TABLE F6-21
P. G. SOMERVILLE: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 3.33 SEC PERIOD

CASE No.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.00212	0.80009	0.81491	0.08029
2	5.00	1	0.00328	0.79034	0.67230	0.06965
3	5.00	5	0.00070	0.79434	0.73290	0.07391
4	5.00	5	0.00128	0.78815	0.42549	0.06727
5	5.80	10	0.00473	0.73397	0.37989	0.19519
6	5.80	20	0.00416	0.71640	0.49586	0.20000
7	6.50	1	0.04135	0.70526	0.41153	0.20000
8	6.50	1	0.05512	0.67985	0.38815	0.20000
9	6.50	1	0.04824	0.67626	0.31782	0.20000
10	6.50	5	0.05056	0.68124	0.58873	0.20000
11	6.50	5	0.02963	0.67494	0.23803	0.20000
12	6.50	50	0.00340	0.70604	0.64597	0.20000
13	6.50	50	0.00514	0.69210	0.92433	0.20000
14	7.00	10	0.02949	0.71144	0.32946	0.20000
15	7.50	50	0.01158	0.70415	0.75431	0.20000
16	7.50	50	0.01515	0.68269	1.01080	0.20000
17	5.00	1	0.00056	0.79876	1.07275	0.07883
18	5.80	5	0.00977	0.71573	0.47570	0.20000
19	5.80	5	0.00530	0.71199	0.45211	0.20000
20	5.00	10	0.00066	0.79787	0.86940	0.07761
21	5.00	10	0.00200	0.78862	0.60788	0.06777
22	5.00	50	0.00012	0.80051	1.02821	0.08014
23	5.00	50	0.00049	0.78999	0.69468	0.06919
24	5.00	160	0.00004	0.81848	1.25153	0.09937
25	5.80	1	0.01358	0.73535	0.50251	0.19959
26	5.80	5	0.01754	0.71726	0.65394	0.20000
27	5.80	5	0.00938	0.71243	0.42227	0.20000
28	5.80	10	0.00517	0.73180	0.44532	0.19274
29	5.80	10	0.00753	0.71857	0.68221	0.20000
30	5.80	10	0.00626	0.72009	0.60544	0.20000
31	5.80	50	0.00073	0.73238	0.96513	0.19074
32	5.80	50	0.00144	0.72463	1.01649	0.20000
33	6.50	5	0.03435	0.69963	0.26675	0.20000
34	6.50	10	0.01888	0.69250	0.25079	0.19993
35	6.50	10	0.02501	0.68785	0.50129	0.20000
36	6.50	10	0.01916	0.68064	0.44058	0.20000
37	6.50	20	0.01007	0.70926	0.35489	0.20000
38	6.50	20	0.01324	0.68423	0.57333	0.20000
39	6.50	20	0.01179	0.68480	0.78724	0.20000
40	6.50	100	0.00135	0.70171	0.90168	0.20000
41	6.50	160	0.00095	0.70171	0.87878	0.20000
42	7.00	1	0.05691	0.70119	0.58391	0.20000
43	7.00	10	0.04173	0.69145	0.52428	0.20000
44	7.00	10	0.02888	0.68326	0.62865	0.20000
45	7.00	50	0.00684	0.70838	0.79110	0.20000
46	7.00	50	0.01008	0.69281	0.99900	0.20000
47	7.50	1	0.07796	0.71433	0.33975	0.20000
48	5.00	10	0.03502	0.70094	0.63890	0.20000
49	5.00	10	0.05615	0.69292	0.71565	0.20000
50	8.00	50	0.03083	0.78137	0.47685	0.20000
51	8.00	160	0.01107	0.78445	0.51313	0.20000

TABLE F6-22
P. G. SOMERVILLE: VERTICAL POINT ESTIMATES
PEAK GROUND VELOCITY

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	2.65124	0.66362	0.39808	0.07893
2	5.00	1	3.68688	0.66494	0.17883	0.07975
3	5.00	5	0.66013	0.66561	0.26741	0.07994
4	5.00	5	0.96828	0.66430	0.21965	0.07914
5	5.80	10	2.37668	0.61922	0.17473	0.16909
6	5.80	20	2.24397	0.60845	0.60395	0.16487
7	6.50	1	13.68076	0.59985	0.23627	0.17461
8	6.50	1	18.01303	0.59288	0.45881	0.17465
9	6.50	1	15.20432	0.59298	0.39291	0.17667
10	6.50	5	16.30697	0.59062	0.49712	0.17078
11	6.50	5	10.52329	0.59058	0.33527	0.17433
12	6.50	50	0.97511	0.59841	0.41709	0.16702
13	6.50	50	1.57279	0.59607	0.62754	0.17095
14	7.00	10	10.41637	0.59929	0.21922	0.18707
15	7.50	50	3.50694	0.59006	0.45058	0.19379
16	7.50	50	4.83217	0.58567	0.75462	0.19531
17	5.00	1	0.70917	0.66362	0.32042	0.07893
18	5.80	5	3.98799	0.60486	0.34393	0.16629
19	5.80	5	2.55361	0.60488	0.50608	0.17134
20	5.00	10	0.83952	0.67145	0.18448	0.08344
21	5.00	10	1.90272	0.66019	0.60964	0.07667
22	5.00	50	0.12397	0.66922	0.17214	0.08150
23	5.00	50	0.16313	0.64709	0.30707	0.07142
24	5.00	160	0.01747	0.68029	0.51732	0.08893
25	5.80	1	6.76514	0.61360	0.27080	0.16883
26	5.80	5	7.65992	0.60594	0.42510	0.16721
27	5.80	5	4.52524	0.60051	0.27394	0.16761
28	5.80	10	3.00607	0.61751	0.21426	0.16750
29	5.80	10	4.84362	0.60806	0.52434	0.16673
30	5.80	10	2.78572	0.60488	0.40269	0.17134
31	5.80	50	0.28533	0.61897	0.71864	0.16443
32	5.80	50	0.45959	0.61114	0.69462	0.16512
33	6.50	5	11.37272	0.60207	0.27895	0.17491
34	6.50	10	7.50399	0.59826	0.26593	0.16980
35	6.50	10	10.45618	0.59804	0.48593	0.17606
36	6.50	10	7.18017	0.58576	0.37996	0.16991
37	6.50	20	3.59531	0.59663	0.25990	0.16697
38	6.50	20	5.69562	0.59471	0.55034	0.17124
39	6.50	20	3.72142	0.58773	0.50517	0.17167
40	6.50	100	0.44705	0.60370	0.23614	0.17149
41	6.50	160	0.16347	0.59968	0.46234	0.16805
42	7.00	1	16.95840	0.59794	0.28176	0.18852
43	7.00	10	15.26860	0.59464	0.52837	0.18866
44	7.00	10	10.35549	0.58749	0.39525	0.18548
45	7.00	50	1.99607	0.59869	0.38269	0.18393
46	7.00	50	3.03759	0.59432	0.72999	0.18558
47	7.50	1	23.05415	0.59902	0.42991	0.20000
48	5.00	10	13.34890	0.58922	0.22836	0.19484
49	5.00	10	18.30014	0.58844	0.59026	0.20000
50	8.00	50	7.36929	0.62780	0.24077	0.20000
51	8.00	160	1.95719	0.64728	0.35007	0.20000

TABLE F6-23
ADJUSTMENT FACTORS FOR SIMULTANEOUS RUPTURE ON PARALLEL FAULTS

FREQUENCY (HZ)	HANGING WALL SCALE FACTOR	FOOTWALL SCALE FACTOR	ADDITIONAL ALEATORY UNC.	ADDITIONAL EPISTEMIC UNC.
PGV	1.5	1.75	0.3	0.2
20	1.5	1.75	0.3	0.2
10	1.5	1.75	0.3	0.2
5	1.5	1.75	0.3	0.2
2	1.4	1.75	0.3	0.2
1	1.4	1.6	0.3	0.2
0.5	1.4	1.6	0.3	0.2
0.3	1.4	1.6	0.3	0.2
PGV	1.4	1.6	0.3	0.2

TABLE F6-24
ADJUSTMENT FACTORS FOR SIMULTANEOUS RUPTURES ON PARALLEL FAULTS AND A DEEP DETACHMENT SURFACE

FREQUENCY (HZ)	SCALE FACTOR	ADDITIONAL ALEATORY UNC.	ADDITIONAL EPISTEMIC UNC.
PGA	1.0	0.3	0.2
20	1.0	0.3	0.2
10	1.0	0.3	0.2
5	1.0	0.3	0.2
2	1.2	0.3	0.2
1	2.2	0.3	0.2
0.5	2.2	0.3	0.2
0.3	1.7	0.3	0.2
PGV	2.2	0.3	0.2

APPENDIX F7

ESTIMATION OF GROUND MOTION ATTENUATION FOR THE YUCCA MOUNTAIN PROBABILISTIC SEISMIC HAZARD ASSESSMENT

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APPENDIX F7

ESTIMATION OF GROUND MOTION ATTENUATION FOR THE YUCCA MOUNTAIN PROBABILISTIC SEISMIC HAZARD ASSESSMENT

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F7-1 INTRODUCTION

One aspect of the evaluation of Yucca Mountain, Nevada as a potential geological repository for high-level radioactive waste is assessment of seismic hazards at the site. The selected approach to probabilistic seismic hazard assessment uses two panels, seismic source characterization and ground motion evaluation, to provide expert opinion on the likely sizes and probabilities of earthquakes in the region and the ground motions that these sources would produce at Yucca Mountain. The ground motion estimates combined with the likelihood of occurrence of the various seismic sources provide information on the site seismic hazard as a function of time.

Members of the ground motion expert panel were asked to provide point estimates of ground motion for 51 different combinations of magnitude, source distance, and source mechanism. These combinations included moment magnitudes of 5.0, 5.8, 6.5, 7.0, 7.5, and 8.0. The distances considered were horizontal separations of 1, 5, 10, 20, 50, and 160 km. Strike-slip and normal faulting (both foot wall and hanging wall) source mechanisms were included. The ground motions were not calculated for all possible combinations of these parameters, but rather for those combinations selected by the ground motion facilitation team as the most appropriate for hazard at Yucca Mountain. For each of the identified seismic sources, the experts calculated spectral acceleration at 7 frequencies (0.33, 0.5, 1.0, 2.0, 5.0, 10.0, and 20.0 Hz) plus peak ground acceleration (PGA) and peak ground velocity (PGV) for both horizontal and vertical motion components. Each ground motion estimate consists of four (4) numbers: the median ground motion (μ), the aleatory uncertainty in the median (σ), the epistemic uncertainty in the median (σ_μ) and the epistemic uncertainty in the aleatory uncertainty (σ_σ). Thus the experts have calculated a total of 3672 parameters relevant to ground motion at a site called "YM300", which is a surface site but has velocities representative of Yucca Mountain at a depth of 300 m. The ground motion facilitation team for the project regressed the point estimates using standard techniques to develop continuous models of the ground motion attenuation at Yucca Mountain as functions of magnitude and distance.

F7-2 WEIGHTING SCHEME FOR PROPONENT GROUND MOTION MODELS

The ground motion facilitation team provided the experts with a suite of proponent models that were to be considered for their applicability to ground motions at Yucca Mountain. Each expert was required to evaluate each model and decide on its applicability in each of the 918 earthquake-frequency-component combinations. The typical approach was to develop estimates based on a weighted median of the proponent models. Each expert divided the proponent models into different classes, with each class assigned a weight, and then assigned a relative weight to each candidate model within each class. The various classes of proponent models and their weights are discussed in detail in the following sections.

F7-2.1 Classes Of Proponent Models

I chose to define three classes of proponent models: empirical, point source numerical simulation, and finite fault numerical simulation. The empirical models considered include several attenuation relations based on data primarily from California (e.g., Abrahamson and Silva, 1997; Boore *et al.*, 1997; Campbell, 1997; Idriss, 1993, 1997 [University of California, Davis, written communications]; Sadigh *et al.*, 1997), the Spudich *et al.* (1996) model for extensional regime data, the Sabetta and Pugliese (1996) model based on Italian earthquakes, and the McGarr (1984) relation for peak ground acceleration and velocity for close-in, extensional data. Also in this category are the explosion models developed for the Yucca Mountain Project by R.J. Bennett *et al.* (S-Cubed, written communication, 1997) and the Campbell hybrid empirical model (N. A. Abrahamson and A. M. Becker, consultants, written communication, 1997b). The single model of the point source numerical simulation class was developed by W. Silva. Three different approaches to finite fault simulation were also exercised for the YM300 structure; these are the work of Zeng and Anderson; P. Somerville, and W. Silva. N. A. Abrahamson and A. M. Becker (Consultants, written communication, 1997) contains information documenting all four of the numerical simulation models.

F7-2.2 Model Weights: Horizontal Components

All of the proponent models were available for making predictions of the horizontal component data. Many of the empirical models provide estimates for spectral acceleration and peak ground acceleration only, so there were only limited choices in models for the peak ground velocity estimates. A few of the empirical models (Boore *et al.*, 1997; Spudich *et al.*, 1996) did not provide high-frequency (20 Hz spectral acceleration) ground motion values.

In most cases, adjustments were made to the raw horizontal model estimates to make them applicable for the YM300 site. The adjustments that I chose to include were the effects of 1) crustal structure, 2) source differences (chiefly due to stress drop), 3) compensation for the difference between the average horizontal component (applicable for most proponent models) and the random horizontal component (the required estimate), and 4) interpolation for 20 Hz estimates when needed.

Two crustal adjustment factors were available for use by the experts: these were similar, but not identical, band-limited-white-noise-random-vibration theory estimates from Ken Campbell and Walt Silva (N. A. Abrahamson, and A. M. Becker, Consultants, written communication, 1997b). These corrections account for the difference between a "California" crust and the YM300 velocity structure. I chose to apply the Campbell crustal correction to the appropriate empirical models as detailed below. The point source model and the three finite fault simulations were calculated directly for the YM300 model and did not require crustal transfer functions.

Some recent studies (Abrahamson and Silva, 1997; Spudich *et al.*, 1996) have determined that the ground motions expected from normal-faulting earthquakes and also strike-slip earthquakes in extensional regimes may be lower than that expected for "typical" California strike slip and thrust earthquakes. The lower ground motions could be due to lower stress drop parameters for extensional-regime earthquakes. Becker and Abrahamson (1997) studied stress drops for extensional regime earthquakes and found an average stress drop of 45 bars for a limited set of normal faulting earthquakes, and a value near 55 bars for extensional strike-slip earthquakes. These values are lower than those found for typical California events by Silva *et al.* (written communication, Pacific Engineering and Analysis, 1997). Because Yucca Mountain is in an extensional regime, and the expected earthquakes are either normal or strike slip in nature, one might expect lower stress drops for these events and therefore lower ground motions than for the equivalent California events, which have an average stress drop of about 60 bars. This source effect was included in the ground motion estimates by using a source correction based on the same theory as the crustal correction, and coded by Ken Campbell. I chose to use source corrections for all models except those developed specifically for extensional regimes (Spudich *et al.*, 1997; McGarr, 1984). Strike-slip events were assigned a stress drop parameter of 55 bars, and the normal events were assigned 45 bars. The numerical simulations were given the same source corrections as the empirical models.

Most of the empirical models and all of the numerical simulations were calculated for an average horizontal component. Because the desired attenuation relationships were for a random horizontal component, I incorporated additional aleatory uncertainty into the horizontal estimates for the appropriate models using the frequency-varying values of Boore *et al.* (1993).

Two of the empirical models do not provide coefficients applicable for calculating the spectral acceleration at 20 Hz (Boore *et al.* 1997 [BJF]; Spudich *et al.*, 1997 [SEA]). In order to avoid biasing the overall spectral shape for the event, I incorporated the interpolation scheme of Boore (N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b) to estimate 20 Hz values for the BJF and SEA models.

F7-2.2.1 Empirical Models. In an overall sense, I favor the empirical models over the numerical simulations, thus I typically assigned a class weight of 0.6 or 0.7 (out of 1.0) to the empirical class. Slight variations occurred from case to case and even for various frequencies within each case due to different availability of applicable models. For example, there are few empirical models which provide peak ground velocity estimates, so the numerical simulations often received a relatively higher weight for PGV estimates. Generally, however, the empirical models were always assigned a class weight of 0.5 or higher.

The general rules as applied to each model are discussed below. Models within the empirical class ordinarily receive equal weight; exceptions are noted for each model.

Abrahamson and Silva (1997) (AS97). This model is applicable for the entire range of distance (0-160 km) and magnitude (5-8) considered here. AS97 does not provide peak ground velocity estimates, therefore this model was not used for PGV. AS97 has an available adjustment for normal faulting, however for consistency among the models instead of using the AS97-specific normal faulting corrections I applied the Campbell version of the source correction discussed above. For the strike-slip earthquakes, I assigned the stress drop to be 55 bars; 45 bars was chosen for the normal events. The AS97 model was a "workhorse" as it was included in the vast majority of the calculations. It is a modern model based on a good data set using state-of-the-art regression methods.

Boore, Joyner, and Fumal (1997) (BJF). The BJF model was developed using a carefully selected data set and the two-step regression approach (Joyner and Boore, 1993) to model the data. It has few data at small magnitudes and an unusual attenuation shape for large distances. I applied the BJF model in the range recommended by Boore *et al.* (1997); magnitudes greater than or equal to 5.5 and distances less than 100 km. The BJF model also does not include any magnitude saturation at short ranges. Because I believe that some magnitude saturation does occur, I gave the BJF model a lower weight within the empirical class for large events at short distances. I applied crustal and source corrections as detailed above to the BJF model, and applied the Boore (N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b) interpolation scheme to provide 20 Hz spectral values. The model was calculated for a shear wave velocity of 620 m/s, consistent with California 'rock'. This Vs is lower than for the YM300 site, however the crustal transfer function should account for average velocity differences between typical California rock sites and the YM300 site.

Boore, Joyner, and Fumal (1994, class A). I did not use this model in the calculations. Boore (personal communication, 1997) recommended use of the BJF 1997 model.

Boore, Joyner, and Fumal (1997, class B). I did not use this model in the calculations. Boore (personal communication, 1997) recommended use of the BJF 1997 model.

Campbell, 1997 (soft rock) (C97). This model was used for most of the events at distances of 50 km or less. This model has a large degree of magnitude saturation; I gave it a lesser weight in some cases at close distance. Also, the Campbell model predicts higher amplitudes at low frequencies than the other models. In cases where the spectral shape was significantly different from my preference, I gave it a lower weight at .33, .5, and 1. Hz. The soft rock parameters are consistent with use of the Campbell crustal transfer function described above.

Campbell, 1997 (hard rock). I did not use this model in the calculations. According to Campbell (personal communication, 1997) the soft rock 1997 model is better suited for use in this study, coupled with the crustal and source transfer functions that he developed.

Campbell, 1993-1994 (hard rock). This model was not used. Campbell (personal communication) confirmed that the more recent 1997 model is more applicable.

Campbell, 1990-1994 (soft rock). This model was not used. Campbell (personal communication) confirmed that the more recent 1997 model is more applicable.

Campbell, 1990 (Dames and Moore, written communication) (soil/soft rock). This model was not used. Campbell (personal communication) confirmed that the more recent 1997 model is more applicable.

Idriss, 1993 and 1997 (University of California, Davis, written communications) (rock/stiff soil). This model was used, in combination with the appropriate crustal and source corrections, for magnitudes of 7.0 and less and distances of less than 100 km. It was generally given equal weight with the other applicable models. Both crustal and source corrections were applied to this model.

Joyner and Boore, 1988 (JB88). This older model uses similar methodology to BJF, but with a smaller data set. It was not used for the spectral acceleration or PGA estimates, but it does provide peak velocity predictions (PGV) and was used for PGV estimates for events in the magnitude range 5.5 to 7.5 and distances closer than 100 km.

Sadigh *et al.*, 1997 (Sa97). I used this model for spectral acceleration and PGA estimates for the events of all magnitudes. Its stated distance limit is 100 km, however I also used it for the 160 km estimates for the magnitude 6.5 and 8.0 cases, as the data distribution illustrations in Sadigh *et al.* (1997) show significant amounts of data beyond 100 km at the higher magnitudes. The Sa97 model was, however, assigned a relatively lower weight for the distant events. The usual crustal and source corrections were applied to this model.

Sabetta and Pugliese, 1996 (SP96). This model is based on data from Italy and does include some normal faulting recordings. The data set is small, however, and the regression method is not as sophisticated as for some of the California models. I used it only for peak velocity estimates. Because the data set included some normal faulting data, I did not apply the source correction to the SP96 model, however I did apply the crustal transfer function. Due to uncertainty in the comparative crustal structure of California and the Italian sites, I added an additional 0.1 of epistemic uncertainty in the median each time the SP96 model was used. Also, this model received a lower weight (typically half) within the empirical class for the peak velocity estimates. It was not used for events larger than magnitude 7.0, or for distances larger than 100 km.

Spudich *et al.*, 1997 (SEA96). This model is the first to be developed specifically for extensional regime data (strike-slip and normal faulting). The data were carefully selected and are applicable to the Yucca Mountain exercise without source correction. Because of the few data available, however, Spudich *et al.* were forced to place additional constraints on their regression that makes the shape of their model with frequency very similar to that of the BJF model. I used the SEA96 model for events from magnitude 5.5 through 7.0, and for distances less than 100 km. The crustal transfer function was applied, although its applicability to this worldwide data set is not as well known; I made the assumption that the crustal structure for the worldwide data (which included significant data from California) is similar to the generic California structure used in the transfer function. The SEA96 model did not provide 20 Hz spectral acceleration values, and the method proposed by Boore was used to interpolate a 20 Hz value for use in the point estimates.

McGarr, 1984. I used McGarr's model for horizontal PGV estimates only, in the distance range of 20 km and less and for magnitudes of 7 and less (McGarr, 1984 and McGarr, personal communication, 1997). As it was developed for extensional regime data, no source correction was applied to this model, but the crustal transfer function was applied since McGarr's data set includes several California events.

Bennett, Murphy, and Barker, 1997 (Model 1). This model was developed using the underground nuclear explosion (UNE) data from the Nevada Test Site. Because Yucca Mountain is located in the immediate vicinity, the UNE data should be appropriate for the local crustal structure. UNE sources, however, differ from earthquake sources in a number of important ways. One difference is the large amount of surface wave energy generated in UNE data as a consequence of the shallow UNE burial. I do not believe that the spectral shape for this model is appropriate for earthquakes and therefore did not incorporate it into the calculations.

Bennett, Murphy, and Barker, S-Cubed, written communication, 1997 (Model 2). Bennett *et al.*, cognizant of the potential problems associated with Model 1, provided a model that is scaled to the spectral shape of Sadigh *et al.* (1997) at 10 km. This Bennett *et al.* Model 2 also contain the NTS-appropriate crustal attenuation. I judged this model to be the most applicable of the three Bennett *et al.* UNE models and applied it to a subset of the calculations, limited to certain magnitudes that most closely match the UNE yields. Bennett *et al.* provided a yield-magnitude relation; it shows that the UNE data are applicable for magnitude range less than 6. Due to the lack of close-in data in the UNE database, I chose to apply Model 2 to only the magnitude 5.8 events at distances of 20 km or greater (while UNE data are available at 10 km, this Model 2 is identical to the Sadigh *et al.* 1997 model at 10 km, and therefore would provide only redundant data). No crustal correction was applied, but a source correction was applied to the calculations. Typically, I gave this model half of the weight of the other empirical models.

Bennett, Murphy, and Barker, S-Cubed, written communication, 1997 (Model 3). This version of the Bennett *et al.* models used the Little Skull Mountain earthquake spectrum to scale the UNE attenuation. I chose not to use this model due to this event's small size (not much long-period energy) and somewhat unusual spectral shape.

Campbell Hybrid Empirical Model (1997). Campbell developed a methodology to combine estimates from different empirical models with varying weights, including theoretical crustal and source corrections as outlined above. I chose not to use this model directly, although the concept of weighting the empirical models within the class and applying crustal and source corrections is quite similar to this model. The hybrid empirical model does not include any models that are not outlined above, therefore no information is lost by combining the various models in the way I chose as opposed to the perhaps more elegant hybrid empirical approach.

F7-2.2.2 Numerical Simulations. There are two types of proponent models that are numerical simulations of ground motion at the YM300 site. Silva developed a stochastic point source approach which can be viewed as a baseline for comparison to the more sophisticated finite-fault simulations. My use of these models in the ground motion calculations is outlined below.

F7-2.2.2.1 Point Source Simulation. Silva (N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b) developed a band limited white noise/random vibration theory (BLWN/RVT) stochastic point source method for calculating ground motions from a point source. The methodology combines the effects of the point source, path operator, and site operator to predict site-specific ground motion. He provided spectral accelerations, PGA, and PGV values for the full suite of 51 cases, using the YM300 crustal model. I generally assigned the stochastic point source model a class weight of about 0.1. It received a lower weight for the cases of large magnitude and short distances, where it would tend to overpredict the ground motion, and for the long period (0.33 Hz, 0.5 Hz) estimates for most cases. This model did receive weight up to 0.2, however, in cases where there were few other numerical simulations to include in the point estimate. For example, only the Zeng/Anderson finite fault model provided estimates for magnitude 5.0 earthquakes, so the point source model received a higher class weight for those cases. Because this model was the only one in its class, its relative weight within the class is always 1.0. I applied the source correction factors for stress drop to this model, but did not apply a crustal correction. This model requires a stress drop variability which I assigned to be 0.5 natural log units based on the studies of stress drop variability by Becker (Ground Motion Data Package). The model also incorporates the epistemic uncertainties in the median stress drop and standard deviation which I assigned to be 0.2 natural log units for both based on the results from Becker and on judgment.

F7-2.2.2.2 Finite-Fault Simulations. There are three proponent models that use finite fault simulations of ground motions. In all three cases, these simulations were performed for the YM300 structure directly and no crustal correction was applied. This class of models generally received a class weight of 0.3 or 0.35, depending on the other available models and their limitations for the particular case. If only one finite fault simulation was available for a particular case, it was assigned a class weight of 0.2.

Zeng and Anderson, 1997 (ZA). The estimates from this model (described in N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b) were developed from the composite fractal finite fault source method developed and described by Zeng *et al.* (1994). Its validation has not included any normal faulting earthquakes, and like the other finite fault models, it has also not been thoroughly validated for vertical data. Zeng and Anderson provided predictions for the full suite of events and distances. I used the results for this model in all cases, although in some instances it received a lower weight than the other finite fault simulations. If no other finite fault simulation was available for a particular case, the ZA model received a weight of 1.0 and its overall contribution was controlled by the class weight for the finite fault class. In my judgment, this model produced excessively high predictions for normal faulting events on the hanging wall, and as Anderson (personal communication, 1997) agreed that many of them seemed high and did not offer an explanation as to the cause, I weighted the ZA model at half weight for all hanging wall estimates. In other specific cases, this model also received a lower weight because it was an outlier, that is, different from all of the other model predictions by a factor of 2 or more. I applied the source corrections (stress drops of 55 and 45 bars for strike-slip and normal events, respectively) with a median stress drop uncertainty of 0.2.

Somerville (1997). This model uses a combination of theoretical (at long period) and empirical (at short periods) Green's functions to calculate ground motions from a specified finite fault (N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b). Due to limitations on the available empirical Green's functions, Somerville provided estimates for the events of magnitudes 5.8, 6.5, 7.0, and 7.5 only. Thus his model was not included in estimates for the magnitude 5.0 or 8.0 events. This model generally was weighted equally with the others within the class with the exception of outlier predictions. For this model, some very low ground motions were obtained at low frequencies for some events. I decreased the relative weight of the Somerville model for those instances to half, or occasionally to 1/4, of the other finite fault models. In one or two cases this model was not included at all in the calculations because its prediction over the entire spectrum was extremely different from the other models (cases 31 and 32). The source corrections were applied as in the Anderson model.

Silva (1997). This model is an extension of the point-source stochastic method to finite faults (N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b). Simulations were provided for all events except for the M5.0 cases. In general, the Silva model received a relative weight equal to the other finite fault simulations. Source corrections were also applied to this model in an analogous fashion to the other models.

F7-2.3 Model Weights: Vertical Models

The application of model weights for the vertical models was very similar to that of the horizontal models. The vertical ground motion at the desired frequency was calculated and crustal and source corrections applied. I used only models that included vertical motions and did not use vertical/horizontal motion ratios in order to include models developed only for horizontal motions. This practice resulted in a generally smaller number of models contributing to each weighted median ground motion estimate. In particular, there were often only a few models applicable for vertical PGV.

The crustal correction developed by Campbell is applicable to horizontal motions only, so I developed an alternative approach for calculating the vertical ground motions while incorporating the crustal transfer function. In this procedure, the horizontal ground motions were scaled by the crustal correction factors and then scaled by the Yucca Mountain point source vertical/horizontal ratios. This method was applied to empirical models only (because the numerical simulations were done directly for the YM300 structure), and will be described in section 2.3.1.

The class weights for the vertical motions are generally the same as for the horizontal motions. Because there are fewer available data and models, the epistemic uncertainty is typically higher for the vertical; this will be discussed below in the uncertainty section.

F7-2.3.1 Empirical Models. There are four proponent empirical models that provide vertical attenuation relations: Abrahamson and Silva (1997), Campbell (1997), Sadigh *et al.* (1997), and Sabetta and Pugliese (1996). The SP96 model was used only for peak ground velocity. The Campbell model also provides PGV but the AS97 and Sa97 models do not, thus the number of empirical models used for vertical PGV was small.

The class weight for the empirical models is typically 0.6 - 0.7.

To apply the Campbell crustal correction, developed for horizontal motions, to the vertical data, I used the following simple method. Silva provided the ground motion experts with vertical to horizontal (z/h) ratios for the stochastic point source calculations. I started with the *horizontal* prediction for the empirical model and multiplied it by the horizontal crustal correction and then the appropriate point source z/h ratio to produce a crust-corrected vertical ground motion estimate. Both the aleatory and epistemic uncertainties were increased for model estimates obtained with this procedure; more explanation is given in the uncertainty section below.

The AS97, Campbell, and Sadigh models generally received equal weights within the empirical class. Exceptions are similar to those for the horizontals as described above. Each model's range of applicability is the same for vertical motions as it is for horizontal motions.

F7-2.3.2 Numerical Simulations. Three of the four numerical simulation proponent models provided vertical ground motion estimates. These were used as the horizontals, with source corrections but no crustal corrections. The class weights were assigned in a manner analogous to the horizontal estimates.

F7-2.3.2.1 Point Source Simulation. Silva provided z/h ratios for the stochastic point source simulations to convert the horizontal to vertical estimates. The class weight for the point source model is typically 0.1 as discussed above. This model is applicable to all of the spectral amplitudes, PGA, and PGV. Deviations from the standard weighting scheme are as for the horizontal components.

F7-2.3.2.2 Finite Fault Simulations. The Zeng and Anderson and Somerville models provided vertical component estimates, while the Silva model did not. The ZA and Somerville model weights were applied as for the horizontal estimates described above. The Somerville model is not applicable for magnitude 5.0 or 8.0 events, therefore for these event sizes the ZA model is alone in this model class. In these cases, the class weights were adjusted so that typically the empirical model class would receive a relative weight of 0.6 with the point source and ZA models assigned 0.2 each. Exceptions to the general weighting scheme are chiefly for data outliers as discussed above for the horizontal components.

F7-3 ADJUSTMENTS TO WEIGHTED ESTIMATES

Case-specific adjustments to the weighted estimates were made based on judgement.

F7-4 ESTIMATES OF UNCERTAINTIES

Three types of uncertainty were calculated for each median ground motion estimate. The FORTRAN program WT_AVE (N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b) was used to provide statistical calculations of all three uncertainty values. The expert was provided the opportunity in the input file to WT_AVE to add additional uncertainty to that provided by the model proponent in any of the three uncertainty categories. These additions will be discussed below.

F7-4.1 Aleatory Uncertainty: σ

The aleatory uncertainty for each point estimate was calculated as a weighted average of the stated uncertainty for each model. The effect of the random horizontal component was included in this uncertainty for the appropriate model using the method recommended by Boore *et al.* (1993). The finite fault simulations include both parametric and modeling uncertainty in this term, while the empirical models typically provide a single number for uncertainty.

For the vertical component empirical and stochastic point source estimates, additional aleatory uncertainty associated with the regression fit to the point source z/h ratios was added (assuming no correlation) to the aleatory uncertainty. The proponents of the numerical simulations did not provide uncertainty estimates specific for the vertical components. To convert the horizontal aleatory uncertainty to a value appropriate for the vertical component, I used the horizontal uncertainty value (without random effect) and multiplied it by an average vertical/horizontal uncertainty ratio determined from the applicable empirical relationships.

F7-4.2 Epistemic Uncertainty For Median Point Estimate: σ_μ

The FORTRAN program WT_AVE calculates statistical values of the epistemic uncertainty on the median point estimate. For the horizontal components, I assigned epistemic uncertainty to have several components: 1) effect of uncertainty in crustal correction, 2) effect of uncertainty in source correction (as quantified by an uncertainty in median stress drop of 0.2) and 3) additional added uncertainty for some models. This additional assigned epistemic uncertainty included 0.1 for the SP97 model due to increased uncertainty in crustal structure, and 0.2 assigned to the numerical simulations that did not provide epistemic uncertainty estimates: stochastic point source, ZA, and Silva finite fault. The 0.2 value is similar to that obtained for the empirical models and is the same as Somerville value assigned from his expert judgment.

Each model thus has an epistemic uncertainty value assigned to it. In addition, the effect of the weighted deviation of each individual model from the median is included using standard statistics. The weighted individual model epistemic uncertainty estimates and the deviation effect are combined as documented by N. Abrahamson at the April, 1997 ground motion workshop. I have additionally defined a floor value for epistemic uncertainty of 0.2, such that if the calculation produces a value of less than 0.2, it is adjusted upward to 0.2.

For the vertical estimates, I included all of the above uncertainties, with some additions. I defined the σ_μ for the finite fault and point source simulations to be 0.3 rather than the 0.2 used for the horizontals, because due to lack of data and modeling efforts for vertical ground motions there is more uncertainty associated with these estimates that could be reduced given additional information. I also assigned additional epistemic uncertainty of 0.2 above the statistical crustal and source corrections to the empirical models. This is meant to incorporate the additional uncertainty of applying the point source z/h ratio and the horizontal crustal transfer function. The deviation from the median part of the epistemic uncertainty was included in the vertical estimate as well, with a total floor of 0.3 for any vertical σ_μ value.

F7-4.3 Epistemic Uncertainty In Aleatory Uncertainty: σ_σ

The epistemic uncertainty associated with the aleatory uncertainty was also calculated via the FORTRAN program WT_AVE. Here the main component is the variability in the σ estimates from model to model. A component was also included to allow inclusion of individual σ_σ estimates for each model, however only the Somerville finite fault model provided a σ_σ estimate, so in order to avoid model bias I did not include a contribution in this term. The vertical σ_σ computations were done in a manner analogous to the horizontal σ_σ.

F7-5 FINAL POINT ESTIMATES OF GROUND MOTION FOR THE 51 CASES

Tables F7-1 to F7-9 contain my horizontal component point estimates for the 51 cases, 9 frequencies. Tables F7-10 to F7-18 contain my vertical component point estimates. For each of the 918 event-frequency-component combinations, the four ground motion parameters (median and three uncertainties) are presented.

F7-6 EVALUATION OF REGRESSION FIT TO POINT ESTIMATES

The facilitation team applied regression models to all four ground motion parameters for each case, frequency, and component and provided plots of the regression results for my approval. In general, the regression fits were very satisfactory representations of my point estimates.

F7-6.1 Median Estimate: μ

Illustrations and tables elsewhere in this report present the results of the regressions on the 918 median ground motion estimates. In general, these regression lines are a good representation of my results. The regression lines for the peak velocity values do not always fit the data as well as the other spectral points; this could reflect greater uncertainty in the peak velocity values themselves due to fewer contributing models and less experience in predicting peak velocities.

With my approval, the effects of the hanging wall and foot wall were included in the normal faulting regressions. The hanging wall effect is a "bump" between 3 and 20 km, which increases with increasing magnitude. The foot wall effect is a more subtle trough in the regression relation at the same distance. There were no foot wall calculations for the magnitude 5.0 events. The hanging wall effect for magnitude 5.8 events is rather small and increases rapidly with size. The effect at magnitude 8.0, however, is unknown because no point estimates were made for normal faulting earthquakes at this large magnitude.

F7-6.2 Aleatory Uncertainty: σ

The facilitation team also provided regressions for the aleatory uncertainty. In all cases, the σ values decrease with increasing magnitude, and are generally tightly clustered for the horizontal estimates, with more scatter evident for the vertical estimates. In all cases the regressions provide a good representation of my σ estimates.

F7-6.3 Epistemic Uncertainty In The Median: σ_μ

The epistemic uncertainty regressions provide the most challenge in the regression process, as the statistical values are generally quite scattered. Each expert was offered the opportunity to specify σ_μ values as functions of magnitude and distance and/or to specify the functional form used in the regression. Generally, the epistemic uncertainty values are higher at small and large distance, and have a minimum around 10-20 km distance. This may reflect the larger body of data available for developing experience in the medium distance range. A magnitude dependence is not well defined therefore I chose a magnitude-independent regression. A quadratic distance dependence is appropriate for these data. In general, the σ_μ value for a given event-frequency-component combination has a fairly large uncertainty associated with it due to the large scatter around the regression curve.

F7-6.4 Epistemic Uncertainty In The Aleatory Uncertainty: σ_σ

The regressions for the uncertainty in the aleatory uncertainty are simple in form and generally have tightly clustered data that adequately define the regression line. The σ_σ values generally increase with magnitude, and, like the σ values themselves, there is considerably more scatter in the vertical σ_σ values than the horizontal values. The effect of distance is very small on this parameter. The regression lines are a good representation of the σ_σ estimates.

F7-7 SPECIAL CASE FAULT RUPTURE SCENARIOS

The experts were asked to provide rule revisions for two special cases of fault rupture: multiple parallel faults and a low-angle normal fault.

F7-7.1 Multiple Parallel Faults

The multiple parallel fault scenario consists of three or more parallel normal faults dipping at 60 degrees that all rupture essentially simultaneously. One example would be three magnitude 6.5 events that would have a combined moment magnitude of about 6.8. Paul Somerville provided a simulation of peak ground acceleration (N. A. Abrahamson and A. M. Becker, Consultants, written communication, 1997b) using his finite fault model for evaluating the effects of the multiple fault rupture. He determined that in all cases the three faults rupturing simultaneously resulted in higher ground motions than one magnitude 6.8 at the closest equivalent distance. Unfortunately, no simulation data is available for evaluating frequencies other than PGA.

As a distance measure for parallel multiple faults, I recommend using the rupture distance modified to be the distance to the closest fault rupture of all the available faults.

For predicting ground motion amplitudes, I recommend summing the ground motions for the multiple events incoherently (square root of the sum of the squares, or SRSS). In coming to this conclusion, I examined the relative ground motions at the relevant frequencies for a multiple fault scenario using the AS97 model. I compared the SRSS for a magnitude 6.5 at 1 km (foot wall), a magnitude 6.5 at 1 km (hanging wall) and a magnitude 6.5 at 5 km (hanging wall) to a single magnitude 6.8 event at 1 km (hanging wall). I also examined coherently adding the ground motions of these three events, which resulted in very high ground motions. The PGA for the single 6.8 event is about 35% lower than the SRSS combined amplitudes. This is quite similar to the Somerville prediction for a similar situation. The difference between the single 6.8 and the SRSS of the three 6.5s decreased with decreasing frequency, however the SRSS value is still significantly higher than that of the single 6.8 down to 0.33 Hz, by about 25-30%. Thus using the SRSS-combined events is consistent with the available modeling, and because the degree of coherency expected among the multiple faults at low frequencies is unknown and certain to vary due to interevent timing differences, the SRSS approach should provide an adequate estimate of expected ground motion amplitudes.

I also recommend increasing the epistemic uncertainty for such a calculation by 0.1 at frequencies at and above 1 Hz, and by 0.2 for frequencies below 1 Hz.

F7-7.2 Low Angle Fault

A low angle normal fault rupture could occur in an area where a detachment fault exists. Unfortunately, while there are very few actual ground motion data for normal faults in general, there are none of which I am aware for low-angle normal faults. While thrust faults have shallower dips than normal faults, they are widely known to produce higher ground motions than strike-slip events, thus it is unlikely that a thrust-fault-based estimate would be appropriate for a low-angle normal fault in an extensional regime.

I recommend using the Yucca Mountain attenuation relations as they stand for a low-angle normal fault. The distance measure can also remain the same. Due to the high level of uncertainty stemming from lack of data, it is appropriate to increase the epistemic uncertainty on the median by 0.25 for all frequencies for the case of a low-angle normal fault.

F7-8 REFERENCES

Abrahamson, N. A., and Silva, W. J., 1997, Empirical response spectral attenuation relations for shallow crustal earthquakes: Seismological Research Letters, v. 68, n. 1, p. 94-127.

Becker, A. M., and Abrahamson, N. A., 1997, Stress drops in normal faulting earthquakes (abstract): Seismological Research Letters, v. 68, n. 2, p. 322.

Boore, D., Joyner, W.B., and Fumal, T.E., 1993, Estimation of response spectra and peak accelerations from western North American earthquakes - An interim report: U. S. Geological Survey Open-File Reptort 93-509, 72pp.

Boore, D.M., Joyner, W.B., and Fumal, T.E., 1994, Estimation of response spectra and peak accelerations from western North Amercan earthquakes - An interim report, part 2: U.S. Geological Survey Open-File Report 94-127, 40 p.

Boore, D.M., Joyner, W.B., and Fumal, T.E., 1997, Equations for estimating horizontal response spectra and peak acceleration from western North American earthquakes - A summary of recent work: Seismogical Research Letters, v. 68, n. 1, p. 128-153.

Campbell, K.W., 1993, Empirical prediction of near-source ground motion from large earthquakes, *in* V.K. Gaur, ed., Proceedings, International Workshop on Earthquake Hazard and Large Dams in the Himalaya: Indian National Trust for Art and Cultural Heritage (INTACH), New Delhi, India, p. 93-103.

Campbell, K.W., 1997, Empirical near-source attenuation relationships for horizontal and vertical components of peak ground acceleration, peak ground velocity, and pseudo-absolute acceleration response spectra: Seismological Research Letters, v. 68, n. 1, p. 154-179.

Campbell, K.W., and Bozorgnia, Y., 1994, Near-source attenuation of peak horizontal acceleration from worldwide accelerograms recorded from 1957 to 1993: 5th U.S. National Conference on Earthquake Engineering, Chicago, IL, July 10-14, 1994.

Joyner, W.B. and Boore, D.M., 1988, Measurement, characterization, and prediction of strong ground motion, *in* Proceedings, Conference on Earthquake Engineering and Soil Dynamics II: GT Div/. ASCE, Park City, UT, 27-30 June 1988, p. 43-102.

Joyner, W.B., and Boore, D.M., 1993, Methods for regression analysis of strong-motion data: Bulletin of the Seismological Society of America, v. 83, p. 469-487.

McGarr, A., 1984, Scaling of ground motion parameters, state of stress, and focal depth: Journal of Geophysical Research, v. 89, p. 6969-6979.

Sabetta, F., and Pugliese, A., 1996, Estimation of response spectra and simulation of nonstationary earthquake ground motions: Bulletin of the Seismological Society of America, v. 86, p. 337-352.

Sadigh, K., Chang, C.-Y., Egan, J. A, Makdisi, F., and Youngs, R. R. ,1997, Attenuation relationships for shallow crustal earthquakes based on California strong motion data: Seismological Research Letters, v. 68, n. 1, p. 180-189.

Spudich, P., Fletcher, J. B., Hellweg, M., Boatwright, J., Sullivan, C., Joyner, W.B., Hanks, T.C., Boore, D.M., McGarr, A., Baker, L. M., and Lindh, A.G., 1997, SEA96 -- a new predictive relation for earthquake ground motions in extensional tectonic regimes: Seismological Research Letters, v. 68, n. 1, p. 190-198.

Zeng, Y., Anderson, J.G., and Yu, G., 1994, A composite source model for computing realistic synthetic strong ground motions: Geophysical Research Letters, v. 21, p. 725 - 728.

TABLE F7-1
M. C. WALCK: HORIZONTAL POINT ESTIMATES
PEAK GROUND ACCELERATION

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.15747	0.69327	0.35738	0.16200
2	5.00	1	0.14893	0.69514	0.35111	0.16200
3	5.00	5	0.05358	0.68368	0.32129	0.16400
4	5.00	5	0.05457	0.68461	0.32675	0.16400
5	5.80	10	0.09241	0.59828	0.25933	0.16400
6	5.80	20	0.06166	0.59607	0.26755	0.16400
7	6.50	1	0.38852	0.57062	0.36402	0.16900
8	6.50	1	0.35251	0.56816	0.41030	0.16900
9	6.50	1	0.33806	0.57273	0.39394	0.16900
10	6.50	5	0.30374	0.56602	0.36025	0.16800
11	6.50	5	0.21798	0.57258	0.32663	0.16900
12	6.50	50	0.02796	0.56754	0.29064	0.16800
13	6.50	50	0.02521	0.56492	0.29747	0.16700
14	7.00	10	0.23732	0.53881	0.29775	0.17400
15	7.50	50	0.05798	0.53528	0.25147	0.18000
16	7.50	50	0.05518	0.53230	0.25711	0.17900
17	5.00	1	0.06367	0.68896	0.29045	0.16500
18	5.80	5	0.13394	0.59970	0.30801	0.16400
19	5.80	5	0.08310	0.60148	0.30195	0.16400
20	5.00	10	0.06425	0.67839	0.27113	0.16300
21	5.00	10	0.07225	0.68274	0.27208	0.16400
22	5.00	50	0.00604	0.69758	0.30799	0.16000
23	5.00	50	0.00591	0.70637	0.32378	0.15900
24	5.00	160	0.00073	0.69766	0.32037	0.16300
25	5.80	1	0.25740	0.59919	0.37730	0.16500
26	5.80	5	0.19424	0.59512	0.33244	0.16400
27	5.80	5	0.12500	0.59805	0.32680	0.16400
28	5.80	10	0.11239	0.60162	0.27836	0.16500
29	5.80	10	0.13403	0.59540	0.28374	0.16400
30	5.80	10	0.07770	0.59884	0.33817	0.16500
31	5.80	50	0.01418	0.61013	0.33151	0.16200
32	5.80	50	0.01352	0.61205	0.38770	0.16200
33	6.50	5	0.28357	0.56900	0.33092	0.16800
34	6.50	10	0.18387	0.57035	0.30849	0.16900
35	6.50	10	0.22646	0.56756	0.34523	0.16800
36	6.50	10	0.13907	0.56837	0.30764	0.16800
37	6.50	20	0.09308	0.56761	0.27556	0.16800
38	6.50	20	0.10799	0.56864	0.30814	0.16800
39	6.50	20	0.06954	0.56632	0.28629	0.16800
40	6.50	100	0.01204	0.57210	0.36945	0.16200
41	6.50	160	0.00530	0.57536	0.46762	0.17000
42	7.00	1	0.44383	0.53927	0.30919	0.17300
43	7.00	10	0.27758	0.54277	0.34186	0.17600
44	7.00	10	0.17595	0.53825	0.29134	0.17400
45	7.00	50	0.04299	0.53911	0.27352	0.17000
46	7.00	50	0.04130	0.54645	0.25922	0.17400
47	7.50	1	0.49124	0.53707	0.35613	0.18800
48	5.00	10	0.27890	0.52712	0.29747	0.18300
49	5.00	10	0.31205	0.52791	0.41191	0.18100
50	8.00	50	0.07557	0.54384	0.27652	0.18200
51	8.00	160	0.01943	0.53130	0.35089	0.17800

TABLE F7-2
M. C. WALCK: HORIZONTAL POINT ESTIMATES SPECTRAL ACCELERATION AT 0.05 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.32745	0.69777	0.41292	0.16100
2	5.00	1	0.30646	0.69872	0.27924	0.16100
3	5.00	5	0.10396	0.69224	0.37626	0.16100
4	5.00	5	0.10347	0.69318	0.30920	0.16100
5	5.80	10	0.15904	0.60472	0.29881	0.16400
6	5.80	20	0.10212	0.59889	0.29471	0.16400
7	6.50	1	0.67480	0.57475	0.35986	0.16900
8	6.50	1	0.61859	0.57152	0.38692	0.16900
9	6.50	1	0.58774	0.57457	0.38506	0.16900
10	6.50	5	0.54050	0.56827	0.37543	0.16800
11	6.50	5	0.38410	0.57301	0.38250	0.16900
12	6.50	50	0.03878	0.57064	0.33608	0.16800
13	6.50	50	0.03524	0.56754	0.36609	0.16800
14	7.00	10	0.38863	0.53927	0.30178	0.17500
15	7.50	50	0.07473	0.53857	0.31567	0.17700
16	7.50	50	0.07176	0.53858	0.32265	0.17700
17	5.00	1	0.12690	0.69842	0.31469	0.16100
18	5.80	5	0.22890	0.60281	0.33491	0.16300
19	5.80	5	0.14020	0.60523	0.33843	0.16400
20	5.00	10	0.12307	0.69364	0.30121	0.16000
21	5.00	10	0.14356	0.69224	0.28780	0.16100
22	5.00	50	0.01023	0.69524	0.40966	0.16200
23	5.00	50	0.01022	0.70547	0.42930	0.16100
24	5.00	160	0.00111	0.69842	0.35969	0.16700
25	5.80	1	0.46464	0.60265	0.41041	0.16400
26	5.80	5	0.35141	0.60075	0.36053	0.16500
27	5.80	5	0.22026	0.60424	0.42546	0.16500
28	5.80	10	0.19522	0.60634	0.32292	0.16500
29	5.80	10	0.23177	0.59910	0.31638	0.16400
30	5.80	10	0.13811	0.60313	0.43254	0.16400
31	5.80	50	0.02068	0.61316	0.38131	0.16300
32	5.80	50	0.02015	0.61135	0.46664	0.16300
33	6.50	5	0.49601	0.56957	0.31995	0.16800
34	6.50	10	0.32009	0.57524	0.30129	0.17000
35	6.50	10	0.39796	0.56974	0.37291	0.16800
36	6.50	10	0.23872	0.57337	0.36340	0.16900
37	6.50	20	0.15103	0.57323	0.28855	0.16900
38	6.50	20	0.17874	0.57152	0.33335	0.16900
39	6.50	20	0.11310	0.57009	0.36390	0.16200
40	6.50	100	0.01441	0.56538	0.42257	0.16200
41	6.50	160	0.00658	0.56838	0.52760	0.16700
42	7.00	1	0.76340	0.54120	0.33536	0.17500
43	7.00	10	0.47397	0.54504	0.39241	0.17800
44	7.00	10	0.29186	0.54010	0.35777	0.17500
45	7.00	50	0.05792	0.53954	0.31750	0.17100
46	7.00	50	0.05688	0.54780	0.31097	0.17500
47	7.50	1	0.82750	0.53667	0.40126	0.18700
48	5.00	10	0.45640	0.54122	0.34733	0.18400
49	5.00	10	0.50871	0.53438	0.47077	0.17800
50	8.00	50	0.09575	0.54949	0.34048	0.18000
51	8.00	160	0.02069	0.52843	0.43869	0.17900

TABLE F7-3
M. C. WALCK: HORIZONTAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 0.10 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.33655	0.71877	0.29022	0.15900
2	5.00	1	0.31895	0.71684	0.32724	0.15800
3	5.00	5	0.11180	0.71040	0.26946	0.16000
4	5.00	5	0.11507	0.70944	0.32592	0.16000
5	5.80	10	0.16513	0.62111	0.30300	0.16700
6	5.80	20	0.11928	0.61750	0.29574	0.16700
7	6.50	1	0.76878	0.59229	0.38578	0.17400
8	6.50	1	0.71468	0.58667	0.44479	0.17300
9	6.50	1	0.68548	0.59338	0.42280	0.17500
10	6.50	5	0.60124	0.58317	0.38448	0.17100
11	6.50	5	0.43719	0.59112	0.32329	0.17400
12	6.50	50	0.05011	0.58826	0.33069	0.17300
13	6.50	50	0.04542	0.58423	0.30204	0.17200
14	7.00	10	0.41550	0.55633	0.31393	0.17900
15	7.50	50	0.09523	0.55001	0.33531	0.18400
16	7.50	50	0.09276	0.54336	0.32893	0.18000
17	5.00	1	0.13085	0.70790	0.23968	0.16000
18	5.80	5	0.24562	0.62428	0.31138	0.16600
19	5.80	5	0.14893	0.62740	0.30640	0.16600
20	5.00	10	0.13666	0.71290	0.25060	0.15900
21	5.00	10	0.15192	0.70654	0.27228	0.15900
22	5.00	50	0.01282	0.72578	0.30656	0.15600
23	5.00	50	0.01252	0.72608	0.32780	0.15600
24	5.00	160	0.00135	0.72545	0.36412	0.15900
25	5.80	1	0.46931	0.62363	0.38041	0.16800
26	5.80	5	0.37000	0.61710	0.29742	0.16700
27	5.80	5	0.24561	0.62312	0.34714	0.16800
28	5.80	10	0.19745	0.62256	0.29084	0.16800
29	5.80	10	0.24013	0.61671	0.24891	0.16700
30	5.80	10	0.13956	0.61803	0.36625	0.16600
31	5.80	50	0.02105	0.64240	0.44083	0.16500
32	5.80	50	0.02420	0.63434	0.37988	0.16500
33	6.50	5	0.56819	0.59033	0.34507	0.17300
34	6.50	10	0.36498	0.58976	0.32182	0.17300
35	6.50	10	0.45543	0.58429	0.39613	0.17200
36	6.50	10	0.27384	0.58913	0.29071	0.17300
37	6.50	20	0.17989	0.58640	0.31475	0.17100
38	6.50	20	0.20550	0.58572	0.31885	0.17200
39	6.50	20	0.13300	0.58773	0.27961	0.16900
40	6.50	100	0.01894	0.58413	0.43051	0.16300
41	6.50	160	0.00783	0.58750	0.49137	0.16800
42	7.00	1	0.82210	0.55754	0.31198	0.18600
43	7.00	10	0.50176	0.55891	0.35060	0.18200
44	7.00	10	0.31152	0.55683	0.27988	0.18000
45	7.00	50	0.06652	0.55849	0.36973	0.17700
46	7.00	50	0.06517	0.56111	0.31139	0.17900
47	7.50	1	0.93462	0.55758	0.38943	0.19400
48	5.00	10	0.52804	0.55146	0.35314	0.18800
49	5.00	10	0.58427	0.54481	0.44174	0.19000
50	8.00	50	0.11668	0.56637	0.37581	0.18800
51	8.00	160	0.02374	0.55357	0.41943	0.18400

TABLE F7-4
M. C. WALCK: HORIZONTAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 0.20 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.25013	0.74571	0.30485	0.15000
2	5.00	1	0.23865	0.74760	0.34933	0.15000
3	5.00	5	0.08854	0.73459	0.26480	0.15100
4	5.00	5	0.09155	0.73365	0.29509	0.15200
5	5.80	10	0.16983	0.65616	0.25248	0.16300
6	5.80	20	0.11554	0.64789	0.29625	0.16100
7	6.50	1	0.70354	0.62146	0.39807	0.17000
8	6.50	1	0.64469	0.62205	0.44509	0.17100
9	6.50	1	0.62409	0.63182	0.43766	0.17500
10	6.50	5	0.55352	0.61791	0.39052	0.17000
11	6.50	5	0.41151	0.62389	0.31071	0.17100
12	6.50	50	0.05527	0.62160	0.34725	0.17000
13	6.50	50	0.05048	0.61559	0.28077	0.16900
14	7.00	10	0.44910	0.58967	0.32624	0.17700
15	7.50	50	0.11225	0.58207	0.35640	0.17800
16	7.50	50	0.10926	0.57658	0.33698	0.17600
17	5.00	1	0.10364	0.73607	0.22682	0.15300
18	5.80	5	0.23346	0.65466	0.32112	0.16100
19	5.80	5	0.15447	0.65819	0.29528	0.16100
20	5.00	10	0.10765	0.73311	0.24164	0.15000
21	5.00	10	0.12641	0.73365	0.27240	0.15200
22	5.00	50	0.01218	0.75535	0.25559	0.14700
23	5.00	50	0.01121	0.75333	0.30631	0.14800
24	5.00	160	0.00158	0.76487	0.32903	0.15100
25	5.80	1	0.43968	0.65283	0.40415	0.16200
26	5.80	5	0.33978	0.64741	0.33800	0.16200
27	5.80	5	0.22173	0.65332	0.29380	0.16200
28	5.80	10	0.19720	0.65519	0.29763	0.16300
29	5.80	10	0.23340	0.64770	0.31001	0.16200
30	5.80	10	0.14015	0.65486	0.26688	0.16200
31	5.80	50	0.02748	0.67622	0.28952	0.15900
32	5.80	50	0.02646	0.66936	0.31769	0.15900
33	6.50	5	0.52459	0.62010	0.35504	0.16900
34	6.50	10	0.33960	0.62373	0.31006	0.17100
35	6.50	10	0.41266	0.61916	0.36050	0.17000
36	6.50	10	0.26587	0.61950	0.28059	0.16900
37	6.50	20	0.17721	0.62207	0.29211	0.17200
38	6.50	20	0.21091	0.61666	0.33768	0.16900
39	6.50	20	0.13709	0.62130	0.25582	0.17000
40	6.50	100	0.02370	0.61930	0.39592	0.16500
41	6.50	160	0.01064	0.62699	0.44743	0.16600
42	7.00	1	0.82620	0.59000	0.35074	0.17700
43	7.00	10	0.52239	0.58988	0.37419	0.17800
44	7.00	10	0.34447	0.58827	0.28105	0.17600
45	7.00	50	0.08668	0.59385	0.37181	0.17500
46	7.00	50	0.08283	0.59424	0.31205	0.17700
47	7.50	1	0.94092	0.58805	0.41872	0.18600
48	5.00	10	0.54929	0.58670	0.37104	0.18500
49	5.00	10	0.58369	0.57502	0.43161	0.17700
50	8.00	50	0.13717	0.59726	0.36255	0.18000
51	8.00	160	0.03448	0.59114	0.38604	0.17700

TABLE F7-5
M. C. WALCK: HORIZONTAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 0.50 SEC PERIOD

CASE No.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.11039	0.80160	0.34495	0.12700
2	5.00	1	0.11046	0.79695	0.38764	0.12700
3	5.00	5	0.04213	0.78831	0.27237	0.13000
4	5.00	5	0.04489	0.78552	0.28880	0.13000
5	5.80	10	0.10526	0.71665	0.25882	0.15500
6	5.80	20	0.07631	0.71435	0.27086	0.15600
7	6.50	1	0.51424	0.68397	0.27234	0.16900
8	6.50	1	0.46582	0.67902	0.30448	0.16900
9	6.50	1	0.44663	0.68836	0.29872	0.17200
10	6.50	5	0.39892	0.68177	0.27747	0.17000
11	6.50	5	0.28652	0.68411	0.26640	0.16900
12	6.50	50	0.04598	0.68780	0.29308	0.17100
13	6.50	50	0.04260	0.67773	0.28831	0.16900
14	7.00	10	0.35757	0.65225	0.30192	0.17900
15	7.50	50	0.11236	0.64437	0.27670	0.17900
16	7.50	50	0.10653	0.63609	0.27229	0.17600
17	5.00	1	0.04925	0.78572	0.23161	0.13200
18	5.80	5	0.15782	0.72325	0.27443	0.15400
19	5.80	5	0.09331	0.72727	0.28783	0.15400
20	5.00	10	0.04873	0.78347	0.23432	0.12700
21	5.00	10	0.05659	0.78275	0.27918	0.13000
22	5.00	50	0.00661	0.80633	0.23097	0.12100
23	5.00	50	0.00677	0.81342	0.22079	0.12100
24	5.00	160	0.00141	0.80973	0.24169	0.12300
25	5.80	1	0.27984	0.71461	0.31148	0.15400
26	5.80	5	0.22026	0.71142	0.31178	0.15600
27	5.80	5	0.13672	0.71060	0.28586	0.15300
28	5.80	10	0.12722	0.71777	0.27544	0.15600
29	5.80	10	0.15738	0.71011	0.29657	0.15300
30	5.80	10	0.08649	0.71536	0.30012	0.15300
31	5.80	50	0.02041	0.74643	0.27397	0.14500
32	5.80	50	0.01931	0.74361	0.32748	0.14600
33	6.50	5	0.37861	0.68293	0.30669	0.16900
34	6.50	10	0.25004	0.69312	0.30991	0.16900
35	6.50	10	0.30967	0.68854	0.32048	0.16900
36	6.50	10	0.18707	0.68285	0.28680	0.16900
37	6.50	20	0.13079	0.68413	0.28848	0.16600
38	6.50	20	0.15485	0.68360	0.29918	0.17100
39	6.50	20	0.10309	0.68327	0.24284	0.16900
40	6.50	100	0.02357	0.68660	0.35592	0.16600
41	6.50	160	0.01203	0.68935	0.50722	0.16300
42	7.00	1	0.65664	0.65013	0.27392	0.17800
43	7.00	10	0.42928	0.64941	0.33614	0.17900
44	7.00	10	0.26343	0.65221	0.26255	0.17900
45	7.00	50	0.07800	0.65740	0.29966	0.17800
46	7.00	50	0.07419	0.66071	0.30133	0.18100
47	7.50	1	0.73800	0.64770	0.29866	0.18800
48	5.00	10	0.44275	0.64566	0.28266	0.18400
49	5.00	10	0.48336	0.63731	0.38897	0.17900
50	8.00	50	0.14844	0.66084	0.27606	0.17700
51	8.00	160	0.05004	0.66096	0.37236	0.17200

TABLE F7-6
M. C. WALCK: HORIZONTAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 1.00 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.04240	0.90227	0.26394	0.12400
2	5.00	1	0.04511	0.89384	0.38188	0.12900
3	5.00	5	0.01702	0.82882	0.21964	0.10700
4	5.00	5	0.01845	0.82882	0.25495	0.10700
5	5.80	10	0.05194	0.77611	0.24690	0.13600
6	5.80	20	0.03915	0.76766	0.26170	0.14000
7	6.50	1	0.29071	0.74524	0.21867	0.16000
8	6.50	1	0.26180	0.74327	0.31514	0.16300
9	6.50	1	0.25574	0.74499	0.28978	0.16400
10	6.50	5	0.22943	0.74246	0.28014	0.16200
11	6.50	5	0.15551	0.74085	0.33034	0.16100
12	6.50	50	0.02961	0.73550	0.29476	0.16000
13	6.50	50	0.02758	0.74207	0.30795	0.16200
14	7.00	10	0.20999	0.70235	0.25464	0.17600
15	7.50	50	0.07920	0.69302	0.27814	0.17800
16	7.50	50	0.07820	0.69742	0.28205	0.18000
17	5.00	1	0.01966	0.83187	0.20000	0.11000
18	5.80	5	0.08207	0.78980	0.41204	0.14400
19	5.80	5	0.04702	0.78768	0.34359	0.14100
20	5.00	10	0.01882	0.82546	0.20000	0.10500
21	5.00	10	0.02314	0.81392	0.22509	0.11300
22	5.00	50	0.00283	0.83808	0.30103	0.09800
23	5.00	50	0.00306	0.84839	0.21956	0.09700
24	5.00	160	0.00087	0.85116	0.20000	0.09700
25	5.80	1	0.13646	0.77959	0.32270	0.13800
26	5.80	5	0.11043	0.76846	0.34796	0.13700
27	5.80	5	0.06594	0.77779	0.36178	0.14000
28	5.80	10	0.06103	0.77758	0.25363	0.13700
29	5.80	10	0.07928	0.76959	0.28937	0.13200
30	5.80	10	0.04523	0.76876	0.31707	0.14300
31	5.80	50	0.01093	0.78853	0.25215	0.12900
32	5.80	50	0.01124	0.79169	0.23834	0.13200
33	6.50	5	0.20133	0.74794	0.26541	0.16100
34	6.50	10	0.14162	0.74507	0.29900	0.16000
35	6.50	10	0.18376	0.74018	0.31947	0.16100
36	6.50	10	0.10475	0.74050	0.30865	0.16000
37	6.50	20	0.07433	0.74096	0.26036	0.15900
38	6.50	20	0.08610	0.74314	0.32253	0.16300
39	6.50	20	0.05877	0.74179	0.29597	0.16700
40	6.50	100	0.01558	0.73628	0.31868	0.16000
41	6.50	160	0.00966	0.73900	0.54121	0.14500
42	7.00	1	0.36082	0.70909	0.28703	0.17500
43	7.00	10	0.25392	0.70719	0.33867	0.17700
44	7.00	10	0.15837	0.70422	0.30564	0.17500
45	7.00	50	0.05020	0.71254	0.33456	0.17600
46	7.00	50	0.05052	0.71948	0.31899	0.17900
47	7.50	1	0.44211	0.69949	0.36243	0.18000
48	5.00	10	0.28308	0.69870	0.28780	0.18000
49	5.00	10	0.31676	0.69201	0.43455	0.17700
50	8.00	50	0.11233	0.69906	0.28918	0.18100
51	8.00	160	0.04627	0.71335	0.40257	0.17700

TABLE F7-7
M. C. WALCK: HORIZONTAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 2.00 SEC PERIOD

CASE No.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.01223	0.90638	0.34180	0.10000
2	5.00	1	0.01321	0.89520	0.36787	0.10800
3	5.00	5	0.00528	0.88594	0.29770	0.10900
4	5.00	5	0.00570	0.89246	0.26458	0.10800
5	5.80	10	0.02067	0.85748	0.35377	0.13500
6	5.80	20	0.01499	0.85396	0.36901	0.14300
7	6.50	1	0.13034	0.82080	0.25445	0.16100
8	6.50	1	0.11916	0.80747	0.25991	0.16400
9	6.50	1	0.11032	0.81599	0.27063	0.16700
10	6.50	5	0.09622	0.81345	0.29630	0.16900
11	6.50	5	0.07555	0.81716	0.31728	0.16700
12	6.50	50	0.01519	0.82594	0.35863	0.16000
13	6.50	50	0.01340	0.82717	0.47154	0.16400
14	7.00	10	0.10179	0.78901	0.29082	0.18900
15	7.50	50	0.04994	0.76822	0.38285	0.19700
16	7.50	50	0.04513	0.75873	0.48182	0.19400
17	5.00	1	0.00641	0.88717	0.22050	0.11100
18	5.80	5	0.03367	0.84574	0.37031	0.13800
19	5.80	5	0.02093	0.85015	0.36627	0.13800
20	5.00	10	0.00617	0.88416	0.20623	0.10700
21	5.00	10	0.00719	0.87819	0.24130	0.11900
22	5.00	50	0.00104	0.90441	0.27672	0.08900
23	5.00	50	0.00104	0.91271	0.31086	0.08900
24	5.00	160	0.00046	0.91556	0.20328	0.08900
25	5.80	1	0.05259	0.85720	0.26004	0.13900
26	5.80	5	0.04239	0.83249	0.31911	0.13900
27	5.80	5	0.02943	0.83930	0.33057	0.14700
28	5.80	10	0.02336	0.85634	0.31988	0.14100
29	5.80	10	0.02839	0.84907	0.34359	0.14900
30	5.80	10	0.02035	0.84789	0.33901	0.13900
31	5.80	50	0.00455	0.86675	0.51464	0.12300
32	5.80	50	0.00495	0.87496	0.41651	0.12900
33	6.50	5	0.09457	0.82003	0.25276	0.16000
34	6.50	10	0.06361	0.82054	0.26612	0.16100
35	6.50	10	0.07657	0.81449	0.29887	0.17000
36	6.50	10	0.04914	0.82363	0.36406	0.16500
37	6.50	20	0.03670	0.82377	0.28893	0.16300
38	6.50	20	0.04119	0.81470	0.33250	0.16200
39	6.50	20	0.02837	0.82255	0.40192	0.16800
40	6.50	100	0.00822	0.81432	0.40052	0.15200
41	6.50	160	0.00593	0.82032	0.63580	0.14600
42	7.00	1	0.18443	0.78293	0.26410	0.18400
43	7.00	10	0.11318	0.77324	0.34169	0.18700
44	7.00	10	0.07903	0.78909	0.36750	0.19100
45	7.00	50	0.02956	0.80019	0.31635	0.18800
46	7.00	50	0.02724	0.79772	0.40272	0.19000
47	7.50	1	0.22501	0.76600	0.34122	0.19800
48	5.00	10	0.14676	0.76436	0.40618	0.19400
49	5.00	10	0.15075	0.76181	0.46627	0.19400
50	8.00	50	0.07127	0.76747	0.32439	0.21300
51	8.00	160	0.03580	0.78183	0.47097	0.20500

TABLE F7-8
M. C. WALCK: HORIZONTAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 3.33 SEC PERIOD

Case No.	Magnitude	Distance (km)	Mu	Sigma	Sigma Mu	Sigma Sigma
1	5.00	1	0.00464	0.93238	0.50526	0.10800
2	5.00	1	0.00501	0.90893	0.52239	0.11400
3	5.00	5	0.00205	0.92002	0.50603	0.11600
4	5.00	5	0.00224	0.92535	0.47386	0.11500
5	5.80	10	0.00966	0.85902	0.38489	0.13600
6	5.80	20	0.00619	0.85366	0.42506	0.14400
7	6.50	1	0.06970	0.82151	0.32286	0.18300
8	6.50	1	0.06360	0.79051	0.30294	0.16200
9	6.50	1	0.05945	0.80278	0.33343	0.17100
10	6.50	5	0.05077	0.79863	0.31533	0.17100
11	6.50	5	0.04285	0.80882	0.38311	0.17800
12	6.50	50	0.00829	0.83501	0.45752	0.17800
13	6.50	50	0.00639	0.81328	0.53040	0.17400
14	7.00	10	0.05767	0.79810	0.37422	0.20900
15	7.50	50	0.03143	0.78632	0.38707	0.22200
16	7.50	50	0.02608	0.78038	0.52036	0.22200
17	5.00	1	0.00270	0.89832	0.40974	0.11500
18	5.80	5	0.01369	0.86042	0.33063	0.15200
19	5.80	5	0.00861	0.86169	0.40556	0.14700
20	5.00	10	0.00256	0.91218	0.36592	0.11200
21	5.00	10	0.00282	0.90356	0.44487	0.12900
22	5.00	50	0.00048	0.93104	0.28253	0.08800
23	5.00	50	0.00044	0.93795	0.34788	0.09200
24	5.00	160	0.00017	0.94864	0.23141	0.08300
25	5.80	1	0.02510	0.85231	0.37156	0.13700
26	5.80	5	0.01938	0.84373	0.35537	0.15700
27	5.80	5	0.01446	0.84342	0.36839	0.14200
28	5.80	10	0.01138	0.85178	0.41367	0.13600
29	5.80	10	0.01132	0.83432	0.43811	0.13900
30	5.80	10	0.00935	0.84617	0.47177	0.14100
31	5.80	50	0.00222	0.88998	0.40918	0.12600
32	5.80	50	0.00217	0.87671	0.47531	0.12700
33	6.50	5	0.05288	0.82075	0.32841	0.18000
34	6.50	10	0.03385	0.81739	0.37672	0.17500
35	6.50	10	0.03492	0.79906	0.35211	0.17200
36	6.50	10	0.02619	0.81421	0.49206	0.17600
37	6.50	20	0.01845	0.81122	0.42856	0.16800
38	6.50	20	0.01848	0.82092	0.47534	0.18400
39	6.50	20	0.01482	0.80742	0.54931	0.16900
40	6.50	100	0.00381	0.82571	0.49493	0.15900
41	6.50	160	0.00321	0.86096	0.62653	0.16500
42	7.00	1	0.10849	0.78395	0.34419	0.19700
43	7.00	10	0.05689	0.76936	0.34807	0.19600
44	7.00	10	0.04346	0.78952	0.48616	0.20300
45	7.00	50	0.01778	0.79403	0.38366	0.20700
46	7.00	50	0.01515	0.79208	0.49211	0.21100
47	7.50	1	0.14280	0.78764	0.37969	0.21900
48	5.00	10	0.08623	0.79609	0.49034	0.22200
49	5.00	10	0.07976	0.79161	0.50733	0.21900
50	8.00	50	0.04748	0.79218	0.35157	0.24000
51	8.00	160	0.02279	0.82752	0.40694	0.22100

TABLE F7-9
M. C. WALCK: HORIZONTAL POINT ESTIMATES
PEAK GROUND VELOCITY

Case No.	Magnitude	Distance (km)	Mu	Sigma	Sigma Mu	Sigma Sigma
1	5.00	1	6.41921	0.69059	0.46971	0.14800
2	5.00	1	7.17257	0.67002	0.42351	0.14200
3	5.00	5	2.72278	0.67002	0.34900	0.14200
4	5.00	5	3.22851	0.66818	0.42848	0.14000
5	5.80	10	6.37310	0.71422	0.27348	0.16100
6	5.80	20	4.74515	0.71000	0.32044	0.16100
7	6.50	1	34.15452	0.71099	0.22892	0.17600
8	6.50	1	31.37688	0.70490	0.29075	0.17500
9	6.50	1	29.34413	0.70861	0.29551	0.17600
10	6.50	5	29.49820	0.70438	0.25267	0.17500
11	6.50	5	19.29887	0.70540	0.27023	0.17500
12	6.50	50	2.52660	0.70551	0.30546	0.17300
13	6.50	50	2.29040	0.70223	0.33963	0.17400
14	7.00	10	26.38220	0.70314	0.28532	0.18300
15	7.50	50	7.79752	0.70844	0.33204	0.19300
16	7.50	50	7.81732	0.70389	0.38956	0.19200
17	5.00	1	3.37499	0.64944	0.36703	0.13300
18	5.80	5	10.67598	0.71629	0.37579	0.16200
19	5.80	5	5.97682	0.71689	0.33199	0.16200
20	5.00	10	2.65139	0.68508	0.20743	0.14300
21	5.00	10	3.39941	0.66818	0.20000	0.14000
22	5.00	50	0.33848	0.68465	0.33390	0.15200
23	5.00	50	0.35234	0.68694	0.36638	0.15300
24	5.00	160	0.07464	0.71030	0.44988	0.14600
25	5.80	1	16.54418	0.71572	0.33990	0.16800
26	5.80	5	14.28111	0.70869	0.30680	0.16000
27	5.80	5	8.32652	0.71214	0.27402	0.16100
28	5.80	10	7.22272	0.71721	0.25563	0.16200
29	5.80	10	9.66396	0.71004	0.21227	0.16100
30	5.80	10	5.15102	0.70542	0.30981	0.16400
31	5.80	50	0.97198	0.76116	0.22495	0.15400
32	5.80	50	0.96185	0.76103	0.29571	0.15700
33	6.50	5	24.71942	0.71020	0.20000	0.17500
34	6.50	10	16.56292	0.70913	0.23266	0.18100
35	6.50	10	22.35008	0.70473	0.25199	0.17500
36	6.50	10	12.19726	0.70487	0.30020	0.17400
37	6.50	20	8.44397	0.70803	0.31167	0.17400
38	6.50	20	10.15552	0.70531	0.31577	0.17500
39	6.50	20	6.44230	0.70312	0.36365	0.17400
40	6.50	100	1.17220	0.70684	0.34623	0.17300
41	6.50	160	0.53879	0.76270	0.55741	0.15700
42	7.00	1	48.69814	0.70194	0.31744	0.18200
43	7.00	10	36.54720	0.69952	0.42746	0.18300
44	7.00	10	19.71888	0.69893	0.39890	0.18200
45	7.00	50	4.65942	0.69683	0.30272	0.18000
46	7.00	50	4.57622	0.69608	0.36163	0.18100
47	7.50	1	63.97175	0.71327	0.56319	0.19600
48	5.00	10	34.96797	0.71049	0.37695	0.19400
49	5.00	10	39.83652	0.71226	0.71809	0.18700
50	8.00	50	13.10689	0.71306	0.32048	0.19300
51	8.00	160	3.43297	0.81055	0.43466	0.13300

TABLE F7-10
M. C. WALCK: VERTICAL POINT ESTIMATES
PEAK GROUND ACCELERATION

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.11369	0.69558	0.53612	0.16269
2	5.00	1	0.10072	0.69861	0.40954	0.16195
3	5.00	5	0.03309	0.68234	0.42608	0.16493
4	5.00	5	0.03093	0.68631	0.37652	0.16399
5	5.80	10	0.05344	0.63373	0.38506	0.17229
6	5.80	20	0.03846	0.62149	0.45259	0.16608
7	6.50	1	0.29473	0.58699	0.35841	0.17957
8	6.50	1	0.28070	0.59398	0.33916	0.18452
9	6.50	1	0.27565	0.58956	0.34846	0.18100
10	6.50	5	0.23629	0.58800	0.35774	0.17989
11	6.50	5	0.17714	0.58956	0.34939	0.18100
12	6.50	50	0.01308	0.59100	0.44465	0.18161
13	6.50	50	0.01304	0.58519	0.41643	0.17825
14	7.00	10	0.15579	0.56803	0.33335	0.19961
15	7.50	50	0.02728	0.56205	0.41914	0.20807
16	7.50	50	0.02610	0.55440	0.34875	0.20224
17	5.00	1	0.03642	0.67848	0.45772	0.16576
18	5.80	5	0.07518	0.63065	0.45167	0.16811
19	5.80	5	0.05282	0.63597	0.44772	0.17111
20	5.00	10	0.03811	0.68934	0.39280	0.16461
21	5.00	10	0.05303	0.67942	0.37081	0.16479
22	5.00	50	0.00292	0.71091	0.35426	0.15724
23	5.00	50	0.00271	0.70601	0.33233	0.15803
24	5.00	160	0.00029	0.71185	0.38931	0.15715
25	5.80	1	0.17897	0.64061	0.49009	0.16742
26	5.80	5	0.15631	0.63065	0.40182	0.16811
27	5.80	5	0.09711	0.63350	0.38638	0.16964
28	5.80	10	0.07000	0.63673	0.38964	0.17159
29	5.80	10	0.10067	0.62598	0.39387	0.17385
30	5.80	10	0.05514	0.63426	0.37744	0.17008
31	5.80	50	0.00677	0.66025	0.34001	0.16372
32	5.80	50	0.00718	0.66480	0.38273	0.16559
33	6.50	5	0.21483	0.58743	0.32670	0.17950
34	6.50	10	0.12825	0.59070	0.32432	0.18186
35	6.50	10	0.17978	0.59255	0.41881	0.18333
36	6.50	10	0.10448	0.58843	0.33840	0.18019
37	6.50	20	0.05851	0.58956	0.34824	0.18100
38	6.50	20	0.07648	0.58908	0.44404	0.18130
39	6.50	20	0.04509	0.58743	0.36445	0.17950
40	6.50	100	0.00470	0.60003	0.51108	0.17858
41	6.50	160	0.00159	0.59461	0.51825	0.17519
42	7.00	1	0.31765	0.57089	0.33933	0.20213
43	7.00	10	0.20531	0.57132	0.41746	0.20252
44	7.00	10	0.12475	0.56960	0.34178	0.20097
45	7.00	50	0.01876	0.56932	0.38307	0.20072
46	7.00	50	0.01992	0.56753	0.46811	0.19930
47	7.50	1	0.41683	0.56908	0.49259	0.21532
48	5.00	10	0.18278	0.56205	0.34225	0.20807
49	5.00	10	0.23210	0.56535	0.44386	0.21133
50	8.00	50	0.03980	0.56913	0.44882	0.21311
51	8.00	160	0.00768	0.57462	0.52849	0.21196

TABLE F7-11
M. C. WALCK: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 0.05 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.26123	0.70187	0.58070	0.16050
2	5.00	1	0.22206	0.69952	0.45254	0.16004
3	5.00	5	0.06932	0.69299	0.49648	0.16103
4	5.00	5	0.06365	0.69575	0.43193	0.16052
5	5.80	10	0.10045	0.64158	0.46330	0.16851
6	5.80	20	0.06939	0.63017	0.43620	0.16401
7	6.50	1	0.58764	0.59623	0.44450	0.17630
8	6.50	1	0.54414	0.60327	0.41898	0.18064
9	6.50	1	0.54237	0.60024	0.41497	0.17817
10	6.50	5	0.46094	0.60024	0.40963	0.17817
11	6.50	5	0.33347	0.59909	0.43621	0.17730
12	6.50	50	0.01966	0.60579	0.46599	0.18109
13	6.50	50	0.01999	0.59623	0.44919	0.17630
14	7.00	10	0.28363	0.57958	0.38466	0.19667
15	7.50	50	0.04045	0.57321	0.41686	0.20393
16	7.50	50	0.04023	0.56036	0.39218	0.19403
17	5.00	1	0.07736	0.69004	0.51735	0.16289
18	5.80	5	0.14307	0.64724	0.53519	0.16869
19	5.80	5	0.10098	0.65166	0.47942	0.17164
20	5.00	10	0.07836	0.70283	0.47674	0.16167
21	5.00	10	0.11311	0.69347	0.34895	0.16101
22	5.00	50	0.00541	0.70938	0.36916	0.15902
23	5.00	50	0.00531	0.71376	0.36499	0.15861
24	5.00	160	0.00037	0.71109	0.50776	0.15880
25	5.80	1	0.36625	0.65418	0.61403	0.17107
26	5.80	5	0.29600	0.64628	0.47649	0.16810
27	5.80	5	0.18958	0.64628	0.47061	0.16810
28	5.80	10	0.13519	0.65262	0.47398	0.17233
29	5.80	10	0.19882	0.63719	0.46799	0.17151
30	5.80	10	0.10210	0.64474	0.48033	0.16721
31	5.80	50	0.01126	0.66486	0.37545	0.16697
32	5.80	50	0.01228	0.67379	0.40207	0.17146
33	6.50	5	0.41413	0.60082	0.38354	0.17862
34	6.50	10	0.23822	0.60529	0.37354	0.18244
35	6.50	10	0.33179	0.60269	0.44762	0.18015
36	6.50	10	0.19440	0.60197	0.39894	0.17955
37	6.50	20	0.10381	0.60197	0.37245	0.17955
38	6.50	20	0.13728	0.59883	0.45039	0.17866
39	6.50	20	0.07944	0.59967	0.40135	0.17773
40	6.50	100	0.00596	0.59813	0.57919	0.18078
41	6.50	160	0.00191	0.59482	0.61728	0.17816
42	7.00	1	0.62677	0.58348	0.38877	0.20036
43	7.00	10	0.37784	0.58492	0.43654	0.20182
44	7.00	10	0.22890	0.58160	0.37566	0.19854
45	7.00	50	0.02725	0.58073	0.40219	0.19772
46	7.00	50	0.03087	0.57669	0.47324	0.19462
47	7.50	1	0.81120	0.58247	0.46988	0.21405
48	5.00	10	0.33461	0.57292	0.38328	0.20365
49	5.00	10	0.42845	0.57697	0.45942	0.20781
50	8.00	50	0.05783	0.58663	0.43421	0.21341
51	8.00	160	0.00801	0.57451	0.61532	0.21599

TABLE F7-12
M. C. WALCK: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 0.10 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.22257	0.71774	0.45873	0.16014
2	5.00	1	0.20359	0.72606	0.34144	0.16161
3	5.00	5	0.06819	0.70912	0.35947	0.16227
4	5.00	5	0.06621	0.72128	0.31819	0.16531
5	5.80	10	0.10969	0.65167	0.33890	0.17800
6	5.80	20	0.07294	0.62565	0.44565	0.16730
7	6.50	1	0.59360	0.59764	0.39359	0.17725
8	6.50	1	0.55396	0.60904	0.38729	0.18458
9	6.50	1	0.55181	0.60904	0.41502	0.18458
10	6.50	5	0.44102	0.60671	0.40894	0.18216
11	6.50	5	0.34787	0.60788	0.37240	0.18336
12	6.50	50	0.02516	0.61579	0.50244	0.18651
13	6.50	50	0.02471	0.59802	0.45734	0.17768
14	7.00	10	0.29918	0.58552	0.36855	0.20086
15	7.50	50	0.05142	0.57999	0.46136	0.21044
16	7.50	50	0.05044	0.55033	0.41485	0.18425
17	5.00	1	0.07590	0.70214	0.39009	0.16340
18	5.80	5	0.15377	0.65987	0.38453	0.17652
19	5.80	5	0.10943	0.65987	0.42844	0.17652
20	5.00	10	0.07982	0.72012	0.33161	0.16468
21	5.00	10	0.10474	0.70583	0.39178	0.16092
22	5.00	50	0.00664	0.74176	0.33983	0.15899
23	5.00	50	0.00628	0.73478	0.32934	0.15700
24	5.00	160	0.00053	0.73769	0.49384	0.15768
25	5.80	1	0.35946	0.66184	0.40616	0.17357
26	5.80	5	0.29806	0.65987	0.40200	0.17652
27	5.80	5	0.18920	0.65676	0.36647	0.17397
28	5.80	10	0.13979	0.66317	0.36152	0.17942
29	5.80	10	0.19493	0.64487	0.45157	0.17584
30	5.80	10	0.10868	0.65754	0.37187	0.17459
31	5.80	50	0.01416	0.70133	0.35690	0.17885
32	5.80	50	0.01447	0.69987	0.37130	0.17780
33	6.50	5	0.41821	0.60788	0.34647	0.18336
34	6.50	10	0.25621	0.60846	0.35544	0.18396
35	6.50	10	0.33891	0.60846	0.49280	0.18396
36	6.50	10	0.20996	0.60730	0.36038	0.18276
37	6.50	20	0.11406	0.60730	0.37715	0.18276
38	6.50	20	0.14591	0.60045	0.50022	0.18049
39	6.50	20	0.09063	0.60570	0.36312	0.18115
40	6.50	100	0.00829	0.60479	0.57721	0.17993
41	6.50	160	0.00269	0.60669	0.59005	0.18176
42	7.00	1	0.63139	0.58786	0.37876	0.20362
43	7.00	10	0.38649	0.59151	0.47925	0.20817
44	7.00	10	0.24426	0.58552	0.36133	0.20086
45	7.00	50	0.03583	0.58450	0.44241	0.19969
46	7.00	50	0.03792	0.57709	0.47672	0.19451
47	7.50	1	0.81662	0.58438	0.56737	0.21612
48	5.00	10	0.35482	0.57897	0.39824	0.20916
49	5.00	10	0.44539	0.58204	0.50211	0.21304
50	8.00	50	0.07230	0.60438	0.48122	0.22485
51	8.00	160	0.01006	0.59918	0.57261	0.22875

TABLE F7-13
M. C. WALCK: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 0.20 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.11915	0.74433	0.46099	0.15222
2	5.00	1	0.11711	0.75668	0.35199	0.15036
3	5.00	5	0.04525	0.73523	0.31430	0.15387
4	5.00	5	0.04276	0.73607	0.31617	0.15257
5	5.80	10	0.08215	0.66781	0.31789	0.17158
6	5.80	20	0.05601	0.64832	0.48157	0.16777
7	6.50	1	0.43463	0.62042	0.35342	0.17432
8	6.50	1	0.38876	0.63068	0.36436	0.17789
9	6.50	1	0.38907	0.63011	0.39949	0.17733
10	6.50	5	0.34692	0.62883	0.43720	0.17609
11	6.50	5	0.26044	0.62769	0.39517	0.17503
12	6.50	50	0.02324	0.63441	0.54840	0.17535
13	6.50	50	0.02210	0.61833	0.51736	0.17207
14	7.00	10	0.25064	0.60924	0.41303	0.19042
15	7.50	50	0.05149	0.60135	0.53266	0.19615
16	7.50	50	0.04785	0.57198	0.42092	0.17459
17	5.00	1	0.04978	0.72934	0.34039	0.15551
18	5.80	5	0.11164	0.67566	0.39388	0.16775
19	5.80	5	0.08028	0.67889	0.47775	0.16994
20	5.00	10	0.04987	0.74005	0.33575	0.15345
21	5.00	10	0.06689	0.74659	0.48302	0.15230
22	5.00	50	0.00540	0.76547	0.45873	0.14813
23	5.00	50	0.00483	0.75416	0.34783	0.14895
24	5.00	160	0.00058	0.76150	0.44249	0.14803
25	5.80	1	0.25883	0.68229	0.35921	0.16723
26	5.80	5	0.21636	0.68819	0.44543	0.17131
27	5.80	5	0.14038	0.67889	0.35944	0.16994
28	5.80	10	0.10689	0.68612	0.31807	0.17562
29	5.80	10	0.13886	0.67016	0.47128	0.17194
30	5.80	10	0.08159	0.67642	0.37356	0.16825
31	5.80	50	0.01247	0.72315	0.38009	0.16311
32	5.80	50	0.01377	0.72315	0.49615	0.16311
33	6.50	5	0.31946	0.62769	0.36472	0.17503
34	6.50	10	0.19532	0.62514	0.36132	0.17279
35	6.50	10	0.26109	0.63011	0.52854	0.17733
36	6.50	10	0.16446	0.62769	0.38885	0.17503
37	6.50	20	0.09588	0.62883	0.44118	0.17609
38	6.50	20	0.11907	0.62223	0.57674	0.17642
39	6.50	20	0.07675	0.62826	0.44514	0.17556
40	6.50	100	0.00908	0.62450	0.56489	0.17302
41	6.50	160	0.00354	0.63396	0.55902	0.17563
42	7.00	1	0.48332	0.60924	0.39263	0.19042
43	7.00	10	0.31922	0.61411	0.55553	0.19605
44	7.00	10	0.20255	0.61010	0.42556	0.19138
45	7.00	50	0.03515	0.60767	0.50128	0.18872
46	7.00	50	0.03689	0.59903	0.55346	0.18347
47	7.50	1	0.59964	0.59538	0.56119	0.19448
48	5.00	10	0.30787	0.60421	0.45452	0.19951
49	5.00	10	0.36676	0.60565	0.55797	0.20126
50	8.00	50	0.07284	0.63330	0.54117	0.21369
51	8.00	160	0.01423	0.62612	0.55591	0.20965

TABLE F7-14
M. C. WALCK: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 0.50 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.05254	0.79817	0.49726	0.13044
2	5.00	1	0.05047	0.79709	0.39457	0.12836
3	5.00	5	0.01809	0.78444	0.40182	0.13411
4	5.00	5	0.01817	0.78201	0.32900	0.13091
5	5.80	10	0.04862	0.70898	0.32493	0.16448
6	5.80	20	0.03522	0.68355	0.49364	0.16595
7	6.50	1	0.26046	0.66311	0.31076	0.17141
8	6.50	1	0.25599	0.67514	0.32902	0.17372
9	6.50	1	0.25030	0.67570	0.34003	0.17426
10	6.50	5	0.21875	0.67234	0.37300	0.17117
11	6.50	5	0.17562	0.67402	0.34578	0.17267
12	6.50	50	0.01727	0.67899	0.40296	0.16882
13	6.50	50	0.02007	0.65947	0.47511	0.16778
14	7.00	10	0.18989	0.65343	0.42984	0.18477
15	7.50	50	0.04685	0.63512	0.49617	0.18548
16	7.50	50	0.04191	0.60962	0.35319	0.16940
17	5.00	1	0.02069	0.78229	0.39086	0.13604
18	5.80	5	0.06261	0.72751	0.37420	0.16513
19	5.80	5	0.04214	0.72060	0.37315	0.16033
20	5.00	10	0.02157	0.78034	0.33218	0.13074
21	5.00	10	0.02888	0.78008	0.44162	0.13339
22	5.00	50	0.00251	0.82298	0.34002	0.12094
23	5.00	50	0.00254	0.81573	0.34006	0.12160
24	5.00	160	0.00039	0.81926	0.44692	0.12106
25	5.80	1	0.12397	0.73377	0.46365	0.16056
26	5.80	5	0.11968	0.73483	0.43466	0.17129
27	5.80	5	0.08098	0.72265	0.34352	0.16165
28	5.80	10	0.06269	0.72920	0.32493	0.16646
29	5.80	10	0.07990	0.71914	0.44963	0.16347
30	5.80	10	0.04784	0.73182	0.34934	0.16863
31	5.80	50	0.00820	0.77517	0.35071	0.14141
32	5.80	50	0.00935	0.78105	0.49730	0.14395
33	6.50	5	0.21049	0.67822	0.34638	0.17679
34	6.50	10	0.13791	0.69044	0.40088	0.17810
35	6.50	10	0.16898	0.67096	0.47860	0.16861
36	6.50	10	0.11383	0.66152	0.38903	0.16974
37	6.50	20	0.06886	0.66311	0.43389	0.17141
38	6.50	20	0.08859	0.65348	0.53994	0.16899
39	6.50	20	0.05327	0.67402	0.37758	0.17267
40	6.50	100	0.00857	0.67613	0.51114	0.16707
41	6.50	160	0.00381	0.68825	0.52168	0.16865
42	7.00	1	0.33895	0.65991	0.35161	0.19225
43	7.00	10	0.23344	0.64425	0.51943	0.18264
44	7.00	10	0.14661	0.64228	0.38422	0.18017
45	7.00	50	0.02874	0.64144	0.40444	0.17916
46	7.00	50	0.03161	0.64172	0.51339	0.17949
47	7.50	1	0.40965	0.65294	0.43353	0.19822
48	5.00	10	0.23162	0.64716	0.40666	0.19133
49	5.00	10	0.26688	0.63587	0.45521	0.18643
50	8.00	50	0.06587	0.65451	0.52987	0.19284
51	8.00	160	0.01910	0.69134	0.52989	0.19626

TABLE F7-15
M. C. WALCK: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 1.00 SEC PERIOD

CASE No.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.02251	0.82804	0.46249	0.11372
2	5.00	1	0.02162	0.83488	0.36788	0.10950
3	5.00	5	0.00788	0.81083	0.40687	0.11886
4	5.00	5	0.00790	0.80683	0.32138	0.11478
5	5.80	10	0.02338	0.74780	0.38817	0.14346
6	5.80	20	0.01840	0.73324	0.40292	0.14699
7	6.50	1	0.13153	0.71625	0.41345	0.15660
8	6.50	1	0.14071	0.72165	0.32905	0.16053
9	6.50	1	0.13355	0.73078	0.35747	0.16117
10	6.50	5	0.12701	0.73171	0.39018	0.16190
11	6.50	5	0.09859	0.71721	0.31007	0.15688
12	6.50	50	0.01109	0.72501	0.45279	0.16362
13	6.50	50	0.01210	0.69576	0.42580	0.15553
14	7.00	10	0.10564	0.70855	0.32721	0.18648
15	7.50	50	0.03093	0.68810	0.37006	0.18806
16	7.50	50	0.02795	0.67171	0.36903	0.18290
17	5.00	1	0.00800	0.80548	0.53900	0.11542
18	5.80	5	0.03312	0.75813	0.43764	0.14630
19	5.80	5	0.02428	0.76054	0.42325	0.14803
20	5.00	10	0.00845	0.80315	0.45959	0.11574
21	5.00	10	0.01200	0.80507	0.32359	0.11546
22	5.00	50	0.00108	0.85685	0.33059	0.09833
23	5.00	50	0.00128	0.84866	0.30000	0.09884
24	5.00	160	0.00021	0.85072	0.52215	0.09788
25	5.80	1	0.06203	0.78386	0.51717	0.14895
26	5.80	5	0.05985	0.77411	0.46828	0.14523
27	5.80	5	0.04261	0.75590	0.33461	0.14483
28	5.80	10	0.03090	0.76114	0.34215	0.14477
29	5.80	10	0.04244	0.75289	0.38668	0.14543
30	5.80	10	0.02904	0.76129	0.35133	0.14859
31	5.80	50	0.00455	0.82066	0.30000	0.12692
32	5.80	50	0.00573	0.80867	0.44832	0.12181
33	6.50	5	0.11199	0.72668	0.33152	0.16498
34	6.50	10	0.07813	0.71656	0.32849	0.16174
35	6.50	10	0.09479	0.70703	0.35995	0.15821
36	6.50	10	0.07016	0.69993	0.32895	0.15772
37	6.50	20	0.03809	0.72668	0.36417	0.16498
38	6.50	20	0.05025	0.69901	0.40078	0.15694
39	6.50	20	0.03421	0.69836	0.34980	0.15642
40	6.50	100	0.00557	0.73882	0.42781	0.15057
41	6.50	160	0.00259	0.74653	0.59736	0.15446
42	7.00	1	0.19294	0.70481	0.38614	0.18404
43	7.00	10	0.13571	0.68314	0.40176	0.17496
44	7.00	10	0.09317	0.68314	0.33263	0.17496
45	7.00	50	0.01894	0.69873	0.38136	0.17908
46	7.00	50	0.02135	0.69583	0.48485	0.17897
47	7.50	1	0.24159	0.72152	0.38300	0.21899
48	5.00	10	0.13607	0.68880	0.33792	0.18873
49	5.00	10	0.16174	0.67551	0.42032	0.18432
50	8.00	50	0.04540	0.69122	0.32018	0.19859
51	8.00	160	0.01538	0.70538	0.47162	0.18755

TABLE F7-16
M. C. WALCK: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 2.00 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.00678	0.88549	0.46852	0.11450
2	5.00	1	0.00705	0.87631	0.42081	0.11343
3	5.00	5	0.00237	0.86803	0.47049	0.12583
4	5.00	5	0.00250	0.85719	0.36052	0.12271
5	5.80	10	0.00886	0.79801	0.46183	0.14454
6	5.80	20	0.00727	0.81344	0.33804	0.15070
7	6.50	1	0.07251	0.76337	0.33918	0.15573
8	6.50	1	0.07745	0.76214	0.36434	0.16170
9	6.50	1	0.06760	0.76037	0.30883	0.15981
10	6.50	5	0.06404	0.74678	0.44093	0.15909
11	6.50	5	0.04945	0.76037	0.33229	0.15981
12	6.50	50	0.00535	0.77626	0.38745	0.16491
13	6.50	50	0.00621	0.74366	0.65569	0.16232
14	7.00	10	0.04862	0.75534	0.41696	0.18841
15	7.50	50	0.01718	0.75305	0.66741	0.21330
16	7.50	50	0.01527	0.72573	0.46999	0.21606
17	5.00	1	0.00247	0.86758	0.63817	0.12585
18	5.80	5	0.01447	0.81085	0.39998	0.14838
19	5.80	5	0.00922	0.81158	0.41625	0.14896
20	5.00	10	0.00248	0.86179	0.56762	0.12443
21	5.00	10	0.00374	0.86622	0.35662	0.12600
22	5.00	50	0.00036	0.91215	0.46018	0.08829
23	5.00	50	0.00047	0.91124	0.42230	0.08891
24	5.00	160	0.00011	0.92172	0.38971	0.08684
25	5.80	1	0.02713	0.84228	0.38846	0.15603
26	5.80	5	0.02661	0.77117	0.49684	0.15336
27	5.80	5	0.01983	0.81219	0.42325	0.15853
28	5.80	10	0.01067	0.81180	0.47696	0.14521
29	5.80	10	0.01604	0.82565	0.46240	0.16092
30	5.80	10	0.01108	0.81283	0.40427	0.15009
31	5.80	50	0.00169	0.84566	0.45976	0.10900
32	5.80	50	0.00247	0.87637	0.61765	0.12119
33	6.50	5	0.05162	0.77992	0.34342	0.16857
34	6.50	10	0.03555	0.76717	0.32074	0.16505
35	6.50	10	0.04262	0.74065	0.48919	0.16670
36	6.50	10	0.03273	0.74970	0.42895	0.16294
37	6.50	20	0.01794	0.77992	0.34190	0.16857
38	6.50	20	0.02280	0.77295	0.43695	0.17419
39	6.50	20	0.01647	0.77198	0.40151	0.17324
40	6.50	100	0.00263	0.81180	0.51824	0.15910
41	6.50	160	0.00157	0.81300	0.64078	0.16017
42	7.00	1	0.09206	0.73172	0.43005	0.17722
43	7.00	10	0.06411	0.71896	0.48616	0.18208
44	7.00	10	0.04760	0.76282	0.44026	0.20344
45	7.00	50	0.00971	0.76625	0.49027	0.19859
46	7.00	50	0.01151	0.75081	0.66155	0.19843
47	7.50	1	0.11826	0.76896	0.47227	0.22853
48	5.00	10	0.06665	0.76261	0.49973	0.22342
49	5.00	10	0.08976	0.75221	0.58175	0.22755
50	8.00	50	0.02813	0.75332	0.43307	0.23856
51	8.00	160	0.01338	0.80370	0.66215	0.23060

TABLE F7-17
M. C. WALCK: VERTICAL POINT ESTIMATES
SPECTRAL ACCELERATION AT 3.33 SEC PERIOD

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	0.00241	0.90833	0.66442	0.11871
2	5.00	1	0.00277	0.90426	0.55143	0.11727
3	5.00	5	0.00094	0.89903	0.57642	0.12042
4	5.00	5	0.00108	0.90315	0.46535	0.11697
5	5.80	10	0.00426	0.83225	0.40409	0.15340
6	5.80	20	0.00321	0.84909	0.40232	0.15410
7	6.50	1	0.03634	0.78356	0.35702	0.17110
8	6.50	1	0.04273	0.78651	0.43780	0.17901
9	6.50	1	0.03870	0.78438	0.37080	0.17622
10	6.50	5	0.03914	0.76508	0.59273	0.17178
11	6.50	5	0.02519	0.78340	0.32541	0.17496
12	6.50	50	0.00274	0.81220	0.41241	0.19414
13	6.50	50	0.00311	0.76463	0.63762	0.17965
14	7.00	10	0.02779	0.80165	0.37850	0.23034
15	7.50	50	0.00993	0.78826	0.63386	0.24121
16	7.50	50	0.00860	0.74546	0.45127	0.22953
17	5.00	1	0.00087	0.91422	0.76265	0.12259
18	5.80	5	0.00637	0.84923	0.49327	0.15425
19	5.80	5	0.00413	0.84872	0.43662	0.15372
20	5.00	10	0.00088	0.91044	0.70143	0.12040
21	5.00	10	0.00136	0.91191	0.52932	0.12201
22	5.00	50	0.00014	0.93455	0.54743	0.08650
23	5.00	50	0.00019	0.93234	0.61792	0.08622
24	5.00	160	0.00003	0.94559	0.67308	0.08926
25	5.80	1	0.01215	0.85398	0.44284	0.16412
26	5.80	5	0.01384	0.79933	0.57890	0.16080
27	5.80	5	0.00860	0.84047	0.45190	0.15874
28	5.80	10	0.00481	0.84917	0.45811	0.15302
29	5.80	10	0.00657	0.86264	0.50811	0.16649
30	5.80	10	0.00473	0.85045	0.45738	0.15562
31	5.80	50	0.00078	0.87094	0.44210	0.11855
32	5.80	50	0.00109	0.90785	0.69911	0.13429
33	6.50	5	0.03042	0.78883	0.35740	0.18087
34	6.50	10	0.01731	0.78293	0.34091	0.17305
35	6.50	10	0.02206	0.78088	0.52409	0.19043
36	6.50	10	0.01512	0.76552	0.44788	0.17245
37	6.50	20	0.00915	0.81616	0.34224	0.19917
38	6.50	20	0.01088	0.79579	0.39062	0.18952
39	6.50	20	0.00849	0.79654	0.47104	0.19049
40	6.50	100	0.00123	0.84113	0.58334	0.17460
41	6.50	160	0.00080	0.84113	0.60910	0.17460
42	7.00	1	0.05222	0.75311	0.49502	0.19450
43	7.00	10	0.03658	0.80251	0.49129	0.22854
44	7.00	10	0.02523	0.79074	0.51698	0.22303
45	7.00	50	0.00532	0.79930	0.53770	0.22316
46	7.00	50	0.00598	0.77920	0.67899	0.22049
47	7.50	1	0.07115	0.79929	0.39738	0.25134
48	5.00	10	0.03541	0.78628	0.55567	0.23882
49	5.00	10	0.04708	0.76023	0.56543	0.23797
50	8.00	50	0.01743	0.78519	0.58667	0.26068
51	8.00	160	0.00803	0.84737	0.65950	0.25360

TABLE F7-18
M. C. WALCK: VERTICAL POINT ESTIMATES
PEAK GROUND VELOCITY

CASE NO.	MAGNITUDE	DISTANCE (KM)	MU	SIGMA	SIGMA MU	SIGMA SIGMA
1	5.00	1	4.51356	0.66047	0.53075	0.14023
2	5.00	1	4.29438	0.67793	0.38538	0.14361
3	5.00	5	1.33613	0.66075	0.49131	0.14046
4	5.00	5	1.54938	0.67738	0.57971	0.14321
5	5.80	10	2.69191	0.65374	0.31002	0.15986
6	5.80	20	2.13480	0.63642	0.43392	0.15093
7	6.50	1	17.03227	0.63830	0.30000	0.16385
8	6.50	1	19.31325	0.64194	0.33219	0.16810
9	6.50	1	17.14802	0.64291	0.31767	0.16917
10	6.50	5	18.23540	0.63959	0.36093	0.16561
11	6.50	5	11.03472	0.64139	0.30343	0.16750
12	6.50	50	0.90034	0.64793	0.40357	0.16787
13	6.50	50	1.06003	0.63207	0.53879	0.16160
14	7.00	10	10.69709	0.64638	0.30000	0.18118
15	7.50	50	2.73714	0.61448	0.45160	0.19726
16	7.50	50	2.56927	0.59904	0.39884	0.18716
17	5.00	1	1.60177	0.67650	0.64331	0.14313
18	5.80	5	5.25829	0.65530	0.47390	0.15895
19	5.80	5	2.82126	0.65751	0.45774	0.16116
20	5.00	10	1.19757	0.68012	0.38232	0.14528
21	5.00	10	2.00067	0.65947	0.30000	0.13940
22	5.00	50	0.14050	0.68443	0.32431	0.15158
23	5.00	50	0.16511	0.67262	0.34160	0.14482
24	5.00	160	0.02683	0.69038	0.70235	0.15590
25	5.80	1	8.41111	0.66134	0.42743	0.16207
26	5.80	5	9.35552	0.65622	0.38035	0.15986
27	5.80	5	4.93251	0.65383	0.32411	0.15754
28	5.80	10	3.26196	0.66237	0.33981	0.16340
29	5.80	10	5.24598	0.65690	0.35237	0.16526
30	5.80	10	2.93759	0.65751	0.38580	0.16116
31	5.80	50	0.40833	0.70338	0.30830	0.17142
32	5.80	50	0.59621	0.73215	0.54833	0.16423
33	6.50	5	12.35000	0.64661	0.30216	0.16952
34	6.50	10	7.42157	0.64329	0.33021	0.16604
35	6.50	10	11.62291	0.64346	0.39110	0.16979
36	6.50	10	6.71575	0.63835	0.34967	0.16436
37	6.50	20	3.34907	0.64137	0.34078	0.16416
38	6.50	20	4.75040	0.63207	0.43228	0.16160
39	6.50	20	3.16873	0.63959	0.46847	0.16561
40	6.50	100	0.43082	0.67610	0.31885	0.16552
41	6.50	160	0.19098	0.70913	0.58774	0.16540
42	7.00	1	22.95208	0.65020	0.36876	0.19157
43	7.00	10	18.73886	0.64368	0.51185	0.18170
44	7.00	10	9.81755	0.64174	0.38473	0.17944
45	7.00	50	1.60028	0.64429	0.40706	0.17889
46	7.00	50	1.92625	0.64085	0.52861	0.17896
47	7.50	1	26.02660	0.65398	0.41984	0.21336
48	5.00	10	13.98912	0.64336	0.34566	0.20143
49	5.00	10	18.11451	0.64312	0.59717	0.20581
50	8.00	50	5.24948	0.65526	0.43019	0.21662
51	8.00	160	2.16459	0.86826	0.45761	0.14152

APPENDIX G

HISTORICAL SEISMICITY CATALOGUE FOR YUCCA MOUNTAIN

HISTORICAL SEISMICITY CATALOGUE FOR YUCCA MOUNTAIN

by
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HISTORICAL SEISMICITY CATALOGUE FOR YUCCA MOUNTAIN

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INTRODUCTION

A historical earthquake catalogue of all known events within a 300-km radius circular region centered on the Yucca Mountain site was compiled for use in the: (1) characterization of the regional seismicity; (2) evaluation of the seismicity for any possible associations with geologic structures, particularly late-Quaternary faults; and (3) computation of earthquake recurrence parameters for the various seismotectonic provinces that make up the Yucca Mountain region. These activities are all part of the Probabilistic Seismic Hazard Analysis Project for Yucca Mountain.

The Yucca Mountain catalogue, which covers the time period from 1868 to 1996, was compiled from all available regional and national earthquake catalogues. Two catalogues for the Yucca Mountain region compiled prior to this study were used as a basis for this work (Meremonte and Rogers, 1987; S. Gross and S. Jaume, UNR, written communication, 1995). The catalogue described in this report differs from the previous catalogues in that it covers a much larger geographical region in order to satisfy the U.S. Nuclear Regulatory Commission's regulatory standards. Also, unlike the other catalogues, the Yucca Mountain catalogue lists all known magnitudes assigned to each event to derive values using a common magnitude scale. A best-estimate moment magnitude (M_W) value was calculated for each earthquake for this project. All known Nuclear Test Site (NTS) blasts were identified and were removed along with the associated dependent events using declustering algorithms. The historical catalogue was declustered using two different approaches, the results of which were compared for their effectiveness.

DATA SOURCES

The Yucca Mountain catalogue was compiled from the following regional and national catalogues (abbreviations for each catalogue are listed in parentheses):

- Catalogue for the Southern Great Basin network for the period 1978 to 1992 (Rogers *et al.*, 1987) (SGB)
- Seismological Laboratory of the University of Nevada, Reno catalogue for Nevada, 1874 to 1994 including the Southern Great Basin network data for 1992 to 1996 (UNR)
- California Institute of Technology Seismological Laboratory and U.S. Geological Survey catalogue for southern California, 1932 to 1996 (CIT)
- University of California at Berkeley Seismographic Station catalogue for northern California, 1910 to 1972 (UCB)
- U.S. Geological Survey catalogue for northern and central California, 1969 to 1996 (USGS)
- Catalogue of Southern Great Basin earthquakes, 1868 to 1978, compiled by Meremonte and Rogers (1987) (MER)
- University of Utah Seismographic Stations catalogue for Utah, 1881 to 1996 (UUTAH)
- California Division of Mines and Geology catalogue for California, 1868 to 1932 (CDMG)
- Stover, Reagor and Algermissen state catalogues for Utah and Arizona compiled by the National Earthquake Information Center (NEIC), 1881 to 1985 (SRA)
- NEIC Preliminary Determination of Epicenters catalogue for Utah and Arizona, 1938 to 1996 (PDE)
- Northern Arizona University catalogue for Arizona, 1891 to 1992 (NAU)
- Decade of North American Geology catalogue, 1868 to 1985 (Engdahl and Rinehart, 1988) (DNAG)

CATALOGUE COMPILATION

In the compilation of the Yucca Mountain catalogue, only specific time periods of several catalogues were used due to the availability of higher quality data from other networks. For example, only data prior to 1972 was used from the UCB catalogue, because the USGS network has provided much wider and denser seismographic coverage for northern and central California since 1972. Only earthquakes prior to 1932 were extracted from the CDMG catalogue, since the CIT, UCB, and USGS catalogues are more complete for

California after 1932. All available magnitude and intensity estimates, however, were extracted from each catalogue used in the compilation.

All events from the source catalogues within the 300-km Yucca Mountain region were combined into a single catalogue. This catalogue was then subdivided into seven subregions to remove duplicate events: southwestern Utah, northwestern Arizona, north-central Nevada, southern Nevada, east-central California, Mammoth Lakes, and southeastern California (Figure G-1). Each region had a different constituent catalogue hierarchy to retain the most precise location for each earthquake (Table G-1). The seven subregions overlap to retain events that may straddle the boundaries (Figure G-1).

In each subregion catalogue, multiple entries for the same earthquake were removed. The duplicate removal procedure compares the inter-event time and distances to user-specified time and distance windows to identify multiple entries for the same earthquake. If two earthquakes from the same source catalogue (e.g., CIT) occur within the user-specified time window, the time window is automatically reduced to just less than this inter-event time. If the inter-event times and distances of earthquakes from other source catalogues are small enough (i.e., lie within the user-specified time and distance windows or the adjusted time window), the events are identified as belonging to a duplicate group. The most accurate entry for each event within the group is then selected according to the specified catalogue hierarchy for that region (Table G-1). The allowable time and distance windows are greater for the historical period (1868 to 1964), and are reduced for the instrumental period (1965 to 1996). We used a time window of 1.5 minutes and a distance window of 1° for the period 1868 to 1964 and time and distance windows of 1.25 minutes and 0.75°, respectively, for the period 1965 to 1992. For the period 1993 to date, the parameters were 1.0 minute and 0.55°, respectively.

Duplicate entries were checked visually because the computer algorithm may not always identify every duplicate. This often occurs for historical earthquakes which may have uncorrected origin times or for earthquakes which occurred on the edge of or outside a network and may have significantly different locations. In some cases, referral to the original data sources (e.g., Townley and Allen, 1939 or U.S. Earthquakes) was necessary to discern whether the entries were duplicate sets or not. The events within each duplicate group were examined, and if a different entry was preferred to the event flagged by the computer algorithm based on azimuthal gap, minimum station distance, or standard errors, then this event was flagged manually as the preferred event. The file of flagged preferred events was then used to produce the final subregion catalogues.

The subregion catalogues were combined sequentially and duplicate events were removed for overlap regions. In the duplicate removal procedure, all available magnitudes were extracted and kept in the final catalogue, along with their associated magnitude scale and data source. The final catalogue was truncated at August 31, 1996, the end date of the component catalogue CIT, to produce uniform coverage in space and time. The resulting catalogue contains 271,223 earthquakes of approximately M 0.5 and greater, from 1868 to 1996. Figure G-2 shows the events since 1904 and Table G-2 lists all earthquakes of M_w 5 and greater in the catalogue.

MAGNITUDE ESTIMATES AND CONVERSION TO MOMENT MAGNITUDE

Since the Yucca Mountain catalogue was compiled from several source catalogues, a uniform magnitude scale for all earthquakes was required in order to properly compute the earthquake recurrence for the region. In addition, it was necessary to assign magnitudes to historical earthquakes that occurred prior to calibrated seismographic instrumentation. Such magnitude estimates are usually based on the felt area or the maximum Modified Mercalli (MM) intensity. This is particularly problematic in the Basin and Range province where settlement and population growth have been erratic and sparse due to the boom and bust nature of mining operations and the rugged environment.

For each earthquake within the Yucca Mountain catalogue, a M_W was calculated from the best available magnitude estimate. Published relationships between seismic moment (M_o) and M_W or local magnitude (M_L) (or other magnitude scale) were used when available (Table G-3), and previously determined M_w values (Stover and Coffman, 1993; Doser and Smith, 1989) were added to the catalogue. Otherwise, magnitudes were first converted to M_L, from which an M_W was derived. The M_W conversion employed depended upon the source catalogue from which the earthquake was derived and upon the type and source of the magnitude. A hierarchy of magnitude types and sources were developed for each catalogue (Tables G-4 and G-5). The procedures used for each source catalogue are described below

We have not addressed the issue of the standard errors in converting the magnitudes to M_W, but there is uncertainty in all the relationships used that can be incorporated into the recurrence estimates. Standard errors in converting maximum MM intensity into M_W are much larger due to the larger uncertainty.

Southern Great Basin Network Catalogue

The USGS SGB catalogue lists an M_L (USGS Digital Recording; USGSDR) magnitude for the majority of earthquakes recorded by the digital network. Other magnitude types listed include M_V (USGSDR), a local magnitude derived from the vertical records, M_C (USGSDR) the coda-amplitude magnitude and M_D (USGSDR), the duration magnitude, all of which are described in detail in Rogers *et al.* (1987). Both M_C and M_D were originally calibrated to the USGS M_L. The digital network was operated by the USGS from October 1981 to September 1992, when the responsibility was relinquished to the University of Nevada, Reno (UNR). During the handover in September of 1992, M_L computed by both the USGS and UNR (CUSP), were collected and a comparison (D. von Seggern, UNR, written communication, 1996; Figure G-3) indicates that the two are essentially equivalent in the range M_L 1.5 to 4. This is the only direct comparison of the two methodologies for computing M_L within the SGB.

D. von Seggern (UNR, written communication, 1996) also compared M_o with M_L for the Southern Great Basin region (Figure G-4). The M_L's are derived from both the Southern Great Basin Seismic Network (SGBSN) from before and after 1992 and from Savage and Anderson (1995). The seismic moments are from Mayeda and Walter (1996) and other unpublished data computed by Ken Smith and Feng Su (UNR). Von Seggern concluded that above M 3, the moment-magnitude relation was essentially the same as that from Hanks and Kanamori (1979) relationship $\log M_o = {}^3/_2\, M_L + 16$ (Figure G-4). For $M_L < 3$, the moment-magnitude relation has a slope of 1 and was fixed to the Hanks and Kanamori (1979) curve at M_L 3 (D. von Seggern, UNR, written communication, 1996). The relationship for $M_L < 3$ is

$\log M_o = M_L + 17.55$. The relation between M_o and M_W (Hanks and Kanamori, 1979) of $M_W = {}^2/_3 \log M_o - 10.7$ was used to calculate M_W from M_L. The relations are $M_W = M_L$ for $M_L \geq 3$ and $M_W = {}^2/_3 M_L + 1$ for $M_L < 3$.

All earthquakes recorded by the SGB digital network for the period October 1981-September 1992 assigned M_L values were converted to M_W using the above relationships. However, many earthquakes within the catalogue only have M_C, M_V and/or M_D designations. For these earthquakes, a M_L value was first estimated from regressions developed in this study (Figures G-5 to G-7; Table G-3). The magnitude conversions, which are only valid for ranges indicated by the regressions, were used in a few cases for magnitudes just outside the specified ranges. M_L estimated from M_V was considered the best estimate followed in order by M_L estimates from M_C and M_D.

For the period prior to installation of the digital network, August 1978 to September 1981, and after 1981 in the event of computer failure, a M_D was computed from develocorder records. M_D (USGS Develocorder; USGSDV) was regressed with M_D values from UNR (Figure G-8; Table G-3). UNR M_D values were calibrated to M_L from UNR and BRK. M_W was estimated assuming the same relationships between M_W and M_L as were used for the Southern Great Basin.

University of Nevada, Reno Catalogue

All M_L magnitudes from UNR prior to September 1992 were converted to M_W using the same relationships between M_W and M_L as discussed above for the Southern Great Basin. M_D is calibrated to M_L for the range $1.5 \leq M_L \leq 5.7$ and is assumed to be equivalent to M_L UNR. After September 1992, magnitudes were determined by UNR from the CUSP (Caltech USGS Processing) system for the Southern Great Basin and are mostly M_D values. The relationship between M_D and M_L from CUSP for the period 1993-1995 is $M_L = -1.244 + 1.31 M_D$ (Figure G-9), where $M_L = M_D$ at a value of 4.0 (D. von Seggern, UNR, written communication, 1996). M_D values were first converted to M_L and then to M_W using the Southern Great Basin relationships between M_W and M_L.

California Institute of Technology Catalogue

Most earthquakes from the CIT catalogue have a M_L PAS designation which was converted to M_W assuming that $M_L = M_W$ for $M_L \geq 3$ (L. Wald, USGS, personal communication, 1996). All $M_L < 3$ were converted to M_W using the relationship of Chung and Bernreuter (1981) for California (Table G-3) since no regressions have been performed for this magnitude range for the region of interest (L. Wald, USGS, K. Hutton and L. Jones, California Institute of Technology, personal communications, 1996).

University of California, Berkeley Catalogue

Most of the earthquakes from the UCB catalogue give a M_L BRK (also designated BERK and UCB) and were converted to M_W directly using a relationship developed by R. Uhrhammer (UCB, personal communication, 1996) for $3.6 \leq M_L \leq 6.8$. Below M_L 3.6 the relationship was assumed to be the same (R. Uhrhammer, UCB, personal communication, 1996).

USGS Northern California Catalogue

Most earthquake magnitudes listed in the USGS catalogue are a M_L or M_D. Relationships between M_L and M_W developed for the Mammoth region (Chavez and Priestly, 1985) were used to convert the M_L values (Table G-3). These are valid for ranges of $1 \leq M_L \leq 6$ and $\frac{1}{2} \leq M_L \leq 3$ respectively. Since the second equation is less reliable (Chavez and Priestly, 1985), it was only used for $M_L < 1$. If M_L was not available for a particular earthquake, the preferred alternative was M_D which has been calibrated to M_L. Other magnitudes were used if necessary (Tables G-3 and G-4).

Southern Great Basin Historical Earthquake Catalogue

The Southern Great Basin historical catalogue compiled by Meremonte and Rogers (1987) lists many magnitude data sources, many of which are unknown (UK). The catalogue includes the results from several microearthquake surveys conducted in the vicinity of the NTS which were assigned M_D values. These M_D values were assumed to be the same as M_D

computed by UNR. All M_L values from UNR, PAS and BRK were converted to M_W using the appropriate relationships (Table G-3). Surface-wave magnitudes (M_S) were converted using the formula $M_W = 0.79M_S + 1.24$ (M.L. Jost and R.B. Herrmann, St. Louis University, written communication, 1990). Body-wave magnitudes (m_b) were assumed to be equivalent to M_L and then converted to M_W (Boore and Joyner, 1982) Other unspecified magnitudes were assumed to be equivalent to M_L for the Southern Great Basin and then converted to M_W. The magnitude conversion hierarchy (Table G-4) was based on the reliability of each magnitude type (Meremonte and Rogers, 1987).

University of Utah Catalogue

Most earthquakes from the University of Utah catalogue were assigned an M_L (UVUTAH, UU or SLC) and were converted to M_W directly using relationships developed by Shemeta and Pechmann (1989; unpublished work). These relationships are similar to the California relationships. Alternatively, M_D values (UVUTAH) calibrated to M_L for $M_D < 2.5$, were used when M_L was not available.

CDMG, SRA and PDE Catalogues

The CDMG, SRA, and PDE catalogues list magnitudes from a variety of sources. Relations between M_L and M_W for original sources were used where possible (i.e., UCB, CIT, UNR, and USGS). m_b or m_{bLg} magnitudes were converted to M_L using the m_b-M_L formula described in the MER catalogue section. M_L values from Arizona were assumed to be equivalent to M_L for the SGB catalogue. Any magnitudes of unknown origin from the CDMG catalogue were assumed to be equivalent to M_L from UCB.

Northern Arizona University Catalogue

A small number of earthquakes came from the NAU catalogue, which in most cases gives adopted magnitudes. M_L (AE) values were assumed to be equivalent to M_L for the Southern Great Basin. Conversions of other magnitudes used in the NAU catalogue (Table G-4) are described elsewhere in this section.

Decade of North American Geology Catalogue

Adopted magnitudes from UCB, CIT, UNR, and USGS contained in the DNAG catalogue were converted using the appropriate M_w relations. Unknown magnitudes and intensity-based magnitudes (M_I) from UCB and CIT were assumed to be equivalent to an M_L from the same institution, and UK or M_I magnitudes were assumed to be equivalent to M_L for the Southern Great Basin.

Maximum Modified Mercalli Intensity

Earthquakes with no magnitude but an assigned maximum MM intensity (I_0) were converted to M_L from I_0 depending on the location of the earthquake. For California and Nevada earthquakes, the Toppozada (1975) relation was used and for earthquakes in Arizona and Utah, the Gutenberg and Richter (1956) relation was used.

REMOVAL OF NTS EXPLOSIONS AND ASSOCIATED DEPENDENT EVENTS

For 40 years, the U.S. government conducted unannounced underground nuclear weapons tests at the Nevada Test Site (NTS) near the Yucca Mountain site. Many unannounced tests were detected by regional seismograph networks but were often not distinguished from earthquakes. A catalogue of 742 nuclear explosions conducted at or near the NTS (Figure G-10, Table G-6) was compiled and used to identify all blasts in the Yucca Mountain catalogue. The list was also used to remove events from the Yucca Mountain catalogue induced by or associated with the NTS explosions.

Underground nuclear tests were conducted at the NTS from 26 July 1957 to 23 September 1992. Atmospheric tests conducted from 1951 to 1957 were excluded from this catalogue. Testing at the NTS was halted on 2 October 1992. In 1994, DOE released data all nuclear tests conducted at the NTS (DOE, 1994).

Several data sources were combined to create a comprehensive nuclear explosion catalogue containing date and time, location, and equivalent magnitude. The most complete list of blasts came from the California Institute of Technology (Riley, CIT, written communication, 1996). However, many tests announced by the DOE were not included in this list or did not contain pertinent information such as location or magnitude. Additional information was obtained from the Lawrence Livermore National Laboratory (LLNL) Containment Database (G. Pawloski, LLNL, personal communication, 1997) and Seismological Database (T. Hauk, LLNL, personal communication, 1997), and from the UCB Seismograph Stations (Collins and Uhrhammer, 1988; Becker *et al.*, 1990). These data sources were cross-referenced to create as complete a record as possible for each blast. The depths of burial given by the DOE were all significantly less than 1 km, so all blasts were assigned a zero depth.

To remove nuclear blast-induced aftershocks and possible cavity collapses from the Yucca Mountain catalogue, the events were removed using the Youngs *et al.* (1987) declustering algorithm described in the next section. Time and distance windows created by the declustering algorithm are a function of magnitude, so each nuclear blast with no recorded magnitude was assigned a calculated value.

Magnitudes for most of the tests were given in the original data sources, but many blasts had no magnitude, particularly blasts prior to 1963. For the approximately 225 blasts without recorded magnitudes, we calculated a magnitude based on yield (total effective energy released in a nuclear explosion), using the equation

$$M_L=3.603+0.3774\ \ln W$$

where M_L is the local magnitude and W is the yield in equivalent kilotons of TNT (M. Walck, Sandia Laboratories, personal communication, 1997). Blasts with both a known magnitude and yield were used to compare the calculated M_L with recorded body-wave magnitudes. The average difference between recorded m_b and calculated M_L magnitudes was 0.29.

Although recorded blast magnitudes and magnitude-yield relationships are not classified by the U.S. government, nuclear test yields are classified information. For some tests, an exact yield has been released by the DOE and for some, no information has been released. For most events, however, yield information was released as a range of values (e.g., 12-20 kt).

For approximately 35 blasts with an exact yield released by the DOE, M_L values were calculated. Approximately 13 blasts with a yield range of 20 to 200 kt were assigned M_L 5.15, the average of the maximum (M_L 5.6) and minimum (M_L 4.7) possible magnitudes for this yield range. Approximately 160 blasts with a yield range given by the DOE as "less than 20 kt" or "12 - 20 kt" were assigned a value of M_L 4.7, which corresponds to the maximum possible yield of 20 kt. Blasts with an assigned yield value of "$\leq$ 1 kt" or for which yield was listed as "sparse" without elaboration were assigned a value of M_L 3.6, the minimum magnitude from this equation. Approximately 11 events with neither known magnitude nor listed yield range were assigned M_L 3.6.

DECLUSTERING OF THE HISTORICAL SEISMICITY CATALOGUE

To assess the hazard from "background" earthquakes, estimates of earthquake recurrence are required. The background earthquake is defined as an event that can occur without an apparent association with a known tectonic feature. Recurrence is estimated from a catalogue of independent earthquakes which are assumed to follow a Poissonian distribution of earthquake occurrence. Dependent events (foreshocks and aftershocks or smaller events within an earthquake swarm) are identified using various criteria and then removed from the catalogue.

The 300-km catalogue was declustered using procedures developed by Youngs *et al.* (1987) and Veneziano and Van Dyck (1985). In the Youngs *et al.* (1987) method, dependent events were identified using empirical criteria for the size in time and space of foreshock-mainshock-aftershock sequences developed by Arabasz and Robinson (1976), Gardner and Knopoff (1974), and Uhrhammer (1986). If an event was identified as dependent by two of the three criteria, it was deleted from the catalogue.

The Veneziano and Van Dyck (1985) procedure is more sophisticated than that of Youngs *et al.* (1987) and allows for spatial nonhomogeneities and apparent nonstationarity caused by catalogue incompleteness. The method first sorts earthquakes by size and then date. Each earthquake in turn is statistically tested from largest to smallest for clustering. To accomplish this testing, the seismicity rates of a local temporal and spatial window are compared with that for an extended temporal and spatial window. Cluster dimensions are then estimated based on this comparison, and all identified secondary events (dependent events) within the cluster are deleted from the catalogue. The procedure is repeated iteratively until no secondary events are removed.

The declustering algorithm of Reasenberg (1985) was not used to decluster the 300-km catalogue based on discussions with M. Savage (Victoria University, written communication, 1997). The Reasenberg code uses California-specific parameters which are not suitable for Nevada, a region with lower rates of earthquake occurrence. Savage has modified the Reasenberg code as part of a study to determine foreshock probabilities for Nevada (Savage and dePolo, 1993), but met with limited success (M. Savage, Victoria University, written communication, 1997).

Only 26,250 and 31,147 earthquakes remained in the 300-km catalogue after declustering with the Youngs *et al.* (1987) and Veneziano and Van Dyck (1985) methods, respectively (see Figures G-11 and G-12 for plots of declustered catalogues within 100 km of Yucca Mountain).

Distance-time plots for the 100 km catalogue before and after declustering (Figures G-13 to G-15) were used to test the effectiveness of the declustering procedures. In addition, earthquakes in the vicinity of Little Skull Mountain were plotted as a function of time after declustering (Figures G-16a-g and G-17a-g). The Youngs *et al.* (1987) procedure appears to miss some aftershocks that occurred up to four years after the 1992 mainshock. Two of the three methods used in the Youngs *et al.* (1987) procedure were developed for California and therefore may be inappropriate for the lower rates of seismicity of the Southern Great Basin. In comparison, the more sophisticated Veneziano and Van Dyck (1985) procedure produced a more even temporal distribution without the large year-to-year differences seen in the Youngs *et al.* declustered catalogue, particularly from 1993 to 1994 (Figures G-16d-e and G-17d-e). Both approaches, however, leave in aftershocks, particularly a year after the 1992 mainshock. The Little Skull Mountain fault zone as defined by the aftershock distribution is somewhat less pronounced in the plots of the Veneziano declustered catalogue (Figures G-16a and G-17a).

LAKE MEAD RESERVOIR-INDUCED SEISMICITY

Since the early 1940's, reservoir-induced-seismicity has occurred at Lake Mead, the reservoir impounded by Hoover Dam (Rogers and Lee, 1976). One of the issues to be addressed in the Probabilistic Seismic Hazard Analysis Project is whether such seismicity will contribute to the hazard at the Yucca Mountain site in the future and if so, if it should be incorporated into the hazard analysis. The reservoir-induced earthquakes at Lake Mead were retained in the Yucca Mountain catalogue and it was left to the judgments of the experts to keep or delete the events for their analysis.

REFERENCES

Abe, K., and Noguchi, S., 1983, Determination of magnitude for large shallow earthquakes, 1898-1917: Physics of the Earth and Planetary Interiors, v. 32, p. 45-59.

Arabasz, W.J., and Robinson, R., 1976, Microseismicity and geologic structure in the northern South Island, New Zealand: New Zealand Journal of Geology and Geophysics, v. 19, p. 561-601.

Becker, A.M., Mc Kenzie, M.R., and Uhrhammer, R.A., 1990, Bulletin of the Seismographic Stations - Earthquakes and the Registration of Earthquakes from January 1, 1989 to December 31, 1989, University of California at Berkeley Seismographic Stations, v. 59, 117 p.

Boore, D.M., and Joyner, W.B., 1982, The empirical prediction of ground motion: Bulletin of the Seismological Society of America, v. 72, p. S43-S60.

Chavez, D.E., and Priestley, K.F., 1985, M_L observations in the Great Basin and M_o versus M_L relationships for the 1980 Mammoth Lakes, California earthquake sequence: Bulletin of the Seismological Society of America, v. 75, p. 1583-1598.

Chung, D.H., and Bernreuter, D.L., 1981, Regional relationships among earthquake magnitude scales: Review of Geophysics and Space Physics, v. 19, p. 649-663.

Collins, E.R., and Uhrhammer, R.A., 1988, Bulletin of the Seismographic Stations - Earthquakes and the Registration of Earthquakes from January 1 1987 to December 31, 1987, University of California at Berkeley Seismographic Stations, v. 57, 98 p.

Doser, D.I., and Smith, R.B., 1989, An assessment of source parameters of earthquakes in the Cordillera of the western U.S: Bulletin of the Seismological Society of America, v. 79, p. 1383-1409.

Eaton, J.P., 1992, Determination of amplitude and duration magnitudes and site residuals from short-period seismographs in northern California: Bulletin of the Seismological Society of America, v. 82, p. 533-579.

Engdahl, E. R., and Rinehart, W.A., 1988, Seismicity map of North America: Decade of North American Geology Catalogue, The Geological Society of America, scale 1:5,000,000.

Fisher, F.G., Papenek, P.J., and Hamilton, R.M., 1972, The Massachusetts Mountain earthquake of 5 August 1971 and its aftershocks, Nevada Test Site: U.S. Geological Survey Report USGS-474-149, NTS-238, 20 p.

Gardner, J.K., and Knopoff, L., 1974, Is the sequence of earthquakes in Southern California, with aftershocks removed, Poissonian?: Bulletin of the Seismological Society of America, v. 65, p. 1363-1367.

Gutenberg, B., and Richter, C.F., 1956, Earthquake magnitude, intensity, energy and acceleration: Bulletin of the Seismological Society of America, v. 46, p. 105-145.

Hanks, T.C., and Kanamori, H., 1979, A moment magnitude scale: Journal of Geophysical Research, v. 84, p. 2348-2350.

Mayeda, K., and Walter, W.R., 1996, Moment, energy, stress drop , and source spectra of western United States earthquakes from regional coda envelopes: Journal of Geophysical Research, v. 101, p. 11,195-11, 208.

Meremonte, M.E., and Rogers, A.M., 1987, Historical catalog of Southern Great Basin earthquakes, 1868-1978: U.S. Geological Survey Open-File Report 87-80, 204 p.

Papanek, P.J., and Hamilton, R.M., 1972, A seismicity study along the northern Death Valley-Furnace Creek fault zone, California-Nevada boundary: U.S. Geological Survey Report USGS-474-141, 41 p.

Reasenberg, P., 1985, Second-order moment of central California seismicity, 1969-1982: Journal of Geophysical Research, v. 90, p. 5479-5495.

Rogers, A.M., Harmsen, S.C., and Meremonte, M.E., 1987, Evaluation of the seismicity in the Southern Great Basin and its relationship to the tectonic framework of the region: U.S. Geological Open-File Report 87-408, 196 p.

Rogers, A.M., and Lee, W.H.K., 1976, Seismic study of earthquakes in Lake Mead: Bulletin of the Seismological Society of America, v. 66, p. 1657-1681.

Rogers, A.M., Woulett, G.M., and Covington, P.A., 1977, Seismicity of the Pahute Mesa area, Nevada Test Site, 8 October 1975 to 30 June 1976: U.S. Geological Survey Report USGS-474-184, 63 p.

Savage, M. K., and Anderson, J. G., 1995, A local magnitude scale for the Western Great Basin-Eastern Sierra Nevada from synthetic Wood-Anderson seismograms: Bulletin of the Seismological Society of America, v. 85, p. 1236-1243.

Savage, M.K., and dePolo, C.M., 1993, Foreshock probabilities in the western Great Basin, eastern Sierra Nevada: Bulletin of the Seismological Society of America, v. 83, p. 1910-1938.

Shemeta, J.E., and J.C. Pechmann, 1989, Source parameters of aftershocks of the 1983 Borah Peak, Idaho, earthquake (abstract): EOS, Transactions of the American Geophysical Union, v. 70, p. 1188.

Slemmons, D.B., Jones, A.E., and Gimlett, J.I., 1965, Catalog of Nevada earthquakes, 1852-1960: Bulletin of the Seismological Society of America, v. 55, p. 537-583.

Smith, B.E., Hamilton, R.M., and Jackson, W.H., 1971, Seismicity of the central Nevada test area, 26 September 1969 - 1 October 1970: U.S. Geological Survey Report USGS-474-109, 27 p.

Stover, C.W., and Coffman, J.L., 1993, Seismicity of the United States, 1568-1989 (Revised): U.S. Geological Survey Professional Paper 1527, 418 p.

Thatcher, W., and Hanks, T.C., 1973, Source parameters of southern California earthquakes: Journal of Geophysical Research, v. 78, p. 8547-8576.

Toppozada, T.R., 1975, Earthquake magnitude as a function of intensity data in California and western Nevada: Bulletin of the Seismological Society of America, v. 65, p. 1,223-1,238.

Townley, S.D., and Allen, M.W., 1939, Descriptive catalog of earthquakes of the Pacific Coast of the United States: 1769 to 1928: Bulletin of the Seismological Society of America, v. 29, p. 1-297.

U.S. Department of Energy (DOE), 1994, Announced United States Nuclear Tests, July 1945 through September 1992: DOE/NV 209 (Rev. 14), 96 p.

Uhrhammer, R.A., 1986, Characteristics of northern and central California seismicity (abstract): Earthquake Notes, v. 57, p. 21.

Veneziano, D., and Van Dyck, J., 1985, Statistical discrimination of "aftershocks" and their contribution to seismic hazard, Appendix A-4, *in* Seismic Hazard Methodology for Nuclear Facilities in the Eastern United States: EPRI Research Project Number P101-29, p. A121-A186.

von Seggern, D.H., and Brune, J.N., 1996, Seismicity in the Southern Great Basin, 1868-1992: Geological Society of America Special Volume: Tectonic Characterization of Yucca Mountain - A potential geologic repository for nuclear waste (in press).

Youngs, R.R., Swan, F.H., III, Power, M.S., Schwartz, D.P., and Green, R.K., 1987. Probabilistic analysis of earthquake ground-shaking along the Wasatch front, Utah, *in* W.W. Hays and P.L. Gori ,eds., Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah: U.S. Geological Survey Professional Paper (in press).

TABLE G-1
HIERARCHIES FOR REMOVAL OF DUPLICATE EVENTS IN SUBREGION CATALOGUES

SUBREGION CATALOGUES (LISTED IN ORDER OF PREFERENCE)						
North-Central Nevada	**Northwestern Arizona**	**Southern Nevada**	**Southeastern California**	**Mammoth Lakes**	**East-Central California**	**Southwestern Utah**
UNR	MER	SGB	CIT	USGS*	USGS	UUTAH
SGB	SGB	MER	CDMG	UNR	UCB	DNAG
MER	UNR	UNR	UNR	UCB	CDMG	MER
DNAG	NAU	COMG	UCB	CDMG	UNR	SGB
CDMG	SRA	DNAG	NAU	CIT	CIT	UNR
CIT	PDE	CIT	SRA	DNAG	DNAG	PDE
USGS	DNAG	UCB				SRA
UCB	UUTAH	USGS				NAU
UUTAH	CIT	PDE				CIT
	USGS	NAU				USGS
		SRA				
		UUTAH				

* The USGS location was exclusively used for all Mammoth Lakes events after 1982

TABLE G-2
EARTHQUAKES OF MAGNITUDE 5 OR GREATER IN THE YUCCA MOUNTAIN HISTORICAL SEISMICITY CATALOGUE

Cat. No.	Year	Mo.	Day	Time (GMT)			Lat.	Long.	Depth	Mag1	Scale	Mag1 Source	Mag2	Scale	Mag2 Source	Location
				Hour	Min	Sec			(km)							Source
1	1868	7	25	2	30	00.0000	36.3000	-119.3000	n c	5.28	Mw	MITOPO	-9.99			NEIC
2	1871	7	5	21	6	00.0000	36.4000	-118.0000	n c	5.13	Mw	UK DMG	5.20	UK	DMG	NEIC
3	1872	3	26	10	30	00.0000	36.7000	-118.1000	n c	7.75	Mw	STOCOF	7.80	MW	H&K	NEIC
4	1872	3	26	14	6	00.0000	36.9000	-118.2000	n c	6.63	Mw	UK DMG	6.70	UK	DMG	NEIC
5	1872	4	3	12	15	00.0000	37.0000	-118.2000	n c	6.53	Mw	UK DMG	6.60	UK	DMG	NEIC
6	1872	4	11	19	0	00.0000	37.5000	-118.5000	n c	6.53	Mw	UK DMG	7.00	MI	CDMG	NEIC
7	1872	4	18	12	0	00.0000	36.5000	-117.8000	n c	6.26	Mw	MITOPO	-9.99			NEIC
8	1872	11	12	0	0	00.0000	39.5000	-117.0000	n c	6	Mw	UK	6.00	UK		DNAG
9	1875	4	2	2	0	00.0000	39.5000	-115.8000	n c	5.5	Mw	MD UNR	5.50	MD	UNRENO	UNRENO
10	1886	4	14	3	20	00.0000	37.2000	-117.7000	n c	4.9	Mw	MD UNR	5.00	MS	BRP	UNRENO
11	1889	2	7	5	20	00.0000	34.1000	-116.7000	n c	5.23	Mw	UK DMG	5.30	UK	DMG	NEIC
12	1889	9	30	5	20	00.0000	37.2000	-118.7000	n c	5.53	Mw	UK DMG	5.60	UK	DMG	NEIC
13	1891	4	20	13	55	00.0000	37.1063	-113.5735	n c	4.83	Mw	MI UU	5.00	MI	UVUTAH	UVUTAH
14	1894	7	30	5	12	00.0000	34.3000	-117.6000	n c	5.83	Mw	UK DMG	5.90	UK	DMG	NEIC
15	1896	8	17	11	30	00.0000	36.7000	-118.3000	n c	5.83	Mw	UK DMG	5.90	UK	DMG	NEIC
16	1899	7	22	0	46	00.0000	34.2000	-117.4000	n c	5.43	Mw	UK DMG	5.50	UK	DMG	NEIC
17	1899	7	22	20	32	00.0000	34.3000	-117.5000	n c	6.35	Mw	STOCOF	6.50	UK	DMG	NEIC
18	1902	11	17	19	50	00.0000	37.3930	-113.5200	n c	6	Mw	WCFS1	6.33	MI	SRA	UVUTAH
19	1902	12	5	-1	-1	00.0000	37.3947	-113.5200	n c	4.83	Mw	MI UU	5.00	MI	SRA	UVUTAH
20	1905	1	6	14	30	00.0000	35.5000	-118.7000	n c	4.93	Mw	UK TO	5.00	UK	TO	NEIC
21	1905	12	23	22	23	00.0000	35.3000	-118.8000	n c	4.93	Mw	UK TO	5.00	UK	TO	NEIC
22	1907	9	20	1	54	00.0000	34.2000	-117.1000	n c	5.93	Mw	ML RI	6.00	ML	RI	NEIC
23	1908	11	4	8	37	00.0000	36.0000	-117.0000	n c	6.43	Mw	ML RI	6.50	ML	RI	NEIC
24	1910	5	6	16	40	00.0000	37.3300	-118.4200	n c	4.93	Mw	MICDMG	5.67	MI	BRK	UCB
25	1910	11	7	17	20	00.0000	37.5000	-117.0000	n c	5.5	Mw	MD UNR	5.70	MS	BRP	MER
26	1910	11	19	2	25	00.0000	38.0000	-118.0000	n c	5.5	Mw	MD UNR	5.70	MS	BRP	MER
27	1910	11	21	23	23	00.0000	38.0000	-118.0000	n c	6.1	Mw	MD UNR	6.33	MI	SGB	MER
28	1910	11	22	0	30	00.0000	38.0000	-118.0000	n c	4.9	Mw	MD UNR	5.00	MS	BRP	MER
29	1910	11	22	6	5	00.0000	38.0000	-118.0000	n c	5.5	Mw	MD UNR	5.70	MS	BRP	MER
30	1912	1	5	3	54	00.0000	37.3300	-118.4200	n c	4.93	Mw	MICDMG	5.67	MI	BRK	UCB
31	1915	5	29	6	46	00.0000	36.0800	-118.8200	n c	4.93	Mw	UK TO	5.00	UK	TO	NEIC
32	1916	11	10	9	11	00.0000	36.2000	-116.9000	n c	6.1	Mw	MD UNR	6.10	MD	UNRENO	UNRENO
33	1917	7	6	11	1	00.0000	36.5800	-118.0800	n c	5.28	Mw	MITOPO	-9.99			NEIC
34	1919	2	16	15	57	00.0000	35.0000	-119.0000	n c	4.93	Mw	UK TO	5.67	MI	USN	NEIC

TABLE G-2
EARTHQUAKES OF MAGNITUDE 5 OR GREATER IN THE YUCCA MOUNTAIN HISTORICAL SEISMICITY CATALOGUE

Cat. No.	Year	Mo.	Day	Time (GMT)			Lat.	Long.	Depth	Mag1	Scale	Mag1 Source	Mag2	Scale	Mag2 Source	Location
				Hour	Min	Sec			(km)							Source
35	1920	11	26	0	0	00.0000	37.1063	-113.5735	n c	4.13	Mw	MI UU	5.00	MI	USN	UVUTAH
36	1926	6	30	13	31	00.0000	35.6000	-118.8000	n c	4.93	Mw	UK TO	5.00	UK	TO	NEIC
37	1927	9	18	2	7	07.0000	37.5000	-118.7500	n c	5.93	Mw	ML BRK	6.00	ML	GR	UCB
38	1929	9	26	20	0	22.7000	34.8300	-116.5200	n c	5.03	Mw	ML RI	5.10	ML	RI	NEIC
39	1929	11	28	19	49	00.0000	36.9000	-118.1900	n c	5.43	Mw	UK TO	5.50	UK	TO	NEIC
40	1929	12	2	7	0	00.0000	37.0000	-118.1700	n c	4.93	Mw	MICDMG	5.00	MI	CDMG	UCB
41	1929	12	8	12	45	00.0000	37.0000	-118.1700	n c	4.93	Mw	MICDMG	5.00	MI	CDMG	UCB
42	1930	1	16	0	24	33.9000	34.1800	-116.9200	n c	5.13	Mw	ML EH	5.20	ML	EH	NEIC
43	1930	1	16	0	34	03.6000	34.1800	-116.9200	n c	5.03	Mw	ML EH	5.10	ML	EH	NEIC
44	1931	9	23	8	25	00.0000	37.0800	-118.1700	n c	4.93	Mw	MICDMG	5.00	MI	USN	UCB
45	1932	12	21	6	10	04.0000	38.8000	-117.9800	n c	6.8	Mw	DOSSM1	7.20	ML	PAS	UNRENO
46	1932	12	24	12	41	00.0000	38.8000	-118.0000	n c	5	Mw	MD UNR	5.00	MD	UNRENO	UNRENO
47	1932	12	25	3	55	00.0000	38.8000	-118.0000	n c	5.5	Mw	MD UNR	5.50	ML	UNW	UNRENO
48	1932	12	26	5	2	00.0000	38.0200	-117.6200	n c	5.3	Mw	MD UNR	5.30	MD	UNRENO	UNRENO
49	1932	12	29	6	21	00.0000	38.8000	-118.0000	n c	5.2	Mw	MD UNR	5.20	ML	UNW	UNRENO
50	1932	12	29	6	38	00.0000	38.8000	-118.0000	n c	5	Mw	MD UNR	5.00	MD	UNRENO	UNRENO
51	1932	12	29	6	46	00.0000	38.8000	-118.0000	n c	5	Mw	MD UNR	5.00	MI	USN	UNRENO
52	1933	1	4	1	2	00.0000	38.4000	-118.1000	n c	5.1	Mw	MD UNR	5.10	MD	UNRENO	UNRENO
53	1933	1	5	6	51	00.0000	38.7700	-117.7400	n c	5.9	Mw	MD UNR	5.90	UK	MAK	UNRENO
54	1933	1	6	13	6	00.0000	39.0000	-117.8000	n c	5.1	Mw	MD UNR	5.10	MD	UNRENO	UNRENO
55	1933	1	11	17	30	00.0000	38.9000	-117.8000	n c	5.2	Mw	MD UNR	5.20	MD	UNRENO	UNRENO
56	1933	1	29	13	52	00.0000	38.5000	-118.0000	n c	5	Mw	MD UNR	5.00	UK	RYC	UNRENO
57	1933	2	3	3	26	00.0000	37.3333	-118.8333	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
58	1933	2	13	22	9	00.0000	38.0000	-118.0000	n c	5.5	Mw	MD UNR	5.50	ML	BRP	MER
59	1933	3	12	20	45	00.0000	38.8000	-117.6000	n c	5	Mw	MD UNR	5.00	ML	UNW	UNRENO
60	1933	5	9	9	47	00.0000	38.5000	-117.9000	n c	5.1	Mw	MD UNR	5.10	UK	RYC	UNRENO
61	1933	6	4	14	9	00.0000	38.5000	-117.9000	n c	5.2	Mw	MD UNR	5.20	MD	UNRENO	UNRENO
62	1933	6	11	8	35	00.0000	38.7000	-117.7000	n c	5.2	Mw	MD UNR	5.20	UK	MAK	UNRENO
63	1933	10	27	10	59	00.0000	38.9000	-117.6000	n c	5.5	Mw	MD UNR	5.50	MD	UNRENO	UNRENO
64	1934	1	30	19	24	00.0000	38.3000	-118.4000	n c	5.6	Mw	MD UNR	5.67	MI	NEV	UNRENO
65	1934	1	30	20	16	35.0000	38.2800	-118.3700	n c	6.1	Mw	DDSSM1	6.60	ML	PAS	UNRENO
66	1934	1	30	20	30	00.0000	38.3000	-118.4000	n c	5.7	Mw	MD UNR	5.70	ML	UNW	UNRENO
67	1934	1	30	23	40	00.0000	38.1000	-118.5000	n c	5.4	Mw	MD UNR	5.40	MD	UNRENO	UNRENO
68	1934	1	31	0	25	00.0000	38.3000	-118.4000	n c	5	Mw	MD UNR	5.00	MD	UNRENO	UNRENO

TABLE G-2
EARTHQUAKES OF MAGNITUDE 5 OR GREATER IN THE YUCCA MOUNTAIN HISTORICAL SEISMICITY CATALOGUE

Cat. No.	Year	Mo.	Day	Time (GMT)			Lat.	Long.	Depth	Mag1	Scale	Mag1 Source	Mag2	Scale	Mag2 Source	Location
				Hour	Min	Sec			(km)							Source
69	1934	1	31	3	55	00.0000	38.3000	-118.4000	n c	5	Mw	MD UNR	5.00	MI	USN	UNRENO
70	1934	2	1	11	1	00.0000	38.3000	-118.4000	n c	5	Mw	MD UNR	5.00	ML	UNW	UNRENO
71	1934	2	1	11	19	00.0000	38.3000	-118.4000	n c	5.2	Mw	MD UNR	5.20	MD	UNRENO	UNRENO
72	1934	2	1	11	46	00.0000	38.3000	-118.4000	n c	5.4	Mw	MD UNR	5.40	MD	UNRENO	UNRENO
73	1934	2	9	9	21	00.0000	38.3000	-118.4000	n c	5.5	Mw	MD UNR	5.50	MD	UNRENO	UNRENO
74	1934	3	13	16	20	00.0000	37.9000	-118.5000	n c	4.7	Mw	MD UNR	5.00	ML	BRK	UNRENO
75	1934	4	15	12	9	00.0000	38.0000	-115.0000	n c	5	Mw	MD UNR	5.00	MS	BRP	MER
76	1935	10	24	14	48	07.6000	34.1000	-116.8000	n c	5.1	Mw	ML PAS	5.10	ML	PAS	CIT
77	1936	5	10	17	40	00.0000	37.5000	-118.5300	n c	4.93	Mw	ML BRK	5.00	ML	UCBMLT	UCB
78	1936	7	2	16	29	00.0000	39.2000	-117.5000	n c	4.93	Mw	ML BRK	5.00	ML	UCBMLT	UCB
79	1937	2	19	9	9	00.0000	38.3000	-118.3000	n c	5	Mw	MD UNR	5.00	ML	UCBMLT	UNRENO
80	1937	11	12	0	39	00.0000	36.0000	-114.8000	n c	3.5	Mw	UK RYC	5.00	MI	UVUTAH	MER
81	1938	12	3	17	42	00.0000	37.5000	-118.7700	n c	5.43	Mw	ML BRK	5.70	ML	PAS	UCB
82	1939	5	4	20	44	48.3600	35.7680	-114.7850	8	5	Mw	ML PAS	5.00	MI	NEV	MER
83	1939	5	11	18	40	00.0000	38.6000	-117.8000	n c	5.5	Mw	MD UNR	5.50	ML	UCBMLT	UNRENO
84	1939	6	11	19	15	00.0000	36.0000	-114.8000	n c	5	Mw	ML RWL	5.00	ML	RWL	MER
85	1939	6	13	17	15	32.0700	37.0070	-117.2290	8	4.93	Mw	ML BRK	5.00	ML	UCBMLT	MER
86	1940	3	10	18	1	53.3100	37.3890	-114.9370	8	5	Mw	ML PAS	5.00	UK	RYC	MER
87	1940	5	18	5	3	58.5000	34.0833	-116.3000	n c	5.4	Mw	ML PAS	5.40	ML	PAS	CIT
88	1940	5	18	5	51	20.2500	34.0667	-116.3333	n c	5.2	Mw	ML PAS	5.20	ML	PAS	CIT
89	1940	5	18	7	21	32.7000	34.0667	-116.3333	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
90	1940	7	8	10	57	40.0000	37.4500	-119.0000	n c	4.93	Mw	ML BRK	5.00	ML	UCBMLT	UCB
91	1941	9	14	16	43	32.0000	37.5700	-118.7300	n c	5.93	Mw	ML BRK	6.00	UK	PAS	UCB
92	1941	9	14	18	21	19.0000	37.5700	-118.7300	n c	5.43	Mw	ML BRK	5.50	ML	PAS	UCB
93	1941	9	14	18	39	12.0000	37.5700	-118.7300	n c	5.93	Mw	ML BRK	6.00	ML	PAS	UCB
94	1941	9	14	21	16	01.0000	37.5700	-118.7300	n c	4.93	Mw	ML BRK	5.00	ML	UCBMLT	UCB
95	1941	12	31	6	48	44.0000	37.5700	-118.7300	n c	5.43	Mw	ML BRK	5.50	UK	PAS	UCB
96	1942	7	11	16	41	48.0000	38.3000	-116.1000	n c	5	Mw	MD UNR	5.00	ML	PAS	UNRENO
97	1942	8	18	21	55	24.0000	38.6000	-118.5000	n c	5	Mw	MD UNR	5.00	UK		UNRENO
98	1942	9	9	5	15	00.0000	36.0000	-114.7000	n c	5	Mw	ML RWL	5.00	ML	RWL	MER
99	1943	5	31	20	16	53.0000	37.3800	-118.6000	n c	4.44	Mw	ML BRK	5.00	MI	PAS	UCB
100	1943	8	9	5	30	04.0000	38.2000	-118.2000	n c	5.5	Mw	MD UNR	5.50	ML	UCBMLT	UNRENO
101	1943	8	29	3	45	13.0000	34.2667	-116.9667	n c	5.5	Mw	ML PAS	5.50	ML	PAS	CIT
102	1943	12	22	15	50	28.0000	34.3333	-115.8000	n c	5.5	Mw	ML PAS	5.50	ML	PAS	CIT

TABLE G-2
EARTHQUAKES OF MAGNITUDE 5 OR GREATER IN THE YUCCA MOUNTAIN HISTORICAL SEISMICITY CATALOGUE

Cat. No.	Year	Mo.	Day	Time (GMT)			Lat.	Long.	Depth	Mag1	Scale	Mag1 Source	Mag2	Scale	Mag2 Source	Location
				Hour	Min	Sec			(km)							Source
103	1945	3	20	21	55	07.0000	34.2500	-116.1667	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
104	1945	6	14	3	30	13.0000	37.0833	-117.5000	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
105	1946	3	15	13	21	00.9000	35.7533	-117.9863	n c	5.2	Mw	ML PAS	5.20	ML	PAS	CIT
106	1946	3	15	13	49	35.9000	35.7252	-118.0547	22	6.06	Mw	STOCOF	6.30	ML	PAS	CIT
107	1946	3	15	14	0	35.4000	35.7148	-118.0740	n c	5.3	Mw	ML PAS	5.30	ML	PAS	CIT
108	1946	3	15	19	18	53.6000	35.7143	-117.9772	n c	5.4	Mw	ML PAS	5.40	ML	PAS	CIT
109	1946	3	15	21	54	33.4000	35.7513	-118.0290	n c	5.2	Mw	ML PAS	5.20	ML	PAS	CIT
110	1946	3	16	9	46	17.9000	35.7450	-118.0388	n c	5.1	Mw	ML PAS	5.10	ML	PAS	CIT
111	1946	3	17	14	45	53.0000	38.3000	-117.9000	n c	5	Mw	MD UNR	5.00	MD	UNRENO	UNRENO
112	1946	3	18	15	50	42.6500	35.7467	-117.9085	4.4	5.3	Mw	ML PAS	5.30	ML	PAS	CIT
113	1946	7	18	14	27	58.0000	34.5333	-115.9833	n c	5.6	Mw	ML PAS	5.60	ML	PAS	CIT
114	1947	1	11	11	57	48.0000	37.6000	-118.4300	n c	4.34	Mw	ML BRK	5.00	MI	CDMG	UCB
115	1947	4	10	15	58	06.0000	34.9833	-116.5500	n c	6.51	Mw	STOCOF	6.20	ML	PAS	CIT
116	1947	4	10	16	3	00.0000	34.9667	-116.5500	n c	5.1	Mw	ML PAS	5.10	ML	PAS	CIT
117	1947	4	10	17	18	22.0000	34.9500	-116.5333	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
118	1947	4	11	7	47	00.0000	34.9667	-116.5500	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
119	1948	11	2	16	48	08.0000	35.9830	-114.7830	n c	5	Mw	ML RWL	5.00	ML	RWL	MER
120	1949	2	11	21	5	24.0000	37.0833	-117.7500	n c	5.6	Mw	ML PAS	5.60	ML	PAS	CIT
121	1949	11	2	2	30	-01.0000	37.1063	-113.5735	n c	4.7	Mw	ML PAS	5.00	MI	PAS	UVUTAH
122	1951	12	28	2	49	27.0000	37.5700	-118.5800	n c	5.13	Mw	ML BRK	5.20	ML	PAS	UCB
123	1952	2	20	13	41	11.0000	36.0000	-114.7000	16	3.6	Mw	ML PAS	5.00	UK	RWL	MER
124	1952	5	24	4	15	15.4400	35.9390	-114.7320	8	4.9	Mw	ML PAS	5.00	MI	SGB	MER
125	1952	7	21	12	5	31.0000	35.0000	-119.0000	n c	6.27	Mw	STOCOF	6.40	ML	PAS	CIT
126	1952	7	21	12	19	36.0000	34.9500	-118.8667	n c	5.3	Mw	ML PAS	5.30	ML	PAS	CIT
127	1952	7	21	15	13	58.0000	35.1833	-118.6500	n c	5.1	Mw	ML PAS	5.10	ML	PAS	CIT
128	1952	7	21	17	42	44.0000	35.2333	-118.5333	n c	5.1	Mw	ML PAS	5.10	ML	PAS	CIT
129	1952	7	21	19	41	22.0000	35.1333	-118.7667	n c	5.5	Mw	ML PAS	5.50	ML	PAS	CIT
130	1952	7	23	0	38	32.0000	35.3667	-118.5833	n c	5.7	Mw	STOCOF	6.10	ML	PAS	CIT
131	1952	7	23	3	19	23.0000	35.3667	-118.5833	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
132	1952	7	23	7	53	19.0000	35.0000	-118.8333	n c	5.4	Mw	ML PAS	5.40	ML	PAS	CIT
133	1952	7	23	13	17	05.0000	35.2167	-118.8167	n c	5.76	Mw	STOCOF	5.70	ML	PAS	CIT
134	1952	7	23	18	13	51.0000	35.0000	-118.8333	n c	5.2	Mw	ML PAS	5.20	ML	PAS	CIT
135	1952	7	25	13	13	08.2500	35.3108	-118.4992	2.8	5	Mw	ML PAS	5.00	ML	PAS	CIT
136	1952	7	25	19	9	44.6200	35.3173	-118.4945	5.5	5.76	Mw	STOCOF	5.70	ML	PAS	CIT

TABLE G-2
EARTHQUAKES OF MAGNITUDE 5 OR GREATER IN THE YUCCA MOUNTAIN HISTORICAL SEISMICITY CATALOGUE

Cat. No.	Year	Mo.	Day	Time (GMT)			Lat.	Long.	Depth	Mag1	Scale	Mag1 Source	Mag2	Scale	Mag2 Source	Location
				Hour	Min	Sec			(km)							Source
137	1952	7	25	19	43	23.6700	35.3153	-118.5158	11.2	5.94	Mw	STOCOF	5.70	ML	PAS	CIT
138	1952	7	29	7	3	47.0000	35.3833	-118.8500	n c	6.27	Mw	STOCOF	6.10	ML	PAS	CIT
139	1952	7	29	8	1	46.0000	35.4000	-118.8167	n c	5.1	Mw	ML PAS	5.10	ML	PAS	CIT
140	1952	7	31	12	9	09.0000	35.3333	-118.6000	n c	5.8	Mw	ML PAS	5.80	ML	PAS	CIT
141	1952	8	22	22	41	24.0000	35.3333	-118.9167	n c	5.78	Mw	STOCOF	5.80	ML	PAS	CIT
142	1952	8	23	10	9	07.1500	34.5193	-118.1982	13.1	5	Mw	ML PAS	5.00	ML	PAS	CIT
143	1952	10	20	7	26	39.0000	36.0000	-114.8000	n c	4.9	Mw	MD UNR	5.00	MS	BRP	MER
144	1954	1	27	14	19	48.0000	35.1500	-118.6333	n c	5	Mw	ML PAS	5.00	ML	PAS	CIT
145	1954	5	23	23	52	43.0000	34.9833	-118.9833	n c	5.1	Mw	ML PAS	5.10	ML	PAS	CIT
146	1954	7	20	0	11	38.0000	38.2000	-116.4000	n c	5	Mw	MD UNR	5.00	MD	UNRENO	UNRENO
147	1954	12	16	11	7	11.0000	39.2800	-118.1200	15	7.1	Mw	DOSSM1	7.30	MD	UNRENO	UNRENO
148	1954	12	16	11	11	00.0000	39.6700	-117.9000	12	6.8	Mw	DOSSM1	-9.99			DOSSM1
149	1955	1	1	12	13	54.0000	39.0000	-118.0000	n c	5.1	Mw	MD UNR	5.10	MD	UNRENO	UNRENO
150	1955	1	9	9	10	50.0000	39.0000	-118.0000	n c	5	Mw	MD UNR	5.00	MI	USN	UNRENO
151	1955	6	19	19	20	00.0000	38.9700	-118.2500	n c	5.2	Mw	MD UNR	5.20	ML	UCBMLT	UNRENO
152	1955	6	19	19	25	16.0000	39.0000	-118.5000	n c	4.93	Mw	ML BRK	5.00	ML	UCBMLT	DNAG
153	1955	8	8	10	35	38.0000	38.3300	-118.6700	n c	5.2	Mw	MD UNR	5.20	ML	UCBMLT	UNRENO
154	1956	12	31	17	37	45.0000	38.2500	-118.9300	n c	5	Mw	MD UNR	5.00	MD	UNRENO	UNRENO
155	1956	12	31	17	39	24.0000	38.2800	-118.9700	n c	5.1	Mw	MD UNR	5.10	MD	UNRENO	UNRENO
156	1958	4	19	9	1	02.0000	36.0000	-114.8000	n c	4.9	Mw	MD UNR	5.00	MS	BRP	MER
157	1959	6	18	0	29	40.0000	37.5500	-118.5700	n c	4.64	Mw	ML BRK	5.00	MI	BRK	UCB
158	1959	6	23	15	4	34.0000	38.9300	-118.7700	n c	5.4	Mw	DOSSM1	5.50	UK	BRK	DNAG
159	1959	8	4	7	36	59.0000	37.3500	-118.5500	n c	5.2	Mw	MD UNR	5.20	ML	PAS	UNRENO
160	1960	1	26	4	17	36.0000	38.0000	-116.5000	n c	4.9	Mw	MD UNR	5.00	MI	SGB	UNRENO
161	1960	6	5	7	47	07.0000	37.5200	-118.7300	n c	5.13	Mw	ML BRK	5.20	ML	PAS	UCB
162	1961	1	28	8	12	46.1800	35.7782	-118.0487	5.5	5.3	Mw	ML PAS	5.30	ML	PAS	CIT
163	1961	2	2	0	4	16.0000	37.4500	-118.6300	n c	5.23	Mw	ML BRK	5.30	ML	UCBMLT	UCB
164	1961	2	2	0	7	42.0000	37.4200	-118.6700	n c	5.03	Mw	ML BRK	5.10	ML	PAS	UCB
165	1962	4	13	15	38	51.9000	38.2200	-119.4500	n c	5.03	Mw	ML BRK	5.10	ML	UCBMLT	UCB
166	1963	3	25	9	28	42.7700	36.0180	-114.7710	8	4.9	Mw	ML PAS	5.00	MS	BRP	MER
167	1963	4	13	15	38	51.9000	38.2160	-119.4330	16	5.1	Mw	MD UNR	5.10	MD	UNRENO	UNRENO
168	1963	12	6	8	34	25.7000	37.5400	-118.4200	n c	4.7	Mw	MD UNR	5.00	MI	PAS	UNRENO
169	1964	3	22	16	30	55.9000	38.7000	-118.8000	n c	5.5	Mw	MD UNR	5.50	MD	UNRENO	UNRENO
170	1964	10	23	13	57	05.0000	38.7000	-118.1000	n c	5.3	Mw	MD UNR	5.30	ML	BRK	UNRENO