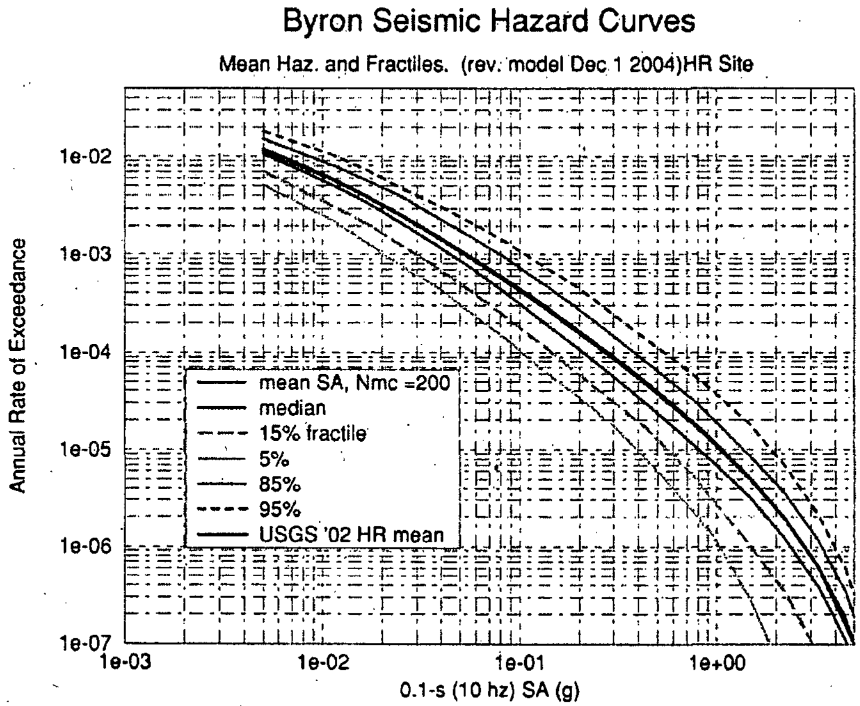
(4) Brunswick

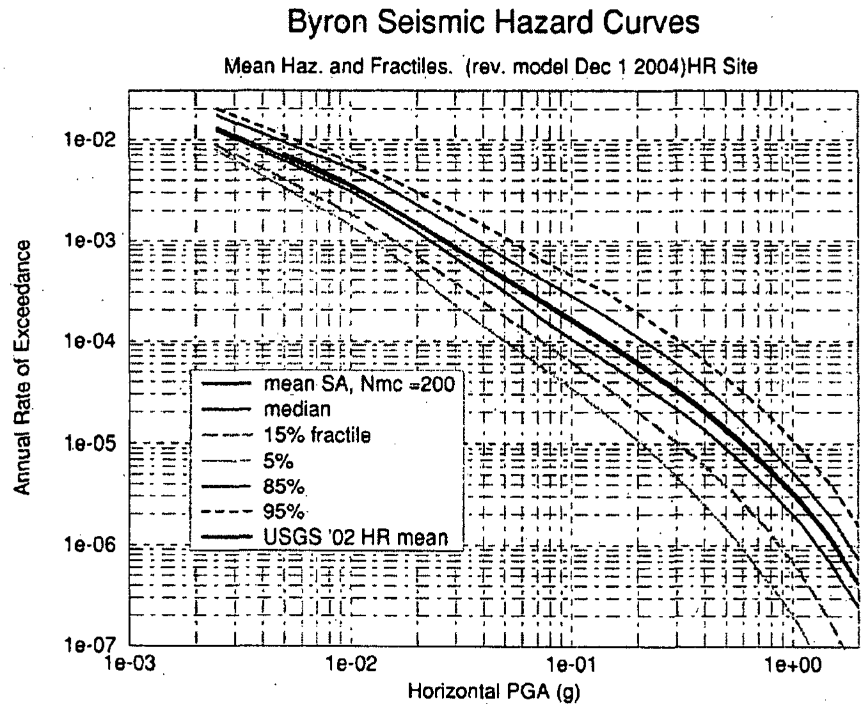

Brunswick Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean


Brunswick Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

(5) Byron

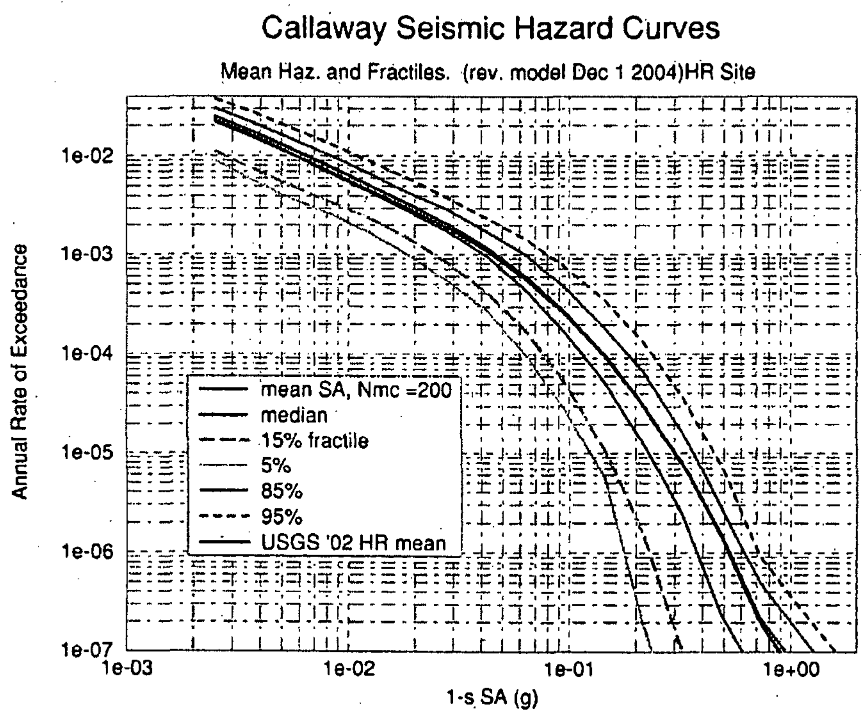

Byron Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

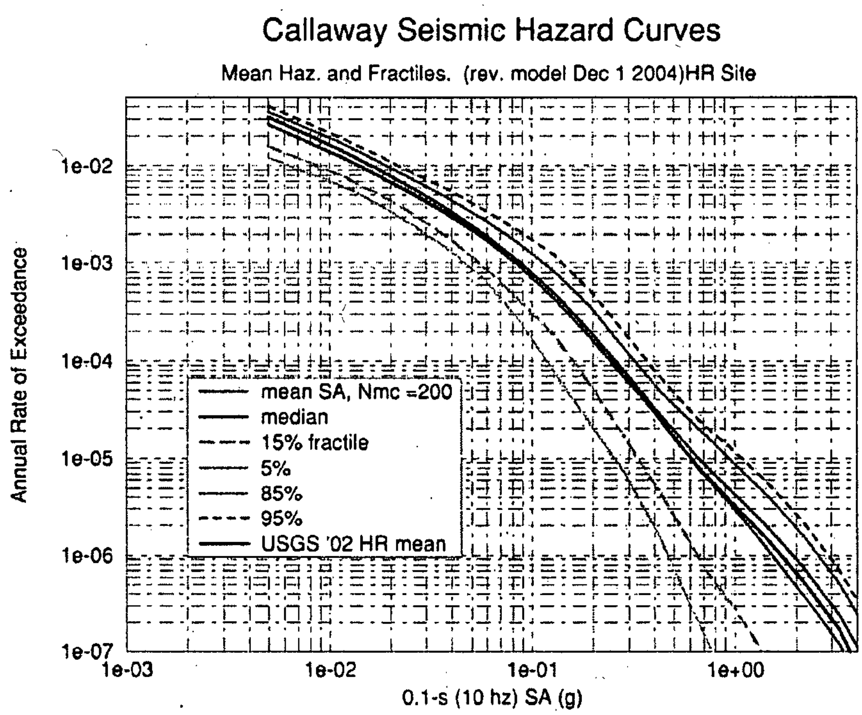

Byron Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



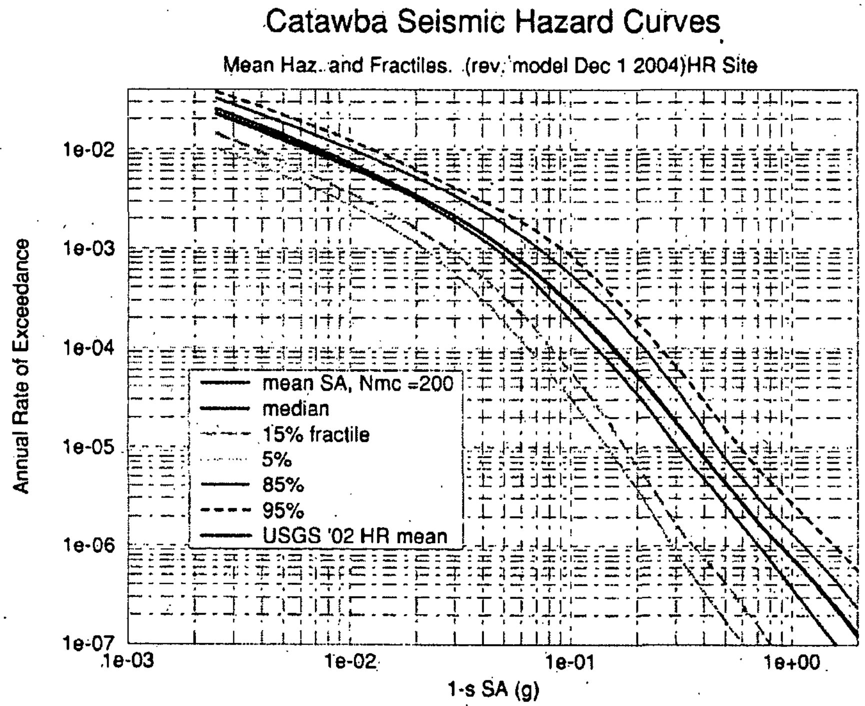
Byron Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
Horizontal PGA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

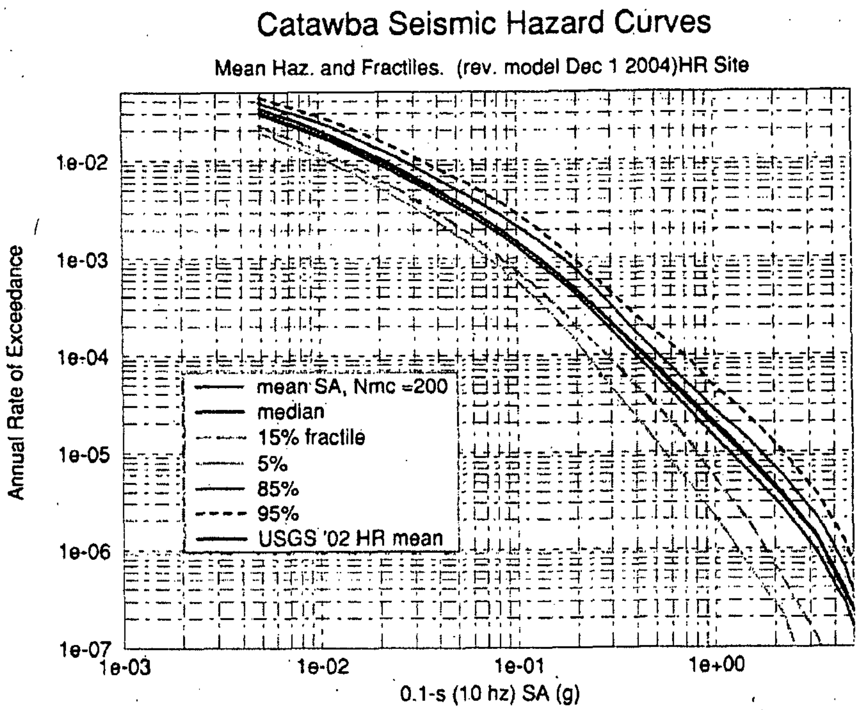
(6) Callaway


Callaway Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean


Callaway Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

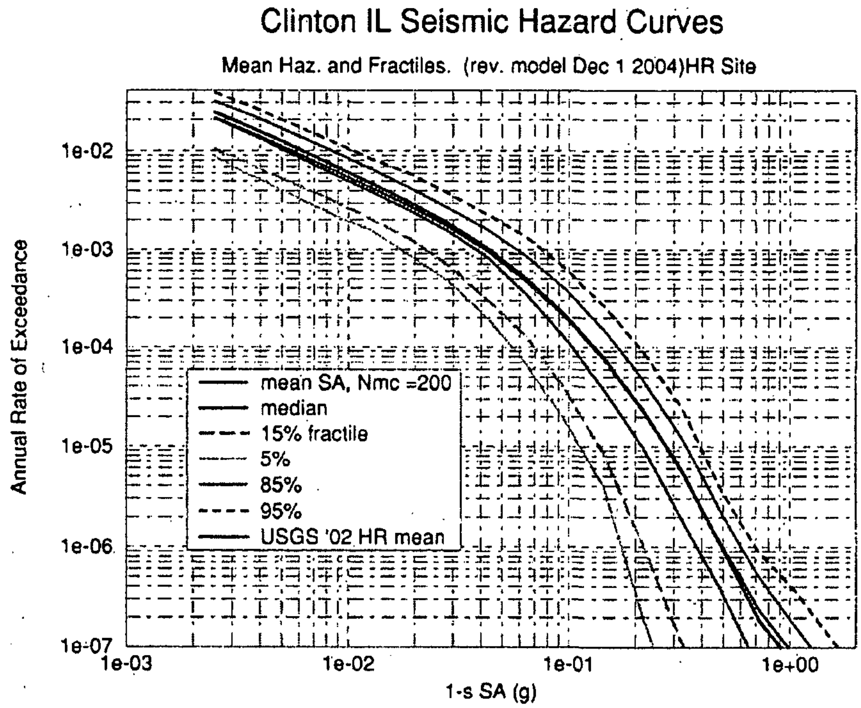
(7) Catawba

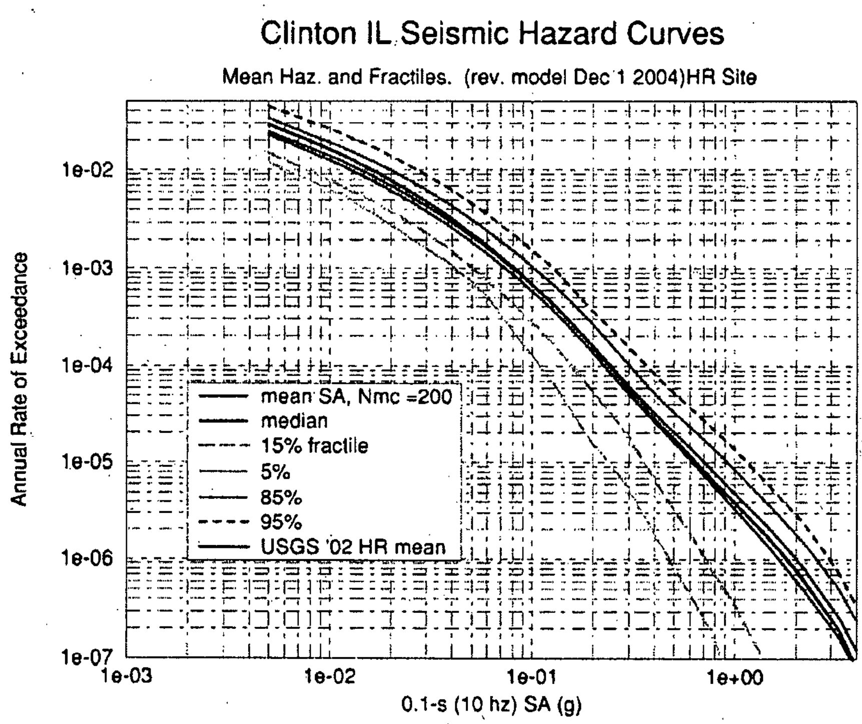

Catawba Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



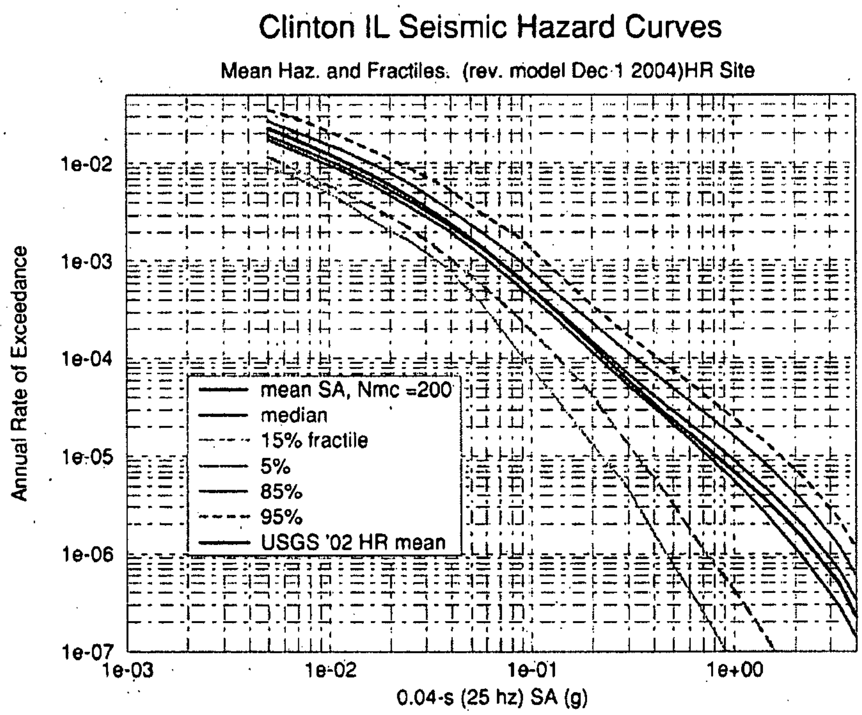
Catawba Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

(8) Clinton

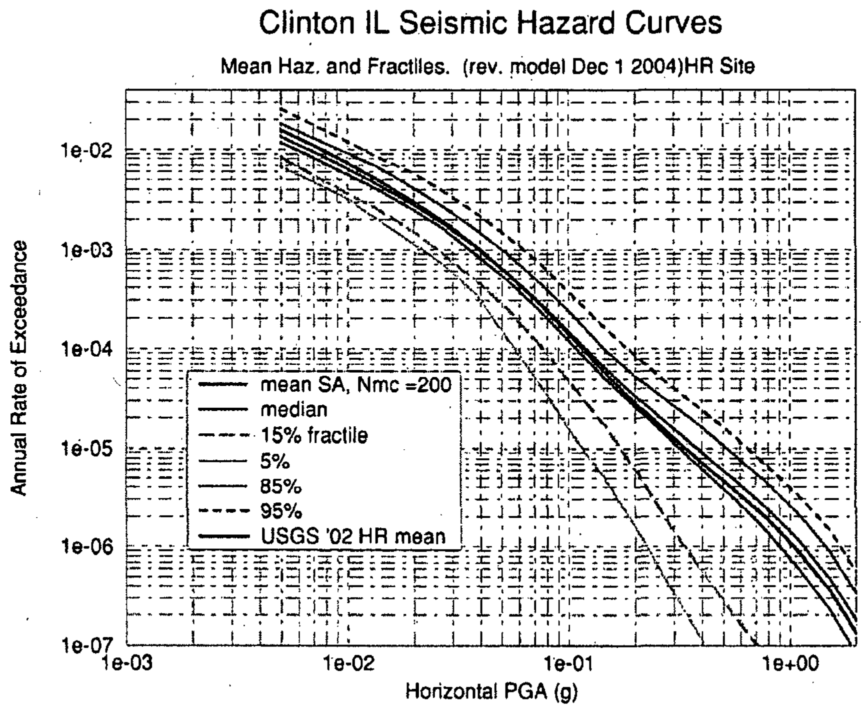

Clinton IL Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



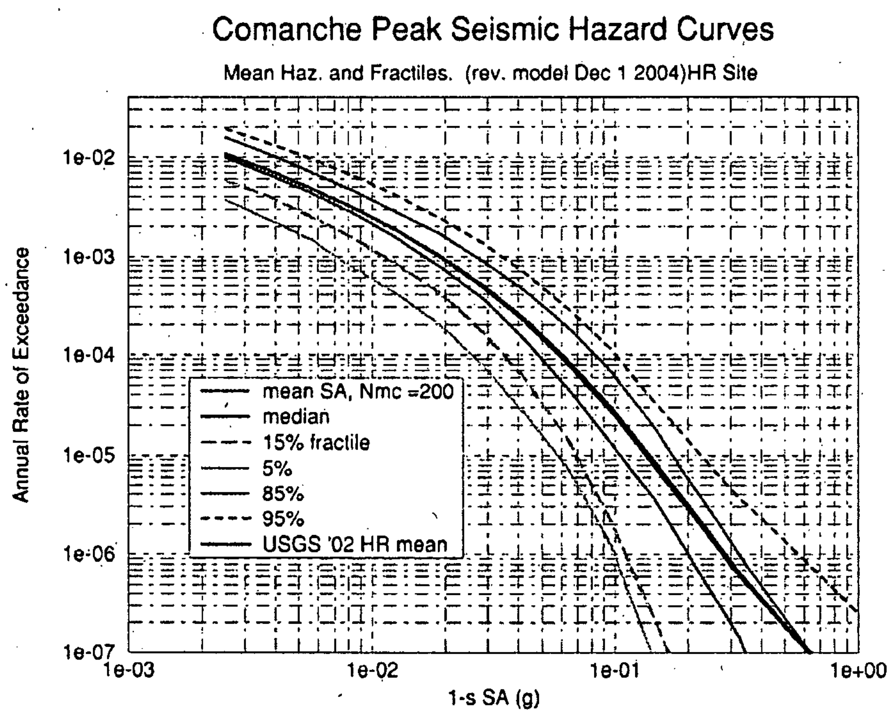
Clinton IL Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

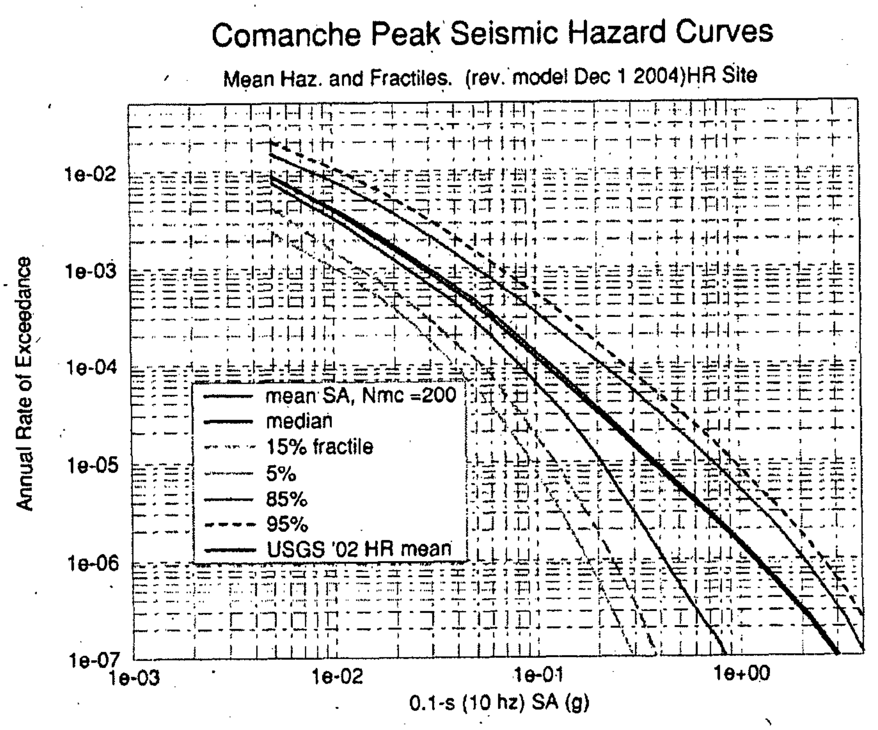


Clinton IL Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.04-s (25 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

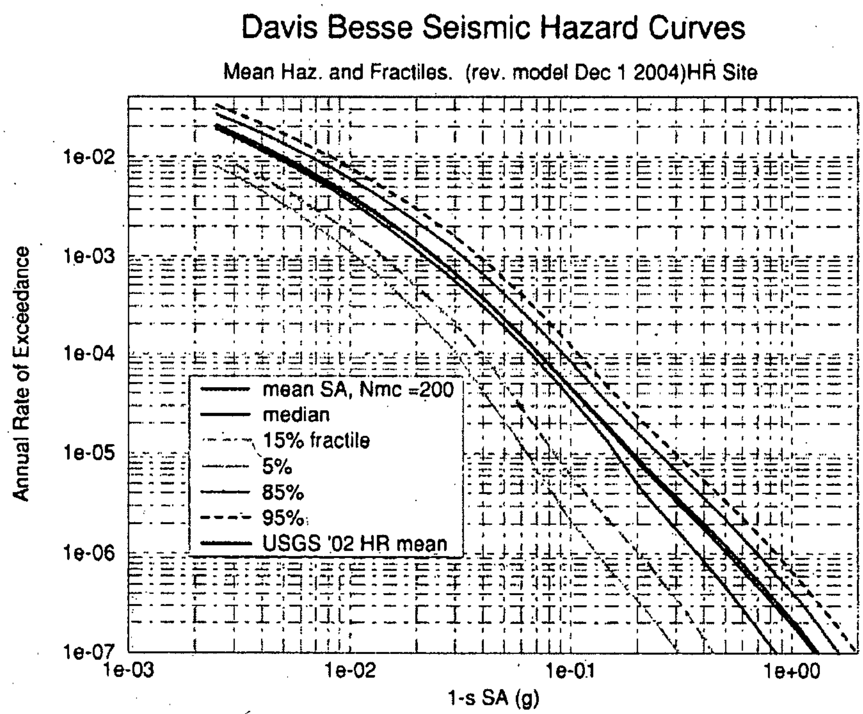


(9) Comanche Peak


Comanche Peak Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

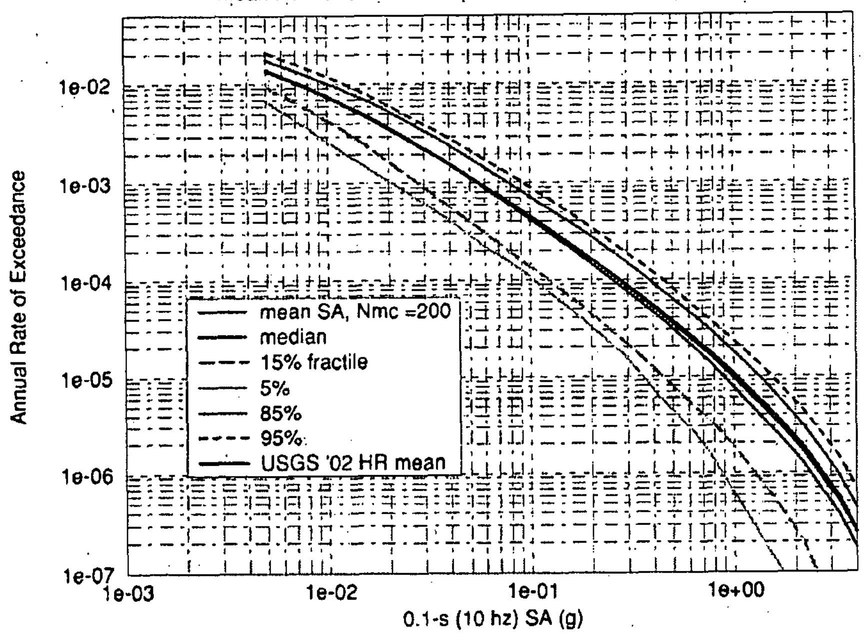


(10) Davis-Besse

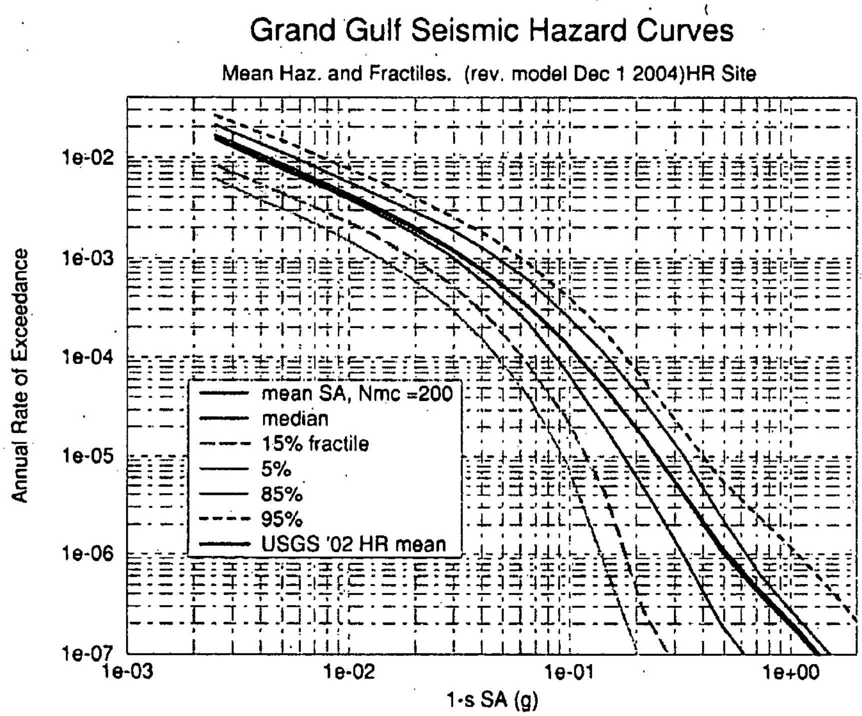

Davis Besse Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

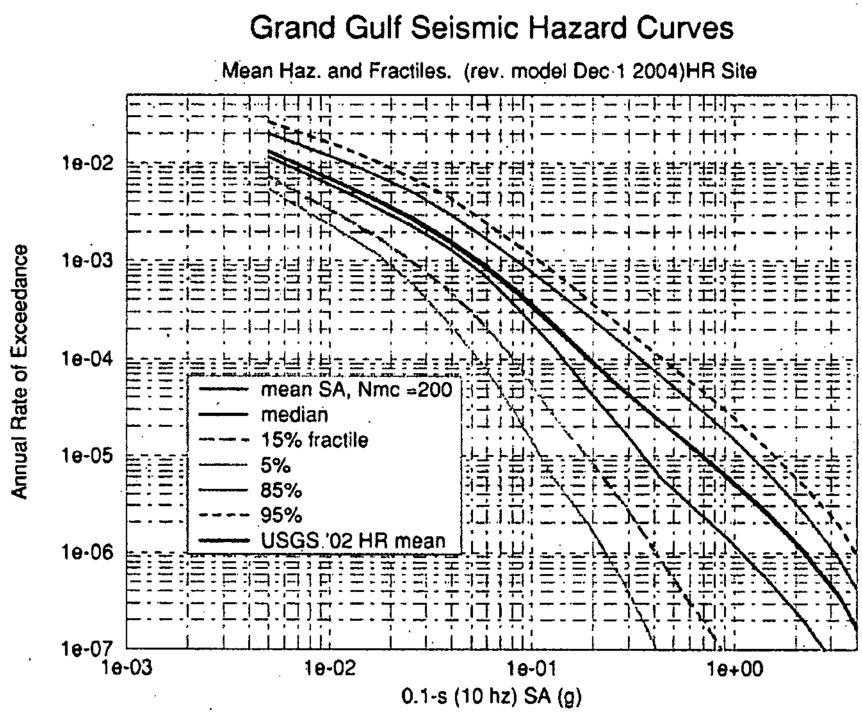
Davis Besse Seismic Hazard Curves

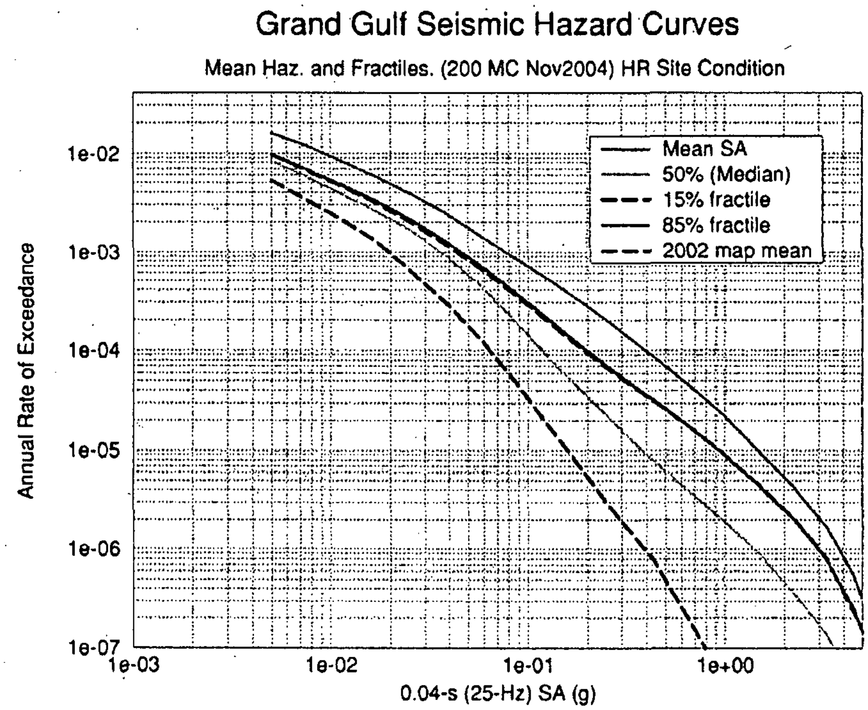
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site

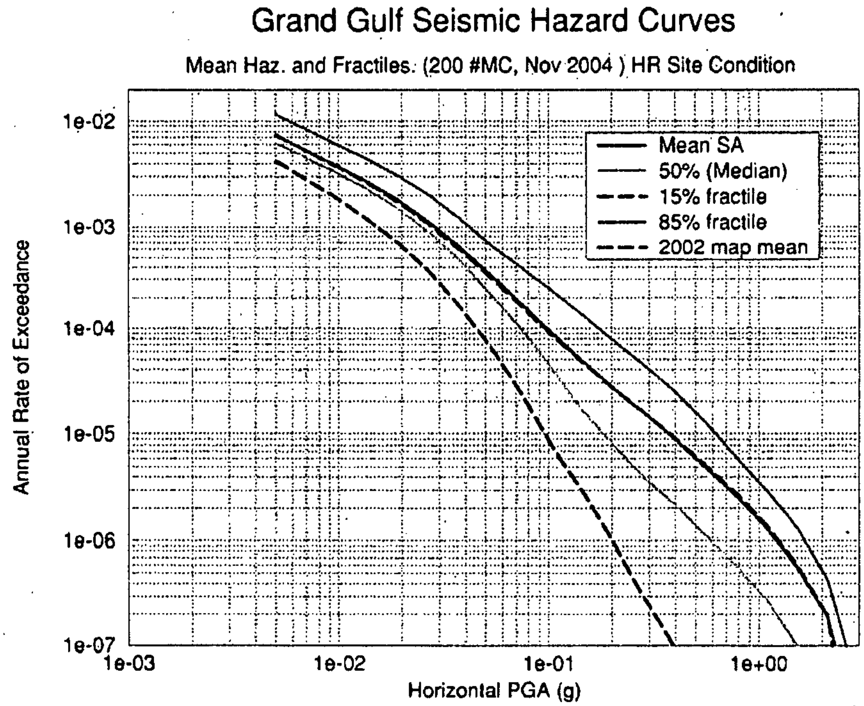


(11) Grand Gulf

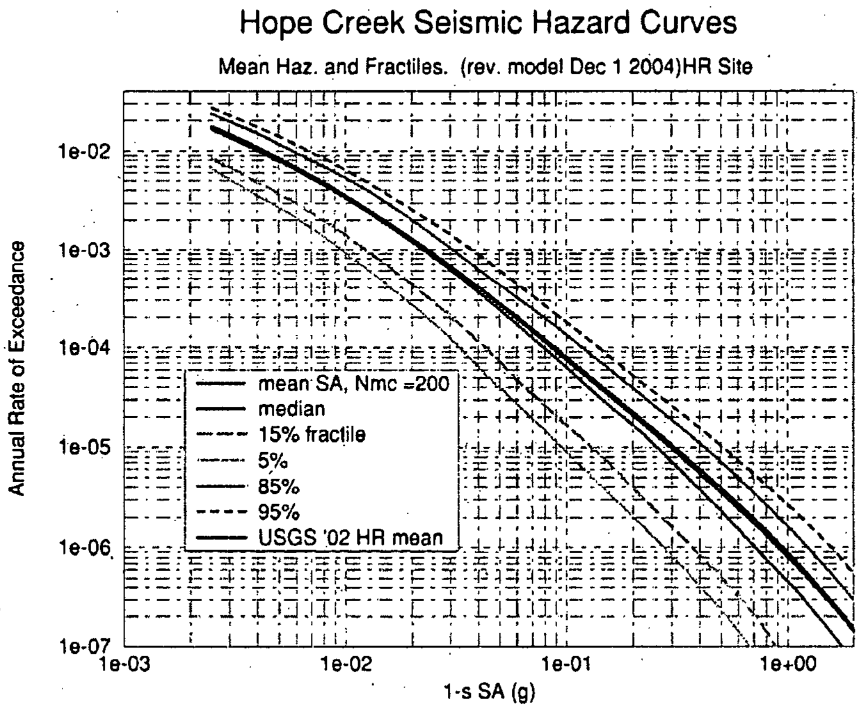

Grand Gulf Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

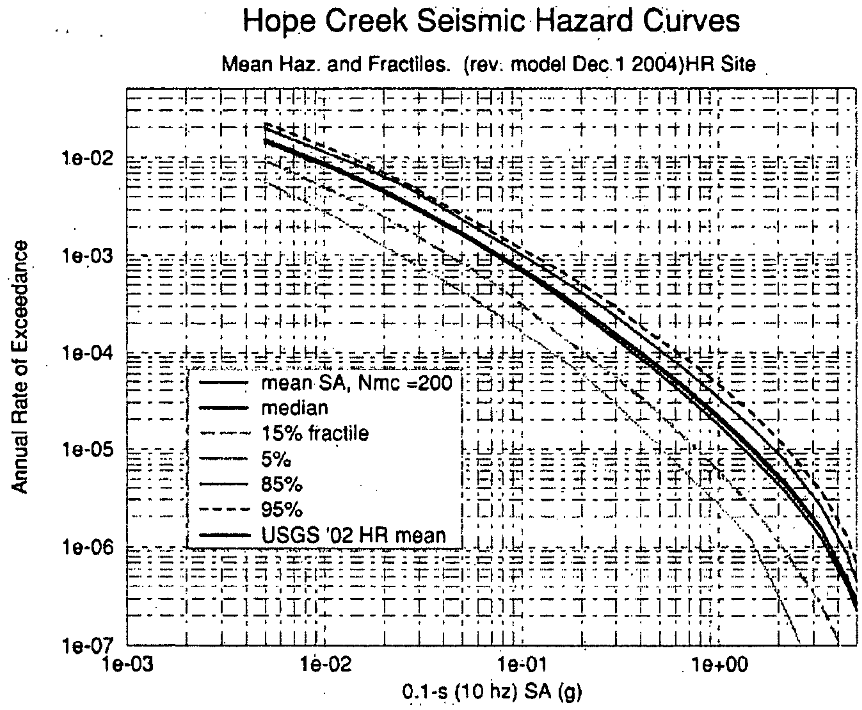

Grand Gulf Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean


Grand Gulf Seismic Hazard Curves
Mean Haz. and Fractiles. (200 MC Nov2004) HR Site Condition
Mean SA
50% (Median)
15% fractile
85% fractile
2002 map mean
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
Annual Rate of Exceedance
1e-03
1e-02
1e-01
1e+00
0.04-s (25-Hz) SA (g)

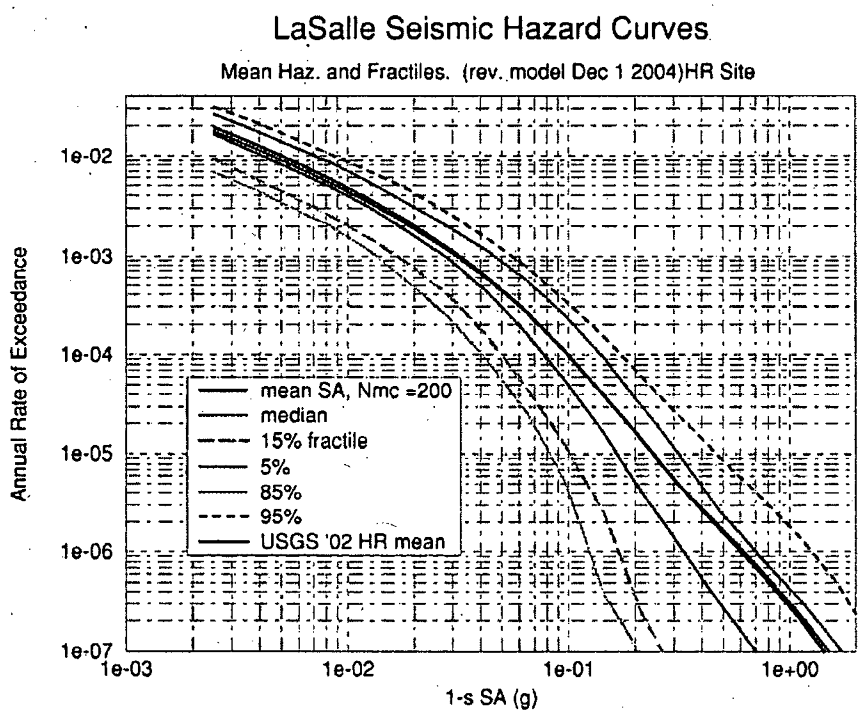


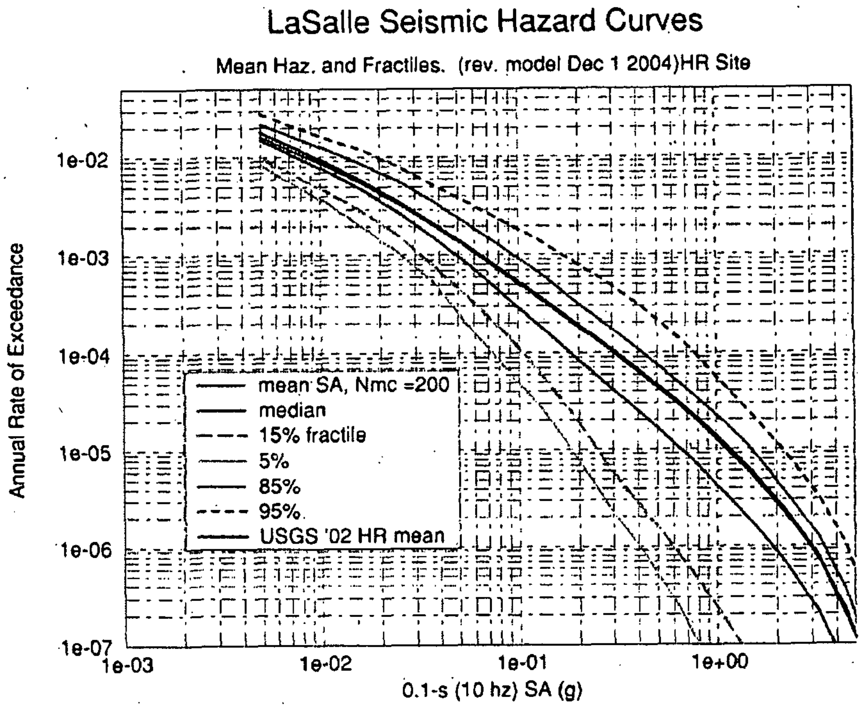
(12) Hope Creek:


Hope Creek Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean


Hope Creek Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

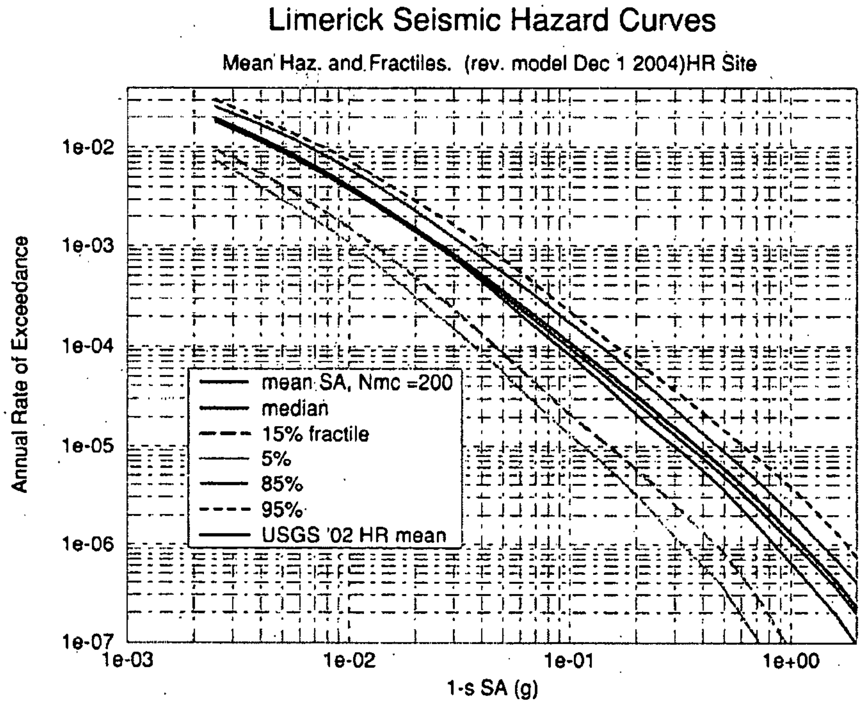
(13) La Salle:

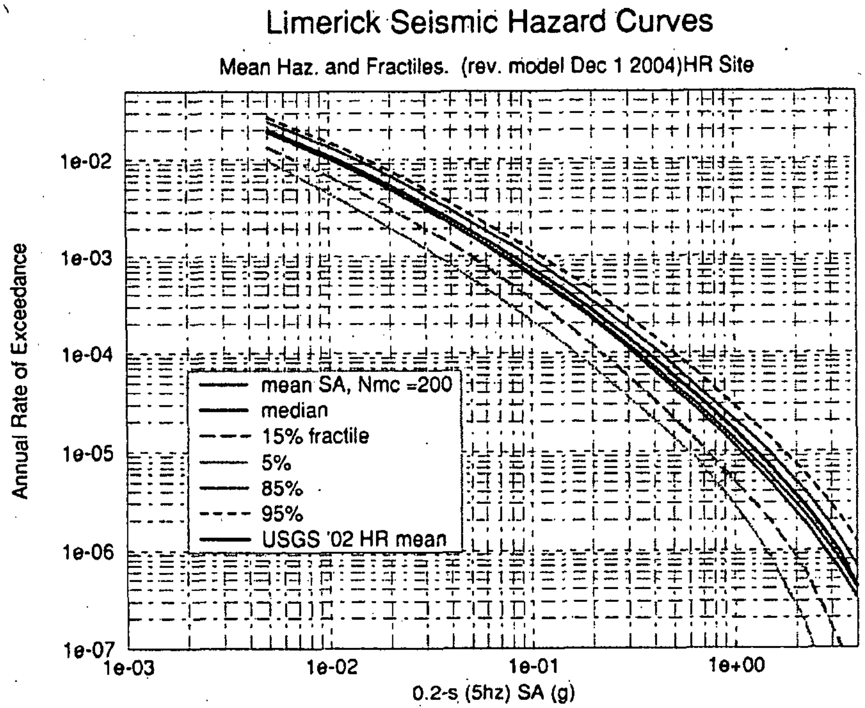

LaSalle Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

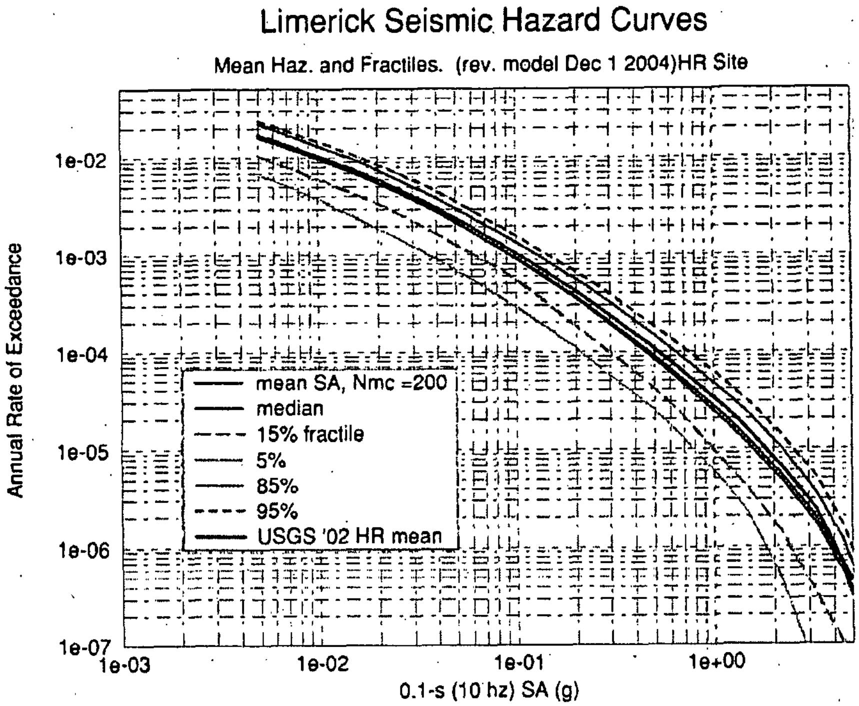


LaSalle Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

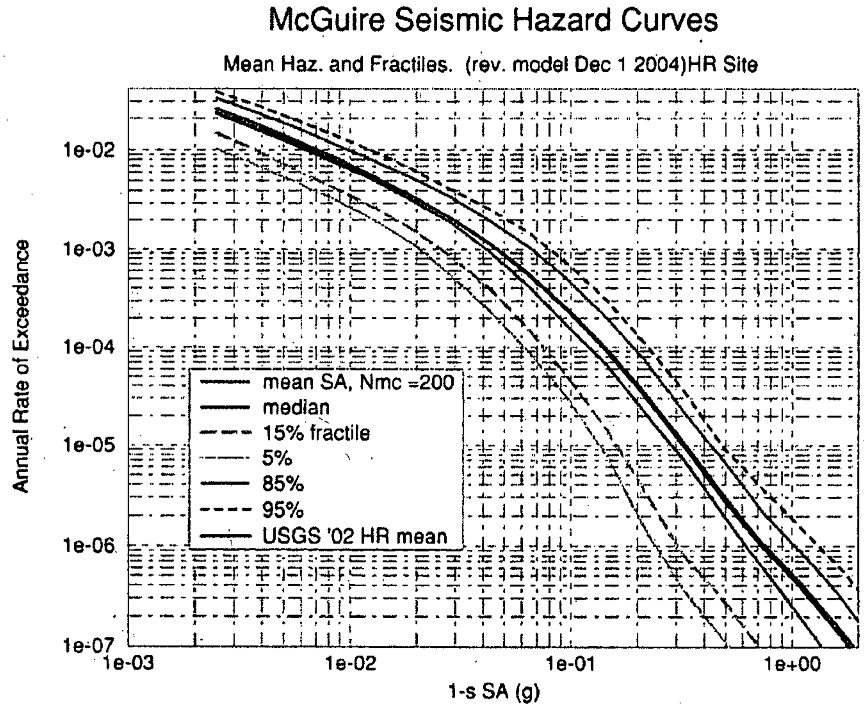
(14) Limerick:

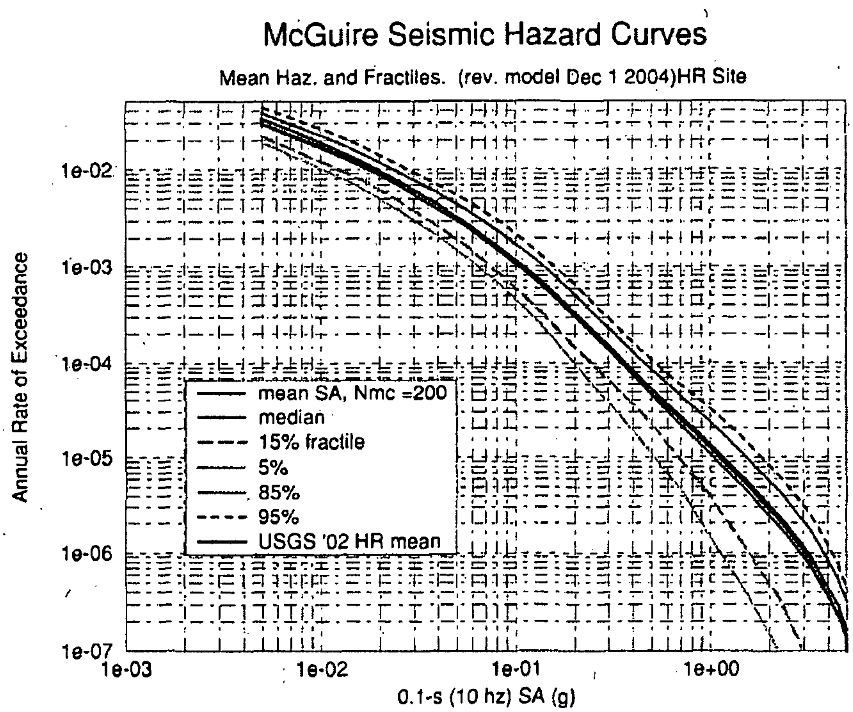

Limerick Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean


Limerick Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.2-s (5hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

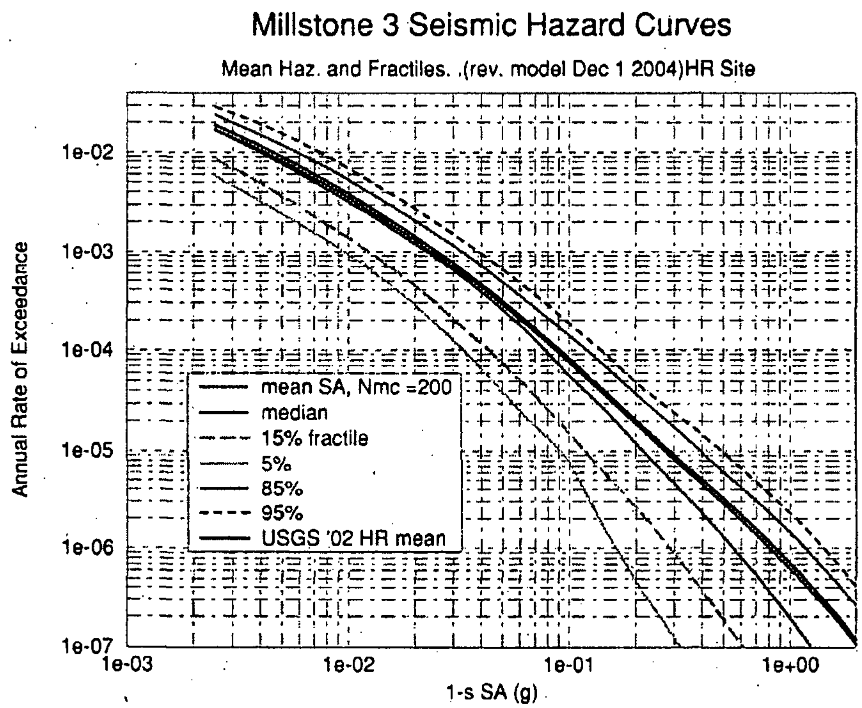

Limerick Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

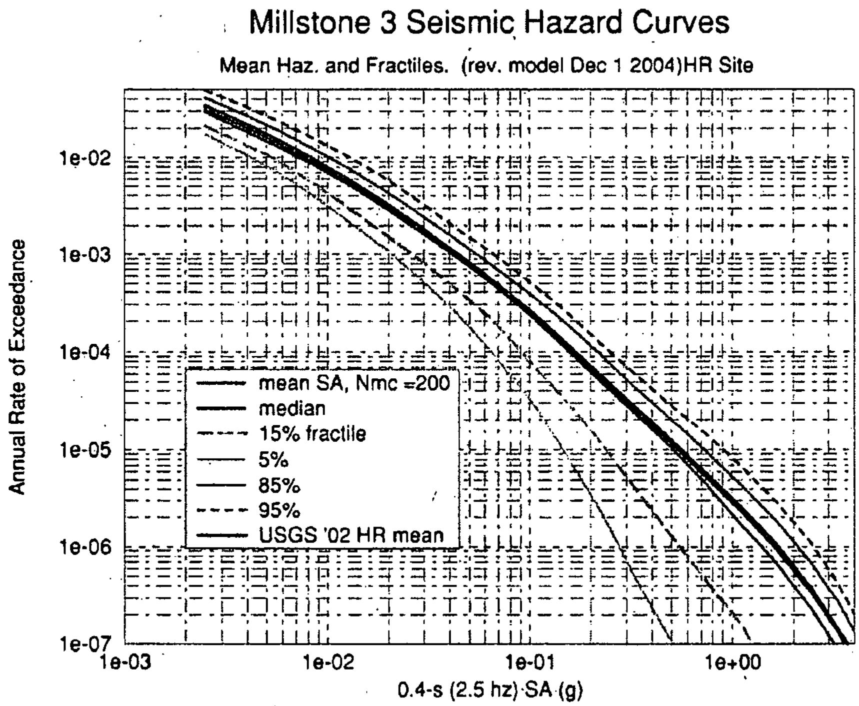
(15) McGuire:

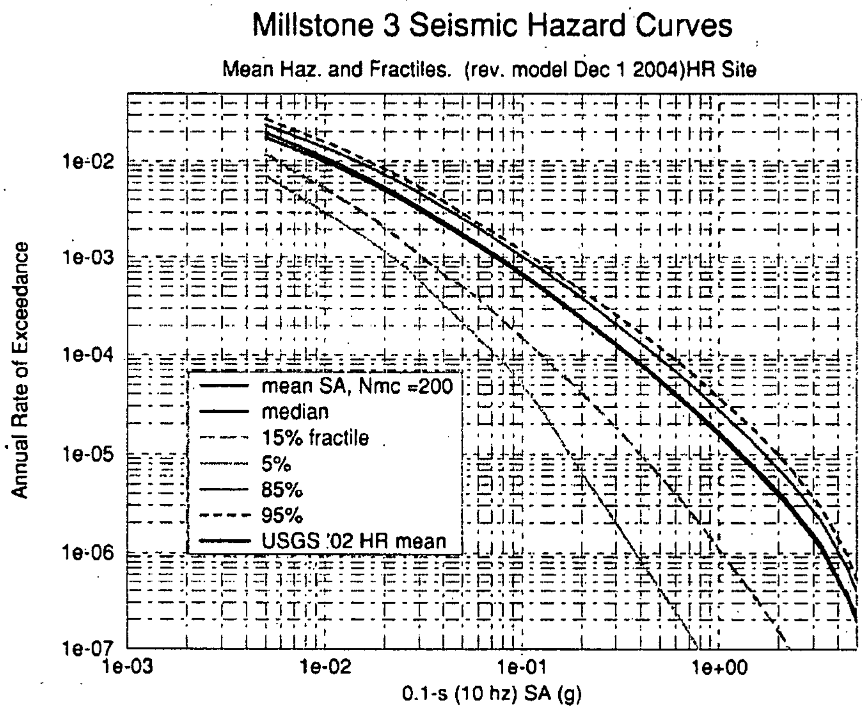

McGuire Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean
1e-03
1e-02
1e-01
1e+00
1-s SA (g)



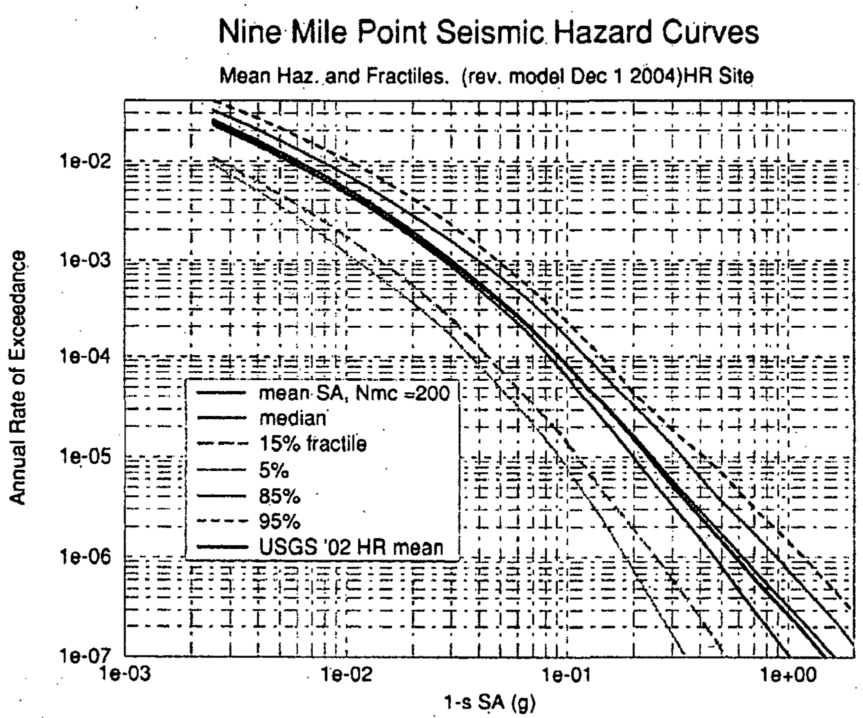
(16) Millstone 3:

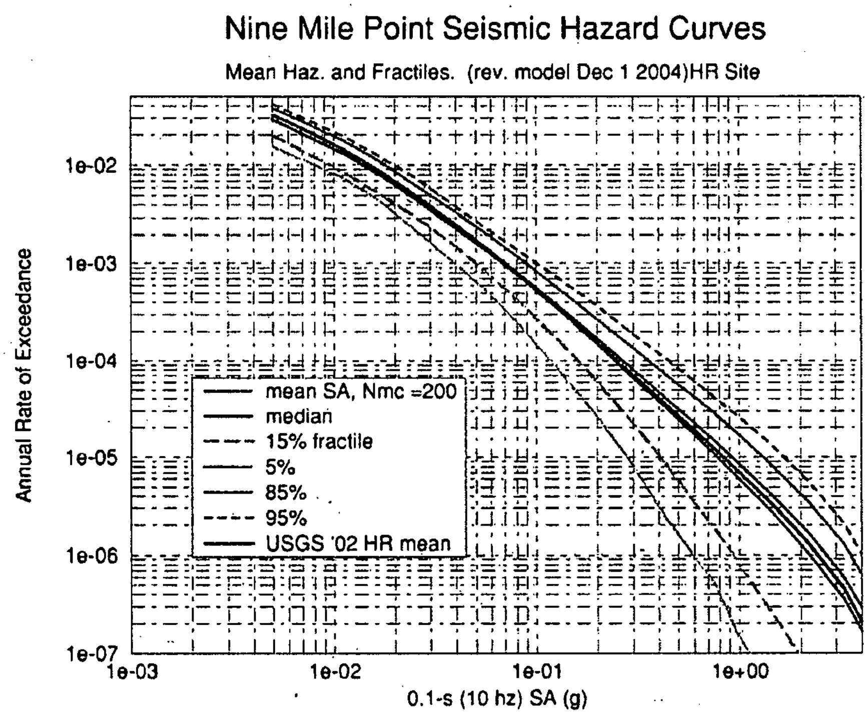

Millstone 3 Seismic Hazard Curves
Mean Haz. and Fractiles. .(rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

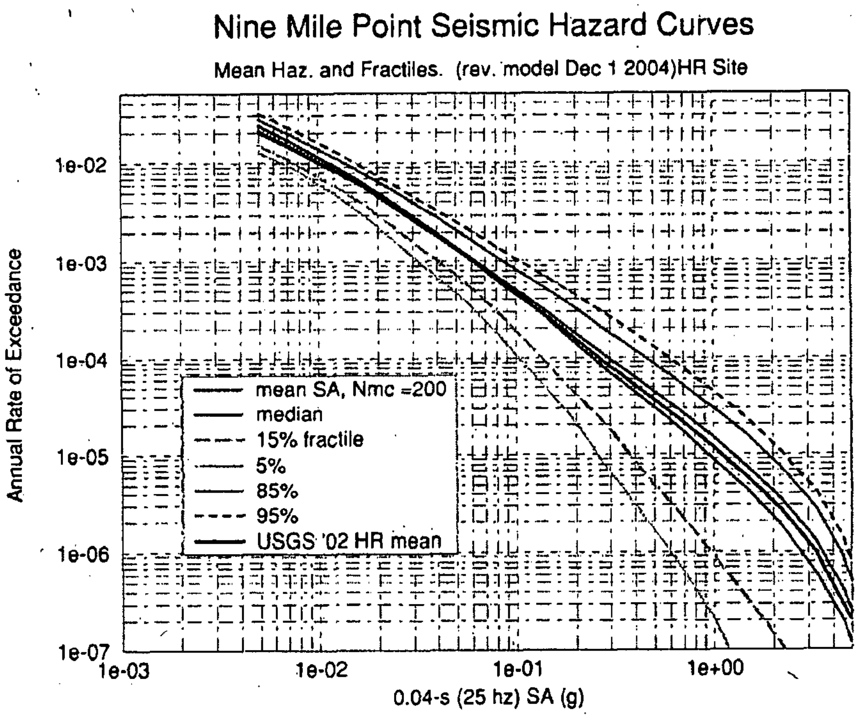

Millstone 3 Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.4-s (2.5 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



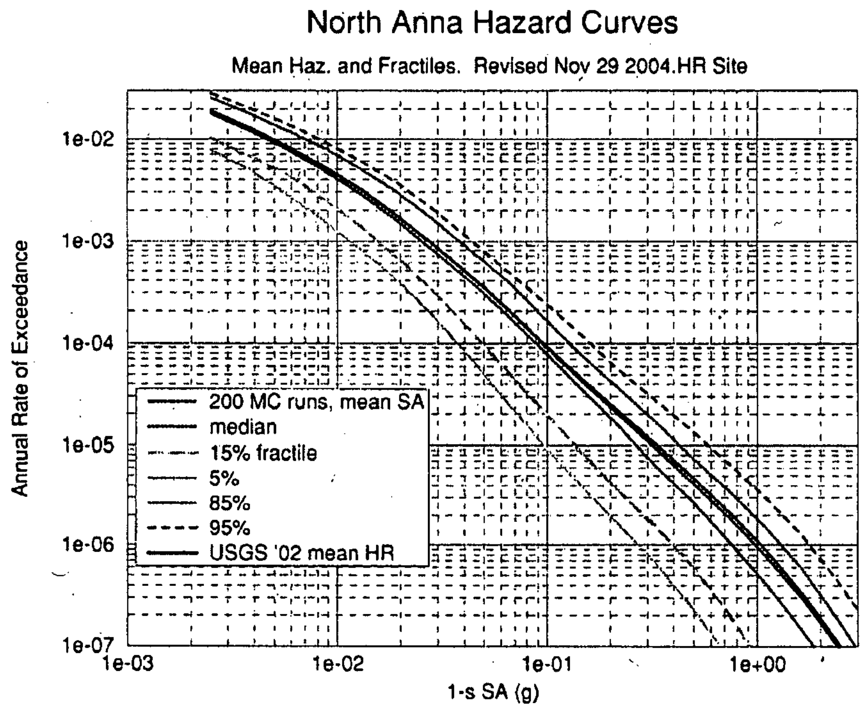
(17) Nine Mile Point:

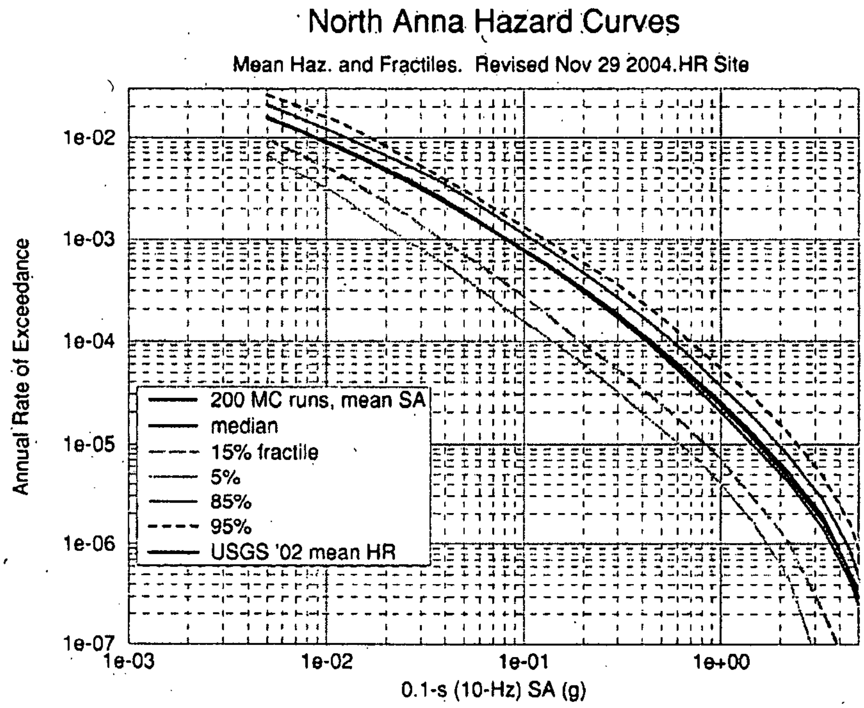

Nine Mile Point Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

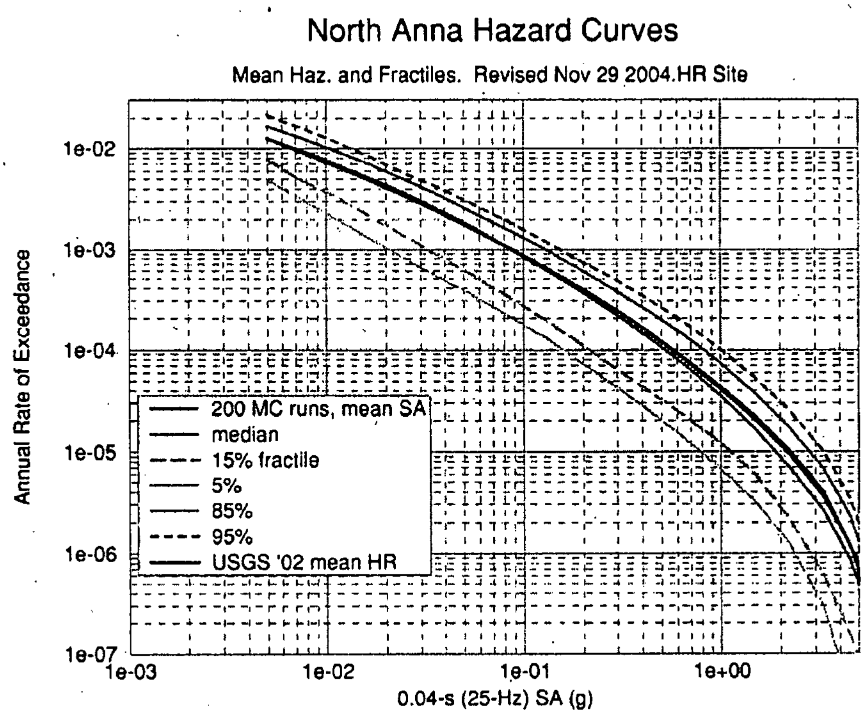

Nine Mile Point Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

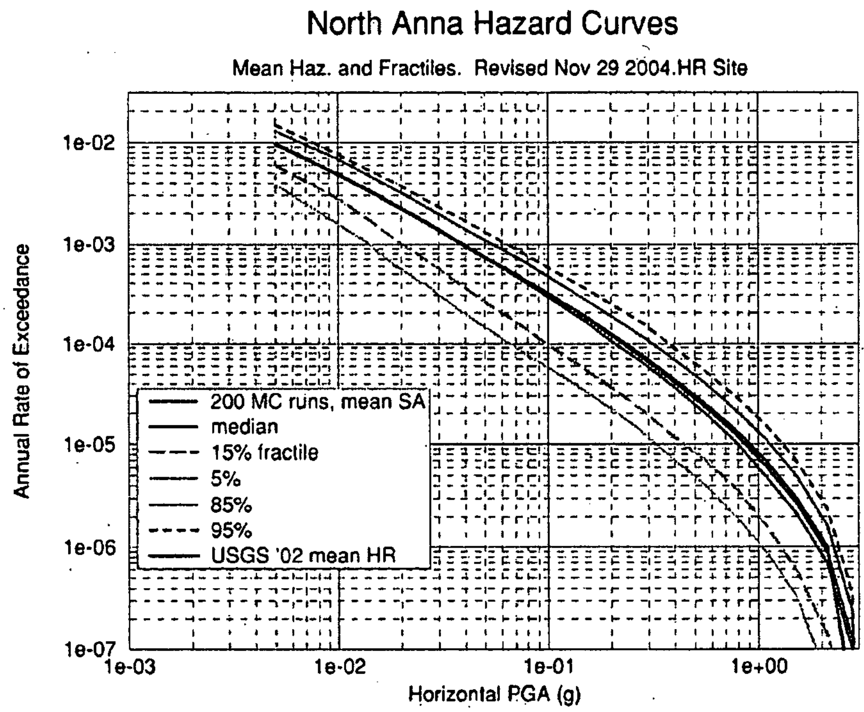


(18) North Anna:

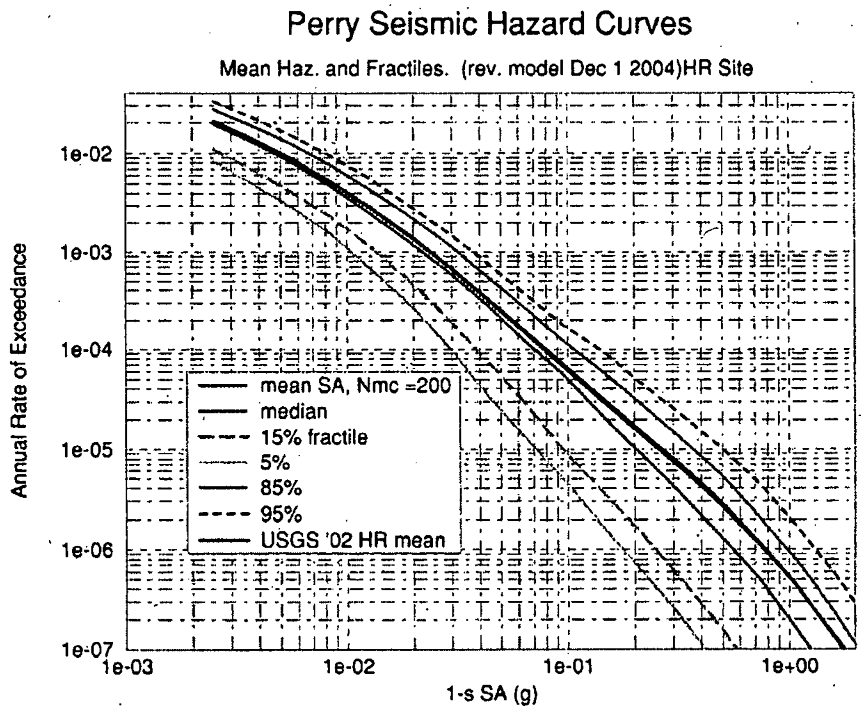

North Anna Hazard Curves
Mean Haz. and Fractiles. Revised Nov 29 2004.HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
200 MC runs, mean SA
median
15% fractile
5%
85%
95%
USGS '02 mean HR

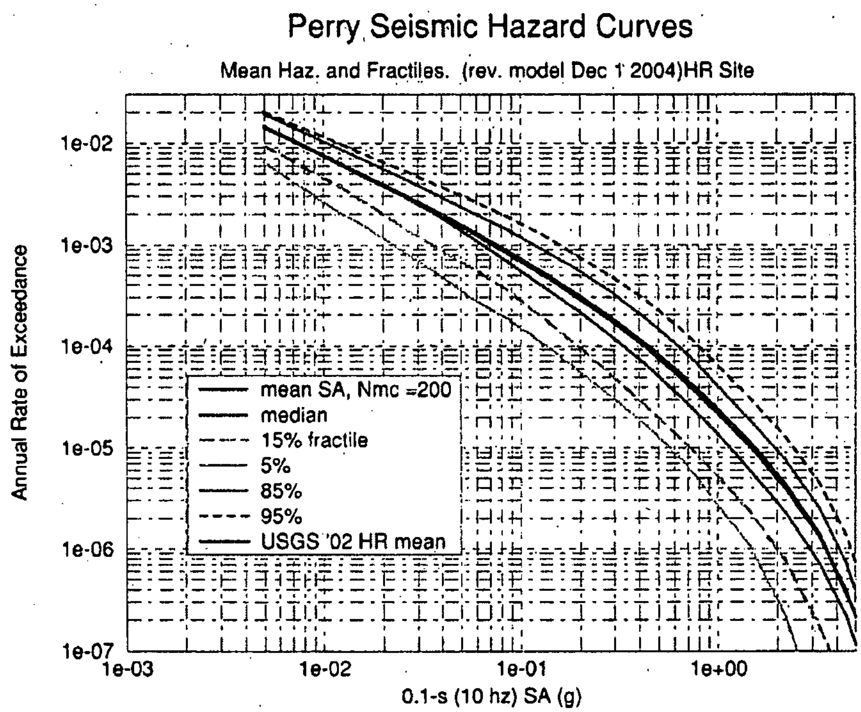

North Anna Hazard Curves
Mean Haz. and Fractiles. Revised Nov 29 2004.HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10-Hz) SA (g)
200 MC runs, mean SA
median
15% fractile
5%
85%
95%
USGS '02 mean HR


North Anna Hazard Curves
Mean Haz. and Fractiles. Revised Nov 29 2004.HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.04-s (25-Hz) SA (g)
200 MC runs, mean SA
median
15% fractile
5%
85%
95%
USGS '02 mean HR

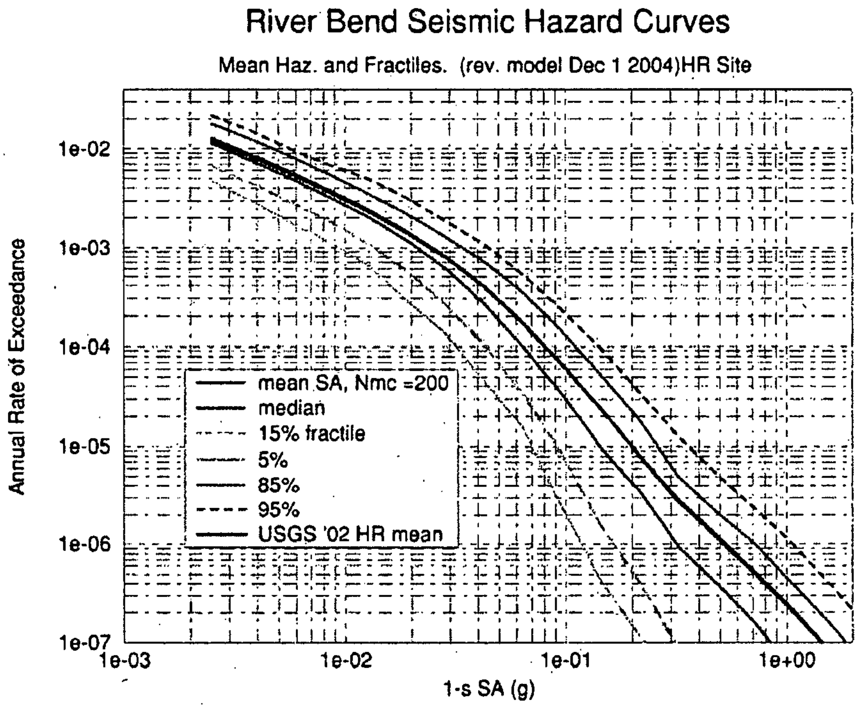

North Anna Hazard Curves
Mean Haz. and Fractiles. Revised Nov 29 2004.HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
Horizontal PGA (g)
200 MC runs, mean SA
median
15% fractile
5%
85%
95%
USGS '02 mean HR

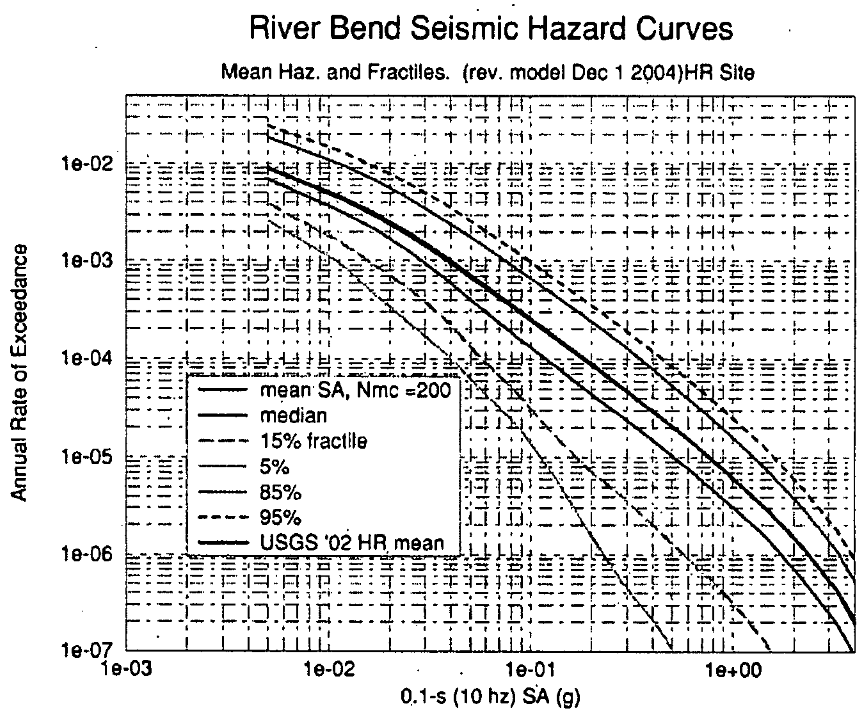
(19) Perry:


Perry Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

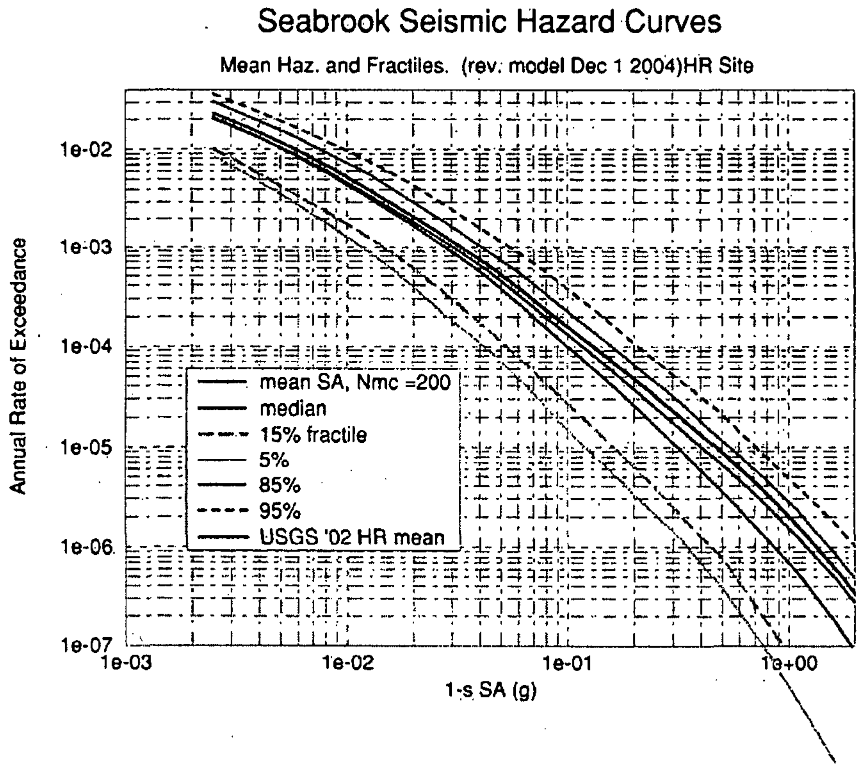


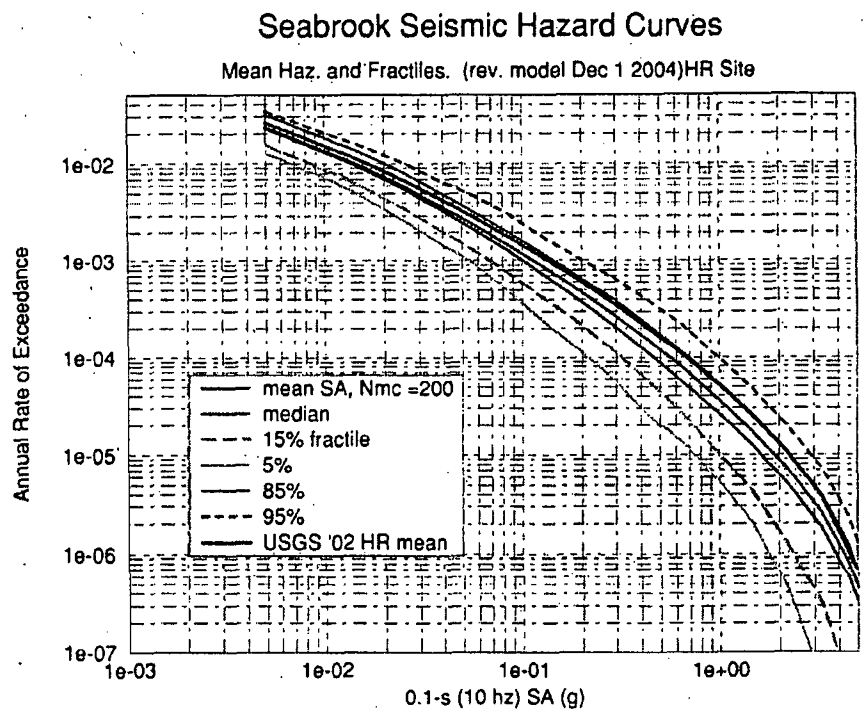
(20) River Bend:


River Bend Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

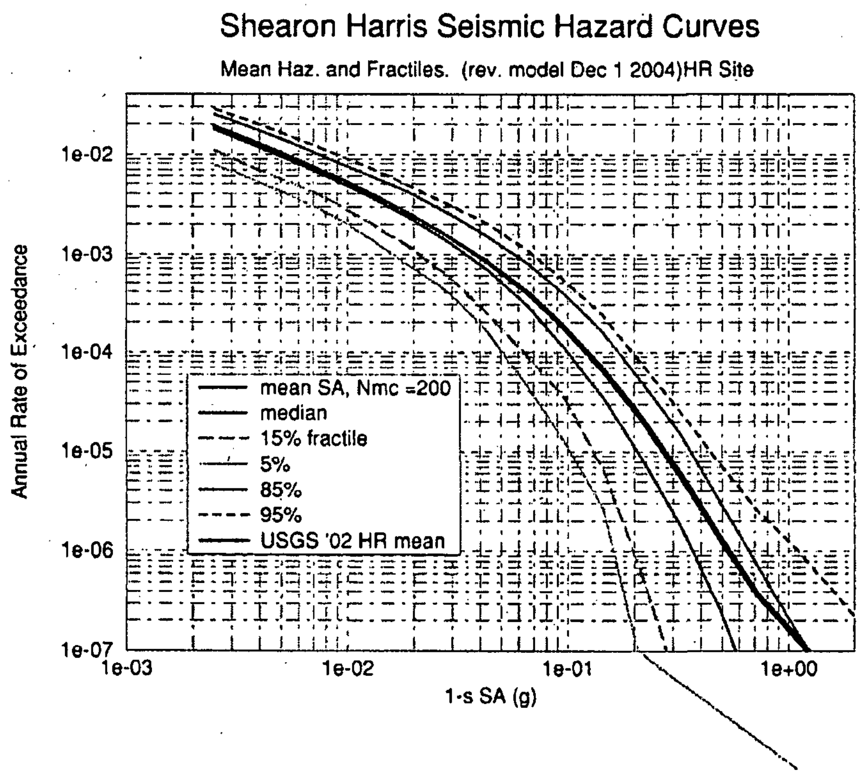

River Bend Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

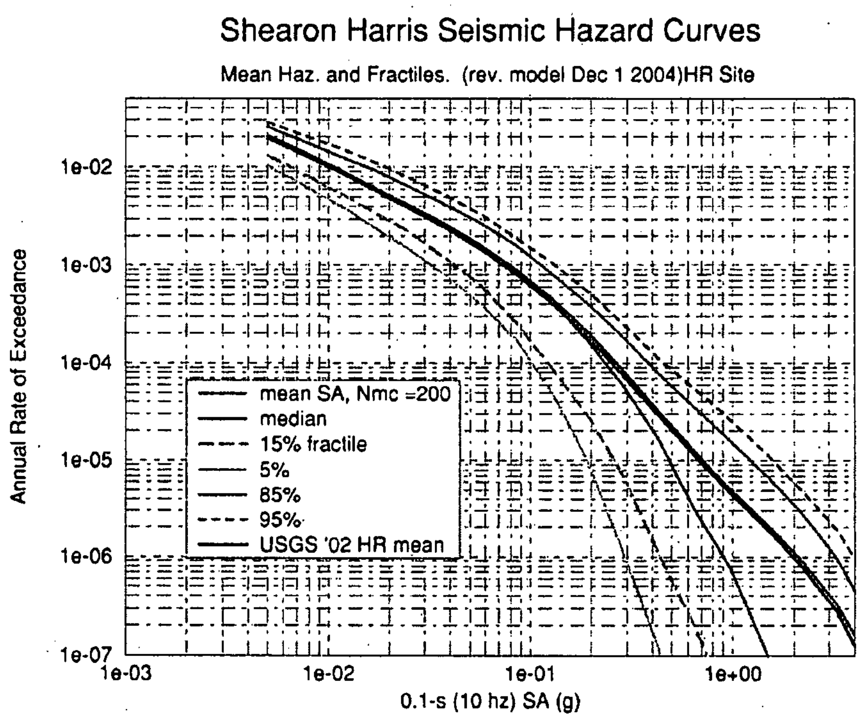
(21) Seabrook:


Seabrook Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

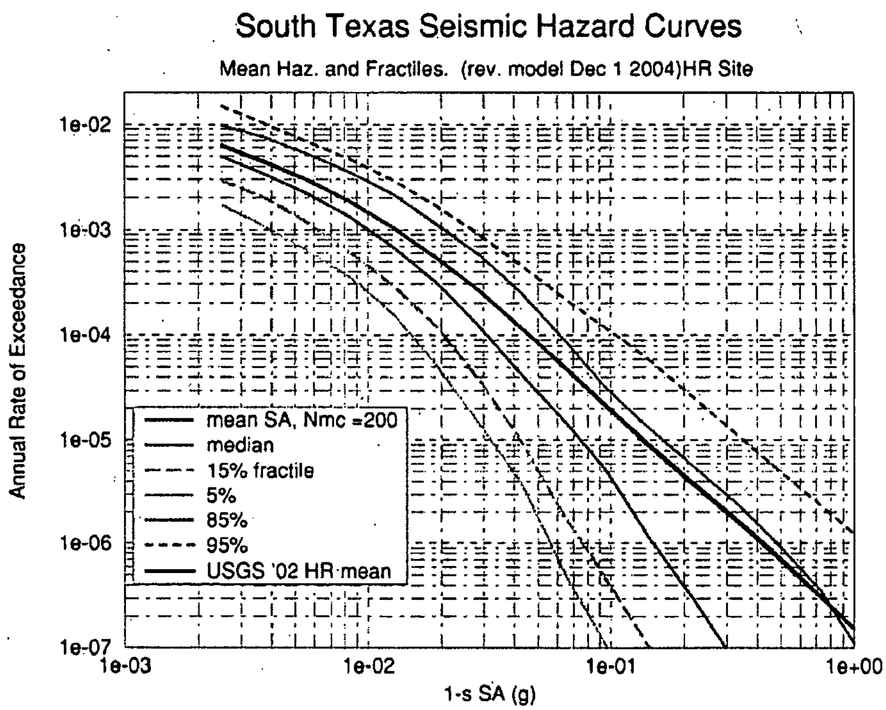


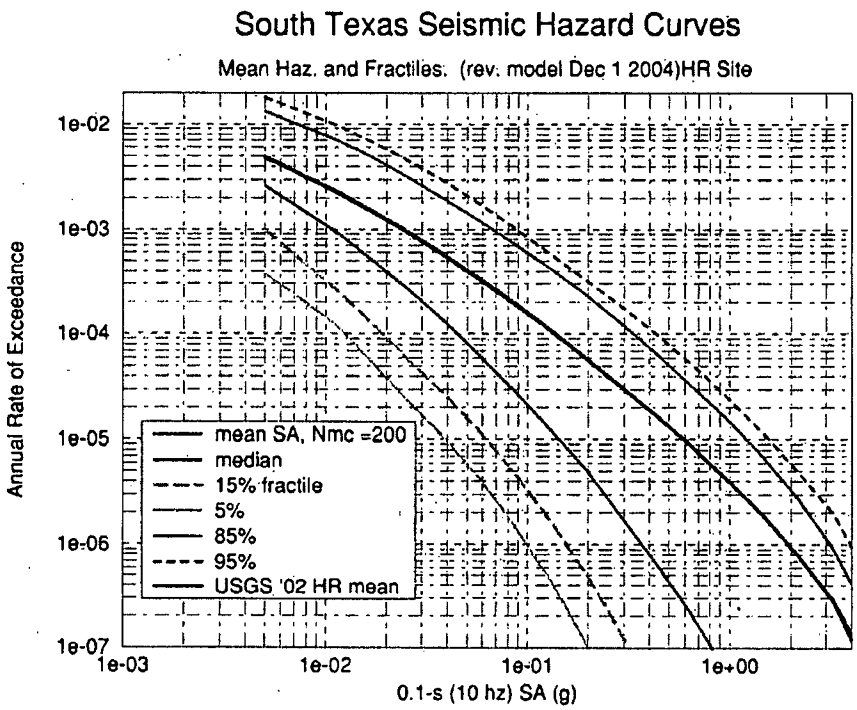
(22) Shearon Harris:


Shearon Harris Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



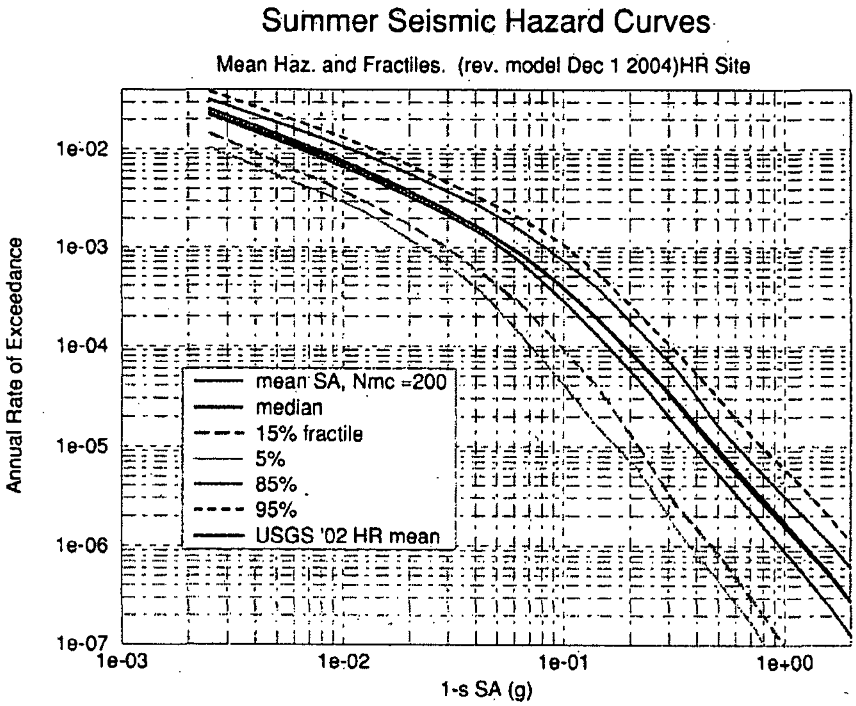
(23) South Texas:

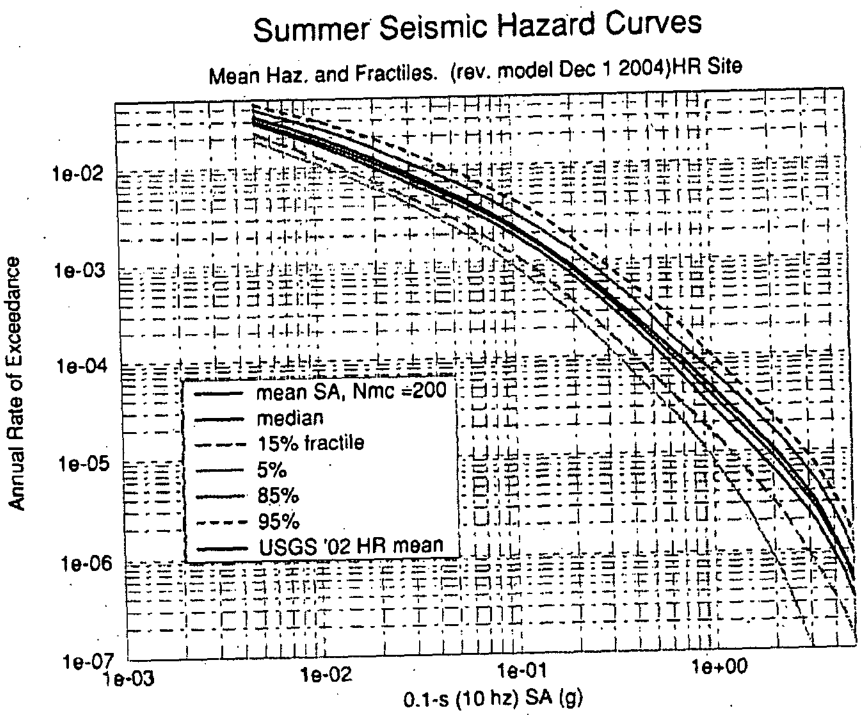

South Texas Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



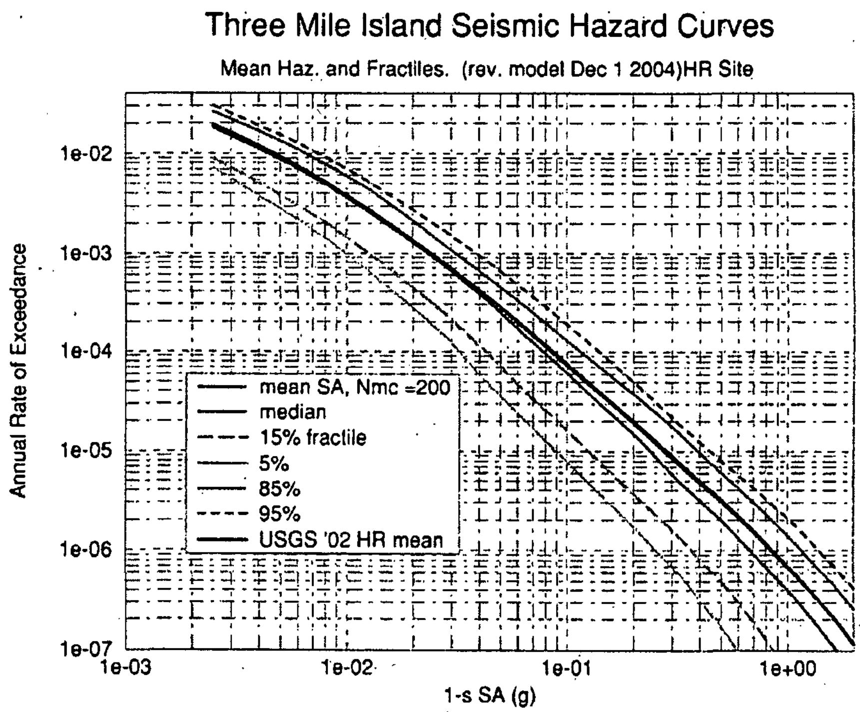
South Texas Seismic Hazard Curves
Mean Haz. and Fractiles: (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

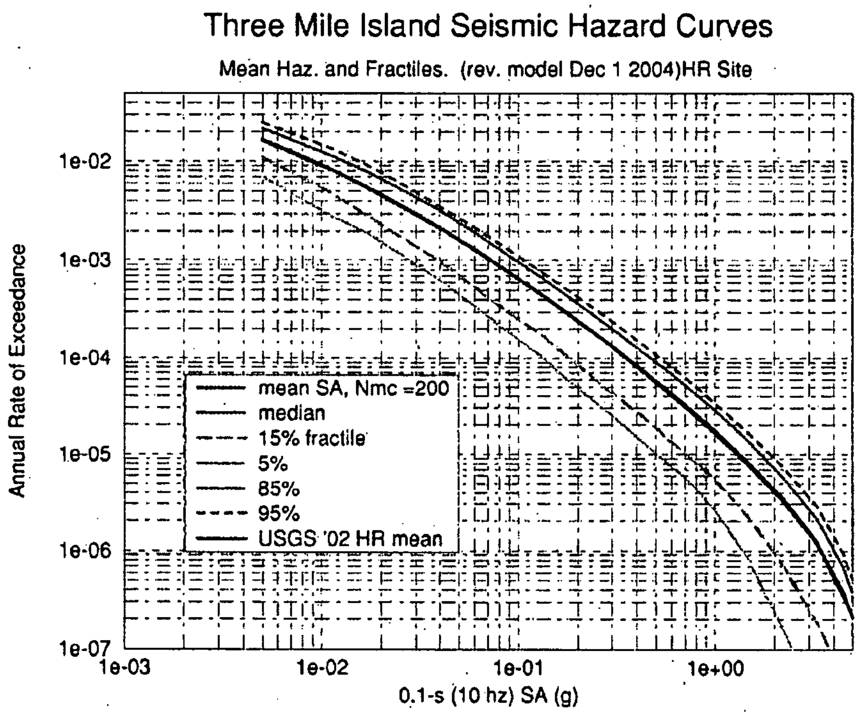
(24) Summer:


Summer Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

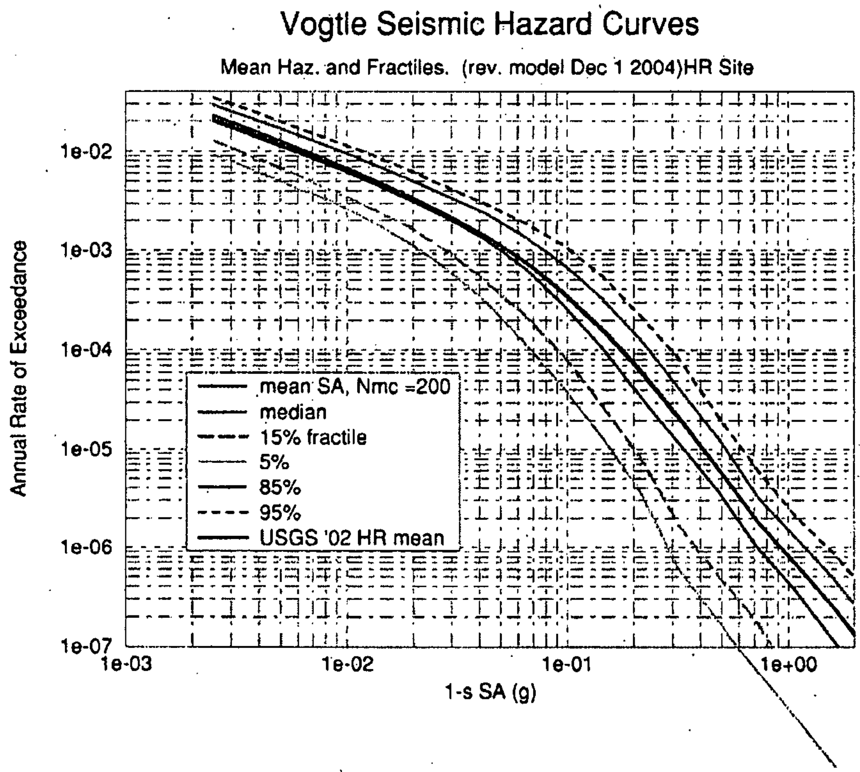


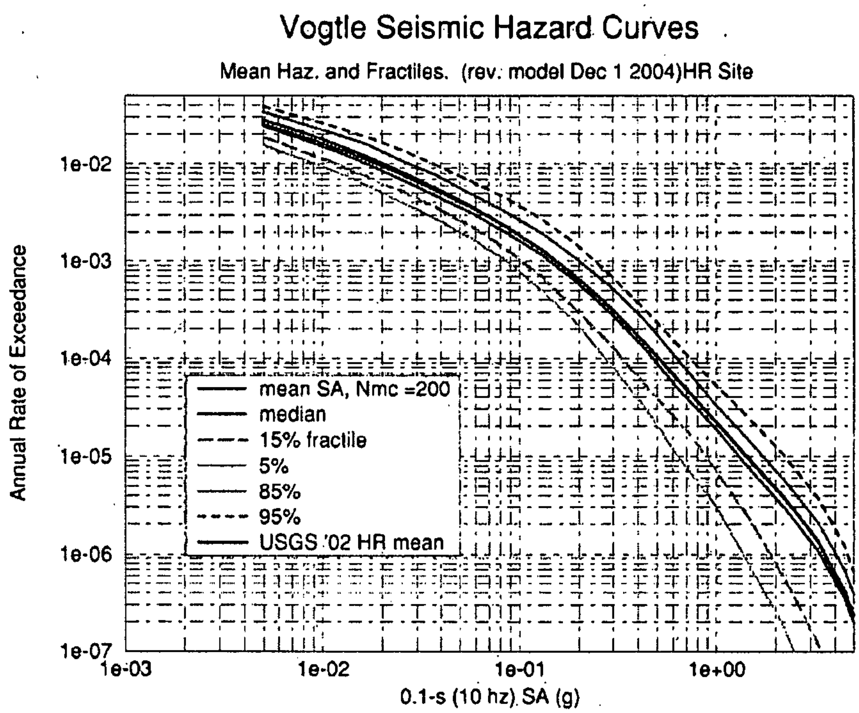
(25) Three Mile Island:


Three Mile Island Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

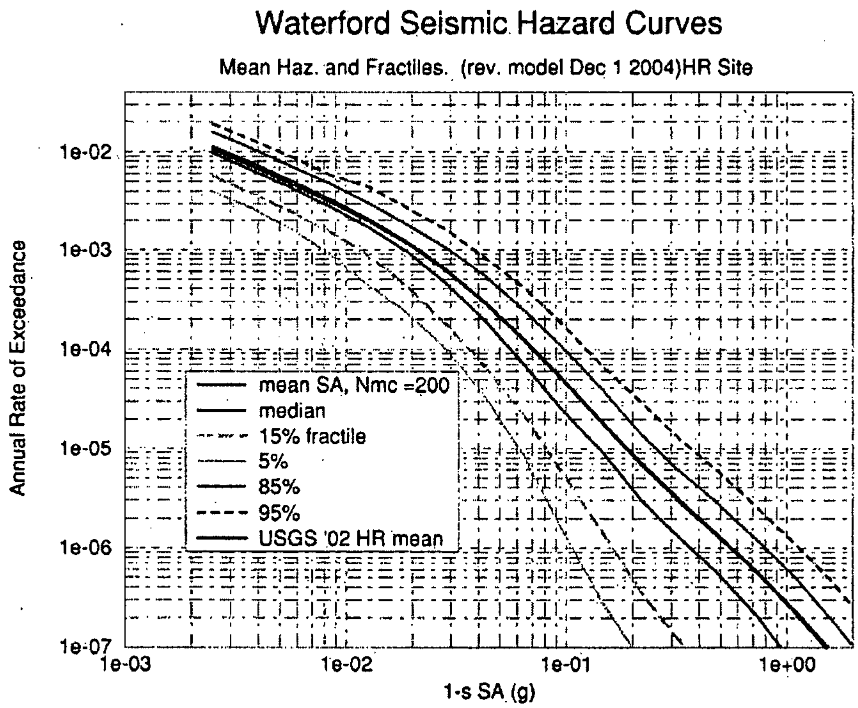

Three Mile Island Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

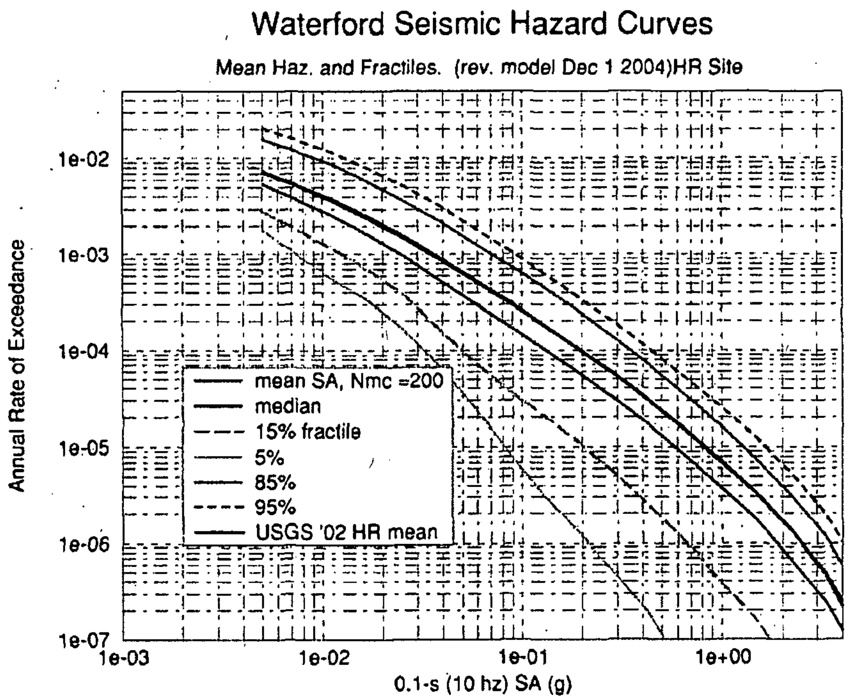
(26) Vogtle:


Vogtle Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean


Vogtle Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

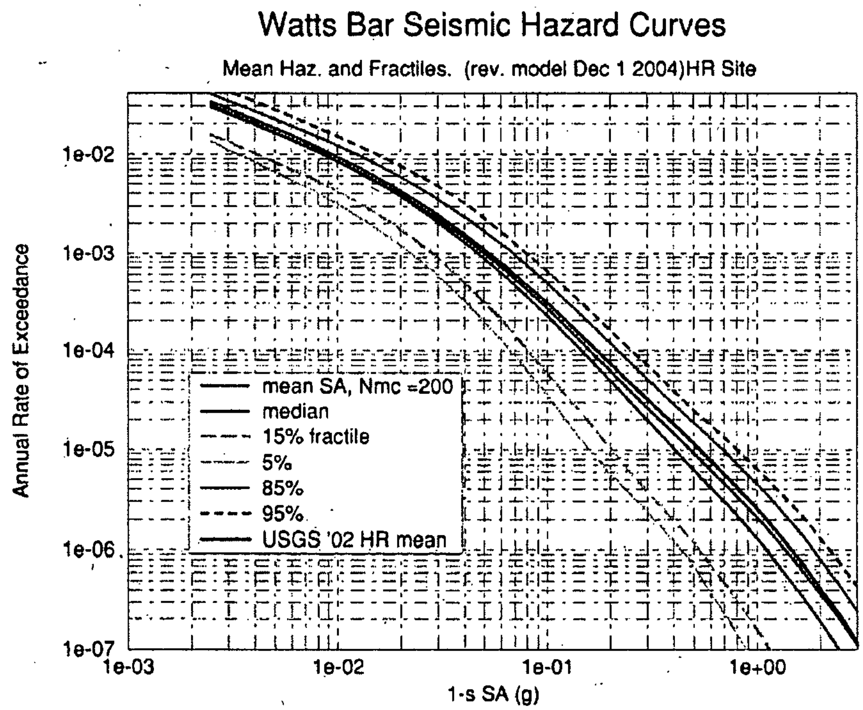
(27) Waterford:

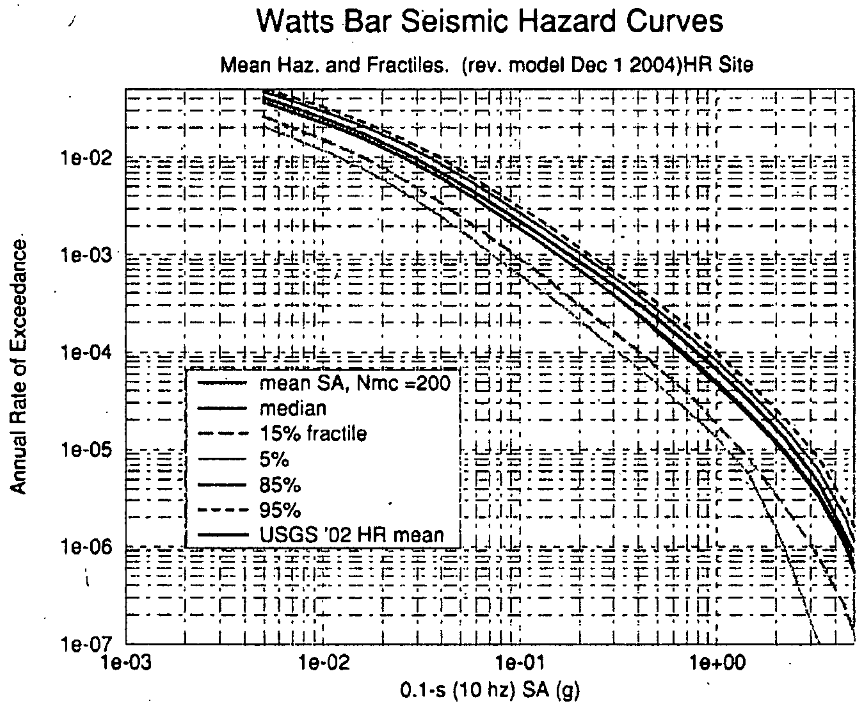




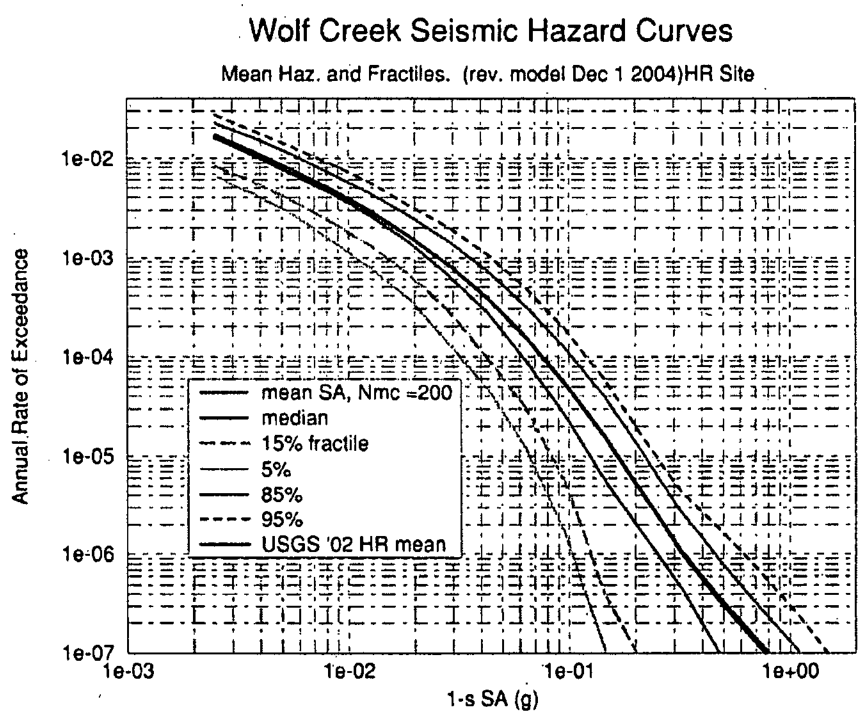
Waterford Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
0.1-s (10 hz) SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean

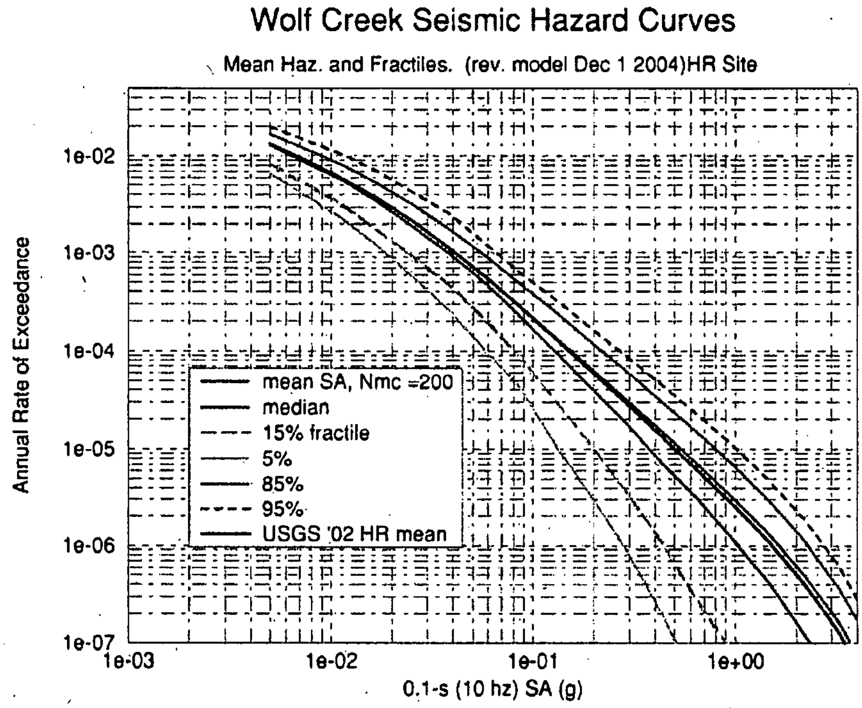
(28) Watts Bar:


Watts Bar Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



(29) Wolf Creek:


Wolf Creek Seismic Hazard Curves
Mean Haz. and Fractiles. (rev. model Dec 1 2004)HR Site
Annual Rate of Exceedance
1e-02
1e-03
1e-04
1e-05
1e-06
1e-07
1e-03
1e-02
1e-01
1e+00
1-s SA (g)
mean SA, Nmc =200
median
15% fractile
5%
85%
95%
USGS '02 HR mean



Conclusions:

- Most of the 29 sites' mean seismic hazard curves for the 200 Monte Carlo runs overlaps the USGS "2002 model" within 5%.

- The mean of the 200 MC runs can be higher or lower than the map mean by more than 5% at 10^{-5} PE, although not much more than 10% higher or lower. A site where the MC mean is higher than the map mean is Clinton. Two sites where the MC mean is lower than the map mean are Bellefonte and Seabrook.

- (1) The use of adaptive weighting in the national maps is one likely reason why the two means are in a few instances different. In the Monte Carlo runs, agrids are not modified by adaptive weighting. (2) Random statistical fluctuations should not be ruled out as a possible reason. (3) Other potential reasons for differences?

Reference:

Frankel, Arthur D., Mark D. Petersen, Charles S. Mueller, Kathleen M. Haller, Russell L. Wheeler, E.V. Leyendecker, Robert L. Wesson, Stephen C. Harmsen, Chris H. Cramer, David M. Perkins, and Kenneth S. Rukstales (2002). Documentation for the

2002 Update of the National Seismic Hazard Maps, U.S. Geological Survey Open-File Report 02-420.

Marple, R. T. and P. Talwani, 2000. Evidence for a buried fault system in the Coastal Plain of the Carolinas and Virginia - Implication for neotectonics in the southeastern United States, *Geol. Soc. Am. Bull.*,**112**, p. 200-220.

USGS PSHA Software Verification

Program: grda02gen.f
Module:
Version number:
Technical Contact: Art Frankel
Email: afrankel@usgs.gov
Verification Date: November 29, 2004

Purpose of Code:
This code produces seismicity rate grids (agrids) for use in the seismic hazard codes. The code uses the re-sampled catalogs. The code calculates the sum of earthquakes in each grid cell, corrects for incompleteness, and spatially smooths the seismicity grid using a Gaussian function. Special treatment is made for the Eastern Tennessee and New Madrid areal zones, where the seismicity rate is specified to be uniformly distributed across the zone. This code closely parallels the code used to make the agrids for the national maps.

Current Tests:

A Monte Carlo simulation with 200 runs was done, with a seismicity rate grid saved for each run. The mean seismicity rate for each grid cell was then calculated and compared with that from the four original seismicity grids used to make the 2002 national maps. Maps of the mean rates from these two approaches were visually compared and were numerically compared at selected locations. We found good agreement between the mean rates. Figure 1 shows the mean seismicity rate grids for the 2002 map and from the 200 runs used in the Monte Carlo simulation. We would not expect the two grids to be identical since the Monte Carlo runs involved re-sampling the catalog and using a logic tree on the smoothing parameters. However, there are no systematic differences between the grids, indicating that the grda02gen program is running correctly.

In another test, we separately calculated the mean rates for each model draw from grda02gen, i.e., for the M>=3, M>=4, M>=5, and background model draws. Then the mean rate for each model was compared to that from the model used in the 2002 maps. Again, very good agreement was found, indicating that grda02gen works as it is supposed to.

In a third test, grda02gen was applied to the original catalog used in the 2002 maps and the resulting seismicity rate grids (M3, M4, M5 models) was compared to those used in the 2002 maps. They were found to be identical, again indicating that the grda02gen program is running properly.

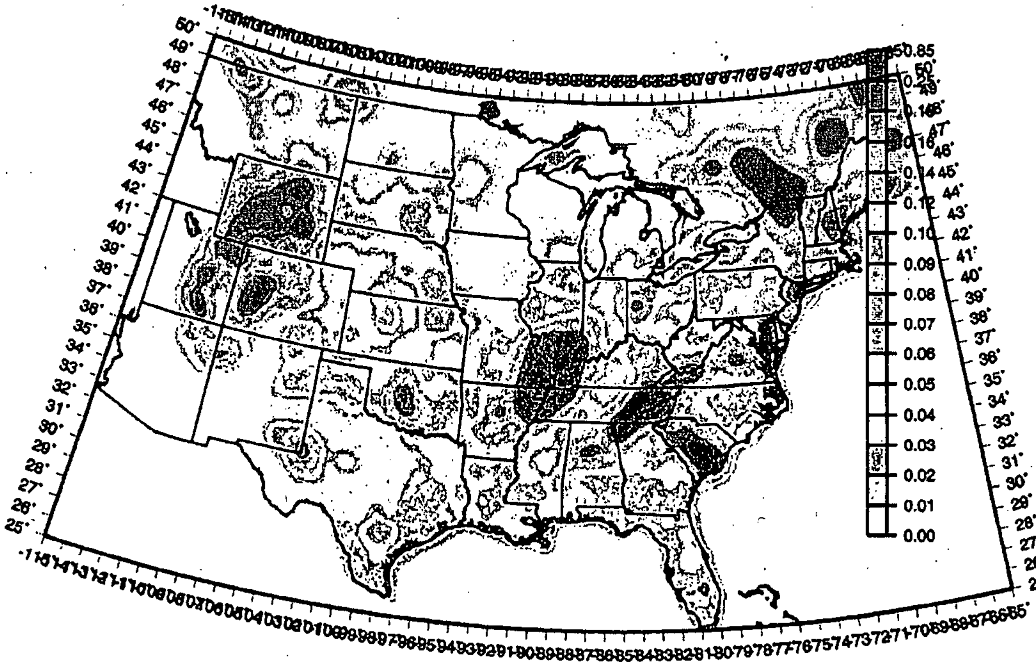


Fig. 1a. Mean seismicity rate grid from the four seismicity models used in th 2002 hazard maps.

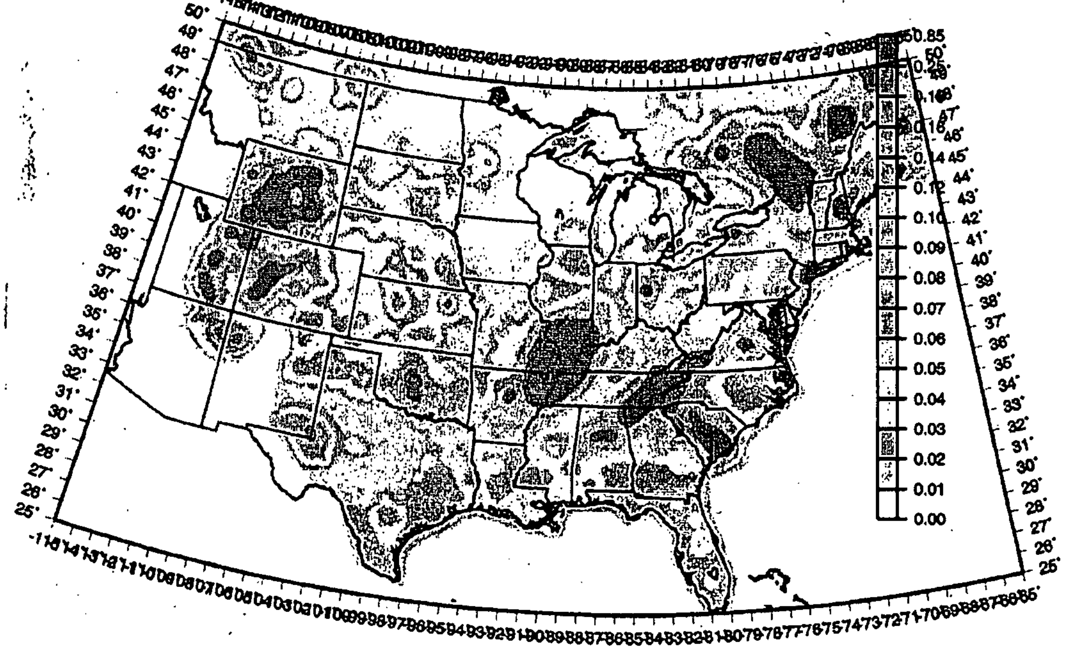


Fig. 1b. Mean seismicity rate grid from averaging the 200 seismicity rate grids from the Monte Carlo runs.

USGS PSHA Software Verification

Programs: ceuscatab02.f and grdaz02gen.f and
Module:
Version number:
Technical Contact: Art Frankel
Email: afrankel@usgs.gov
Verification Date: November 29, 2004

Purpose of Codes:
ceuscatab02.f calculates seismicity rates in each background zone using the re-sampled catalog for that Monte Carlo run. The seismicity rates are adjusted for the limited completeness times as was done in the 2002 national maps. grdaz02gen.f takes these rates and generates a seismicity rate grid (agrids) for the background zones for use in the seismic hazard codes.

Current Tests:

A Monte Carlo simulation with 200 runs was done, with a seismicity rate grid saved for each run. The mean seismicity rate for each draw involving the background zones was calculated. Figure 2 compares the background seismicity rate grid used in the 2002 maps with the grid of the mean seismicity rate of the background zone draws used in the Monte Carlo simulation. The good agreement between the two indicates that the re-sampling of the catalog and the calculation of mean rates in the zones is correct in the Monte Carlo code, specifically in ceuscatab02.f and grdaz02gen.f.

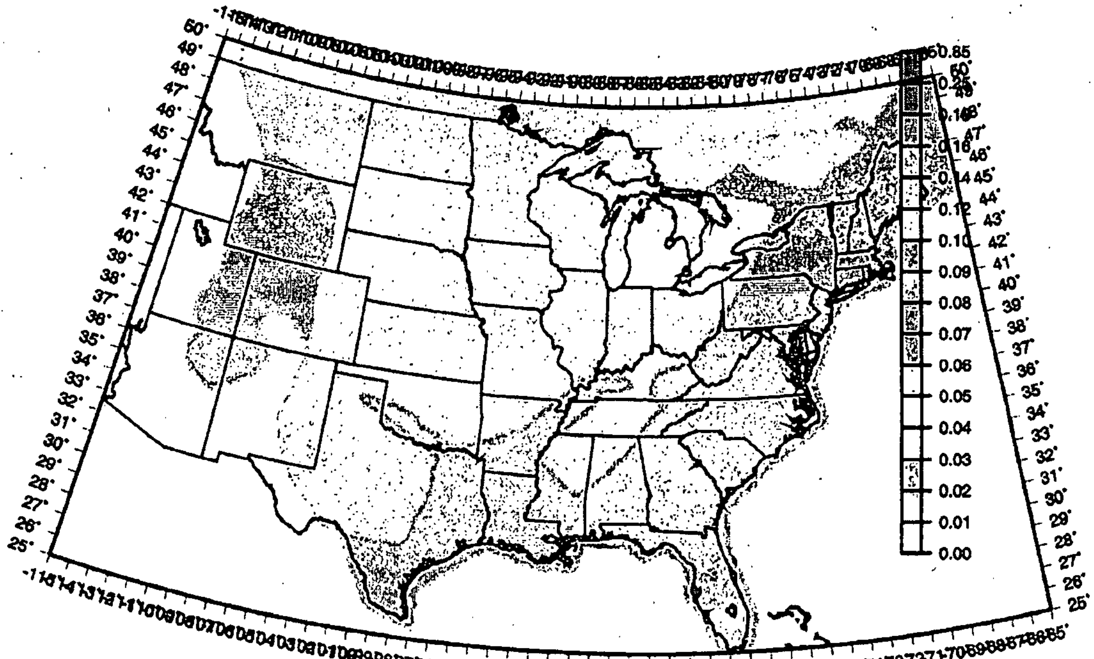


Fig. 2a. Seismicity rate of background zones used in 2002 maps.

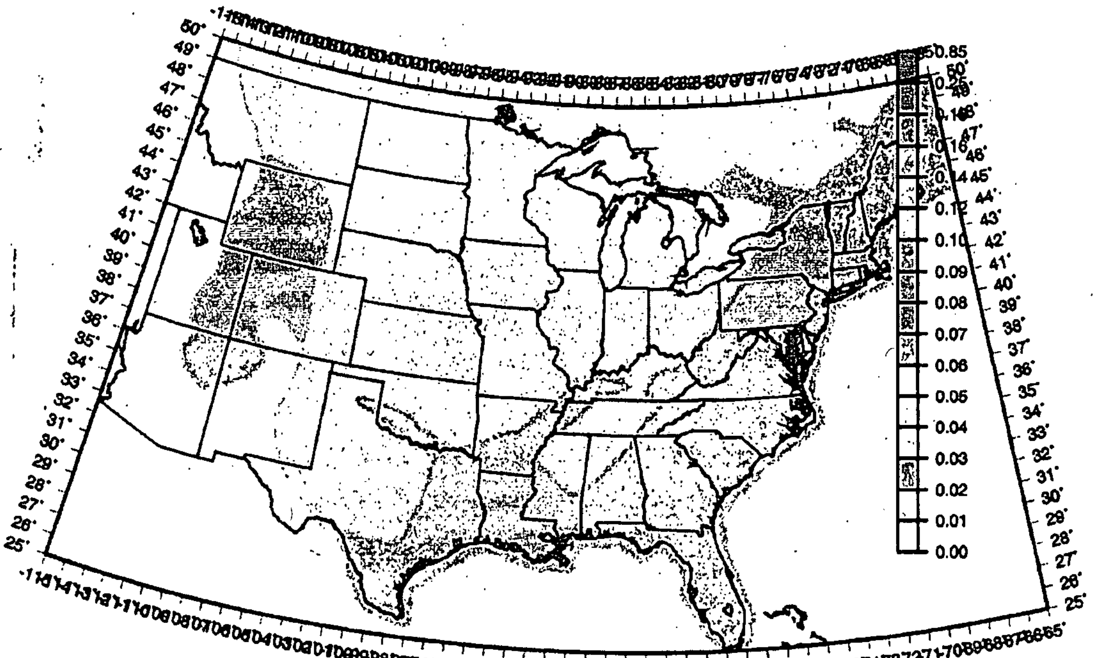


Fig. 2b. Mean seismicity rate of background zones used in Monte Carlo simulation.

USGS PSHA Software Verification

Program: ceusruns.f
Module: calculation of recurrence interval for New Madrid characteristic source
Version number:
Technical Contact: Art Frankel
Email: afrankel@usgs.gov
Verification Date: November 29, 2004

Purpose of Code:
This portion of the code calculates the recurrence rate of characteristic New Madrid earthquakes for each Monte Carlo run. This code uses a log normal distribution of recurrence rate using a mean annual rate of 1/500. Using the standard deviation (in ln units) of 0.5 we calculate the median recurrence rate from the mean rate. This is then used to calculate the recurrence rate distribution. In previous versions of the code, the recurrence interval was specified as a log normal function, which led to a mean recurrence rate that was higher then 1/500. A similar problem and solution is noted for the Charleston characteristic source (see separate documentation).

Current Test: A Monte Carlo simulation with 200 runs was completed. The mean rate for New Madrid characteristic earthquakes was calculated from the results of the 200 runs. We found a mean rate of 1/521, which is close to the desired 1/500. The difference is just due to the random sampling in the Monte Carlo run. The relevant portion of the code is listed below.

```
c . Choose recurrence interval for NMSZ
      vv = 0.25 ! gives mean in this case
      if(lri .and. irup .gt. 0) vv = gasdev(idum,iset,gset,iy,iv)
c----- changed by ADF  11/16/04
c       rinm = log(440.) + vv*.5 ! 500y mean recurrence interval
      rmed= (1./500.)/exp(0.5**2/2.)
      rinm= alog(rmed) + vv*0.5
      rinm = exp(rinm)
c---- convert to recurrence interval
      rinm= 1./rinm
```