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## Extreme Ground Motion Studies

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**SCIENTIFIC INVESTIGATION PLAN  
(SIP)**

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REVISION HISTORY

Revision Number	Effective Date	Description and Reason for Change
0	10 July 2006	Initial Issue

## 1) SCOPE AND OBJECTIVES

This project consists of two separate investigations into extreme ground motions due to seismic events. First, it includes field studies of geological formations that should put an upper bound on extreme ground motions that have happened at the site of the formations. The locations are critically selected to provide the most effective constraints possible on the validity of the probabilistic seismic hazard analysis for Yucca Mountain. Second, this project surveys recorded ground motions from around the world, and aims to draw general conclusions from these as to the conditions where extreme ground motions are observed.

This work is subject to NSHE QA Program requirements, except as noted below.

## 2) APPROACH

**Subtask 1: Constraints on Yucca Mountain extreme ground motions based on precariously balanced rocks, unstable precipitous cliffs, and un-fractured sandstones along the San Andreas fault.**

## INTRODUCTION

Probabilistic seismic hazard analysis (PSHA) is based on statistical assumptions which are very questionable when extended to very-low-probability maximum ground motions ( $10^{-6}$  to  $10^{-8}$ ) annual probabilities, with ground motions of the order of 10 g acceleration and 10 m/s velocity. The short historical database for instrumental recordings is not sufficient to determine the uncertainties in the statistical assumptions. This suggests that we look for geomorphic and geologic evidence constraining ground motions over long periods in the past. Because the PSHA extrapolated ground motions are so large, we might expect to find evidence for them if they have occurred in recent geologic time. Such evidence considered here is: lack of precariously balanced rocks (10 ka to 100 ka age constraint), rock avalanches from (formerly) unstable cliffs (a few hundred ka age constraint), and fractures in 5 ma sandstones along the San Andreas Fault in California. The latter, because of the higher rate of seismicity near the San Andreas Fault, provides about 200 times as long of an equivalent time sample as is available at Yucca Mountain. We plan a synthesis report of preliminary data from Yucca Mountain, NTS (Nevada Test Site), and the San Andreas fault to determine the feasibility of an extensive study using QA (Quality Assurance) cosmogenic age dating, more in-depth studies of the NTS mega-breccias, and un-fractured San Andreas sandstones. Interpretation based on preliminary, non-QA'd, age dating suggests that we will be able to provide constraints on ground motion for the last several hundred thousand years to perhaps millions of years, and that these constraints will be considerably lower than estimates based on the extant Yucca Mountain PSHA (Probabilistic Seismic Hazard Analysis).

## PRECARIOUS ROCK CONSTRAINTS ON EXTREME GROUND MOTIONS

As a result of the discovery of numerous precariously balanced rocks in the vicinity of Yucca Mountain, a methodology was developed to use these rocks as constraints on the probable ground motion to be expected at the potential repository. The precarious rock methodology gives a direct indication of the upper bound on the amplitude of past ground shaking at a site. (This is in contrast to the indirect inference provided by the extensive trenching studies at Yucca Mountain, which cannot directly constrain characteristics of ground motions associated with observed fault slip evidence.)

We previously presented estimates of peak acceleration made from observations of precarious or toppled rocks at the Nevada Test Site (NTS). We improved our estimates by field-testing of rocks and by using observed waveforms of nuclear explosions in our shake table tests. Results of these studies are in the published literature.

## COSMOGENIC AGE DATING OF PRECARIOUS ROCK PEDESTALS

Subsequent to the studies reported above, we collected non-QA'd preliminary determinations of cosmogenic age dates of precarious rock pedestals in Solitario Canyon. The cosmogenic age dates for precarious rock pedestals all exceed previous estimates based on rock varnish. This is not unexpected, since the rock varnish dates are minimum dates because the rock varnish formation process can be "reset" by periods of intense weathering, as might be expected during ice ages. Cosmogenic pedestal age dates range from about 36 ka to 250 ka, with most values about 50-100 ka. These are considerably higher than the minimum dates from rock varnish (generally ~10.5 ka). Although we have not fully analyzed and qualified these results, the preliminary analyses suggest that these dates are consistent with the earlier conclusion of Brune and Whitney that no large ground motions (greater than about 0.3 g) have occurred since before the most recent large event proposed from trenching studies (about 70 ka ago on the Solitario Canyon fault, and about 90 ka ago on the Paintbrush Canyon fault). The results further confirm that the erosion rates at Yucca Mountain are very low and that portions of the slopes at Yucca Mountain are extremely stable, with surface age dates of tens of thousands of years on exposed rocks.

## CONCLUSION FOR PRECARIOUS ROCKS

The relatively large horizontal ground accelerations predicted for  $10^4$  or more years by the recently completed Yucca Mountain Probabilistic Seismic Hazard Analyses (PSHA, Stepp et al., 2001) are not consistent with the preliminary results from the precarious rock survey, nor the results found by the DOE Task ORD-FY04-020 up to this time and the non-QA'd age dates. Therefore we anticipate that further development of the precarious rock methodology, especially further QA'd cosmogenic age dating, will provide important constraints on the questionable statistical assumptions which lead to extremely high ground motion predictions at very low probabilities.

## UNSTABLE PRECIPITOUS CLIFFS IN THE VICINITY OF YUCCA MOUNTAIN

In addition to numerous precarious and semi-precarious rocks in the vicinity of Yucca Mountain, discussed above, there are numerous unstable cliff faces with numerous loose rocks stacked on top of each other. Such cliffs are common throughout the area, a result of differential erosion of welded and unwelded tuffs. These cliffs appear to be obviously unstable with regard to horizontal ground shaking.

### NTS Rock Avalanches: Correlation with Ground Motion Predictions from Large Underground Nuclear Explosions.

Further north in NTS cliff faces have been shaken down by ground motion from nuclear explosions. Very near large NTS explosions, there are no precarious rocks. In addition, cliff faces are shattered and numerous recent rockfalls and mega-breccia rock avalanches. These are evidenced by fresh white surfaces covered by caliche (calcium carbonate) and chalcedony (silica), providing a clear indication that the rockfalls have been caused by the explosions. As the distance from the explosions increases, rock avalanches disappear and less and less rockfalls are observed. Thus lack of evidence of mega-breccia rock avalanches at Yucca Mountain and along the San Andreas fault is a constraint on extreme ground motions over the time period necessary to remove the evidence of such avalanches (preliminarily estimated at hundreds of thousands of years).

In May 2005 we carried out a reconnaissance field survey of sites of rock avalanches created by large nuclear explosions. We estimated the peak ground accelerations from the map based on the empirical curves for ground motion for nuclear explosions as a function of magnitude and distance. From standard ground-motion regression curves on yield and distance, it is presumed that some of the sites of rock avalanche sites were exposed to ground accelerations of several g and ground velocities of a few meters/sec.

In numerous cases very large blocks of rock, up to several meters in dimensions, were moved large distances and thrown downhill to form very impressive large-block rubble piles. The fact that such large blocks of rock could undergo such large displacements testifies to the huge energies involved. This contrasts strongly with the precipitous cliffs existing at Yucca Mountain, where the cliffs would be turned into block rubble piles with ground accelerations considerably less than 1 g. If, in addition, large accelerations, comparable to those generated by nuclear explosions, had occurred at Yucca Mountain, very large blocks (meters in dimension) would also have been thrown from the cliffs onto the rubble piles. Solitario Canyon would be the site of numerous large rock avalanche rubble piles, similar to those described above for northern NTS.

There is no evidence that rock avalanches of the type described above for northern NTS have ever existed at Yucca Mountain. The time constraint associated with the lack of evidence for rock avalanches at Yucca Mountain is the time for natural processes to eliminate the evidence of such rock avalanches. We believe this is the order of  $10^5$  years, but this needs to be quantified

by extensive cosmogenic estimates of erosion rates and other geomorphic processes. There are a few large boulders on the pediment (little or no alluvium) at the north end of Solitario Canyon. Cosmogenic age dates on some of these boulders, as well as boulders in other environments, including cliffs and colluvium at Yucca Mountain, will provide necessary estimates of erosion rates of boulders exposed to subaerial processes. John Whitney et al. have done considerable background estimates of long term erosion rates, and results of their study will be critical information for evaluation of the results of the research described here.

## CONCLUSION FROM UNSTABLE PRECIPITOUS CLIFFS AT YUCCA MOUNTAIN

A useful constraint on strong ground motion at Yucca Mountain can be obtained by estimating the time it would take for shaken-down cliffs, with consequent rock avalanches (piles of rubble at the cliff base) to be re-eroded to their current unstable conditions (no rubble at the base of the cliffs, many unstable stacks of rocks). Preliminary estimates based on cosmogenic age dating described above, suggest hundreds of ka, thus implying that such large ground motions have not occurred at Yucca Mountain in this time period; but final constraints will require extensive QA (Quality Assurance) age data and associated analytical interpretation.

## CONSTRAINTS ON EXTREME GROUND MOTIONS FROM UNFRACTURED PRECIPITOUS SANDSTONE CLIFFS ALONG THE SAN ANDREAS FAULT

Large sandstone outcrops occur at several locations along the San Andreas Fault between Tejon Pass and Cajon Pass. These sandstones are as old as or older than the San Andreas Fault and thus have been exposed to San Andreas earthquakes for about 5 million years. At the current inferred rate of occurrence of large earthquakes, this might translate into about 20,000 M<sub>8</sub> events, with about 200 occurring in the last 50 ka, enough to provide statistical constraints at very low probabilities. The equivalent comparable time scale translated to Yucca Mountain would be more than a billion years (because of the about 200 times greater rate of seismicity). Preliminary measurements of tensile strength of surface samples of the San Andreas sandstones indicate values of less than 10 bars. If these values correspond to the true tensile strength of rocks in bulk at depth, over the history of the rocks, they provide constraints on very rare ground motions. Internally, if the particle velocities exceeded about 1 m/s at about ¼ wavelength depth, the internal strains would fracture the rocks in tension. There is no evidence of such tension fracturing in these sandstones.

At several sites there are near vertical sandstone cliffs several tens of meters high. Since the sandstones are considerably weaker than the welded tuffs at NTS, we would certainly expect mega-breccia rock avalanches of the type observed at NTS if similar extreme ground motions

had occurred. There is no evidence of such avalanches in these cliffs. Although the precise erosion rate of the sandstones needs to be better established, probably no such avalanches have been created in the last 10 ka to 100ka, if ever. The suggested upper limits on ground motion are consistent with the current rock's instrumental strong motion data set (covering only about 50 yrs) and suggest that large UNE-type ground motions have not occurred over the much longer history of the San Andreas Fault, which would give an equivalent time constraint at Yucca Mountain of over  $10^9$  years.

In order to quantify these estimates, the following activities are needed:

1. Measure the shear-wave velocity of the sandstones. This is because fracture or lack of fracture depends on the shear strains in the rock, which in turn are proportional to particle velocity divided by shear-wave velocity. This data will be obtained under the supervision of Prof. John Louie.
2. Measure the tensile strength of the sandstones. These measurements will be made by Prof. Jaak Daemen and his student.
3. Carry out more extensive examination of the sandstone outcrops to increase our confidence that there are no extant earthquake-caused fractures.

## **Subtask 2: Prepare summary report on large recorded ground motions**

Results of the PSHA, as mentioned above, give ground motions on the order of 10g and 10 m/s for  $10^4$  years and greater. To put these numbers into perspective, for our second subtask we plan to carry out a thorough study of all available strong motion records, to determine what are the extremes that have been observed. While these extremes will be much less than the PSHA predictions, Hanks (2004) recognized that such a systematic review of the existing data has not been carried out recently. The expected outcome is an understanding of those conditions that have in the past always been associated with extreme ground motion observations. To the extent that those conditions are present or absent at Yucca Mountain, we anticipate this study will produce conclusions that are highly relevant for evaluation of the PSHA predictions.

This part of our proposal responds to the following recommendation ("C.2") in the Hanks et al (2004).

### *C.2. The Larger PGA's and PGV's*

*In a like manner, the Committee recommends documentation and analysis of the 100 largest PGA's and PGV's, in a manner building on Anderson's presentation. Further, the Committee recommends a synthesis of the analysis of ground-motion outliers as parameterized by their normalized residuals, after Bommer's presentation. Of particular importance is the association of the largest known absolute values (PGA's and PGV's) and relative values (normalized residuals) with forward directivity, faulting mechanism, and earthquake magnitude. These empirical results can then be compared to the numerical calculations of the non-linear modeling of the source and wave propagation.*

We have some preliminary results on extreme ground motions. Figure 1 shows the statistics of extreme recorded accelerations worldwide, and Figure 2 shows the statistics of extreme recorded velocities worldwide. Figure 1 shows 35 records that have been identified with peak accelerations greater than  $800 \text{ cm/s}^2$ . Figure 2 shows about 25 records for which one or more component exceeded  $75 \text{ cm/s}$ .

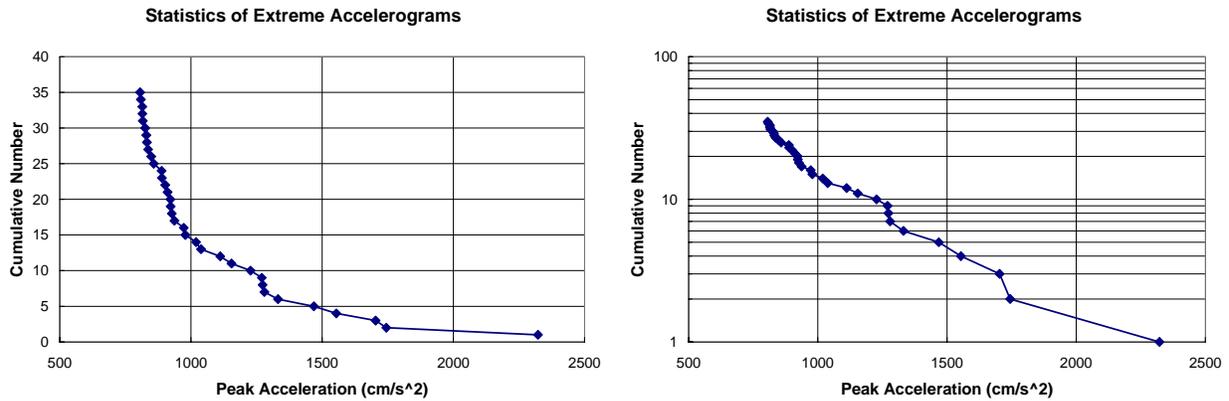


Figure 1. Extreme accelerations. The table with extreme records has been drawn from the COSMOS database. A) Plotted on linear axes. B) Plotted with logarithmic ordinate axis. Note that there is no physical reason to expect a linear relationship on semilog axes, but this presentation better illustrates the highest observed values.

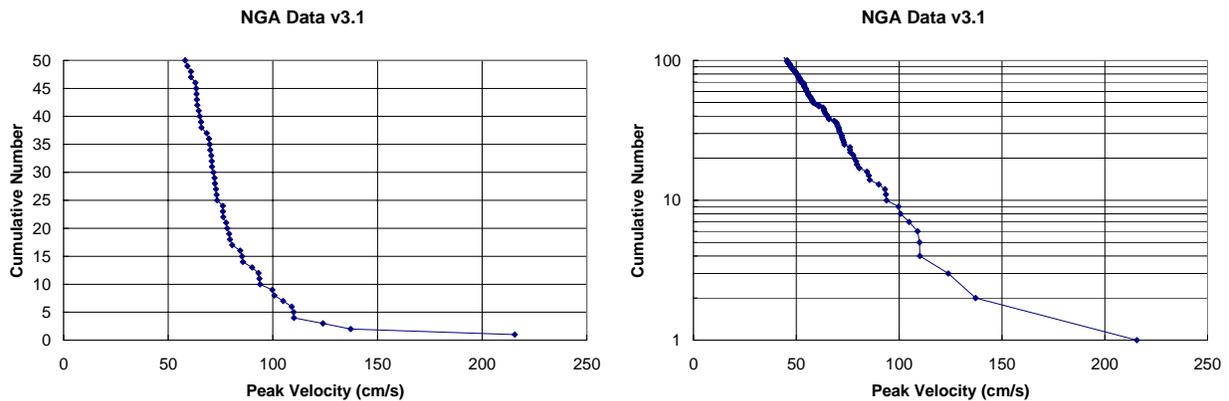


Figure 2. Extreme velocities. The table with extreme velocity records has been drawn from the PEER NGA database. As in Figure 1, the points are on both linear and semilogarithmic axes.

This is a good beginning for a project to examine the 100 largest accelerations and velocities observed to date. Specific information that needs to be gathered for each extreme accelerogram and each extreme velocity:

- Map of fault and station location
- Identify epicenter / directivity
- Focal mechanism
- Site condition
- Kappa, spectral amplitudes, time series rms
- Is this an isolated spike?
- Topography of the station

A preliminary impression is that most of the extreme velocities are associated with near-fault pulses for earthquakes with  $M > 6$ . However, that remains to be examined in more detail.

The 36 accelerograms identified so far with peak acceleration in excess of  $800 \text{ cm/s}^2$  come from 22 earthquakes, 1971-2003. Two earthquakes contribute six records each: Japan, 2003 May 26,  $M_w = 7.0$  (HRV), Depth = 61 km, and Northridge, 1994,  $M_w = 6.7$ , shallow. Of these records, 14 accelerograms from 12 earthquakes caused peak acceleration in excess of 1g. On 78% of the records, the horizontal component was the strongest.

A preliminary conclusion is that all cases of extreme accelerations occur in one or more of the following limited set of conditions:

- Thrust faulting: 69%
  - Hanging wall: 47%
- Forward directivity:  $\geq 33\%$
- Dam abutments (Topographic amplification): 20%
- Site Condition
  - Soil site condition:  $\geq 33\%$
  - Recognizable strong resonance: 6%
- Deep source (perhaps very high stress drop): 20%
- The parameter kappa is less than 30 ms on all but one of the extreme records examined.
- Several of the peaks occur in isolated spikes that are much greater than the rest of the record.

There was no obvious tendency for the extreme peak accelerations to occur more frequently with higher magnitude events. The preliminary study found more points in the magnitude 6.5-7.0 range than at higher magnitudes. However, most of the overall data set is also in that range, so care will be needed to evaluate the statistical significance, if any, of that inference.

Analysis of these data will focus on issues that are relevant for Yucca Mountain. We will determine which of the parameters described above are statistically significant for predicting extreme motions. We will determine which combination of conditions are most likely to result in extreme ground motions. We will examine whether this analysis indicates that there are conditions likely to lead to even stronger ground motions than the largest observed. Finally we will compare the conditions of extreme observations with the conditions seen at Yucca Mountain, and draw conclusions for Yucca Mountain.

## RESEARCH—SUBTASK 1

This is a two-year subtask to fully evaluate the possible ground-motion constraints (unexceeded ground motions) provided by precarious rocks and precipitous cliffs (lack of evidence for rock avalanches) both at Yucca Mountain and along the San Andreas fault, and unfractured sandstones along the San Andreas fault. This will involve evaluation of our preliminary non-QA'd cosmogenic age dates, field surveys, collection and testing of samples from along the San

Andreas Fault, geophysical surveys to determine sandstone velocities at depth along the San Andreas Fault, and associated geomorphologic interpretation, both at Yucca Mountain and along the San Andreas Fault. We will obtain 6 additional QA'd cosmogenic age dates at Yucca Mountain and along the San Andreas Fault by the middle of the second year. This will involve additional QA training and effort on the part of researchers. The last half of the second year will involve extensive interpretation and analysis associated with preparation of a final report.

QA Status: *"Sample collection and analysis and reporting under Subtask 1 will be conducted in accordance with the NSHE QA Program. Some preliminary data that will be considered in this research is obtained from unqualified sources. Our reports will clearly distinguish between conclusions based on the two categories of data."*

## RESEARCH- SUBTASK 2

This is a two-year subtask for evaluation of the 100 largest peak accelerations and peak velocities from past worldwide earthquakes and of the 100 peak accelerations and velocities that are the greatest number of standard deviations higher than expected from ground motion prediction equations. This subtask runs concurrently with subtask 1. In the first year we will:

- Search strong-motion databases to compile the largest documented records of peak acceleration and peak velocity in earthquakes.
- To the extent possible, gather the seismograms into a single database. This data was not gathered under QA procedures, but it is what is used in the engineering seismology community. We will compile this data and submit it to the records section for convenient future use by others.
- Use this data, combined with simple Matlab routines, to make plots and to check on the peak values obtained from readings made by others and compiled in the databases we will search. Plots will allow us to expand the records so that we can see the detailed nature of the ground motions causing the extreme values. Matlab routines needed for this are simple: to read data and plot, and need only use a small number of Matlab functions. They will be documented in the scientific notebook, and the notebook will include tests to demonstrate that they are correct. For instance a routine to read and plot the data can be tested by showing that the plot is the same as a plot of the data as obtained from the web site that distributes the data.
- Document, to the extent possible, the site conditions, topography, and source-station geometry for all of this data.
- Prepare an interim summary report.

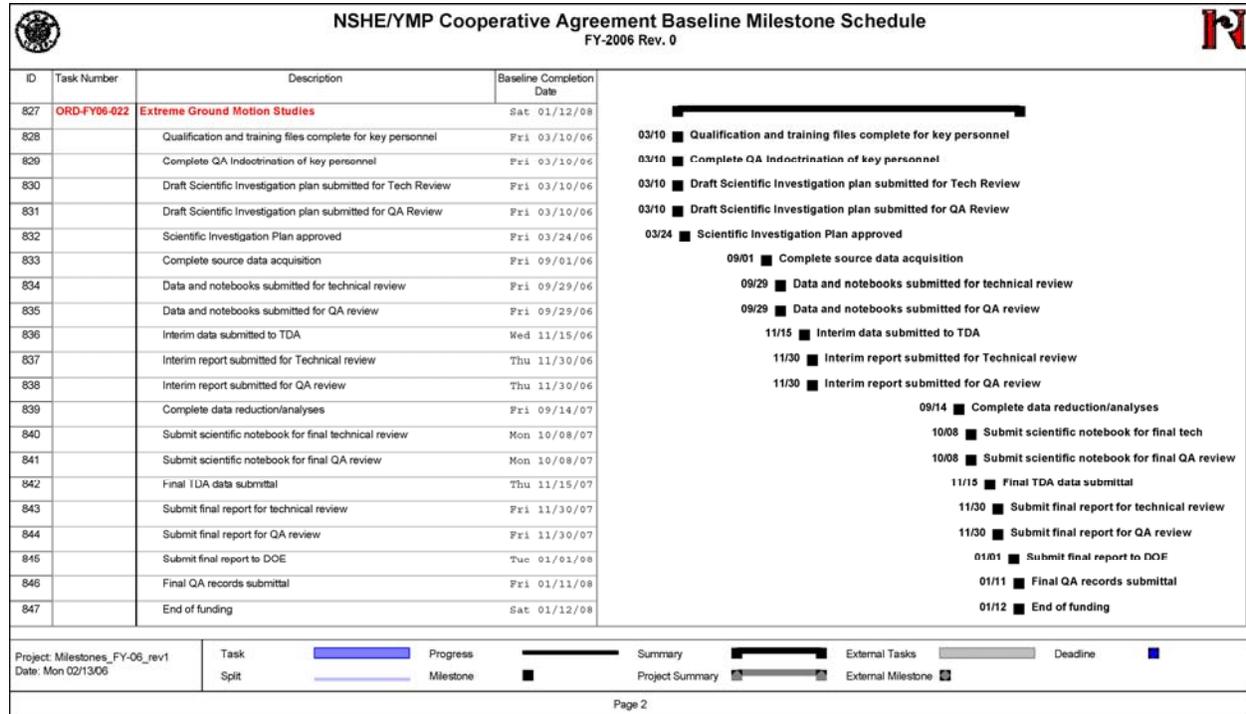
In the second year, we will focus on ground motions that are large numbers of standard deviations higher than expected based on ground-motion prediction equations. Analysis will be similar to year one for the different set of data. Outliers in this case are somewhat dependent on the choice of the ground-motion prediction equation. A major effort is now underway under the sponsorship of the Pacific Earthquake Engineering Research (PEER) Center to develop the "Next Generation" of these relations. These are not published yet, but should be by the time we start this phase of the project. We currently plan to choose one (or more) of these new relations,

and to explain our choice as part of our report. A final report will include all the year one and year two investigations.

Products/transmittals: Data generated in support of this report will be made available to the Technical Data Management System via the NSHE Technical Data Archive.

*QA Status: Our report under subtask 2 will not qualify under the NSHE QA Program because it will not be possible to qualify the strong-motion data collected from locations all over the world. However, data collection and analysis will treat all data as if it were qualified.*

### 3) SCHEDULE



### 4) INTERFACE CONTROLS

When technical issues arise, we will contact the Technical Task Representative at the Yucca Mountain Project. In April, 2006, this is Drew Coleman. Our primary contact for administrative and Quality Assurance issues is the NSHE Co-op Project Director. In April, 2006, this is Raymond Keeler. We will closely co-ordinate with John Whitney of USGS in scheduling, field work, sampling, analysis and report preparation. Technical contacts associated with the project management have suggested that the research described for the second year of Task 2 should be carried out in collaboration with Dr. J. Bommer at the Imperial College, London. We will closely co-ordinate with Dr. Bommer, as he has previously initiated this line of research, as noted above. As of May 2006 a mechanism for funding Dr. Bommer’s research had not yet been established. Thus our interaction may be limited to utilizing his analysis of the data as a starting point.

### 5) STANDARDS

There are no special standards and 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 HRC.

## **6) IMPLEMENTING PROCEDURES (IP'S)**

A scientific notebook will be maintained for Subtask 1, and a separate scientific notebook will be maintained for Subtask 2. For most activities, there is no implementing procedure because the work is not routine; and therefore activities will be documented in the scientific notebooks.

No new implementing procedures will be needed.

Scoping study samples of sandstone will be gathered by James Brune. GPS will be used to control sample locations, and IPR001 subsection 3.8 will be followed in the use of GPS receivers. Samples will be controlled under QAP-8.0, "Identification and Control of Items and Samples".

Data to be used to measure the velocity of sandstone will be obtained under IPR-024, "Procedure for deployment of the Texan seismic microtremor arrays".

The strength of sandstone samples, including scoping study samples, will be evaluated under the supervision of Jaak Daemen under IPR-012, "Preparation of Rock Core Specimens for the Determination of Mechanical Properties of Rock", IPR-010, "Splitting (Brazilian) Tensile Strength Test of Rock", and IPR-011, "Determining Uniaxial Compressive Strength of Rock".

## **7) SAMPLES**

Non-QA'd scoping study samples of San Andreas sandstones will be collected by James Brune.

## **8) EQUIPMENT AND INSTRUMENTATION**

The equipment that is used for testing the strength of sandstone samples is described in IPR-010, "Splitting (Brazilian) Tensile Strength Test of Rock", IPR-011, "Determining Uniaxial Compressive Strength of Rock", and IPR-012, "Preparation of Rock Core Specimens for the Determination of Mechanical Properties of Rock". This equipment is located in a controlled location on the University of Nevada campus in Reno, Nevada, and only authorized persons are allowed access. These IPRs describe methods for calibration of this test equipment. The PI of this project will assure that the calibration procedures described in those IPRs are followed.

The equipment that is used to measure the velocity of sandstone is described in IPR-024, "Procedure for deployment of the Texan seismic microtremor arrays". That equipment is also located in a controlled location on the University of Nevada campus in Reno, Nevada, and only authorized persons are allowed access. During field deployment, the equipment will be transported to the test location in a Nevada Seismological Laboratory truck and kept locked and under control of NSL personnel at all times. Actual measurements at any one location are carried out in one day. During the deployment, authorized personnel are present at all times to assure that the equipment is secure and not tampered with. IPR-024 describes in full all necessary calibration of this equipment. The PI will assure that all requirements of IPR-024 including calibrations are carried out in accordance with the procedure.

## **9) SOFTWARE**

Tables of extreme ground motion will be compiled using Excel. Analysis of strong motion data will all be handled using MATLAB Version 7.0.1. Analysis procedures will be simple and non-routine, and will be documented in the scientific notebook. Any extensive macros, routines, or code that will be written in MATLAB will be qualified in accordance with QAP-3.2.

## **10) PROCUREMENTS AND SUBCONTRACTS**

Unqualified age dating will be sub-contracted to Lawrence Livermore National Laboratory. Other than this, all work including sample collection, strength testing, and field measurement of rock velocities will be performed by UNR personnel under the Nevada System of Higher Education QA program.

## **11) HOLD POINTS**

None.

## **12) QUALITY CONTROL—ACCURACY, PRECISION, ERROR, AND UNCERTAINTY**

Subtask 1 will use estimates of shear velocities of sandstones taken in the field. Measurements will specify locations using GPS, for which accuracy of locations is 10 meters horizontal and 20 m vertical. The field uncertainty in shear velocities is 10%-20%, considering complex geometries and spatial variability. Uncertainties will be propagated through subsequent analyses. Rock samples strength probably has a much greater variability from one sample to the next than laboratory uncertainties in measurement, so uncertainties will be estimated from this variability and propagated through subsequent analyses. The accuracy and uncertainty in age dating of samples is dependent on local conditions and rock type, and can only be determined by the dating procedure itself. The accuracy obtained will be factored in for determining the reliability of final conclusions.

Subtask 2 will seek to know all extreme values to within 10% of the extreme value. Greater accuracy is possible for some of the records, but that depends on the age of the data and the procedures used by the agencies that gathered the data. Uncertainties will be propagated as appropriate through subsequent analyses. Our best estimate of the accuracy obtained will be factored in for determining the reliability of final conclusions.

## **13) DATA RECORDING, REDUCTION, AND REPORTING**

For Subtask 2, strong-motion data are readily available via the web from the agencies that gather the data. The COSMOS virtual database, which is maintained by the University of California at Santa Barbara as an activity of the Consortium of Operators of Strong-Motion Observation Systems (COSMOS) and supported with major funding from the National Science Foundation, is a very useful tool for pointing the user to the sources of the data on the web sites of the agencies

that gathered the data. The COSMOS database is searchable, allowing the user to select, for instance, all data with peak acceleration greater than some threshold. The data does not qualify under QA procedures. Very little reduction will be required. In particular, we will rely on integrations by others to the extent possible to obtain velocity from recorded accelerations. When that is not possible, in a few cases, we will use the simplest possible approach and document it thoroughly in the scientific notebook. Traceability of the strong-motion data and metadata to the agency that gathered it will be carefully documented. Sources of all seismograms will be documented thoroughly in directories made for each data file and in the scientific notebook.

#### **14) FIELD SURVEYING**

GPS will be used for locations of all field sampling and measurements. IPR001 will be followed to control use of GPS instruments.

#### **15) REVIEWS AND VERIFICATIONS**

Scientific notebooks and associated data started under this task will be reviewed at the end of the subtask, or earlier as needed, or required. Study data and/or results will be reviewed in accordance with QAP-3.0.

#### **16) RECORDS AND SUBMITTALS**

QA records produced as a result of the NSHE QAP's will be controlled in accordance with QAP-17.0. Electronic data gathered from other sources will be protected in accordance with QAP-3.1. Unqualified data will be labeled "unqualified", but still be traceable to its origin. All this data will be protected in computers with passwords and accessible only to persons working on the project. Backups of data will be kept in a safe in LMR building on the UNR campus, as well as a locked office.

Quarterly report submittals will be submitted in accordance with the Cooperative Agreement. At the end of the project a report (submittal) will present results, analyses and interpretations, and implications for seismic hazard elements. This report will be reviewed according to QAP-3.4 (Technical Reports). Records will be submitted in accordance with the Cooperative Agreement from the administrative task PI to DOE. Results will also be reviewed and submitted to a peer-reviewed journal. NSHE QAP-3.0, "Scientific Investigation Control" governs scientific notebooks used in this work plan. Submittal of the notebooks and report constitutes evidence of the work performed. Scientific notebooks will be periodically photocopied, and the photocopies will be filed in a fire-rated safe.

#### **SUBTASK 1**

A review draft of a preliminary report and results of cosmogenic age dating will be submitted by Whitney and Brune by November 30 2006. A review draft of the final report for subtask 1 will be submitted by November 30, 2007.

#### **SUBTASK 2**

A review draft of a preliminary report on results of studies on extreme accelerations and velocities from around the world will be submitted by Anderson by November 30, 2006. A review draft of the final report for subtask 2 will be submitted by November 30, 2007.

The final report (one report for the two tasks) will be submitted before the end of funding on January 11, 2008.

## **17) REFERENCES**

T.C. Hanks, N.A. Abrahamson, M. Board, D.M. Boore, J.N. Brune, and C.A. Cornell (2004). The Workshop on Extreme Ground Motions at Yucca Mountain, August 23, 24 and 25, 2004, U.S. Geological Survey, Menlo Park, CA 94025, 32 pages.

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