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Southern Great Basin Seismic Network Operations

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1.0 Introduction

QAP-3.0 (*Scientific Investigation Control*) of the University and Community College System of Nevada (UCCSN) Quality Assurance (QA) program requires that, prior to initiating work, a Scientific Investigation Plan (SIP) must be prepared and approved. This SIP is intended to cover the seismic monitoring task performed by the Nevada Seismological Laboratory (NSL). The purpose of this SIP is to describe the high-level planning for the overall task such that it can be referred to by individual scientific notebooks. Due to the continuation nature of this task, this SIP contains language that may be considered generic so that new subtasks can be initiated within an established framework without revision of this SIP. The work described in this SIP, except as noted, is subject to UCCSN QA program requirements.

The seismic monitoring task is an ongoing study that was initiated in the 1980's. NSL has performed the task since late 1992, first under USGS QA procedures and then under M&O QA procedures. This work transitioned to the UCCSN QA program on 11/01/99 under the first DOE/UCCSN Cooperative Agreement. This SIP applies to the second Cooperative Agreement, initiated on 10/01/2003. Work under this SIP is designed to provide confirmatory information supporting previously gathered information or to provide new information relevant to the DOE licensing application or to performance confirmation of the repository design.

2.0 Scope, Objectives, and Subtasks

2.1 Scope

This SIP is applicable to current seismicity work specified in the DOE Cooperative Agreement grant. The work encompasses several aspects of seismological monitoring and analysis, including real-time earthquake monitoring, strong-motion data collection and analysis, seismic attenuation investigations, and characterization of earthquake source mechanics. The work scope is contained in the current cooperative agreement proposal sent by the NSL to the UCCSN administrators. Generic subtasks are itemized in section 2.3 below.

2.2 Objectives

The objectives of the work are to: 1) continuously monitor current seismicity with a high-quality seismic network and publish a yearly catalog of earthquakes for the vicinity of Yucca Mountain, 2) collect strong-motion seismic data in the vicinity of Yucca Mountain and report on its implications, and 3) record and analyze seismic signals for determining geologic structure, the nature of stress, and seismic properties relevant to repository performance.

2.3 Subtasks

Subtasks for the current work are described in "Description for the U. S. DOE/UCCSN Cooperative Agreement, Task ORD-FY04-006: Southern Great Basin Seismic Network Operations" and are summarized below:

1) Record and archive data from a permanent seismic network consisting of approximately 30 digital and 10 analog seismic stations and from a network of approximately 18 strong-motion sites.

2) Process seismic data obtained from the permanent network into a preliminary earthquake bulletin.

3) Maintain the seismic stations, the strong-motion stations, the telemetry network, and the computing lab.

4) Prepare and submit a seismicity report on a yearly basis.

5) Maintain and collect data from the nine accelerometers at three boreholes on the pad at the north portal of the ESF.

6) Submit a report on observations through 12/31/2003 made with the borehole accelerometers.

7) Complete a two-year study on kappa in the Yucca Mountain region and submit a final report, including microtremer velocity surveys for SGBDSN stations.

8) Implement a recording system at the well UZ-16 and collect data from the downhole accelerometers.

9) Prepare and submit high-quality papers to peer-reviewed journals on seismic data and interpretations in the YM region.

10) Perform a multiyear telemetry upgrade in order to take advantage of IP packet transmission for the entire YM seismic monitoring network.

All of the above are quality-affecting, except subtasks 9 and 10. This work, except for 9 and 10 is subject to UCCSN Quality Assurance (QA) program requirements. This SIP presents an independent confirmatory study supporting previously gathered information. Prior results were documented under Task 12 of the first Cooperative Agreement (1998-2003), under contract to the M&O (1995 to 1998), and under contract to the USGS (1992-1995).

3.0 Methods and Approach

The approach in the data collection subtasks is to utilize calibrated seismic instruments and high-resolution A/D systems to collect high-quality seismic data from digital sites and small number of non-calibrated seismic instruments to collect a lesser amount of data from a few older analog sites. These sites are all within approximately 50 km of Yucca Mountain. Data from nearly all of these sites will be telemetered continuously to the NSL for collection, processing, and archiving. It will be used to develop a catalog of earthquakes within and near the SGBDSN and to determine focal mechanisms of earthquakes. Data from eight sites of the strong-motion network will be collected at irregular intervals and processed at the NSL. It will be used to complement estimates of seismic hazard to critical facilities at the repository. Permanent stations will be maintained according to approved Implementing Procedures (IP), as listed in section 5.0.

Subtask 7 involves active seismic sources, albeit small, to estimate shallow shear-wave velocity. For these surveys seismic signals will be recorded by arrays with instrument spacing appropriate for waves that sample the subsurface to depths of interest. Seismic sources and the general recording concept will be planned according to the results desired, with data collection details presented in a scientific notebook. Observed waves will be inverted for velocity and perhaps attenuation as a function of depth. Raw data will be collected with stand-alone portable recorders and with standard engineering refraction equipment. Absolute time will be provided by GPS clocks. Site-specific requirements for recorder configuration and performance checks will be described in the scientific notebook**.** Reduction of data collected for defining earth properties, and possibly source characteristics, will be documented in scientific notebooks.

Whether acquired by permanent or portable equipment, processing of data will be done with acquired and developed seismological software (see Section 10.0); usage is described in implementing procedures and scientific notebooks. Raw and certain processed data will be submitted to the RPC. Developed data will be prepared for submission to the Technical Data Management System, as specified in the implementing procedures. Technical reports, as prescribed in annual funding workscopes, will be prepared and submitted according to QA procedures.

The investigation on kappa and stress-drop will involve the data developed from the permanent monitoring network and from portable experiments conducted by NSL personnel over the previous years. It will also involve data from the ANZA monitoring network in California as a means of comparison, and possibly from international strong-motion networks. External datasets will be qualified or accepted in accordance with the applicable QA procedures. Software required to analyze the data will be qualified as needed. An effort integral to this investigation is the assessment of the shallow velocity structure at sites of both the Yucca Mountain seismic monitoring network and the ANZA network. This assessment will be done by microtremor seismic surveys. Software for analysis of the data from the surveys will be qualified by QA procedures. A final report will be prepared and submitted in FY04. A “white paper” prepared by John Anderson is attached to this SIP; this describes in detail the questions to be addressed, the data to be used, and the methods of analysis. An interim technical report was prepared in FY03 to describe the scientific results obtained by 06/30/2003.

The UZ-16 well will be outfitted with a 64-channel A/D data collection system to collect real-time seismic data from sensors already in the well at a sample rate of 500 sps. The development of this system will be documented in a scientific notebook. Developed software will be qualified by QA procedures in order that the collected data is Q. Preliminary observations and results for FY04 will be documented in the scientific notebook. Q data for significant events will be segregated for later study.

4.0 Applicable Standards and Criteria

There are no applicable standards or criteria for this task. All work will be conducted or supervised by professional seismologists, but there are no specific job skills required beyond those stated in the position descriptions filed with the UCCSN Training Coordinator.

5.0 Implementing Procedures/Scientific Notebooks

UCCSN Quality Assurance procedures (QAP) applicable to this SIP are listed in the references (Section 15.0). One or more of these procedures applies to the subtasks listed below, as appropriate. If a listed QAP is superseded by a new procedure issued during the course of the work described in this work plan, applicable work scope will be conducted in accordance with the new procedure.

Implementing procedures and scientific notebooks that are applicable to specific subtasks for NSL seismic monitoring are listed below.

1) Collect, Archive Raw Seismic Data from Permanent Network

IPR-001: *Operation of the Yucca Mountain Digital Seismic Network*
IPR-004: *Operation of the Yucca Mountain Strong Motion Network*
SN #UCCSN-UNR-053, "Seismic Monitoring Network Operations"

2) Process Seismic Data into Preliminary Earthquake Bulletin

IPR-001: *Operation of the Yucca Mountain Digital Seismic Network*
SN #UCCSN-UNR-053 -- same as for subtask 1

3) Operate and Maintain Seismic Stations and Telemetry Network

IPR-001: *Operation of the Yucca Mountain Digital Seismic Network*
SN #UCCSN-UNR-053 -- same as for subtask 1

4) Prepare and Submit Seismicity Report

IPR-002: *Determining the Location of Earthquakes Recorded by the Yucca Mountain Seismic Network*
IPR-003: *Determining the Magnitude of Earthquakes Recorded by the Yucca Mountain Seismic Network*

6) Prepare and Submit a Report on Borehole Operations

IPR-021: *Installation, Operation, and Maintenance of the Yucca Mountain Borehole Strong Motion Network*
SN #UCCSN-UNR-056, "Borehole Accelerometer Network Operations"

7) Complete and Submit the Final kappa Report

IPR-024: *Procedure for the Deployment of 'Texan' Seismic Microtremor Arrays*
SN #UCCSN-UNR-024

8) Implement Seismic Data Recording at UZ-16

SN #UCCSN-UNR-064, "Borehole UZ-16"

9) Prepare and Submit Papers to Peer-Reviewed Journals

non-QA

10) Upgrade Telemetry

non-QA

6.0 Equipment

Field equipment consists of:

* seismometers manufactured by Refraction Technology, Geotech Instruments, Guralp Instruments, Mark Products, Kinemetrics, and Nanometrics. The seismometers and accelerometers are checked for performance according to IPR-001, IPR-004, IPR-021, and IPR-024 and do not require calibration by a supplier.

* digital acquisition units manufactured by Refraction Technology, Quanterra, and Nanometrics. These units are controlled though IPR-001, IPR-004, IPR-021, and IPR-024 and do not require calibration by a supplier.

* GPS (Global Positioning System) units. The GPS does not require calibration. Operation is governed by IPR-001.

* digital multimeters. These meters were initially calibrated by a QSL (Quality Supplier List) supplier according to IPR-001 under the first Cooperative Agreement. Accuracy is to be within at least 1%. Thereafter, they are checked for accuracy according to IPR-001 and recalibrated only if the check indicates they are out-of-tolerance.

Problems that would impact usage of submitted data will be documented in accordance with UCCSN QAP-16.0 (*Nonconformance Reports and Trending*).

Laboratory equipment consists of telemetry equipment, computers, and standard peripherals. None of this laboratory equipment requires calibration.

7.0 Hold Points and Decision Points

There are no particular hold points or decision points in this task.

8.0 Records, Reports, and Deliverables

Data recorded by the permanent seismic network, the strong-motion network, and portable deployments are submitted to the OCRWM Records Processing Center (RPC), or to HRC for submittal to RPC, along with supporting records, as specified in this task's IPR's according to QAP-17.0. These records are specifically:

* Raw seismic data recorded as electronic data
* Digital Site Maintenance and System Check forms
* System Check Analysis Report forms
* Query language documentation not included in a Scientific Notebook
* Polarity check results
* Timing check results
* Multimeter calibration results
* Station phase list
* Daily event sheets
* Station magnitude list
* Earthquake records or other significant seismic records from the strong motion network
* Borehole accelerometer Site Maintenance and System Check forms
* Borehole accelerometer System Check Analysis Report forms

An annual report will be written describing the previous fiscal year's seismicity and its implications for seismic hazard at Yucca Mountain (see details below); this report will be prepared according to QAP-3.4 (*Technical Reports*) and delivered by September 30, 2004. The catalog of earthquakes developed within the report will be sent to UCCSN staff for submission to the TDMS. Scientific notebooks used in this work plan are governed by UCCSN QAP-3.0 (*Scientific Investigation Control*). Submittal of the notebooks, report, and data constitutes evidence of the work performed.

A final technical QA report on kappa and stress drops will be prepared and submitted according to QAP-3.4 (*Technical Reports*) by September 30, 2004. Data used in this report, as well as developed data for kappa and stress drops, and not previously submitted to the TDMS, will be qualified and submitted.

A QA report on preliminary findings at the array of borehole accelerometers on the ESF pad will be prepared and submitted according to QAP-3.4 (*Technical Reports*) by September 30, 2004 also. This report will cover basic observations made in year 2003 since the operation of the array began. Seismograms used in the report will be submitted to UCCSN staff for submission to the TDMS.

Informational memoranda on specific earthquakes or other seismic events will be generated and submitted to the DOE Technical Task Manager as deemed necessary or as requested. Copies will be provided to the UCCSN.

Quarterly administrative reports will be submitted to the appropriate UCCSN coordinator. These reports will describe progress, plans, and problems in the effort on the project.

8.1 Deliverable Description

The format of the seismicity report will be generally consistent with formats adopted for previous yearly reports, which are characteristic of scientific investigation reports. The technical content of the seismicity report will include, but not be limited to, the following topics:

- A section on the regional characterization of seismic events (earthquakes and manmade sources) that were detected and located by the network. This section will include maps showing the location of events scaled according to magnitude. A discussion of these events should include any observed spatial and temporal patterns. A discussion of the accuracy of location for events within, on the fringe of, and outside the network should also be included. Focal mechanisms will be computed for larger events and discussed in terms of the regional tectonic framework.

- A section on seismic events within the Yucca Mountain site area (i.e., within ~10 km). Earthquakes within the Yucca Mountain block and nearby vicinity will be discussed separately. This section will also include a discussion on the possible relationship of the earthquakes (within the uncertainty of the locations) to major faults.

- A section on results from the strong motion network. Recordings of significant events at the surface strong-motion stations including Alcove 5 of the ESF and at the borehole accelerometers will be included in this section. Estimates of maximum acceleration and epicentral distances will be tabulated.

The borehole accelerometer report will describe the installation and recording setup. Background noise levels will be discussed. The report will present and analyze recordings made on the accelerometers through 12/31/2003. Analysis will include absolute amplitude in PGA and PGV, spectral amplitudes, and spectral ratios of surface and downhole accelerometers. Comparison of results to predictions of PSHA will be presented.

The final kappa report will present best estimates of station kappa values for all of the stations in the SGBDSN. It will define the uncertainty bands for the estimates, and all conclusions will be presented in the context of the uncertainties. Stress drops will be estimated as a by-product of the kappa estimation; these will be presented and discussed in the general context of stress levels in the vicinity of Yucca Mountain.

8.2 Deliverable Acceptance Criteria

The event location data compiled for the seismicity report will be submitted to the UCCSN Technical Database Archive (TDA). These data will include: date, origin time, location coordinates, focal depth, magnitude, and error estimates of the locations for each event. The kappa estimates and stress-drop estimates will be submitted to the TDA also. The seismicity, borehole accelerometer, and kappa reports will be considered complete following a review according to QAP-3.4 and acceptance by the reviewers.

9.0 Verifications and Reviews

Reviews of the recorded data from the permanent telemetered network will be performed on a daily basis to ensure that all recording systems are performing properly. Specific system checks and other data quality checks are described in IPR-001.

Scientific notebooks started under this task will be reviewed at the end of the subtask, or earlier as needed. The seismicity report(s) and other technical reports developed under this task will be technically reviewed according to QAP-3.4 prior to submission.

10.0 Computer Software

The following computer programs are used in this task and controlled in software configuration according to QAP-3.2 (*Software Management*).

program name	version	STN	purpose	computer
CALIB	1.1	10073	analyze system check pulses	Sun O/S 2.8
HYPOINVERSE	1.0	10080	determine location of earthquakes	Sun O/S 2.8
MLCALC	2.0	10081	determine magnitude of earthquakes	Sun O/S 2.8
FPFIT	1.0	10083	determine focal mechanism of earthquakes	Sun O/S 2.8
SAC	00.46	10085	process and analyze seismograms	Sun O/S 2.8
DBLOC2	4.3	10638	determine preliminary event locations	Sun O/S 2.8
DBPICK	4.3	10639	determine phase arrival times	Sun O/S 2.8
ARC2DB	1.0	10727	determine preliminary event locations	Sun O/S 2.8
DB2PHS	1.0	10637	convert phase records to HYPOINVERSE	Sun O/S 2.8
TERRA2SAC	2.0	10642	convert TerraTech recordings	Sun O/S 2.8
REF2ORB	1.6	10640	transfer seismic data to processing	Sun O/S 2.8
Q3302ORB	4.5	004*	transfer seismic data to processing	Sun O/S 2.8

*UCCSN tracking number – all others are for the SCM (Software Configuration Management) of DOE

The programs in the above table will process seismic data that is expected to be developed and submitted as product deliverables in the performance of this work. The following programs, also used in the seismic analyses, have been documented in Scientific Notebook M&O UNR-002-V1

("Hardware and Software Maintenance and Development for the SGBDSN"); their results are checked by simple graphical displays:

1) REF2SEGY, Version 1.9 (program to convert from RefTek to SEGY seismic data format)
2) SEGY2SAC, Version 1.9 (program to convert from SEGY to SAC seismic data format)

The following program is industry standard software in the SCM:

MATLAB, Version 5.1 (program to do numerical computations, filtering, and plotting)

Several of the above programs, namely DBLOC2, DBPICK, and Q3302ORB, will need to be requalified when Antelope version 4.6 is delivered in early 2004.

11.0 Interfaces Among M&O, UCCSN, DOE, and NSL Components

Field work for this work plan is conducted within approximately 50 km of Yucca Mountain, at Yucca Mountain, and within the ESF. This work is governed by current revisions of two M&O Field Work Packages: 1) FWP-SB-97-007: *Seismic Monitoring* and 2) FWP-ESF-96-005: *Seismic Monitoring in the Exploratory Studies Facility*. These packages address the safety, health, and environmental controls for the work. The field work in this work plan is monitored by the M&O Test Coordination Office (TCO) within the "Ranch" area near Yucca Mountain. Permits for field sites within this area are secured from the Assistant Manager for Environmental, Safety, and Health, YMSCO. Permits for work on the NTS, Nellis AFB, or land managed by BLM or the USFS are obtained from the appropriate offices. The UCCSN Training Coordinator provides indoctrination and training, as specified by the PI, and tracks the status of personnel training. All quality-affecting equipment procurements and any subcontracts involving QA work are made through UNR purchasing, with approval of the UCCSN Quality Assurance Manager and in accordance with QAP-7.0 (*Control of Quality-Affecting Procurement and Receipt*) and the Cooperative Agreement. The results will contribute to seismic design input, through the Probabilistic Seismic Hazard Assessment, for the seismic engineering of surface and subsurface facilities by the Surface Facilities Operations and Engineered Barrier Systems Operations groups. They will also be included in the site characterization section of the License Application. They are also relevant to Performance Confirmation investigations. All work planned or performed and all Q procurements are subject to review and/or verification by the UCCSN QA Manager and the DOE Office of Quality Assurance.

12.0 Accuracy, Precision, and Representativeness of Results

The accuracy of collected data are ensured with periodic checks as specified in IPR-001, IPR-004, and IPR-021 and documented with records submitted to the RPC. Accuracy and precision of developed data (locations and magnitudes of earthquakes) are controlled by procedures IPR-002 and IPR-003 and will be discussed in the annual seismicity report. It is well known in seismology that neither locations nor magnitudes of seismic events are determined with high accuracy or precision. Use of a dense network of stations such as the SGBDSN, of calibrated amplitude data, and of programs that are in software configuration ensures that these characteristics are being determined nearly as well as possible. Locations and magnitudes of larger earthquakes can be compared to catalog entries from other sources such as the NEIC (National Earthquake Information Center). Representativeness of results is indicated by the low detection threshold of the seismic network (near magnitude 0) and by comparison with previous years of instrumental monitoring. Given the vagaries of seismic activity within the earth, only a sample of that activity obtained over a very long period of time can well approximate the mean behavior. One of the main purposes of this monitoring task is to increase that sample length.

For active-source experiments, requirements for accuracy of recorder timing, instrument location, and amplitude-frequency response are specific to the experiment. Technical motivation and implementation methods to ensure the required accuracy will be described in the scientific notebook. Data reduction in general follows that for seismic network data. Emerging analysis issues regarding accuracy, precision, and representativeness will be documented in the scientific notebook.

13.0 Personnel

The following personnel are involved with the subtasks described in Sections 2.3 and 5.0 and may make entries in the appropriate scientific notebooks:

Title	**Name**
Principal Investigator	James Brune
Co-principal Investigator	John Anderson
Senior Seismologist	John Louie
Senior Seismologist	Frank Vernon (UCSD)
Seismic Network Manager	David von Seggern
Project Coordinator	Ken Smith
Research Professor	Glenn Biasi
Research Professor	Rasool Anooshehpoor
Post-Doc	Deborah Kilb (UCSD)

Note that two positions are held by UCSD (U. California at San Diego) personnel. These personnel will be treated as UNR augmented faculty for QA purposes.

14.0 Schedules

Schedules will be as presented in approved annual proposals for funding.

15.0 References

QAP-1.0, *Organization*
QAP-2.0, *Quality Assurance Program -- Preparation, Approval, and Revision of Procedures*
QAP-2.1, *Qualification, Indoctrination and Training of Personnel*
QAP-3.0, *Scientific Investigation Control*
QAP-3.1, *Control of Electronic Data*
QAP-3.2, *Software Management*
QAP-3.4, *Technical Reports*

QAP-3.6, *Submittal of Data*
QAP-6.0, *Document Control*
QAP-7.0, *Control of Quality-Affecting Procurement and Receipt*
QAP-8.0, *Identification and Control of Items and Samples*
QAP-12.0, *Control of Measuring and Test Equipment*
QAP-16.0, *Nonconformance Reports and Trending*
QAP-16.1, *Stop Work*
QAP-17.0, *Quality Assurance Records*
UNR-001, *Operation of the Yucca Mountain Digital Seismic Network*
UNR-002, *Determining the Location of Earthquakes Recorded by the Yucca Mountain Seismic Network*
UNR-003, *Determining the Magnitude of Earthquakes Recorded by the Yucca Mountain Seismic Network*
UNR-004, *Operation of the Yucca Mountain Network Strong Motion Network*
UNR-021, *Installation, Operation, and Maintenance of the Yucca Mountain Borehole Strong Motion Network*
UNR-024, *Procedure for the Deployment of 'Texan' Seismic Microtremor Arrays*

Attachment 1: Proposed Research Program (under seismic monitoring) in FY03-04: Improve the Physical Understanding of the Parameter Kappa

The parameter kappa was defined by Anderson and Hough (1984) to describe the high-frequency spectral roll-off of the strong motion spectrum. It has subsequently been used in the seismic hazard analysis applied to Yucca Mountain. However, that usage needs close examination. The numerical value used in the seismic hazard analysis is small (20 ms based on Su et al, 1996), where smaller values lead to higher estimated ground motions. An increase of 10 ms in kappa could result in a substantial decrease in the ground motions that come from the PSHA. It is proper that any parameter that plays such a critical role should be examined very closely.

It must be recognized that a large complex of issues are involved. Su et al (1996), confirmed by Anderson and Su (2002), estimated kappa from 12 earthquakes in the magnitude range of 2.8-4.4, with the median magnitude being 3.3. The estimate obtained from these events was applied for earthquakes with magnitude over 5.0. This application is reasonable on the assumption that kappa is a parameter characterizing wave propagation, and specifically attenuation. Following that assumption to its logical limit, one should be able to measure kappa from earthquakes of any magnitude. However, when Biasi and Smith (1998) measured kappa from events of magnitude less than 1.0, they found values from 22-56 ms for rock sites in the YM region. Beroza recently submitted a paper for publication supporting a critical hypothesis used by Biasi and Smith (1998), that the stress drop of extremely small earthquakes is comparable to, and not orders of magnitude smaller than, stress drop for moderate to large earthquakes. Furthermore, in a study unrelated to YMP, Purvance and Anderson studied kappa in Guerrero, Mexico, for earthquakes with magnitude from 3.5-8.1, finding a statistically significant contribution from the earthquake source that contributes to the variability of kappa observed among different stations and earthquakes. They further suggest that there may be some magnitude dependence to kappa in this magnitude range, although additional study is needed to strengthen that conclusion. These studies differ somewhat in the way that kappa is measured. Different techniques to measure kappa are necessary for different magnitude ranges, because the earthquake corner frequency intervenes. The corner frequency falls within the frequency band of most interest for earthquakes in the intermediate magnitude range (M~2-5). An additional observation is that several stations with low values of kappa have low ground motions, rather than high, suggesting that the source model applied to yield high ground motions with high kappa values should be reexamined. The questions that arise from these considerations include: 1) what is the best way to measure kappa; 2) what is its magnitude dependence; 3) more generally, how does the source affect the spectrum. Specific issues for resolution are listed in Table 1.

Table 1. Issues related to kappa that are relevant for Yucca Mountain

Issue	How to resolve this issue	Data Needs
1. Why do the network sites with the smallest values of kappa have low ground motions?	a. Examine the magnitude dependence of spectral amplitudes directly, rather than the slope kappa. b. Sort out the relative contributions of site amplification due to velocity decreases and layering, and of attenuation.	a. Data with a large range of magnitudes. b. Downhole/uphole data pairs from a sufficient number of stations with known velocity structure.
2. Why does kappa measured from tiny earthquakes differ from kappa measured from M3-4.5 earthquakes?	Test the hypothesis that events in the M3-4.5 magnitude range are "rich" in high frequencies compared to tiny events.	Data set with abundant records of events with M in the M3-4.5 range, as well as comparable records with a good signal/noise at smaller magnitudes. Deep downhole records would help as the issue involves earthquake source behavior, and near surface effects complicate the observations on surface seismograms.
3. Is there a magnitude dependence to kappa for M3-7?	Analysis using the Anderson-Humphrey approach that was used by Su et al (1996).	Strong motion data from regions where there are abundant records obtained from common instruments, including events with magnitudes 3-4.5.
4. Is there a source contribution to kappa for events in the M~1 range?	Reanalysis of YM data. May be worthwhile to reconfirm in other regions.	YMP data will provide the best answer. To reconfirm, need another analogous region with abundant digital records of M~1 earthquakes.
5. Is there a source contribution to kappa for events M~4?	Analysis that pays careful attention to the potential contribution from path and stations.	Strong motion data from regions where there are abundant records obtained from common instruments.
6. Is there a source contribution to kappa for events M~7?	Partially answered in Guerrero. Not answered for a tectonic environment like southern Nevada	Strong motion data from regions where there are abundant records obtained from common instruments.

Data from southern Nevada alone are incapable of resolving most of these questions, because there are not enough earthquakes and because much more data from deep boreholes is needed to resolve some of the critical questions. In a global search, we find several relevant data sets. However, none of these provide a perfect analog. Table 2 lists several alternative data sets together with brief discussion of the relevance to the YMP.

Table 2. Potential Data Sets

Data Source	Data Characteristics	Similarities	Differences
Anza, California	3 component digital seismic network, operating since early 1980's, calibrated, some downhole data. Magnitudes <2 to 5.1 within net, larger events outside the net.	Desert climate, but not quite as dry as Yucca Mountain.	Geology is granitic, not extrusive volcanic. Tectonic environment tends toward trans-pression, rather than trans-tension.
Japan, K-net and KIK-net	Digital data magnitude 3.5-7.3, 19 events with M>6.0, readily available, quality stations. Hundreds of downhole stations, typically at least 100 m, one as deep as 2000 m.	Some events are crustal strike slip events.	Most events are in a subduction zone environment.
Turkey	Sparse network of digital strong motion instruments.	Tectonics is trans-tensional.	Most stations not on rock.
Taiwan	Digital strong motion. Magnitude up to 7.7. Data only partially available, but spans a very large magnitude range.		Most stations not on rock. Those that are on rock are on relatively young sediments. Continental thrust environment. Abundant rainfall.
Mexico	Digital strong motion since 1985, all data available, magntiudes <3 to 8.1 (ideal range)		Stations mostly on granite, not extrusive volcanic. Subduction thrust environment. Abundant rainfall.

The needed research which we propose is as follows, referred to the questions in Table 1.

Question 1a.

This question is important for Yucca Mountain because under the present methods used by the ground motion modelers, sites with lower kappa have higher ground motions. A possible explanation is that sites with low kappa actually have more amplification in the frequency band at the low end of the kappa measurement range than do the sites with high kappa. If this is the case, then the way to sort out the different effects is to look at spectral amplitudes directly rather than kappa, which is a spectral slope.

We can first address this by another look at small event data collected on the Yucca Mountain network. For tiny events, it may not always be possible to unambiguously resolve the event corner frequency and kappa, but models that fit the spectrum very well are easy to develop. These then can provide an efficient way to compare estimates of kappa (carrying uncertainties) with spectral amplitudes to quantify the phenomenon.

Data gathered in southern California can also address this issue, with the added advantage of a larger magnitude range of well recorded events. In particular, the Anza, California, seismic network has been recording digital seismograms since the early 1980's, and has records with good signal-to-noise ratios for magnitudes down to 1. They have operated downhole sensors so that data from below the most weathered zone is available for comparison with surface records. They have recorded numerous earthquakes with magnitude in the 3-4 range, and recently obtained records from an M5.2 earthquake within the array. Although the tectonics of southern California are different from those near Yucca Mountain, the area is near enough that one can make the case for relevance of the data. The Anza network can be used to study moderate earthquakes outside of the network also. This will be important, as we can study moderate events outside the YMP network, and scaling properties of kappa in southern California can thus be compared with southern Nevada.

The research that we propose is needed to answer question 1a is as follows:

1. Use surface geophysical techniques to measure the site characteristics (velocity profile) at all sites in the Anza network and in the SGBDSN network. This study will also measure velocity profiles at the temporary stations used by Su et al. This is proposed to enable a quantitative study of the relationship between kappa and site amplification caused by reduced velocities near the surface.

2. Use the same methods applied by Su et al to examine the magnitude dependence of kappa in Anza for both local earthquakes and regional earthquakes. This study will examine the assumption of magnitude independence, especially over the magnitude range from under 1.0 to 5.2. The behavior between M1.0 and 3.5 events can be reexamined on another network. The magnitude range used by Su et al will be represented by a much larger quantity of data, so the uncertainties associated with their approach can be tested. The extrapolation to larger events can be tested by determining how well the M3-4.5 earthquakes can predict the behavior of the M5.2 events. Data from the magnitude 5.2 earthquake will provide confirmation but is insufficient to draw statistically robust conclusions.

3. Examine the relationship between kappa and spectral amplitudes, and the scaling of spectral amplitudes directly, for earthquakes within the Anza network. This will make use of data on the site velocity profiles and inferred site amplifications.

4. Examine the magnitude dependence of kappa and spectral amplitudes for regional earthquakes in both southern Nevada and Anza, over the magnitude range from M<1 to M>5.0. This will extend the work of steps 2 and 3 to regional events where the differences, if any, between southern Nevada and Anza region behavior can be quantified.

Question 1b.
Data from KiKnet in Japan are ideal to address this question. They have over 500 stations with uphole-downhole pairs, most of which have abundant data, easily accessible over the web. Many stations have been characterized with velocity models available on the web. Thus the question of the modifications of the upper 100+ meters to the wave shapes can be addressed empirically, and correlated with characteristics of the velocity model.

Question 2.
This question arises because the results of Biasi and Smith (1998) suggest that kappa may be underestimated by Su et al (1996). Anza data would be a good set to answer this question, and that could be done within the context of the response to Question 1a.

Question 3.
This question is important because the ground motion panel assumed that kappa is an attenuation parameter, and that kappa is not changed over this magnitude range. There is not sufficient data to answer it in California. It can be addressed using data from Mexico, Japan, Taiwan, and possibly Turkey.

Questions 4-6.
The question is broken into three parts and is important because, if there is a source contribution, it violates the assumption made by the ground motion panel that kappa is predominantly influenced by the near-station surficial geology.

Question 4.
This can be answered using Yucca Mountain network data. The abundant data and tight network spacing offers the optimum chance to figure out the cause of such variability. Variability might not necessarily be a “source” term in the strictest sense. It is possible to imagine very small-scale variations in crustal structure in the earthquake fault zones that could cause kappa to have considerable variability. Also, some variability might be caused by some combination of a radiation pattern effect on kappa estimates, variable focal mechanisms, and network coverage.

Question 5.
This question is important for understanding the results of Su et al (1996). There is not sufficient data from southern Nevada to answer this question. Data from Anza, California, would be sufficient. Data from Guerrero and Japan would also be sufficient.

Question 6.
This question is important for its implications to the ground motion panel, which assumed kappa is constant. The variability of kappa at this magnitude would be directly relevant to uncertainty estimates on the ground motions. This question can only be answered with data from Guerrero and Japan. In Guerrero, Purvance and Anderson have already indicated that there is a source contribution which is systematic in its average contribution depending on source location and focal mechanism.

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