RAS 5776 72-22-ISFSI - Staff Exhibit JJ - Rec'd 5/13/02

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Scientific Notebook 353 **August 1, 2000**
Initial Entry: John Stamatakos
Project: 20-01405-041 Private Fuel Storage Facility

Title: Evaluation of PFS Earthquake Analyses for SER on PFSF License Application (SAR)

The entries in this notebook document work done in support of the staff evaluation of the PFS seismic hazard studies for the NRC Safety Evaluation Report (SER) on the Utah PFSF License Application (SAR) and supporting document titled "*Seismic Motion and faulting hazard at Private Fuel Storage Facility in the Skull Valley Indian Reservation, Toelle County, Utah.*"

JS 8/1/2000

Dr. John Stamatakos, Ph.D. - CNWRA Senior Research Scientist
Dr. Rui Chen - CNWRA Senior Research Scientist
Mr. Peter La Femina - CNWRA Research Scientist

Dr. Martin McCann, Ph.D. - Consultant, Jack R Benjamin and Associates, Menlo Park, California

December 18, 2001

Note: All data and reviews pertaining to this project to date are documenting in CNWRA reports (Draft and Final SER, and Stamatakos et al., 1999).No additional calculations or analyses were permed in support of these documents that required entry into this Scientific Notebook. In support of the review of the Supplemental SER, we carried out two additional analyses. These additional analyses will be added to the revision of the Stamatakos et al (1999) report if a revision is published. Current schedule for hearings on the seismic issues may preclude revision of that report. Thus, the additional analysis were added to this notebook for proper QA documentation.

JS 12/18/01

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Scientific Notebook 353
December, 18, 2001
Entry By: John A. Stamatakos

Purpose: To document comparison of Private Fuel Storage Facility (PFS) probabilistic seismic hazard results (PSHA) to other PSHA results for the western United States.

Investigator: John A. Stamatakos

Background Information

In the revisions to the SAR by the applicant completed in the Spring of 2001, the seismic hazard increased by a large amount. The large increase in the hazard appears to be primarily from a revision to the site response models. For example the peak ground acceleration for the 2000 yr return period rose 35% from0.528 g to 0.711g. The following Table summarizes some of the changes in spectral acceleration.

Comparison of PSHA for 2,000-yr Return Period Spectral Acceleration (with 5% Damping)

Period (sec)	**Horizontal Ground Motion (g)**		**Vertical Ground Motion (g)**	
	SAR Revision 22	**SAR Revision 18 (former design)**	**SAR Revision 22**	**SAR Revision 18 (former design)**
PGA	0.711	0.528	0.695	0.533
0.1	1.541	1.046	1.752	1.369
0.5	1.045	1.166	0.509	0.476
2.0	0.164	0.272	0.088	0.088

Data and Procedure:

1. To assess these ground motion results, I plotted the hazard curves for the Skull Valley site against PSHA hazard curves for other sites in the western United States. The skull valley data were provided to me on disk within the responses to RAI package following the March, 2001 meeting in San Antonio.

A set of seven hazard curves were provided to me from Dr. M. McCann n September, 30, 2001. Dr. McCann indicated that the data were from 1993.

The following table is a printout of the Excell work sheet of the data provided to me by Dr. McCann.

Peak ground Accelerations for Seven Western United States Sites

No.	Site	Ground Motion/ Curve Type												
1	SF Bay Bridge	PGA (cm/s/s)	34.34	98.1	196.2	392.4	588.6	784.8	912.33					
		Mean	1.00E-01	6.00E-02	2.22E-02	4.81E-03	1.00E-03	2.35E-04	1.00E-04					
2	Diablo Canyon	PGA (cm/s/s)	109	218	327	436	545	654	763	872	981	1090	1199	1308
		80th Fractile	2.00E-02	1.08E-02	6.00E-03	3.16E-03	1.63E-03	9.00E-04	4.33E-04	2.00E-04	9.00E-05	3.94E-05	1.33E-05	4.00E-06
3	Los Alamos Site 1	PGA (cm/s/s)	55.9	77.5	98.1	196.2	294.3	343.35	392.4	600.37				
		Mean	8.51E-03	5.44E-03	3.30E-03	8.95E-04	2.80E-04	1.86E-04	1.04E-04	1.00E-05				
4	Hanford Site A	PGA (cm/s/s)	19.62	98.1	196.2	294.3	392.4	490.5	686.7	981				
		Mean	8.58E-03	1.44E-03	4.41E-04	1.70E-04	7.59E-05	3.66E-05	1.00E-05	2.42E-06				
5	INEL 1 (LLNL)	PGA (cm/s/s)	50	80	150	250	300	400	500	600	700	800	1000	
		Mean	5.00E-03	2.00E-03	4.00E-04	1.16E-04	6.03E-05	2.82E-05	1.37E-05	8.41E-06	5.32E-06	3.14E-06	1.53E-06	
6	INEL 1 (WCC)	PGA (cm/s/s)	49.05	98.1	196.2	294.3	392.4	490.5	588.6	686.7	784.8			
		Mean	4.16E-03	1.58E-03	4.00E-04	1.58E-04	8.48E-05	4.48E-05	2.42E-05	1.58E-05	1.00E-05			
7	PALO VERDE	PGA (cm/s/s)	10	20	50	70	100	150	200	300	500	1000		
		Mean	3.50E-02	7.20E-03	1.00E-03	5.40E-04	2.80E-04	1.30E-04	6.90E-05	2.10E-05	3.10E-06	2.10E-07		

SF Bay Bridge - Geomatrix Consultants, Inc., PSHA for the San Francisco Bay Bridge, prepared for the California Department of Transportation.

Diablo Canyon - Pacific Gas and Electric Company, "Final Report of the Diablo Canyon Long Term Seismic Program," Docket Nos. 50-275 and 50-323, San Francisco, CA, July 1988.

Los Alamos Site 1 - Woodward Clyde Consultants, Inc., PSHA for the Los Alamos Site, New Mexico, date unknown.

Hanford Site A - Geomatrix Consultants, Inc., "Seismic Hazards Assessment for WNP-3, SATSOP Washington," prepared for Washington Public Power Supply System, Richland, WA, date unknown.

INEL 1 (LLNL) - Lawrence Livermore National Laboratory, date unknown.

INEL 1 (WCC) - Woodward Clyde Consultants, Inc., PSHA for the INEL Site, Idaho, date unknown.

Palo Verde - Risk Engineering, Inc., PSHA for the Palo Verde Nuclear Power Plant Site, Arizona, date unknown.

2. In addition to the data provided to me by Dr. McCann, I gather one additional seismic hazard curve from a publication I found on the web published by the United States geological Survey

Frankel, A., S. Harmsen, C. Mueller, T. Barnhard, E.V. Leyendecker, D. Perkins, S. Hanson, N. Dickman, M. Hopper. 1997. *USGS National Seismic Hazard Maps: Uniform Hazard Spectra, De-aggregation, and Uncertainty*, Proceedings of FHWA/NCEER Workshop on the National Representation of Seismic Ground Motion for New and Existing Highway Facilities, NCEER Technology Report 97-0010, pp. 39-73, http://geohazards.cr.usgs.gov/eq/uncertainties/nceer.html).

The following figure (figure 3) is from that paper. From the figure I digitized values for the Salt Lake City Hazard curve, and converted them to cm/s/s 1 g = 9.8 m/s/s = 980 cm/s/s).

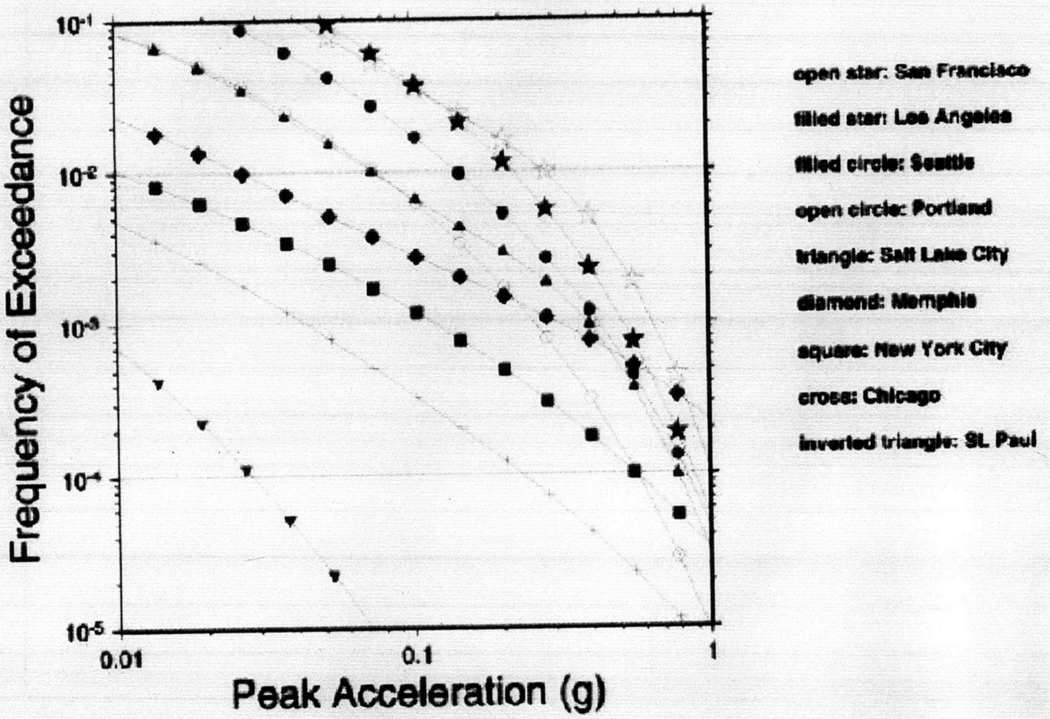

Figure 3. Mean hazard curves for selected cities.

Table of PGA values derived from Frankel et al (1997) curve.

PGA (cm/s/s)	Probability
0	0.064
18.62	0.052
23.52	0.0325
36.26	0.0225
49.98	0.014
73.5	0.01
107.8	0.0064
127.4	0.0042
205.8	0.0028
264.6	0.00175
392	0.00095
529.2	0.00035
764.4	1.00E-04

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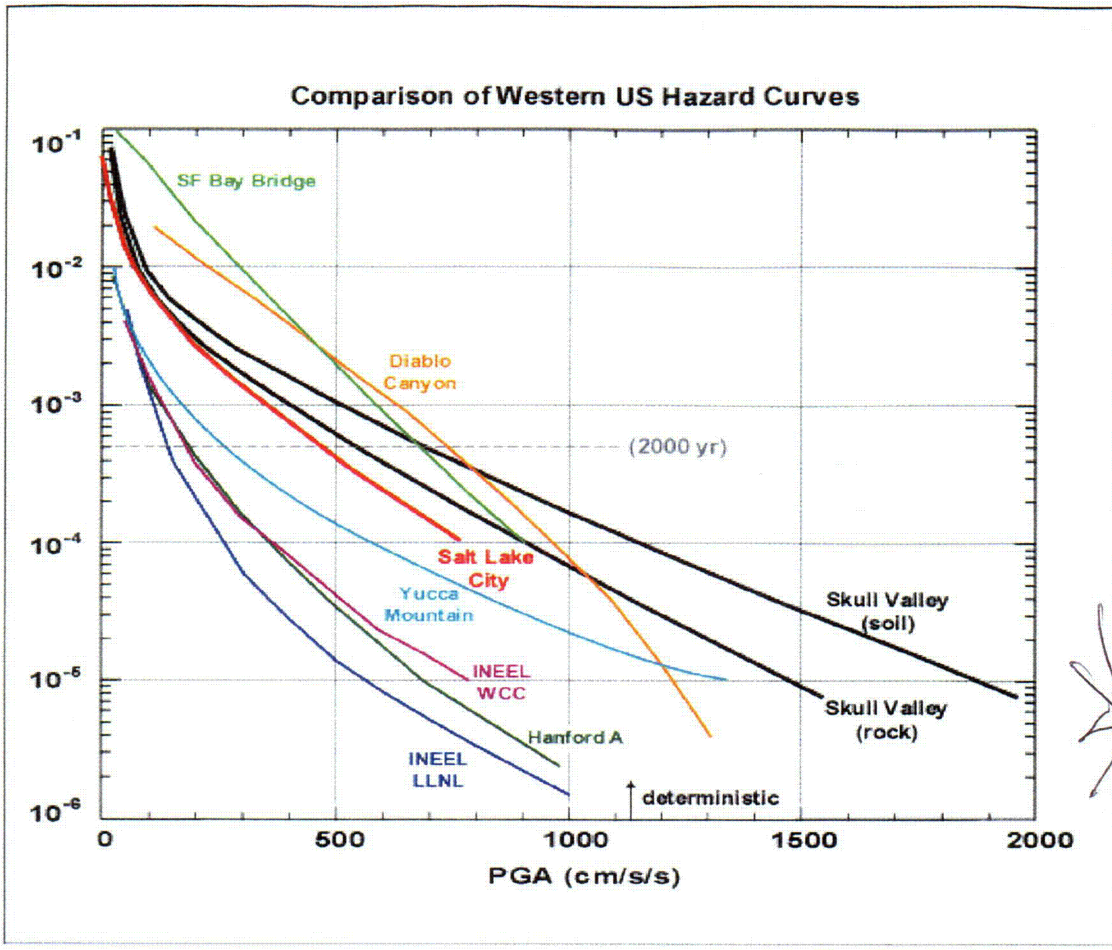
3. I then plotted all the data (using Kaleida Graph, version 3.09) to produce the following graph.



4. Based on deposition testimony by the State during October, 2001, I learned of a seismic hazard study completed by Dames and Moore in 1996 as part of the I-15 Corridor construction project.

Dames & Moore, Inc. 1996. *Final Report Seismic Hazard Analysis of the I-15 Corridor 10600 South to 500 North Salt Lake County, Utah.* UT-47026. Report submitted to Parsons Brinckerhoff. Salt Lake City, UT: Dames & Moore.

In that report, table 4.3 on p. 4-9 provides a summary of PGA values for 9 sites along the I-15 interstate highway corridor for probabilities of exceedence values at approximately 500, 1000, and 2500 yrs. Those values (mean) are:

Site	PGA (mean)
	2500 yr
PB-1	0.654
PG17DhR-15A	0.686
PG17DH-7A	0.674
PB-2	0.65
PB-3	0.602
PB-4	0.575
PB-5	0.566
PG17DH-16A	0.562
PG17DH-17A	0.561

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CO1

Discussion

The results show the conservative nature of the applicant's source characterization and PSHA results presented in the SAR. This conservatism is evident when the results are compared to PSHA results for other sites in Utah, especially those in and around Salt Lake City. This a comparison shows that the seismic hazard in Skull Valley was calculated by the applicant to be higher than seismic hazard estimates that have been performed for sites at, or near, Salt Lake City, despite the fact that fault sources near Salt Lake City are larger and more active than fault sources near the PFS site. For example, the results of the applicant's PSHA for Skull Valley (Geomatrix Consultants, Inc., 2001a) suggest that it is 1.5 times more likely that a ground motion of 0.5g horizontal peak ground acceleration or greater will be exceeded at the PFS site (assuming hard rock site conditions), than at Salt Lake City, based on the USGS National Earthquake Hazard Reduction Program (Frankel et al., 1997).

Similarly, the 2000-yr horizontal peak ground acceleration for Skull Valley (soil hazard) as estimated by the applicant, is higher than the 2500-yr ground motions for the nine sites along the Wasatch Front that were evaluated as part of the Utah Department of Transportation I-15 Reconstruction Project (Dames & Moore, Inc., 1996). The ground motions estimated by the applicant in Skull Valley are higher than those for the I-15 corridor, despite the close proximity of Salt Lake City to the Wasatch fault, which has a slip rate nearly ten times larger than the Stansbury or East Faults (cf., Martinez et al., 1998; Geomatrix Consultants, Inc., 1999a) and is capable of producing significantly larger magnitude earthquakes than the faults near the PFS Facility site in Skull Valley (cf., Machette et al., 1991; Geomatrix Consultants, Inc., 1999a).

Geomatrix Consultants, Inc. 1999a. *Fault Evaluation Study and Seismic Hazard Assessment Private Fuel Storage Facility, Skull Valley, Utah.* San Francisco, CA: Geomatrix Consultants, Inc.

Machette, M.N., S.F. Personius, A.R. Nelson, D.P. Schwartz, and W.R. Lund. 1991. *The Wasatch fault zone, Utah-segmentation and history of Holocene earthquakes.* Journal of Structural Geology 13: 137-149.

Martinez, L., C. M. Meertens, and R. B. Smith. 1998. *Anomalous intraplate deformation of the Basin and Range-Rocky Mountain transition from initial GPS measurements,* Geophysical Research. Letters 24: 2741-2744.

12/18/01

Scientific Notebook 353
December, 18, 2001
Entry By: John Stamatakos

Purpose: Document Slip Tendency Analysis for Supplemental Safety Evaluation Report, Private Fuel Storage, Skull Valley, Utah.

Investigator: John A Stamatakos

Background Information

The previous entry shows concludes that the ground motion hazard for Skull Valley, as estimated by the applicant, is conservative. To assess potential conservatism in the applicant's calculations I performed a slip tendency analysis of the Skull Valley Site using the computer program 3DStress™ (version 1.3.3). The aim of the analysis was to determine if the faults in Skull Valley are in optimal orientations for future slip, given what is known about the current stress conditions in this part of the earth's crust in Utah. Specifically, I wanted to determining if assumptions made by the applicant about rupture initiation and fault length or fault segmentation led to overestimation of the ground motion hazard.

Procedures

The faults from Skull Valley and Central Utah (including the Wasatch fault) were digitized from maps provided in the SAR and rectified in Arcview (verison3.1). The digital files were then exported to 3dStress™. I then asked Dr. David Ferrill and Dr. Alan Morris to run the program for me to assess slip tendency values. The analysis was performed on October 11, 2001.

The slip tendency analysis (Morris et al., 1996) was completed using an interactive stress analysis program (3DStress™) that assesses potential fault activity relative to crustal stress. For Skull Valley, the stress tensor is defined with a vertical maximum principal stress (σ_1), a horizontal intermediate principal stress (σ_2) with azimuth of 355°, and a horizontal minimum principal stress (σ_3) with an azimuth of 085°. The stress magnitude ratios are $\sigma_1/\sigma_3 = 3.50$ and $\sigma_1/\sigma_2 = 1.56$. This orientation for the principal stresses was based on recent global positioning satellite information (Martinez, et al., 1998a). The slip tendency analysis assumed a normal-faulting regime, with rock density equal to 2.7 g/cc, fault dip equal to 60°, water table at a depth of 40 m, and a hydrostatic fluid pressure gradient.

Software:

3DStress v.1.3.3

Stress Tensor Assumptions:

(i) Rock density = 2.7 g/cc
(ii) Water table depth = 40 m
(iii) Stress tensor calculated for depth of 5 km.
(iv) Fluid pressure gradient is hydrostatic
(v) Maximum slip tendency must be sufficient to produce slip on ideally oriented faults (Ts max

greater than or equal to 0.67)

(vi) Normal faulting stress regime - σ_1 vertical, lithostatic

(vii) Faults dip 60°

(viii) Magnitude of intermediate principal stress is centered between max and min principal stresses

Effective Stress Tensor (corrected for fluid pressure):

Effective σ_1 = vertical, 84 Mpa
Effective σ_2 = azimuth 355, 54 Mpa
Effective σ_3 = azimuth 085, 24 MPa

Martinez, L., C. M. Meertens, and R. B. Smith. 1998. *Anomalous intraplate deformation of the Basin and Range-Rocky Mountain transition from initial GPS measurements,* Geophysical Research. Letters 24: 2741-2744.

Morris, A., D.A. Ferrill, and D.B. Henderson. 1996. *Slip-tendency analysis and fault reactivation.* Geology 24, 275-278.

The following two pages are figures from 3DStress™ that summarize the slip tendency results. The first figure is an electronic snapshot of the screen showing the results of the analysis. The second figure is a summary shot showing a close-up of Skull Valley along site the central Utah regional map.

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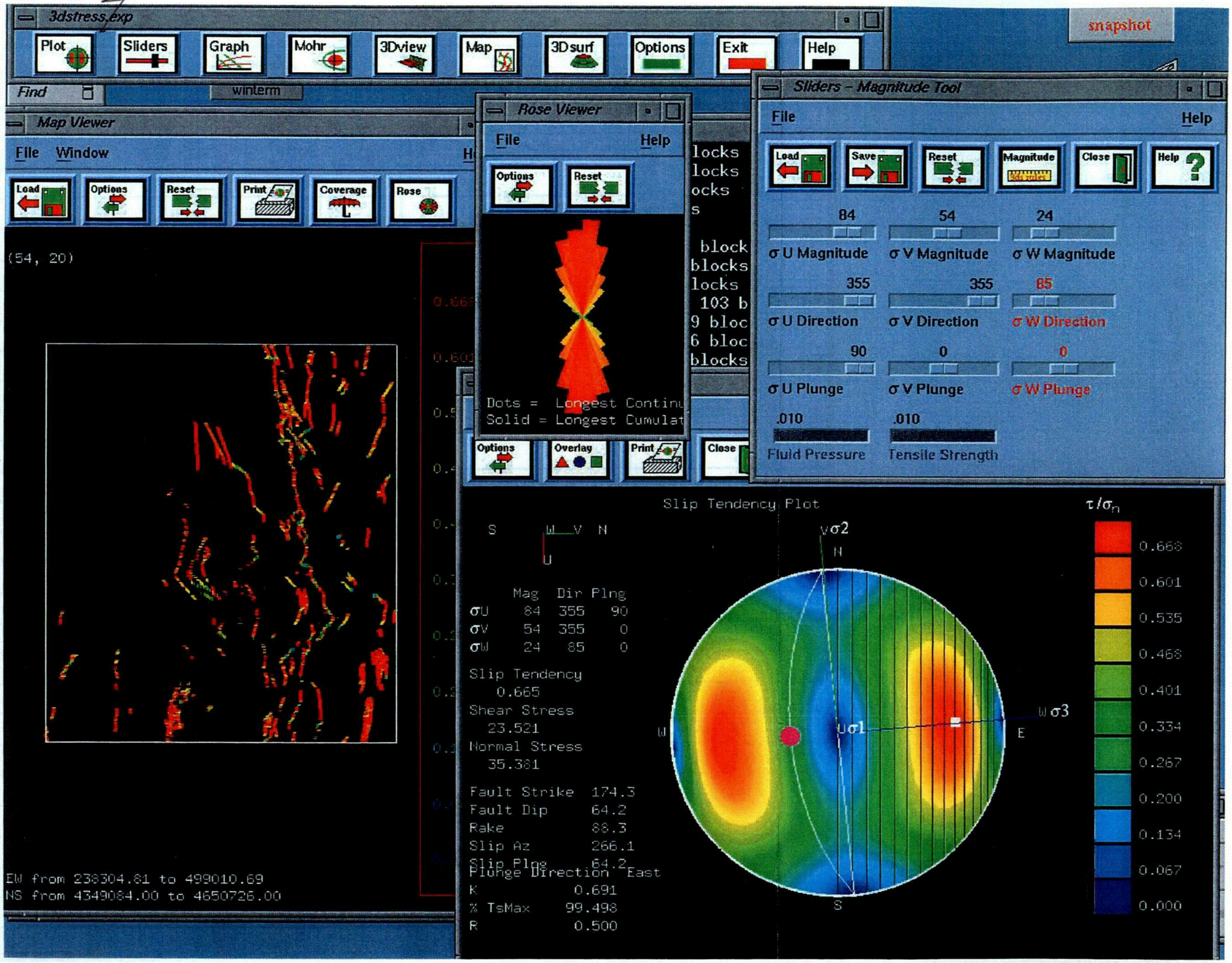
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NS from 4349084.00 to 4650726.00
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File
Help
Options
Reset
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Sliders - Magnitude Tool
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Magnitude
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σ V Magnitude
σ W Magnitude
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355
85
σ U Direction
σ V Direction
σ W Direction
90
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Tensile Strength
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σV 54 355 0
σW 24 85 0
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Shear Stress
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Normal Stress
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Fault Strike 174.3
Fault Dip 64.2
Rake 88.3
Slip Az 266.1
Slip Plng 64.2
Plunge Direction East
K 0.691
% TsMax 99.498
R 0.500
Vσ2
N
Uσ1
Wσ3
E
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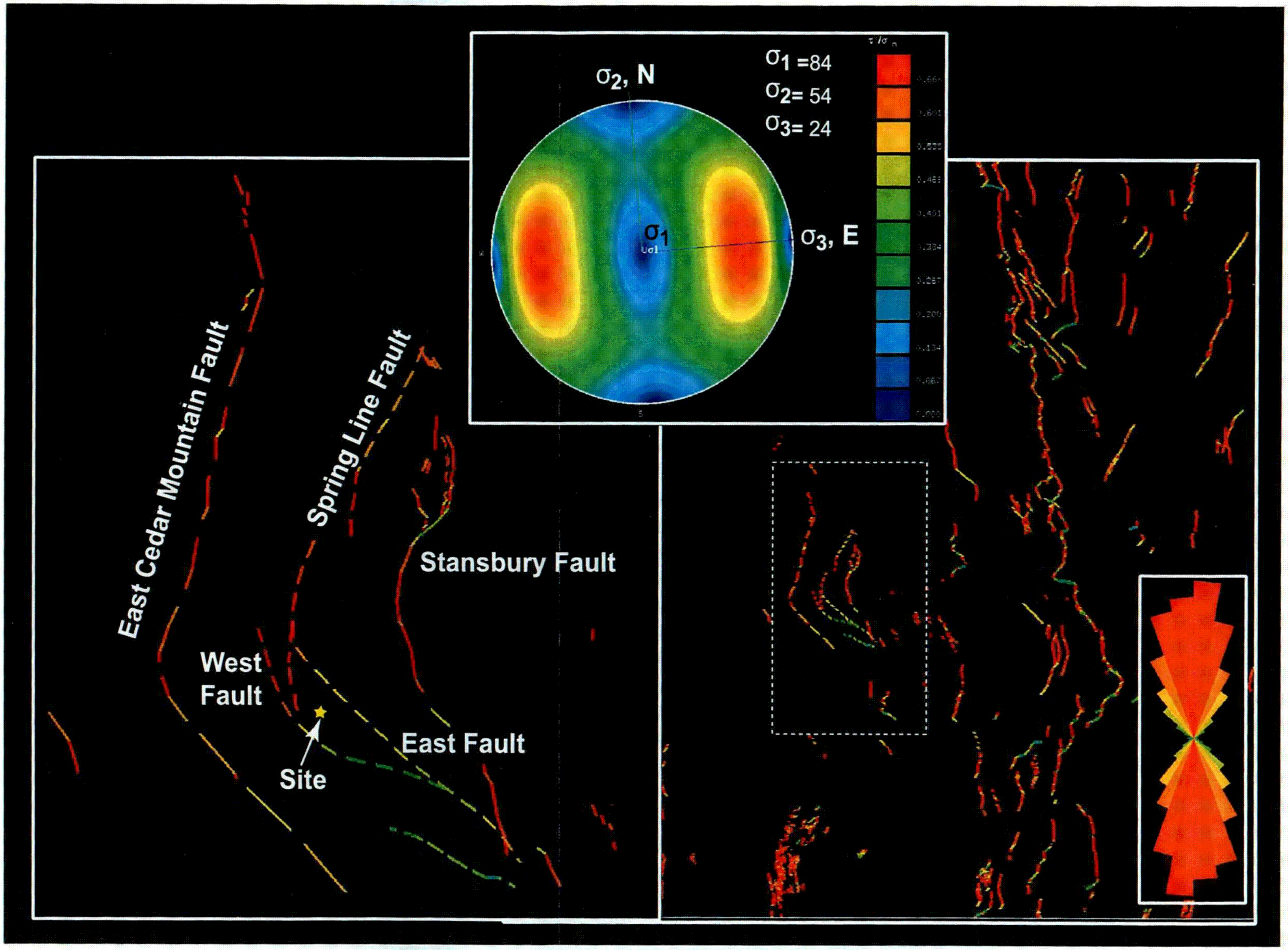
W
τ/σn
0.668
0.601
0.535
0.468
0.401
0.334
0.267
0.200
0.134
0.067
0.000

CO2


σ2, N
σ1 =84
σ2= 54
σ3= 24
σ1
σ3, E
East Cedar Mountain Fault
Spring Line Fault
Stansbury Fault
West Fault
East Fault
Site

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C03

Discussion

In slip tendency analysis, the underlying assumption is that the regional stress state controls slip tendency and that there are no significant deviations due to local perturbations of the stress conditions. This assumption is supported by a similar slip tendency analysis of the Wasatch fault, which shows highest slip tendency values for the segments of the fault considered to be most active (Machette et al., 1991).

The slip tendency analysis shows that segments of the East fault and the East Cedar Mountain fault nearest the PFS site have relatively low slip tendency values compared to segments farther north in Skull Valley. As discussed in the following sections on site-to-source distances and maximum magnitudes, these results indicate that the seismic source characterization of the PSHA study conducted by Geomatrix Consultants, Inc. (1999a, and 2001a) is conservative. Three areas of conservatism are the distribution of site-to-source distance, maximum magnitude earthquakes, and potential of the West fault as a seismogenic source (discussed in Stamatakos et al., 1999).

Distributions of Site-to-Source Distances

Results of the slip tendency analysis indicate that fault segments with approximately North-South strikes (azimuth = 175°) are optimally oriented for future fault slip. Faults with north northeast-south southwest strikes have high slip tendency values. In contrast, fault segments with northwest-southeast strikes, such as the East fault near the PFS Facility site and the southern segments of the East Cedar Mountain fault also near the PFS Facility site, have relatively low slip tendency values. Therefore, these fault segments are less likely to slip in the future than fault segments further from the site. Fault rupture close to the site greatly influence the seismic hazard. The closer the earthquake is to the site, the larger the resulting ground motions compared to an equal magnitude earthquake on a fault segment farther away from the site.

In the site-to-source distributions used in the ground motion attenuation equations, Geomatrix Consultants, Inc. (1999a) assumed uniform distributions of earthquake ruptures along active fault segments. Given the slip tendency analysis described above, this assumption by Geomatrix Consultants, Inc. (1999a) is conservative. The staff concludes that seismic source models that incorporate slip tendency would result in a lower ground motion hazard than the one developed by the applicant.

Maximum Magnitude

The slip tendency results suggest that Geomatrix Consultants, Inc. (1999a) may have overestimated the maximum magnitude of the East and East Cedar Mountain faults near the PSFS site. In the SAR, the applicant first developed conceptual models of the physical dimensions of fault rupture—either rupture area or trace length of surface fault rupture—based on the geologic record (Geomatrix Consultants, Inc.,1999a). Second, the applicant developed distributions of maximum magnitudes for each active fault using empirical scaling relationships developed from the magnitudes and associated rupture dimensions of historical earthquakes (e.g., Wells and Coppersmith,1994). In developing the fault segment models, the applicant conservatively assumed that the entire mapped length of the surface trace length represents active fault segments. Thus, these maximum fault dimensions produce conservative estimates of maximum magnitude.

The slip tendency analysis indicates that parts of the East and East Cedar Mountain faults near the

PFS Facility site have relatively low slip tendency values. Thus, these faults may be smaller than in the fault models used by the applicant to estimate maximum magnitude. Fault rupture models developed using slip tendency analysis would therefore lead to fault segment models with smaller rupture dimensions (length or area) than those used by Geomatrix Consultants, Inc. (1999a). Because distributions of maximum magnitude for each active fault are derived from empirical scaling relationships of rupture area or rupture length (e.g., Wells and Coppersmith,1994), application of the slip tendency analysis would thereby result in smaller predicted maximum magnitudes than those developed by the applicant. Smaller maximum magnitudes would reduce the overall ground motion hazard.

In summary, the staff found that the applicant's considerations of seismic source characteristics and associated uncertainties provide reasonable assurance that all significant sources of future seismic activity have been identified and their characteristics and associated uncertainties are adequately or conservatively described and appropriately included in the evaluation of the seismic ground motion hazard. Stamatakos et al. (1999) provides more details of PFS's seismic source characterization and the staff's independent sensitivity analyses.

Geomatrix Consultants, Inc. 1999a. *Fault Evaluation Study and Seismic Hazard Assessment Private Fuel Storage Facility, Skull Valley, Utah.* San Francisco, CA: Geomatrix Consultants, Inc.

Machette, M.N., S.F. Personius, A.R. Nelson, D.P. Schwartz, and W.R. Lund. 1991. *The Wasatch fault zone, Utah-segmentation and history of Holocene earthquakes.* Journal of Structural Geology 13: 137-149.

Stamatakos, J., R. Chen, M. McCann, and A.H. Chowdhury. 1999. *Seismic Ground Motion at the Private Fuel Storage Facility Site in the Skull Valley Indian Reservation.* San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Wells, D.W., and K.J. Coppersmith. 1994. New empirical relationships among magnitude, rupture length, rupture width, rupture area, and surface displacement. *Bulletin of the Seismological Society of America* 84: 974–1,002.

12/18/01

I have reviewed scientific notebook 353 and find it in compliance with QAP-001. There is sufficient information regarding procedure used for conducting the research and acquiring and analyzing the data so that another qualified scientist could repeat the activity or activities recorded in this scientific notebook.

H. Lawrence McKague 09/05/01

H. Lawrence McKague
GLGP Element Manager