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A Long Baseline Laser Strainmeter for the Exploratory Studies Facility at Yucca Mountain

Frank K. Wyatt
University of California - San Diego

James N. Brune
University of Nevada, Reno, brune@seismo.unr.edu

Drew Coleman

Don Baepler
University and Community College System of Nevada

Amy J. Smiecinski
University of Nevada, Las Vegas, smiecins@unlv.nevada.edu

University and Community College System of Nevada (UCCSN)

SCIENTIFIC INVESTIGATION PLAN (SIP)

Task Title:	**A Long Baseline Laser Strainmeter for the Exploratory Studies Facility at Yucca Mountain**
Task Number:	**ORD-FY04-008** See FTR TR-03-008 (Task 7) for details of earlier related work.
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Author: [redacted]
Frank K. Wyatt — 27-Apr-04
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Approvals:

[redacted]
Technical Reviewer - James Brune — 4/28/04
Date

[redacted]
DOE Technical Task Representative – Drew Colman — 5/06/04
Date

[redacted]
UCCSN Project Director – Donald H. Baepler — 5-6-04
Date

[redacted]
UCCSN QA Manager – Amy Smiecinski — 5-6-04
Date

REVISION HISTORY

Revision Number	Effective Date	Description of Change
0	05/06/2004	Initial Issue. (Continuation of Task 7 from the previous Cooperative Agreement DE-FC28-98NV12081.)

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1.0 Introduction

This Scientific Investigation Plan (SIP), for work under the second Department of Energy/University and Community College System of Nevada (DOE/UCCSN) Cooperative Agreement (10/01/03), DE-FC28-04RW12232, is intended to cover the laser strainmeter operation and monitoring task being conducted by the University of California, San Diego (UCSD), under the oversight of the Nevada Seismological Laboratory of the University of Nevada-Reno (NSL/UNR). UCSD has carried out the design, engineering, and installation of the east-west laser strainmeter (LSM) currently in place in the Exploratory Studies Facility (ESF) at Yucca Mountain.

Continued operation and analysis of the LSM in the ESF is important for understanding the short-term and long-term stability of the proposed National Nuclear Waste Repository site; for this measurement the value of the records increases with the duration of the observing period. Precise deformation monitoring is especially valuable for understanding the hazard posed by the local tectonic environment, for helping to define the engineering requirements for constructing a safe site, and for providing a baseline against which to observe warning signals from any significant future changes in conditions. An LSM represents the current state of the art for measuring changes in rock strain over the widest possible range of frequencies.

The purpose of this SIP is to describe the overall planning for the project such that it can be conducted and the data recorded, processed and analyzed according to established protocol for the University and Community College System of Nevada (UCCSN) Quality Assurance Program (QA).

1.1 Summary of Instrument Fabrication and Installation

Under the first DOE/UCCSN Cooperative Agreement this project was divided into four phases: Phase I of the project — site training, surveying, site selection, and instrument design and engineering — was completed by 2001. Phase II — component fabrication and onsite preparation — was completed by spring 2002. Phase III — assembly of the instrument and the initial test period—was completed in June, 2002. Phase IV— operation, monitoring, and analysis of the data — is currently in progress, and is the focus of this SIP. While the transition from testing to routine operation of this new system in the unusual setting of the ESF occurred over a period of time, since August 21, 2002 (2002:233) recordings of the ESF's deformation have been collected to QA standards.

Details of the earlier work are available in the Final Technical Report for Task 7 (Document ID TR-03-008), for the first Cooperative Agreement.

2.0 Scope, Objectives, and Subtasks

2.1 Scope

Task: A Long Baseline Laser Strainmeter for the Exploratory Studies Facility at Yucca Mountain. This Scientific Investigation Plan presents an independent study intended to augment substantially the previous work conducted in accordance with the UCCSN QA Program.

This work is subject to UCCSN QA Program requirements.

The work encompasses several aspects of laser strainmeter operation, monitoring, data processing and analysis.

2.2 Objectives

The LSM continuously monitors the repository-scale strains from all sources, complementing regional geodetic surveys at the facility by providing an independent check, and much lower noise over a wide frequency range – a factor of 1000 better than geodetic methods at periods of days and shorter.

Continued operation will monitor:

• Establishing the baseline strain rate in the ESF (so far, in the east-west direction only); measuring this, and future changes, will provide a strong check on any strain-rate variations that may occur associated with possible tectonic or volcanic events, or potential repository activities. An extended record is required to understand fully the character of the baseline strain.

• Strains associated with seismic waves, earth tides, and atmospheric pressure variations; analysis of these provides unique information on the bulk rock properties (e.g., elastic modulus) of the potential repository block, and any changes in them.

• Any strains from earthquakes (either from static deformations caused by (future) local earthquakes, or by triggered slip along nearby faults) or from volcanic activity (e.g., in Crater Flat); any such strains would be important in judging the integrity of the repository after such events.

2.3 Subtasks

Operations and monitoring:

Operation includes remote and onsite adjustment of instrument systems to assure continuous operation and production of high-quality data; necessary maintenance and upgrade/repair of instrument subsystems; calibration of equipment essential to production of QA data; routine data downloading; archiving of the data; regular monitoring of the records for any short-term (weeks or less) anomalous signals (see Section 3.0).

Processing and Analysis:

Data processing and analysis include editing of data and application of calibration measurements to produce an optimal estimate of strain changes, submission of raw and edited data to the Document Center for final archiving, and analysis and interpretation of the measurements in terms of geophysical phenomena and repository performance. All data-handling is to be done in accordance with QA procedures (see Sections 3.0 and 8.0).

Instrument activities—upgrades, including:

1. Improving the quality of the strainmeter's laser system by close monitoring of the field laser (adding remote-control features) and by developing a lab test-bed for continuous testing/preparation of a replacement laser. We will also develop further the main laser's fiber light-delivery system, to permit easier absolute laser-frequency measurements at the field site.

2. Preparing a second, complete datalogger/controller for rapid introduction in the event of equipment failure.

3. Introducing a physical length modulator to each optical anchor interferometer, which, along with modified electronics, allow for much greater tolerance in beam-alignment for improved long term operation of the optical anchors at each end of the laser strainmeter. (Our earlier plans called for a more extensive approach to this, but the observed stability of the optics tables (at each end of the instrument) permit a moderated solution.)

4. Increasing the amount of adjustment done through remote control and local automation, notably more control of the laser and fringe-counting electronics.

5. Reducing further the disruption caused by strong ground shaking from mine trains as they pass by the instrument end-structures, causing miscounting of the interferometer, and shortening the laser lifetime—by continued work on a physical isolation system for the LSM laser and by introducing additional monitoring equipment to aid in the recovery from the shaking.

6. Fabricating a number of the circuit boards in line with necessary upgrades; the changes have been designed and documented (readied), the reworking of the board layouts will be done by Wally Nicks of UNR, while the fabrication and testing will be done at UCSD.

7. Replacing compromised interferometer optics – both lenses and mounts – with new components for more reliable laser beam alignment.

8. Improving capabilities of the datalogging system, specifically in prioritizing operations and in data accessibility/security.

9. Adding additional "environmental" sensors to the system to provide records of such signals as air temperature in the tunnel, wind speed, and (outside) solar radiation, to help in the interpretation of the records (e.g., the conspicuous strain-change found to be associated with operation of the tunnel's exhaust fans).

ESF Access:

Maintain staff certification for work in the tunnel.

3.0 Methods and Approach

A laser strainmeter measures the relative displacement between two end-piers separated by several hundred meters, by directing laser light through a straight, evacuated pipe. Mounted on one of the end-piers is a laser interferometer, at the other is a reflector. The interferometer records any changes in the distance separating the two piers in terms of the wavelength of light from a wavelength-stabilized laser. An evacuated pipe is employed to suppress the variations in the index of refraction of the air that would otherwise disturb the optical path-length measurement.

Because the interferometer is capable of detecting displacements of the order of 0.1 μm, the strainmeter is sensitive to strains on the order of 0.1 μm/500 m, or about 2×10^{-10} (0.2 nε). This is the sensitivity of the instrument to strain along the length interval defined by the end-piers. It is thus crucial that there be no spurious motions of the end-piers: displacements of a few micrometers of the piers with respect to the underlying rock would distort the instrument record. To eliminate such spurious motions we use the technique of tying the end-piers to the bedrock using laser "optical anchors" (LOA). These are short-base laser strainmeters which monitor end-pier motion relative to the bottom of two angled boreholes at each end-pier. This technique is used to monitor, to optical precision, any instability of the end-piers relative to the underlying material, in order to remove the effects of end-pier motion from the strain recordings.

The LSM installation consists of systems that (1) maintain the vacuum, (2) (eye-safe) lasers for measuring between points anchored into the rock, (3) simple "counting" electronics, and (4) the data recording. The quality of the vacuum system is assured by monitoring the vacuum pressure continuously with a calibrated vacuum gauge. The LSM's laser stability, as the instrument's length-standard, is assured by referring its operational wavelength against a standard. The digital counting electronics and recording and telemetry systems are calibrated by checking against a calibrated multimeter.

<u>Integrity of the recordings:</u>

Interferometer (LSM and LOAs) and Recording Verification: (A) to check the strainmeter optical sensing system and all of the front-end transducer electronics (pre- Fringe Counter electronics), apply slight pressure on the instrument end-monument and observe on a scope that each interference-fringe of motion (light and dark bands of light) is a full circular revolution, and that it yields 4 counts, of the proper sign (longer instrument: counts "up"), in the Fringe Counter. (B) to complete the system throughput check, from instrument-electronics to computer files, enter a pair of "counts" into the Fringe Counter and verify the recording of this by checking the data file both at the site and after transmission back to the lab. These two calibration operations involve only simple observation, the writing down of numbers, and the subsequent checking of the recorded data. Any changes in instrument gain-settings requires a repeat of step B above.

<u>Laser Frequency Measurements:</u>

Regular checks of the LSM laser's frequency are necessary to establish a history of the laser-frequency stability, for possible correction of the strain record: these are to be performed, at least twice annually, at approximately six month intervals. This requires the use of a calibrated (1) **Reference Laser** and (2) **Frequency Counter**.

<u>Other routine checks and adjustments:</u>

A calibrated (3) **Multimeter** is required for the occasional checking of those analog voltages in the instrument which involve either the strain measurements or possible corrections of the strain signal. All such measurements are to be included in the SN. Other monitoring signals possibly necessary for correcting the strain signal include: a calibrated (4) **Vacuum gauge** for recording the main-tubing vacuum level—we note in the SN the times of all vacuum-system pumpdowns; a calibrated (5) **Air Pressure gauge** for recording the air pressure affecting the instrument/repository, for understanding the response of the rock to this influence. Other routine activities at the time of instrument visits include: observing and optimizing the optical alignments; checking the position of control switches, and the recording of any changes which are made in the SN.

The data logger records the signals at five-minute intervals, and more frequently. We maintain a record of the channel assignments and note any changes in the filter settings for the main signals and any QA-level ancillary measurements.

Additionally, we supply the logger with fixed reference voltages, as a continuous diagnostic of the system. These voltages are checked (using the calibrated multimeter) during field visits. We record any changes in recorder response, code, or hardware that could affect digitization levels and recalibrate main systems if necessary.

Reviews of the recorded data from the laser strainmeter are performed on a weekly basis to ensure that all recording systems are performing properly.

Transmitting and Storing the Data:

We use *gzip* to compress the digital files before transmission, since this includes an error-checking checksum. Data is unzipped with *pkzip*. We check the validity of individual recordings (for system throughput-checks, at the times of calibration) using *Unix* system binary-data utility (viewer) *od*.

In order to comply with temporary records storage requirements, we regularly download a copy of the raw data to the computer system at Scripps and maintain the original raw data on the computer located at the site. This data transfer is typically done daily, but is required to be performed within 60 days of the acquisition of the raw data.

Prior to removing the data from either the computer at the site or from the UCSD/Scripps system, the data will be formally submitted to the Document Control Coordinator (DCC) in accordance with QAP-17.0, 'Quality Assurance Records.'

Data Processing:

We use a small suite of software routines, "LSMDP" (for Laser Strainmeter Data Processing), to visually identify locations of possible bad data and "offset and fill" any data that we judge to be erroneous. The raw data files are not modified in this operation; the processed data are altered by the introduction of an offset across times of bad data with the faulty data flagged (given an "impossible" number) to show the altered results, and a separate file of all such edit times is maintained. There are no established standards for making the editing judgements, and the final processed data, indicates the locations of all edits.

In this process we will also be guided by the use of unqualified data (recorded signals whose calibrations are not to QA standards); these will be used for corroboration purposes only.

The next step for producing the final data series is to add to the edited data the sum of a small set of "correction"" series (e.g., the end-pier motions).

The 'spreadsheet' routines for doing this are largely written. Under this Task we will submit a Software Qualification Request stating why this software suite qualifies as Low Level, and then prepare a Software Activity Plan (SAP) with a listing of the code and a description of what each piece does. The software to be covered would be all the programs which affect the data: programs which act directly on the data series.

Programs whose sole use is only to guide our editing judgements would not be included in the software qualification, since the results of that judgement are all that matter, and (again) these decisions are evident in the final series, and the edits information is maintained as a independent file for redundancy. The program used for visual identification of the locations for edits ("credit") does not modify the data but does play a role (since the data are too voluminous to be worked with by use of a simple listing). We will handle the quality assurance of this by presenting a test which is performed for each data submission; the results of this test will be included as an addendum to the Report sent in to the DCC, for each Report.

<u>Restricted Access:</u>

All YMP strainmeter-project data and software have write-access only for those people involved with the processing, and listed in the SN as having access.

<u>Records/Reporting:</u>

At least annually (and required within 60 days of contract end) send the raw data in a Report to the Document Control Coordinator, so that it becomes a permanent Record, which the DCC can submit to the Record Center. (This would be gzipped files on floppy, CD, or 8-mm tape.)

We note that calibration reports and ongoing SN entries (being quality-affecting) are also “records” and have to be submitted to the DCC in accordance with QAP 17.0, Section 4.5.

<u>Data Transmittals—Technical Data Management System (TDMS):</u>

TDMS maintains version control, and assigns data tracking numbers (DIN) for listing in reports.

Once the processing software is qualified, the processed data collected from the strainmeter will be submitted to the TDMS at least annually, with a latency (the time since the last processed data that is included) of less than 100 days. This latency stems from the routine archiving procedure.

Strain rates will be calculated, in part, based on the previously submitted data, and will be submitted to the TDMS prior to finalizing associated data reports. Records created as a direct result of the data submittal process will be submitted to the DCC by the Technical and Electronic Data Specialist in Las Vegas on behalf of Task ORD-FY04-008 personnel.

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 researchers, but there are not specific job skills required beyond those stated in the position descriptions filed with the UCCSN Training Coordinator.

5.0 Implementing Procedures and 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 above, 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 (IP) and Scientific Notebooks (SN) that are applicable to specific subtasks for the laser strainmeter monitoring are listed below.

IP IPR-028 (to be submitted)	Laser Strainmeter Systems Checks
SN UCCSN-UNR-026, Vol. 1 & 2.	A Long Baseline Laser Strainmeter for the ESF at Yucca Mountain.
SN UCCSN-UNR-061, Vol. 1.	

6.0 Equipment

Calibrations: The following equipment will be calibrated in accordance with QAP-12.0, "Control of Measuring and Test Equipment," and at NIST or by qualified suppliers in accordance with QAP-7.0, "Control of Procurement and Receipt."

		calibration
(1)	Winters Laser, ID# 006039056,	NIST
(2)	Hameg Frequency Counter, ID #008638,	Bechtel-Nevada
(3)	Wavetek Digital Multimeter, ID #008639,	Bechtel-Nevada
(4)	Varian Vacuum Gauges, ID #008839 and #000542*,	Bechtel-Nevada
(5)	Setra Barometric Gauges, ID #008838 and #000543*,	Bechtel-Nevada

*These are the only pieces of calibrated equipment needed for continuous operation. For this reason we maintain two units for exchanging when calibrations are due.

7.0 Hold Points

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

8.0 Records, Reports, and Submittals

We intend to comply with the UCCSN QA Program for the applicable elements as listed and described. Data recorded by the laser strainmeter will be submitted to the Technical Data Archive, along with support records, as specified by QAP 17.0 for raw data and QAP 3.6 for reduced data.

Deliverables, in outline form:

Project-level:
  Scientific Investigation Plan (this document)
  [Field Work Package—Test Coordination Office]

Implementation Procedure(s)
Implementation Procedures to replace repeated Scientific Notebook entries.
Data-processing software qualification
Qualify the software used for the reduction and analysis (processing) of the raw data.
Documentation on training for QA

Operationally/Annually:

Scientific Notebook entries	as due	
Including recording of all IP: Laser Strainmeter System Checks		
Equipment calibrations—NIST & Bechtel	as due	
Laser-frequency check	biannually	
[Training: site access/underground access]		

Regular reporting:

Quarterly Technical Reports (non QA)		To DOE
Field-recorded (raw) data—Data Submission Report	at least annually	
including MetaData on data channels and signals (becomes QA if included in SN)		
Scientific Notebook reviews	as due	
Processed data—Data Submission Report	at least annually	To DOE
Data interpretation (non QA)		

Closeout:

SN Review	
Data Submission	
Calibrations Checks	
Final Technical Report	To DOE
Final Records [and Records review—QA staff]	

9.0 Verifications and Reviews

Scientific Notebooks started under this task will be reviewed at the end of the performance period, or earlier as needed. The other technical reports developed under this task will be technically reviewed according to QAP-3.4 prior to submission.

All data must be reviewed with the Scientific Notebook prior to each submittal of data to the TDA.

10.0 Computer Software

As described in Section 3.0, a software package (LSMDP) will be submitted for qualification and the computer programs used in this task will be controlled in software configuration according to QAP-3.2 (*Software Management*).

11.0 Interfaces among M&O, UCCSN, DOE and Nevada Seismological Laboratory (NSL)

Dr. James Brune of the Seismological Laboratory of the University of Nevada, Reno (UNR), as the Task's primary Principal Investigator, will oversee the entire project and assure the project's integrity and academic and scientific soundness as the work progresses. The Principal Investigator for UCSD (the Task's co-PI), Dr. Duncan Agnew, will delegate responsibilities for implementing this plan as needed and perform reviews and concurrence on all work accomplished.

The Technical Task Representative is Drew Coleman.

Field work for this work plan is conducted within the ESF at Yucca Mountain. This work is governed by the current version of M&O Field Work Package FWP-EST-PA-003 "Laser Strainmeter". This package addresses 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, Contact: Dan Neubauer). The UCCSN QA program provides indoctrination and training as needed. All work planned or performed and all Q procurements are subject to review and/or verification by the UCCSN QA Manager.

12.0 Accuracy and Representativeness

The accuracy of collected data is ensured with periodic checks and documented with records submitted to the Technical Data Archive. Given the variabilities of activity within the earth, only a sample of that activity obtained over a 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. Only with long records comes confidence in their interpretation.

Technical discussion of the precision accuracy and representativeness, as was included in SIP-UNR-019, is as follows:

The precision of the strainmeter measurement can be taken to be the same as the resolution, which is determined by the ratio of the length of the strainmeter (405 m), to the wavelength of the light used (633 nm). Since the measurement is done by counting quarter-fringes and each quarter-fringe corresponds to an eighth-wavelength change in distance, the resolution is 0.195 nanostrain. This finite resolution corresponds to a quantization of the continuously-varying strain signal to changes of this amount. Such quantization introduces a small amount of noise into the strain measurement; the exact amount depends on the sample interval as well as the step size, according to well-established formulas in digital signal analysis. The amount of noise thus added should be much smaller than the size of the signals to be measured.

The accuracy of the strainmeter can be taken to be the degree to which the measurement reflects actual changes in distance between the anchor endpoints. This accuracy is affected by: (1) frequency fluctuations in the reference-standard laser; (2) changes in the index of refraction along the vacuum path (monitored by the vacuum gage); (3) drifts in the counting electronics (monitored by the reference multimeter); (4) by dimensional changes in the anchoring bond material (not possible to observe); (5) long-term dimensional changes in the interferometer components (also not possible to observe) and (6) dimensional changes in the interferometer components from thermal fluctuations. The level of all of (1-3) should not amount to more than $3x10^{-8}$ per year, though (2) may be a source of shorter-term fluctuations, which will be corrected for using the vacuum-gage readings. If a similar correction can be used to reduce the effect of (6), then temperature measurements of the instrument will also need to be QA, but this would not be done initially.

The potential sources of error are the same sources which affect the instrument accuracy.

Uncertainties in the instrument calibration will be less than 0.1%, set primarily by the uncertainty in the voltage calibration. The uncertainty between the measured and large-scale strain can be estimated to 0.1% using the Earth tides.

The representativeness of the measurements may be taken to be the degree to which the measured extension and contraction along the instrument reflect this component of strain elsewhere in the repository. Because of elastic inhomogeneities in the rock mass, the measured strain may depart from the strain elsewhere. A representative bound on the extent of this departure is provided by a comparison of the measured and the theoretical earth tides, which have been found to be in good agreement.

13.0 Personnel

The following personnel are involved with the subtasks described above and may make entries in the appropriate SNs:

Title	Name	
Principal Investigator	Jim Brune	UNR
UCSD Principal Investigator	Duncan Agnew	
Associate Investigator	Frank Wyatt	
Investigator	Don Elliott	
Technician	Stephen Dockter	
Technician	Steve Bralla	
Technician Assistant	Frank Cheng	
DCC/Research Assistant	Deni Menegus	
Dev. & Design Engineer	Wally Nicks	UNR

14.0 Schedules

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

Work schedule:

A. Program:

Key-personnel complete QA training and QT files completed:	March 2004
Site access training: Maintain site-access credentials for field crew (5).	annually
Completion of Field Work Package, for working in ESF.	annually
Instrument-usage IP completed:	30-Jun-04
Software Qualification Request (initial)	30-Apr-04
Submission of Software Activities Plan:	31-May-04
Submission of Data Processing-code software qualification:	1-Jun-04
Completion of Data Processing-code software qualification:	31-Jul-04
Semi-annual technical-data review:	March & Sept.
Semi-annual raw-data records submittal:	March & Sept.
Semi-annual reduced-data to TDA:	March & Sept.
Semi-annual QA-data review:	March & Sept.
Close out:	
Complete data collection through 8-Apr-08:	April 2008
Ongoing site-recording, continued.	
Final calibration/calibration checks:	May 2008
Complete data reduction/analysis:	June 2008
Submission of Final Report:	August 2008
Final Report Submitted to DOE:	September 2008
Final records to DCC:	September 2008

B. Operations and Monitoring:

Inspection; remote adjustments; and/or calls for site-assistant.	daily
Recording of activities in SN	daily
Trips to test/attend-to instrument (multiday).	~monthly; as required
Repairs of failed equipment (in lab).	as required
Reduction of field-checks/calibration-measurements.	as performed
Laser-frequency blue-red shift checks	quarterly
Reference-std, absolute laser-frequency measurements.	semi-annually

C. Calibrations and Checks:

Maintain reference-equipment in calibration (7 units):	annually for each

D. Downloading and Storage of Data:

Recovery and secure archiving of data.	daily

E. Processing and Analysis

Development of data-processing code.	ongoing (50%*)
Editing of field recordings for removal of artifacts/corrections.	monthly
Creation of calibrated-corrections from SN and field-recordings.	semi-annually
Interpretation of measurements in terms of geophysical phenomena.	ongoing

F. Instrument Remediation/Upgrades:

Replacement of all cage-mounted electronics:	April 2004
Secondary instrument controller/recording system:	June 2004
Optical Anchor path-length modulator:	June 2004
ongoing:	
Development of laser system monitoring: lab and instrument.	50%*
Development of remote and automated instrument control - strainmeter.	40%
Improvement of remote and automated instrument control - controller.	30%
Improvement of strainmeter response to disruptive train-passages.	25%
Replacement/upgrade of interferometer optics.	20%
Introducing additional environmental sensors	20%
Upgrade/replacement of circuit boards (incl. remote-control option).	15%

* Percentage to be completed in first year (fy2004)

Attachment SIP-UNR-028

Long-baseline Laser Strainmeter Measurement in the Exploratory Studies Facility at Yucca Mountain

1. Introduction: Current Status

The University of California, San Diego (UCSD), under subcontract to the Seismological Laboratory of the University of Nevada-Reno (UNR), has installed and is operating a laser strainmeter (LSM) in the Exploratory Studies Facility (ESF) at Yucca Mountain, to provide continuous deformation monitoring of the area with high precision and stability. Phase I of the project (site training, surveying, site selection, and instrument design and engineering) was completed by 2001. Phase II (component fabrication and onsite preparation) was completed by spring 2002. Phase III (assembly of the instrument and the initial test period) was completed in June, 2002. Phase IV (operation and analysis of the data) is currently in progress; while the transition from testing to routine operation of a new system in an unusual setting is not always clear-cut, since 2002:233 recordings of the ESF's deformation have been collected to QA standards. In order to meet contract requirements we will soon submit QA raw data from then through 2003:099 to the Document Control Coordinator, along with the Scientific Notebook for this period. Of course, the strainmeter is continuing to operate and monitor Yucca Mountain.

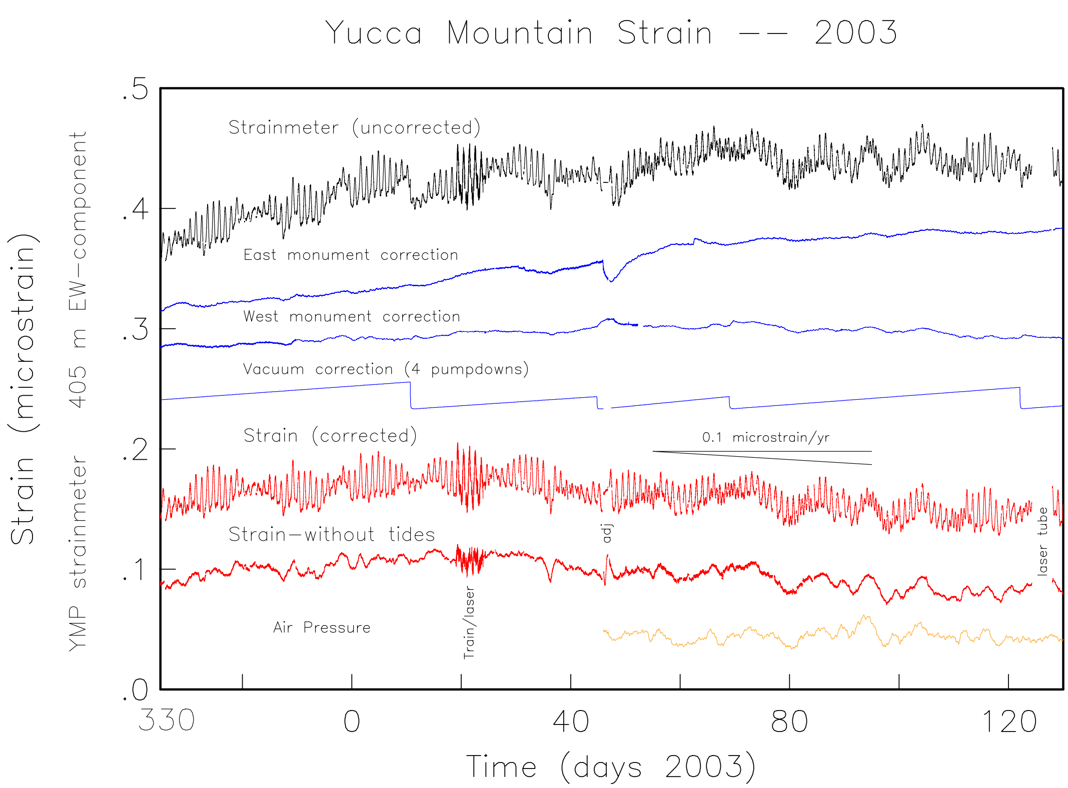

Figure 1

Prior to 2002:330 the data are significantly disturbed by laser-related problems stemming from passage of mine trains, a problem since reduced (though not eliminated) by the qualification and installation of another laser system. Other than this, the instrument has run with remarkably little trouble, providing a continuous record of strain with a resolution of 0.001 microstrain on a day-to-day basis — more than 100 times better than GPS over repository length scales (**Figure 1**). The recorded earth tides match the theoretical tides well; there is no anomalous or nonlinear tidal response. With only 6 months of data, and the likelihood of there being an annual-cycle component to the deformation, the East-West strain rate can be bounded only preliminarily ("Strain-without tides" in figure), but it is certainly within ±0.2 microstrain per year, and could be much smaller.

2. Future Plans I: Instrument Operation and Data Analysis

Work Proposed: We would plan, first, to continue to operate and interpret data from the existing laser strainmeter (LSM) in the south adit of the ESF. Operation would include remote and onsite adjustment of instrument systems to assure continuous operation and production of high-quality data; maintenance and repair of instrument subsystems as needed; calibration of elements essential to production of QA data; and additional measurements and instrument improvements as we continue to work out design issues in this novel environment. Data interpretation would include routine data downloading, local archiving of data, editing of data and application of calibration measurements to produce an optimal estimate of strain changes, submission of raw and edited data to the Document Center for final archiving, and analysis and interpretation of the measurements in terms of repository performance and geophysical phenomena. All data-handling would be done in accordance with QA procedures.

Value to YMP. The value of such continued operation and analysis to the Yucca Mountain Project is that the LSM is critical for understanding the short-term and long-term stability of the site; precise deformation monitoring is essential for understanding the hazard posed by the local tectonic environment, for helping to define the engineering requirements for constructing a safe site, and for providing a baseline against which to observe warning signals from any significant future changes in tectonic, volcanic, or rock conditions. The LSM continuously monitors the repository-scale strains from all sources, complementing regional geodetic surveys at the facility by providing an independent check and much lower noise over a wide frequency range.

Continued operation will monitor the following:

- The baseline strain rate in the ESF; measuring this, and possible future changes, will provide a powerful check for strain-rate variations that might be associated with possible tectonic or volcanic events or potential repository activities.
- Strains associated with seismic waves, earth tides, and atmospheric pressure variations (e.g. the conspicuous correlation of strain and pressure in Figure 1); analysis of these provides unique information on the bulk rock properties (e.g., elastic modulus) of the potential repository block, and any changes in them.
- Any strains from earthquakes (either from static deformations caused by (future) local earthquakes, or by triggered slip along nearby faults) or from volcanic activity (e.g., in Crater Flat); any such strains would be important in judging the integrity of the repository after such events.

Appropriateness of Team: The UCSD group is very familiar with the LSM design, having been the builders of it. There are not currently any other groups in the USA operating or constructing similar instruments.

Duration and Cost: Because of the long-term nature of some of the phenomena being measured (the long-term strain) and the unpredictable nature of others (earthquake-related strains), the operation and interpretation needs to be ongoing, so this proposal is for the full duration of the Cooperative Agreement (5 years). The annual cost would be $150K for the first year, $105K for the second, and $75K/yr averaged over years 3-5. The larger costs for the first 2 years reflect the substantially higher level of effort needed both for bringing the whole data-handling process and software to QA standards and for instrument improvements to make the long-term operation and data-handling more routine. The operation costs are based on our experience at other sites, adjusted for QA requirements. The total 5-year cost is $480K.

3. Future Plans II: A Second Laser Strainmeter (North-South component)

Work Proposed: We would also propose to construct a second laser strainmeter in the ESF, orthogonal to the first one, along the NS part of the tunnel. This would follow the design of the existing instrument, which is now well matched to ESF requirements and site-crew capabilities.

Value to YMP: A second instrument will provide a better characterization of the strain changes mentioned above, both by measuring in an orthogonal direction, and also by providing an independent measurement at some distance from the existing sensor. This last point is particularly important: any signal seen on both has to be assumed to apply to the bulk of the repository, thus significantly improving the confidence of all data interpretation. With a single instrument questions remain.

Appropriateness of Team: The UCSD group is not only, as noted above, the only group in the USA that has built these instruments, but it is also quite experienced at working in the ESF, which has tremendous advantages in saving both cost and time in building a second system.

Duration and Cost: Based on the costs and time incurred for the construction of the existing instrument, we estimate the cost of constructing a second one at $710K. Note that for the first instrument a great many issues that had to be resolved, and designs that had to be developed, should not have to be revisited for the second, since we assume that similar site constraints and capabilities will apply. The table shows the timeline we would expect for construction stages for a second system, as well as what was achieved for the first one; we are confident that a second installation could be completed within a two year period (perhaps more quickly).

Laser Strainmeter Construction — Yucca Mountain ESF

Activity	EW Inst	(Duration)	Projected NS Inst	(Duration)
Initiation of site planning *	3/99		10/03	
Site design/authorization *	11/99	(8 mo)	12/03	(2 mo)
Anchor drilling	1/00	(2 mo)	3/04	(3 mo)
Alcove excavation *	12/00	(11 mo)	6/04	(3 mo)
Anchor installations	3/01	(3 mo)	9/04	(3 mo)
End buildings *	8/01	(5 mo)	1/05	(4 mo)
Vacuum tubing	8/01		2/05	
Anchoring optics	11/01	(3 mo)	4/05	(3 mo)
Strainmeter optics	1/02		6/05	
Initiation of operations	3/02		8/05	
		36 mo		22 mo

* — areas in which we expect substantial saving (in time and money) for a second installation.

Once completed, we anticipate this second instrument would add to the operating cost an incremental amount of roughly $20K per year (years 3-5). This makes the total request for the second strainmeter $770K.