Lawrence Livermore National Laboratory

Update of Earthquake Strong-Motion Instrumentation at Lawrence Livermore National Laboratory

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Disclaimer

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1 Introduction

Following the January 1980 earthquake that was felt at Lawrence Livermore National Laboratory (LLNL), a network of strong-motion accelerographs was installed at LLNL [1]. Prior to the 1980 earthquake, there were no accelerographs installed. The ground motion from the 1980 earthquake was estimated from USGS instruments around the Laboratory to be between 0.2–0.3 g horizontal peak ground acceleration [2]. These instruments were located at the Veterans Hospital, 5 miles southwest of LLNL, and in San Ramon, about 12 miles west of LLNL.

The accelerograph network had two objectives:

- Provide data for analyses of the free-field ground motion (peak ground acceleration) on site
- Provide quantitative information on the severity of ground shaking for the assessment of damage to buildings

The network included a digital nine-channel central recording system in Building 111 (a seven-story Administration and Technical Office Building) and a digital 18-channel central recording system in Building 332 (the Plutonium Research Facility). A multichannel system was also installed on the Nova Laser Facility. In addition to the structural instrumentation, six free-field accelerographs were located on and around the Laboratory. Initially, annual maintenance was conducted on all instruments. As budgets became more constrained, the maintenance decreased.

In June 2005, 10 triaxial accelerographs were installed in the National Ignition Facility (NIF). Three were located at various elevations in the Target Bay, three were located at various elevations in Switchyard 2, three were located in Laser Bay 2, and one free-field instrument was located on the Central Plant slab [3].

In 2011, the Department of Energy (DOE) requested to know the status of our seismic instruments. We conducted a survey of our instrumentation systems and responded to DOE in a letter [4]. During this survey, it was found that the recorders in Buildings 111 and 332 were not operational. The instruments on Nova had been removed, and only three of the 10 NIF instruments installed in 2005 were operational (two were damaged and five had been removed from operation at the request of the program).

After the survey, it was clear that the site seismic instrumentation had degraded substantially and would benefit from an overhaul and more attention to ongoing maintenance. LLNL management decided to update the LLNL seismic instrumentation system. The updated system is documented in this report.

Appendix A contains useful definitions related to seismic instrumentation systems. Appendix B contains Kinemetrics' data sheets for LLNL seismic instruments, and Appendix C contains instrument type, DOE and serial numbers, and IP addresses or phone numbers for the installed instruments.

2 Seismic Setting of LLNL

The Livermore Valley is located in a seismically active region of Central California (see Figure 1). There are a number of major active earthquake faults within the immediate vicinity of the Valley and it can be expected that the Laboratory will be subjected to a number of earthquakes, of varying magnitudes, in the future. Specifically, the Calaveras, Hayward, and San Andreas Faults to the west are

all capable of generating large earthquake motions that could significantly shake the Laboratory. The Greenville Fault and a number of smaller local faults are capable of generating smaller earthquakes that could also shake the Laboratory at lower levels. Most facilities at the Laboratory have been designed to meet earthquake standards established by the Department of Energy, the Uniform Building Code, the International Building Code, or the California Building Code.

Figure 1. Proximity of the LLNL site to major earthquake faults.

3 Current LLNL Seismic Design Criteria

Current seismic design criteria for LLNL facilities follow DOE Order 420.1C-2012, *Facility Safety*, and DOE-STD-1020-2012, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities*, which is a set of performance-based design criteria. The LLNL criteria established Seismic Design Categories (SDC), which range from 1 (lowest) to 4 (highest). Most buildings at LLNL are in SDC-1, General Use Facilities, and therefore essentially use the California Building Code for their seismic design basis. Facilities housing police/security, the emergency communications center, and the firehouse are SDC-2, Essential Facilities. Some programs, like NIF, have placed their facilities in SDC-2 to ensure more seismic protection. The Plutonium Building

currently is the only SDC-3 facility at LLNL, and uses a Design Basis Earthquake (DBE) of 0.57 g peak horizontal ground acceleration (PGA) with a mean centered response spectrum shape, typically at 5% damping. There currently are no SDC-4 facilities at LLNL.

Seismic design criteria for equipment at LLNL are documented in the *Engineering Design Safety Standards Manual*, Section 5.2, "Seismic Design and Evaluation Criteria for Equipment." This document defines the DBE as a PGA of 0.57 g with a response spectrum shape defined for various damping ratios for all programmatic equipment.

The last seismic hazard characterization for the LLNL site was completed in April 2002 [5]. The results generally agreed with the previous 1991 study by J. F. Scheimer. Since DOE Orders require a reevaluation of the seismic hazard every 10 years, LLNL is conducting an update of the site seismic hazard characterization in 2013. This update is expected to be complete by the end of the calendar year. Results of this study may change the current seismic design criteria.

4 Department of Energy Requirements for Seismic Instrumentation

The requirements for seismic instrumentation at DOE sites are cited below:

- DOE Order 420.1C: *Facility Safety*, 12/4/2012, Attachment 2, Chapter IV, *Natural Phenomena Hazards Mitigation*, Section 3, "Requirements," paragraph e., Seismic Detection, states the following:

  Seismic Detection: *DOE sites with nuclear or hazardous materials must have instrumentation or other means to detect and record the occurrence and severity of seismic events.*

- DOE Guide 420.1-2: *Guide for the Mitigation of Natural Phenomena Hazards for DOE Nuclear Facilities and Nonnuclear Facilities*, Approved 3/28/2000.

  This document was canceled by DOE Order 420.1C; however, the guidance is useful. Chapter 6, *Guidelines*, Section 6.5, "Seismic Detection," states the following:

  Seismic Detection: *Facilities or sites with Structures, Systems, or Components in Performance Category-2, (PC-2, with hazardous material), PC-3, or PC-4 should have instrumentation, such as strong motion detectors or other means, to detect and record the occurrence and severity of seismic events. In those cases where safety analysis identifies the need for rapid response reactions, annunciation of seismic event should be considered for personnel evacuation or other vital mitigative actions. For a large site, several representative facilities spread over the site must have such instrumentation.* (**Note:** Previous DOE documentation used the term Performance Category, PC. This has been replaced with Seismic Design Category, SDC, in the latest DOE documentation.)

5 Criteria for Updating Seismic Instrumentation System

We developed the following criteria for updating the LLNL Seismic Instrumentation System:

- Use existing recorders, wiring, and sensors whenever available
- Replace or repair damaged instruments and recorders

- Deploy four existing, self-contained instruments available from those removed from NIF
- Purchase new instruments as needed
- Instrument buildings based on institutional importance and programmatic impact

These criteria were used as the basis for actions that resulted in the updated LLNL Seismic Instrumentation System. Instrument locations for free-field seismic instruments around the LLNL Livermore site are shown in Figure 2, while free-field and building seismic instruments at the LLNL Livermore site are shown in Figure 3.

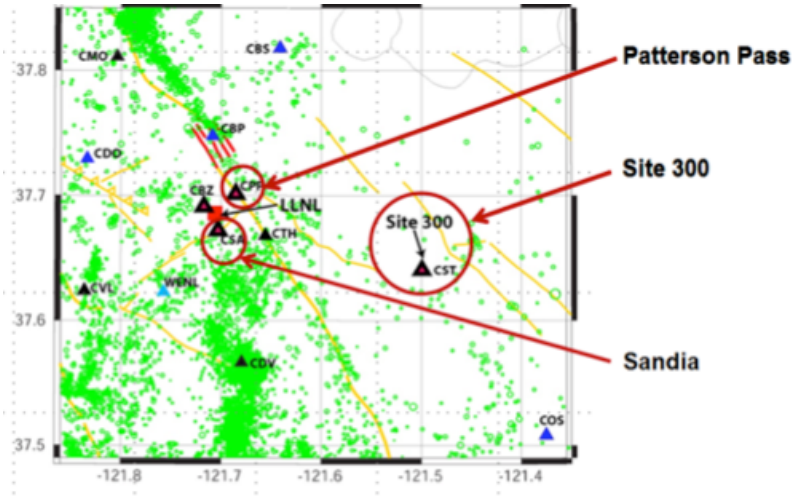

Figure 2. Seismic instruments around the Lawrence Livermore National Laboratory site.

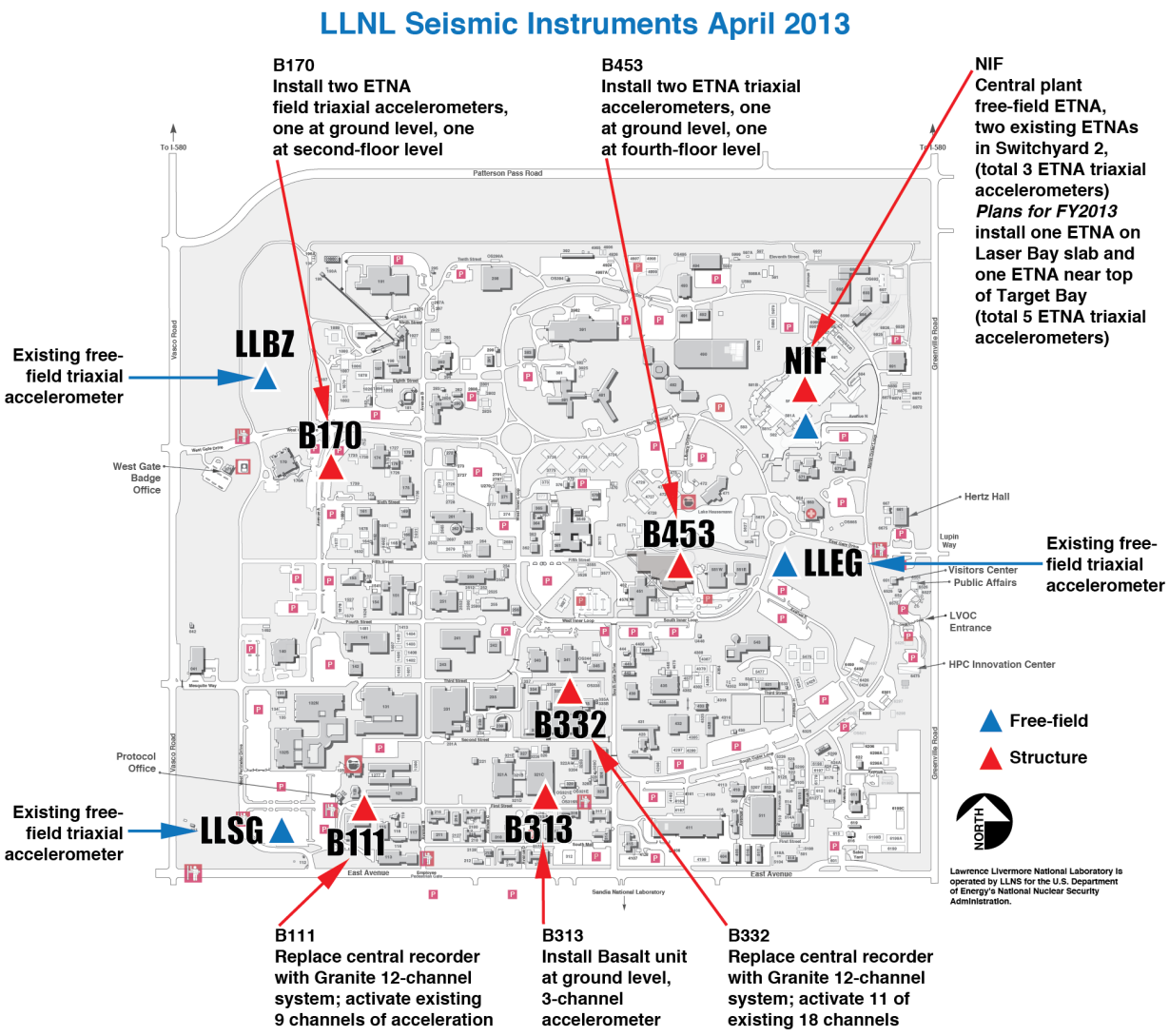

Figure 3. Seismic instrumentation upgrade plan for the Lawrence Livermore National Laboratory, Livermore, site.

6 Free-Field Instruments

The free-field seismic instruments shown in Figure 2 and Figure 3 are listed in Table 1; these instruments are in their original locations from earlier installations.

Table 1. Free-field seismic instruments at LLNL.

Site	SMIP Station Number	Station Name and Coordinates
Buffer Zone (LLBZ)	57252	Livermore—Vasco and Westgate (Located in middle of NW Buffer Zone) N 37.6911°, W 121.7172° Elevation 174 m; alluvium
East Gate (LLEG)	57253	Livermore—Greenville and Eastgate (Located near East Rotary) N 37.6869°, W 121.7005° Elevation 201 m; alluvium
Sandia (CSA)	57254	Livermore—Greenville and Arroyo Seco (Located in Wildlife Reserve) N 37.6724°, W 121.7029° Elevation 208 m; alluvium
Site 300 (CST)	57202	Livermore—Corral Hollow Road (Located inside Building 841) N 37.6384°, W 121.4985° Elevation 200 m; rock (sandstone)
Patterson Pass (CPP)	57201	Livermore—Patterson (Located on Zone 7 Water Treatment Plant grounds) N 37.7009°, W 121.6844° Elevation 235 m; rock (sedimentary)
SW Gate (LLSG)	57227	Livermore—East and Vasco (Located in Parking Lot) N 37.6811°, W 121.7164° Elevation 185 m; alluvium
NIF Slab (NIF)	–	National Ignition Facility Slab

These instruments have been updated previously since their original installation. We initiated a contract with the State of California, Department of Conservation, California Geological Survey (CGS), Strong Motion Instrumentation Program (SMIP), to maintain these six free-field instruments. This includes weekly electronic monitoring of the instruments to assure all systems are operational. Quarterly functional testing of the system will also be performed to confirm operation and recording of test data. These actions are done remotely through communication lines. During the period of February 5–7, 2013, a precision electronics specialist from SMIP conducted on-site maintenance of these six instruments. This maintenance included replacing the batteries, checking the solar panel charging systems, checking the instruments, replacing instruments as needed, checking the cell phones (where present), and checking that the GPS antennas capture at least three satellites. A repeat visit was

conducted on February 26, 2013, to make repairs on instruments and cell phones at Site 300 and the Buffer Zone. Photographs of the free-field instruments maintained by SMIP are shown in Figures 4 through 18. The free-field instruments are each anchored to a concrete pad with a locked fiberglass enclosure over the instrument, batteries, cell phone, and solar panel regulators. The instrument at Site 300 is inside Building 841 within an unlocked wooden enclosure. All other instruments are locked. The free-field instruments can run for about two days on battery power only.

NIF staff maintains the free-field instrument on a slab near the NIF Central Plant.

6.1 LLNL Buffer Zone Seismic Instrument Installation

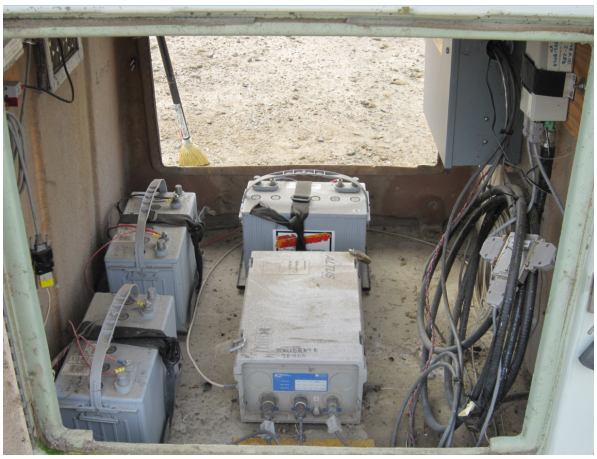

Figure 4. LLBZ K2-4 instrument and batteries.

Figure 5. LLBZ enclosure and solar panels.

6.2 LLNL East Gate Seismic Instrument Installation

Figure 6. LLEG ETNA instrument and batteries.

Figure 7. LLEG enclosure and solar panels.

6.3 Sandia Seismic Instrument Installation

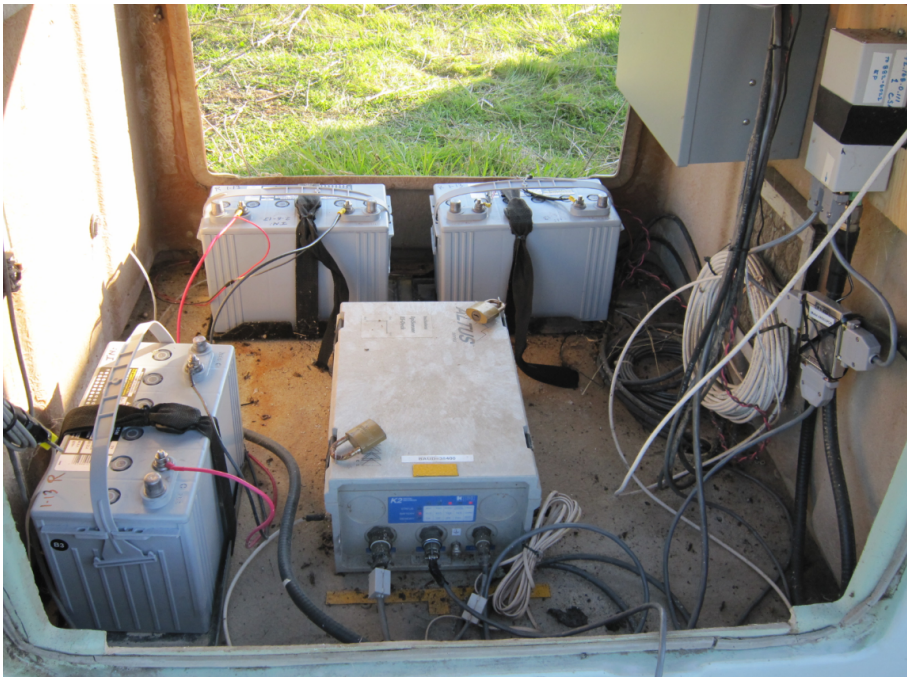

Figure 8. Sandia K2-4 instrument and batteries.

Figure 9. Sandia enclosure and solar panels.

6.4 Site 300 Seismic Instrument Installation

Figure 10. S-300 K2-4 instrument and batteries.

Figure 11. S-300 Building 841 with GPS antenna at roof.

Figure 12. S-300 close-up of GPS antenna at roof.

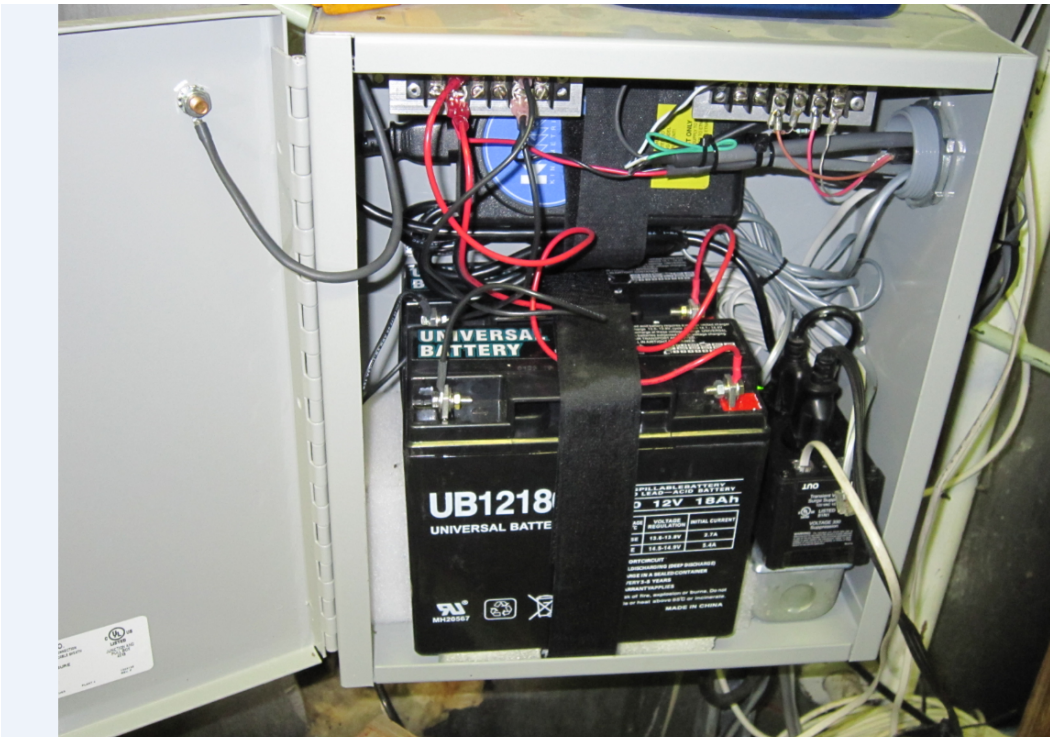

Figure 13. S-300 close-up of battery box.

6.5 Patterson Pass Seismic Instrument Installation

Figure 14. Patterson Pass K2-4 instrument and batteries.

Figure 15. Patterson Pass enclosure and solar panels.

6.6 LLNL South Gate Seismic Instrument Installation

Figure 16. LLSG ETNA instrument.

Figure 17. LLSG battery.

Figure 18. LLSG enclosure.

7 Building Instruments

7.1 Building 111 and Building 332 Central Recording Systems

The seismic recorders in Buildings 111 and 332 were each replaced with a 12-channel Granite system manufactured by Kinemetrics, Inc. The previously installed force balance sensors and wiring were reused. These installations are shown in Figures 19 through 22. The Granite Recorder is a sealed unit. See Shakal and Murray [1] for the location of the nine sensors in Building 111. For Building 332, only 11 channels of the original 18-channel system were connected to the Granite recorder (transducers 5 uniaxial, 6 uniaxial, 9 uniaxial, and 10 uniaxial were not reconnected and transducer 4 uniaxial and 7 biaxial were missing and not reconnected); see Shakal and Murray [1] for other locations within the building.

7.1.1 Building 111 Seismic Instrumentation Installation

Figure 19. 12-channel Granite recorder located on bottom shelf of cabinet, with UPS unit on upper shelf. Building 111, first floor janitor's closet.

Figure 20. GPS antenna mounted near a window in Building 111 to receive time signal from satellites.

7.1.2 Building 332 Seismic Instrumentation Installation

Figure 21. A 12-channel Granite recorder located in a cabinet in the Building 332 control room.

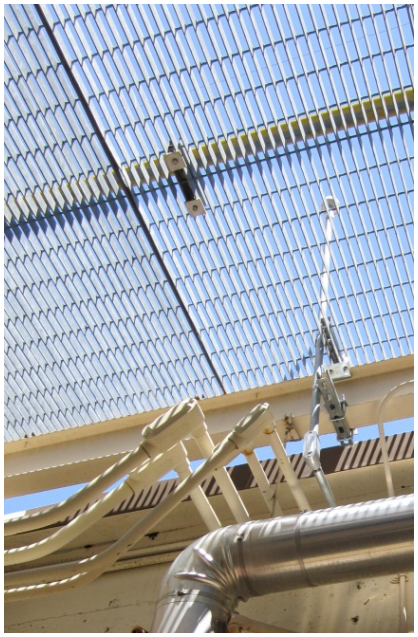

Figure 22. GPS antenna mounted on Building 332 to receive time signal.

7.2 Building 313 Alameda County Emergency Control Center

A new Basalt triaxial accelerograph was installed in Building 313, which is the location of the Alameda County Emergency Control Center. The Basalt is a sealed unit and was installed below the computer floor as shown in Figures 23 through 27.

7.2.1 Building 313 Seismic Instrumentation Installation

Figure 23. A 3-channel Basalt recorder located below computer floor in Building 313 (GPS position 37.681023 N, –121.708050 E).

Figure 24. Basalt recorder anchored to the concrete floor in Building 313.

Figure 25 and Figure 26 show the wall-mounted UPS (Uninterruptible Power System) for the Basalt unit. The GPS antenna to receive time signals is mounted above the roof of Building 313, as shown in Figure 27.

Figure 25. Wall-mounted UPS for Basalt unit below computer floor.

Figure 26. Larger view of UPS unit.

Figure 27. GPS antenna mounted above the Building 313 roof.

7.3 Building 170 National Atmospheric Release Advisory Capability Facility

Two ETNA triaxial accelerographs, available from NIF, were installed in Building 170, the National Atmospheric Release Advisory Capability (NARAC) facility. One instrument was anchored to the ground floor in Room 1036 and the second instrument was anchored to the second floor in Room 2006. Both instruments have battery backup within the unit and are connected to a phone line. These installations are shown in Figure 28 and Figure 29.

7.3.1 Building 170 Seismic Instrumentation Installation

Figure 28. Building 170, Room 1036 ETNA instrument on the first floor.

Figure 29. Building 170, Room 2006 ETNA instrument on the second floor.

7.4 Building 453 Terascale Facility

Two ETNA triaxial accelerographs, also available from NIF, were installed in Building 453, which is a large computing facility. One instrument was anchored to the first floor in Room 1215 and the second instrument anchored to the fourth floor in Room 4025. Both instruments have battery backup within the unit and are connected to a phone line. These installations are shown in Figure 30 and Figure 31.

7.4.1 Building 453 Seismic Instrumentation Installation

Figure 30. Building 453, Room 1215 ETNA instrument on first floor.

Figure 31. Building 453, Room 4025 ETNA instrument on fourth floor.

A maintenance agreement will need to be established for the Building 111, 170, 313, 332, and 453 installations.

7.5 National Ignition Facility Free-Field Instrument

At NIF, the free-field instrument located at the Central Plant was moved outside the Central Plant slab to reduce false triggers from pumps starting and stopping. The NIF free-field instrument, in its protective box, is shown in Figure 32.

Figure 32. Installation of NIF free-field ETNA in a NEMA box. (Left) Instrument on concrete pad. (Right) Instrument in NEMA box.

7.6 National Ignition Facility Building Instruments

There are two existing ETNA instruments in Switchyard 2 located at elevations of 17 ft 6 in. (Figure 33) and 50 ft 6 in. (Figure 34), respectively. In the near future, NIF engineers plan to install one ETNA in Laser Bay 2 and one ETNA near the top of the Target Area, located outside. These instruments are currently available and stored in the NIF Tool Crib. Once they are installed, this system will consist of one free-field triaxial instrument and four building triaxial instruments. There will be no instruments inside the Target Bay. One spare ETNA will be available, as needed, for NIF or other LLNL buildings.

Figure 33. ETNA located on a steel beam in NIF Switchyard 2 at 17 ft 6 in.

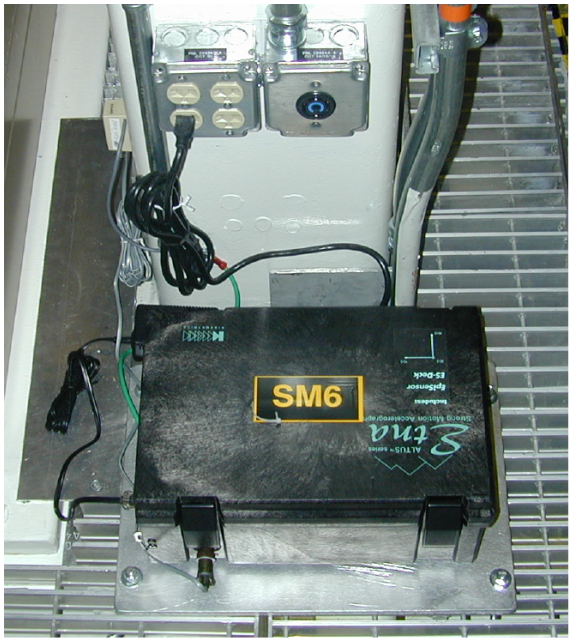

Figure 34. ETNA located on a plate clamped to a grating, which is connected to the steel beams in NIF Switchyard 2 at an elevation of 50 ft 6 in.

NIF has a technician assigned to maintain their free-field and building instruments.

Data sheets for the K2-4, ETNA, Basalt, and Granite instruments are included in Appendix B. Data sheets for the Force Balance Accelerometers, FBA and Episensor, are also included in Appendix B. Additional information is available on the Kinemetrics website at http://www.kinemetrics.com/p-163-Home.aspx.

Appendix C contains information on the SMIP and LLNL seismic instruments.

8 Utilization of Earthquake Ground Motion Data

8.1 Criteria for Halting Operations and Post-Earthquake Inspections

A review was conducted of guidance developed by the International Atomic Energy Agency, the Nuclear Regulatory Commission, and the Electric Power Research Institute for operating commercial nuclear power plants [6–13]. A summary of these documents was developed by Kassawara [14]. The developed guidance is specifically for operating commercial nuclear power plants. Jack R. Benjamin and Associates [7] established criteria for determining when a commercial nuclear power plant Operating Basis Earthquake (OBE) was exceeded using the Cumulative Absolute Velocity (CAV), which is the integrated absolute value of the acceleration time history and the acceleration response spectrum. Yankee Atomic Electric Company [9] extended the CAV to the Standardized CAV (SCAV) by limiting the integration to accelerations above 0.025 g. Commercial nuclear power plants have established an OBE that is typically one-half of its Safe Shutdown Earthquake (SSE), which is the design earthquake for the plant. If the OBE is exceeded, the plant must be shut down and remain shut down until the plant can demonstrate that the earthquake caused no damage that could affect safe operation. The OBE is defined by a velocity or acceleration response spectrum, which is a function of frequency. Typical 5% damped response spectra used at the LLNL site are shown in Figure 35. The Newmark & Hall Acceleration Response Spectrum is the LLNL Design Basis Earthquake Response Spectrum, which is anchored to the appropriate Peak Ground Acceleration. The Acceleration Response Spectrum from the U.S. Nuclear Regulatory Commission Regulatory Guide 1.60 is also shown for comparison.

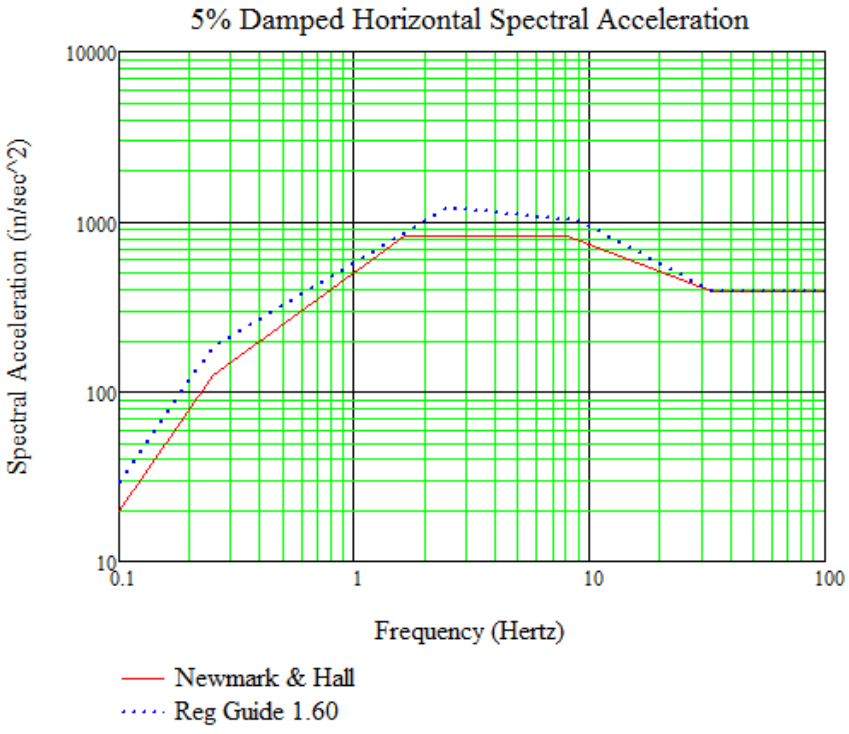

Figure 35. 5% Damped design acceleration response spectra anchored to 1.0 g (386.4 in./sec^2).

Criteria have been established in the above references to determine if the OBE at a commercial nuclear power plant has been exceeded. After an earthquake occurs at or near the LLNL site, the ground motion records (acceleration-time histories from each seismic instrument) must be collected and evaluated.

The following criteria have been adapted from the above references for use at LLNL. Since LLNL does not use an OBE in design, we have elected to use 0.3 g (approximately one-half of our DBE of 0.57 g, which is similar to an OBE for a commercial nuclear power plant at this location) in the response spectrum check. Since LLNL is not a commercial nuclear power plant, this criterion shall be used as guidance for rapidly estimating if the earthquake might have caused damage to LLNL facilities and if a walkdown inspection should be conducted.

The Seismic Safety Study [15] completed in 2008 documents facilities at LLNL's Livermore site and Site 300 that do not meet seismic safety standards as defined in the reference. This study was conducted by Degenkolb Engineers, a San Francisco-based structural/earthquake engineering firm. These facilities should be examined if the PGA exceeds 0.15 g.

Response Spectrum Check
At frequencies between 2 and 10 Hz, the 5% damped response spectrum, calculated from the free-field measured earthquake data, exceeds 0.3 g

or

At frequencies between 1 and 2 Hz, the ground velocity exceeds 6 in./sec.

and

CAV Check
The Standardized CAV (SCAV) is greater than 0.16 g-sec. The largest SCAV is used from the three orthogonal components of earthquake motion from each free-field triaxial recorder.

A computer program to calculate the acceleration response spectrum from the measured data has been developed at LLNL [16]. This program runs on a Windows PC with a 32 bit operating systems. A Mathcad program has also been developed to calculate the acceleration response spectrum. The Mathcad program is an implementation of the procedure outlined by Nigam and Jennings [17]. A Mathcad program has also been written to calculate the SCAV. All of the computer programs have been verified with data presented in the references.

8.2 Processing Earthquake Data

The following procedure is recommended for processing the data obtained by the seismic instruments following any earthquake that has been felt at LLNL.

1. Obtain data from instruments
    a. Free-field data can be obtained for the six free-field instruments on and around LLNL by contacting the State of California, Department of Conservation, California Geologic Survey, Strong Motion Instrumentation Program:
        i. Carl Petersen, (916) 322-9302 Carl.Petersen@conservation.ca.gov
        ii. SMIP Office, (916) 322-3105
        iii. Their website is http://www.quake.ca.gov

    The data should be available shortly (within about 1 hour) after an earthquake has occurred, being posted on the SMIP website automatically after the earthquake. It can be

viewed by looking for *Internet Quick Reports* and clicking on the *Livermore SMIP Station Number* from Table 1.

b. Data from Buildings 111, 313, and 332 can be obtained over the internet using the following IP addresses (see Appendix C, Table C-2, for the Subnet Mask, Gateway, and DNS name):
    i. Building 111: 128.115.193.242
    ii. Building 313: 128.115.221.2
    iii. Building 332: 134.9.139.239

c. Data from Buildings 170 and 453 can be obtained by downloading it directly from the instrument to a laptop computer, or over phone lines using the following numbers:
    i. Building 170 Ground Floor, (925) 423-3026
    ii. Building 170 Second Floor, (925) 424-3140
    iii. Building 453 Ground Floor, (925) 423-2243
    iv. Building 453 Fourth Floor, (925) 423-2306

d. Data from NIF can be obtained from:
    i. Bob Swanson, (925) 423-4650 swanson20@LLNL.gov

To download the data from the instruments, Kinemetrics' software is available at no cost from their website at http://www.kinemetrics.com.

ETNA Instruments: *Tel Net* for dial-up, *Quick Talk* to view data

Granite and Basalt Instruments: *Rock Monitoring*

2. Once the data has been obtained, the free-field data should be processed first as follows:
    a. Determine the Peak Ground Acceleration
    b. Calculate the 5% damped acceleration response spectrum and compare it to 0.3 g between 2 and 10 Hz
    c. Calculate the 5% damped velocity response spectrum and compare it to 6 in./sec between 1 and 2 Hz
    d. Calculate the SCAV and compare it to 0.16 g-sec
    e. If both the acceleration or velocity response spectra and the SCAV are exceeded then active facilities should stop operations. Facility inspections should then be conducted and documented.
3. Building instrument data should be examined to estimate building damage, if any. Story displacements will be compared to acceptable drifts.

8.3 Example of Processed Earthquake Data

The first example is analysis of a measured record from the January 24, 1980 earthquake that was felt at the Livermore Site. The earthquake occurred on a Thursday when the Laboratory was occupied. The earthquake occurred on the Greenville fault near the Laboratory (see Figure 1) and had a magnitude of 5.5 and a peak ground acceleration of 0.26 g. The acceleration time history is shown in Figure 36. The earthquake record was obtained from the PEER Database [18].

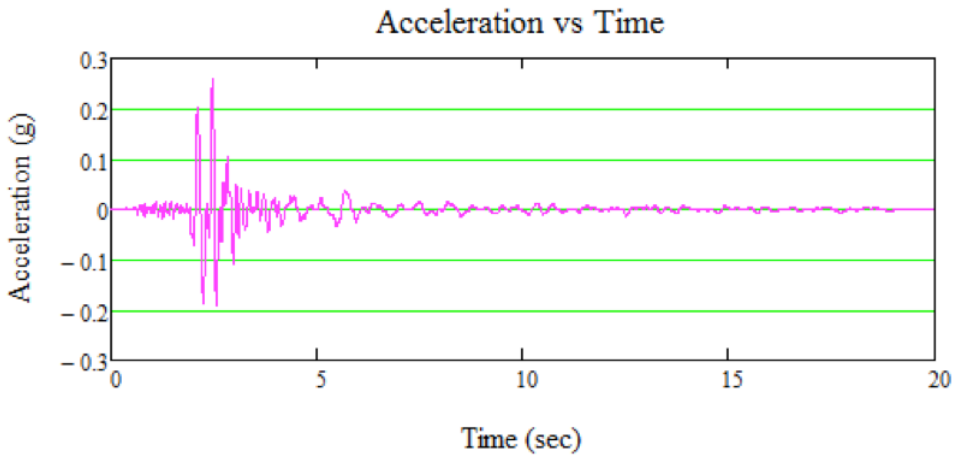

Figure 36. Acceleration time history for the 1980 Livermore earthquake.

The 5% damped acceleration response spectrum for the 1980 Livermore earthquake is shown in Figure 37. The response spectrum exceeds the target acceleration of 0.3 g between frequencies of 2 and 10 Hz.

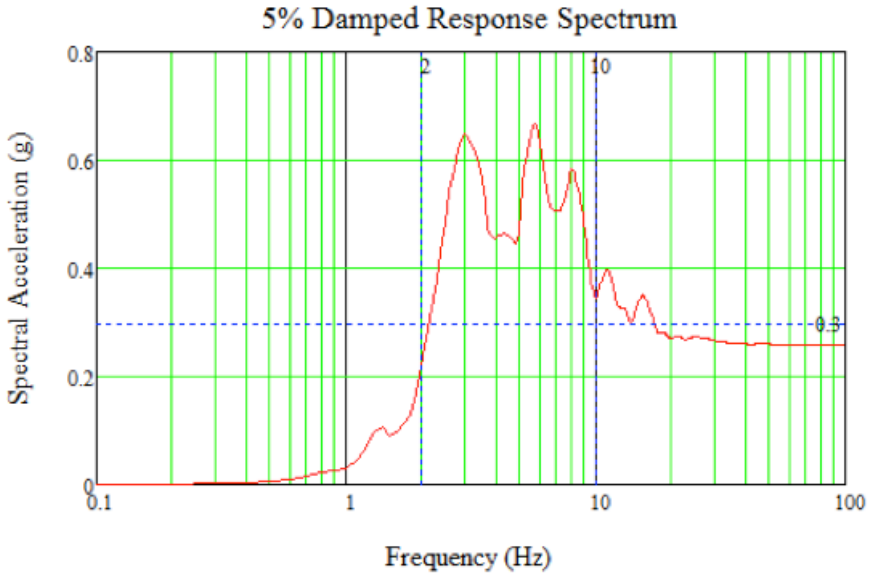

Figure 37. 5% Damped acceleration response spectrum for the 1980 Livermore earthquake.

The CAV and SCAV are both shown in Figure 38. Here, the SCAV does not exceed the threshold value of 0.16 g-sec.

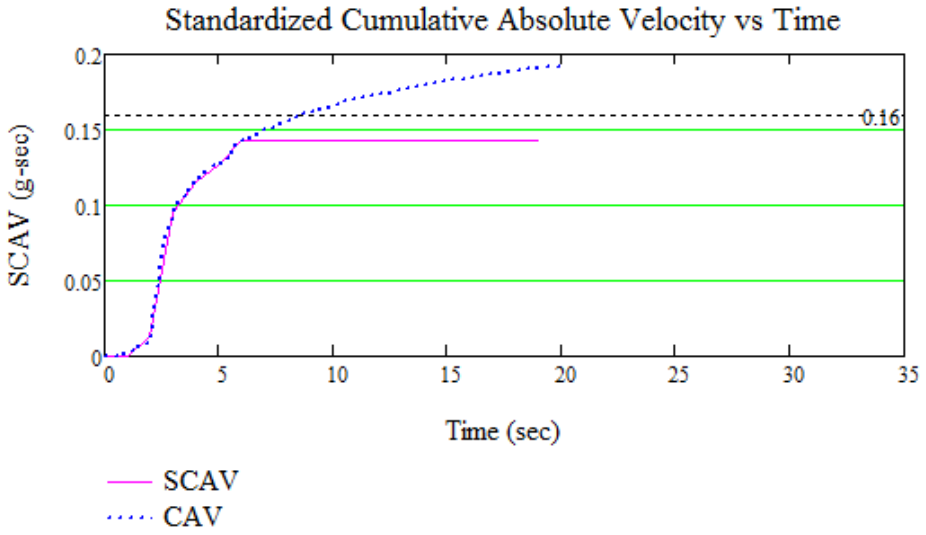

Figure 38. CAV plots for the 1980 Livermore earthquake.

In this case, the response spectrum check exceeded the threshold value but the SCAV did not exceed the threshold value. Since both measurements must exceed their threshold values, this result would indicate continued operation at the location of this record is justified.

As a second example, a record at the Kodak Building in San Ramon during the 1980 Livermore earthquake was analyzed. The acceleration time history is shown in Figure 39. The earthquake record was also obtained from the PEER database. The peak ground acceleration was 0.301 g.

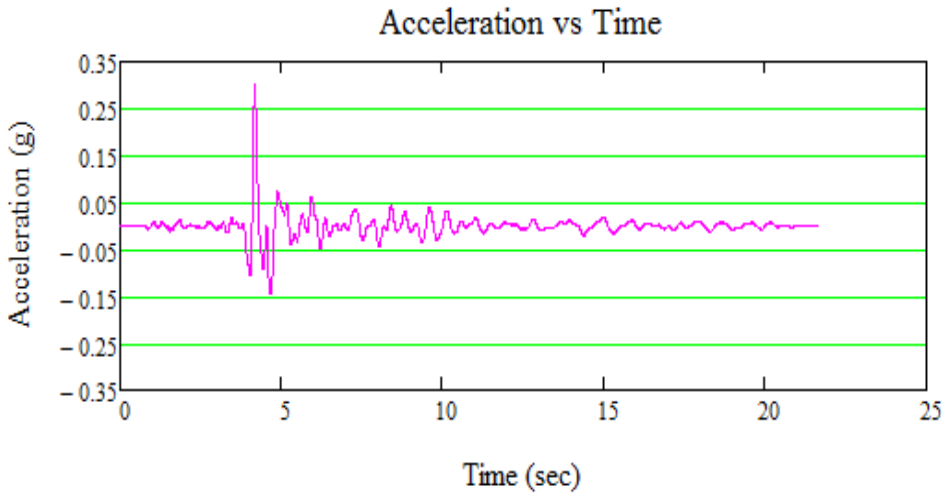

Figure 39. Acceleration time history for the Kodak Building in San Ramon from the 1980 Livermore earthquake.

The 5% damped acceleration response spectrum for the 1980 Livermore earthquake is shown in Figure 40. The response spectrum exceeds the target acceleration of 0.3 g between frequencies of 2 and 10 Hz.

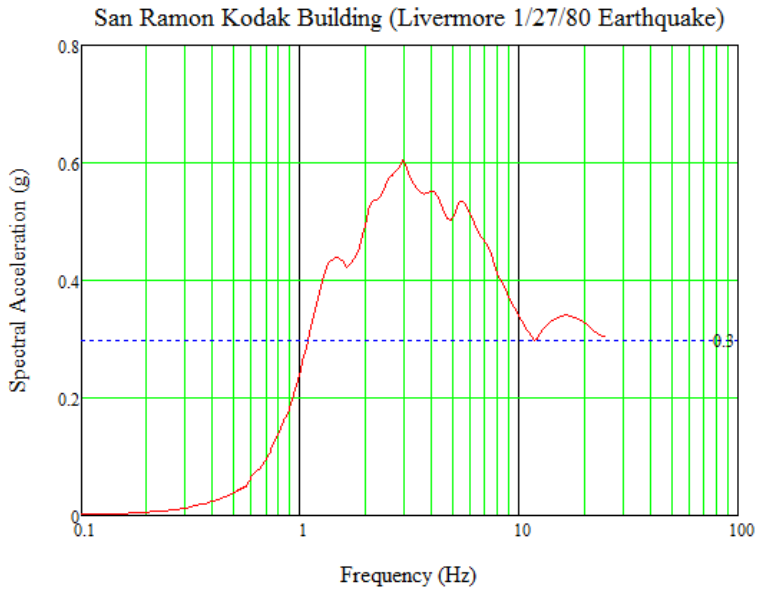

Figure 40. 5% damped acceleration response spectrum for the Kodak Building in San Ramon from the 1980 Livermore earthquake.

The CAV and SCAV are both shown in Figure 41. Here, the SCAV exceeds the threshold value of 0.16 g-sec.

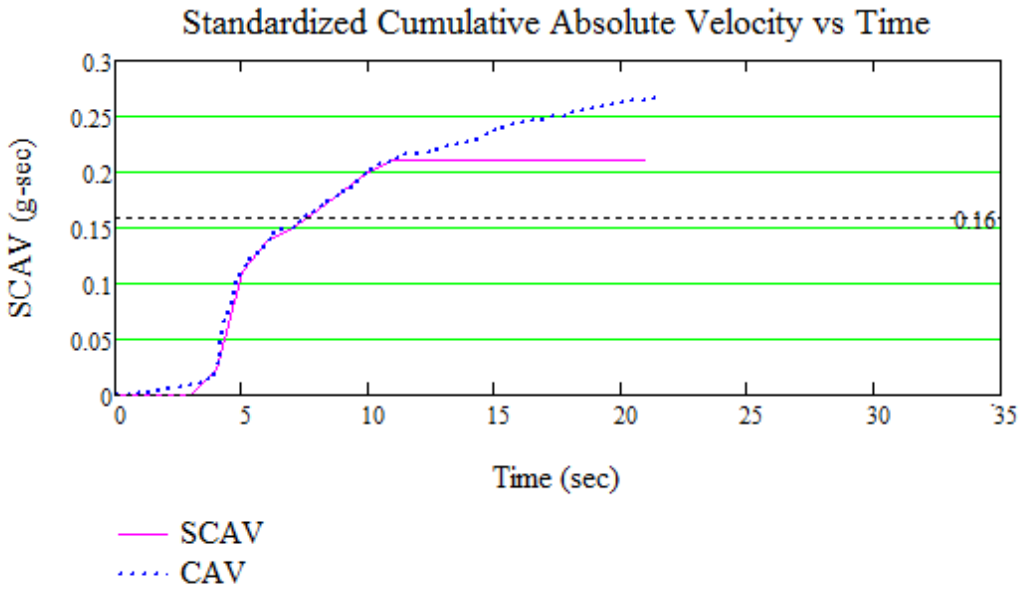

Figure 41. Cumulative absolute velocity plots for the Kodak Building in San Ramon from the 1980 Livermore earthquake.

For the Kodak Building, both the response spectrum check and the SCAV exceeded the threshold values. This would indicate stopping operations and conducting a walkdown inspection for this location would be justified.

9 System Cost

The cost of upgrading the LLNL Seismic Instrumentation System is itemized in Table 2.

Table 2. Cost for updating seismic instrumentation at LLNL (in 2013 dollars).

Item	Cost ($)
Kinemetrics Accelerographs	
Repair ETNAs	4644.00
One Basalt	9835.00
Two Granites	29,490.00
Total Equipment	**43,969.00**
Installation of Instruments	26,031.00
Maintenance Contract (CGS)	5000.00
Project Management	25,000.00
Total	**100,000.00**

10 Summary and Recommendations

With its seven operating strong motion free-field instruments on and around the site and six building instrumentation systems, the LLNL Seismic Instrumentation System will exceed the seismic detection requirements defined in DOE Order 420.1C.

We have presented an approach to evaluate the data generated by a seismic event and decide if continued operation is justified or if walkdown inspections should be conducted prior to continued occupancy and operations.

To remain compliant with the DOE Order, a maintenance agreement with the State of California, Strong Motion Instrumentation Program (SMIP), for the free-field instruments on and around LLNL should be kept current.

The structural instruments in Buildings 111, 170, 313, 332, 453, and NIF should be maintained and checked periodically.

On-site training on the Kinemetrics instruments and the use of Kinemetrics software should be conducted by Kinemetrics for LLNL staff who will be monitoring and using the system.

To ensure readiness, the ability to download data should be confirmed periodically.

The capability to respond to an earthquake by obtaining the recorded data after an earthquake and processing and documenting the data as presented in this report should be maintained. The results and recommendations should be effectively communicated to Laboratory senior management and the programs.

The overall responsibility and budget for the Seismic Instrumentation System at LLNL should be assigned to an organization.

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12 Acknowledgments

I would like to thank Pat Lewis, from the National Security Engineering Division, and Don Graves, John Van Fossen, and their Field Support Team from the Materials Engineering Division for carrying out the installation and set-up of the Seismic Instrumentation System at LLNL.

I would also like to thank Stanley Sommer, from the Laser Systems Engineering and Operations Division, and his team at NIF for locating and constructing a new concrete slab for the NIF free-field instrument and for relocating the instrument to the new slab.

The maintenance of the six free-field Instruments by the State of California, Department of Conservation, California Geologic Survey, Strong Motion Instrumentation Program is also appreciated.

The assistance from Kinemetrics, Inc. in selecting the appropriate instruments for each installation is appreciated.

I would also like to thank Mark Sampson, from the Facilities and Infrastructure Directorate, for conducting a detailed review of this report. C. S. Patel from the National Security Engineering Division also reviewed this report.

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Appendix A. Definitions

Digital Triaxial Time History Recorder (Accelerograph)

A device that records the acceleration-time history of the object to which it is attached in three orthogonal directions when an earthquake occurs. The Kinemetrics K2-4s and ETNAs are examples of digital triaxial recorders.

Free Field

A point located on soil similar to the soil conditions under the site, but far enough away from buildings so it is not influenced by the building motion. Typically, this point is one to three times the major building dimension away from the building.

Peak Ground Acceleration (PGA)

The maximum absolute value of acceleration measured on the ground surface by a seismic instrument located in the free field.

Acceleration Response Spectrum

A plot of the maximum acceleration response of a family of single-degree-of-freedom oscillator, with known frequency and damping, caused by earthquake ground motion.

Design Basis Earthquake (DBE)

The description of the ground motion defined in terms of a design response spectrum anchored to a PGA.

Operating Basis Earthquake (OBE)

Ground motion used for commercial nuclear power plants, which is typically one-half of the Safe Shutdown Earthquake (SSE). If the OBE is exceeded, the plant must shut down until further notice.

Cumulative Absolute Velocity (CAV)

The CAV is a parameter that indicates the potential for an earthquake to cause damage. The CAV is the absolute area under the acceleration versus time plot. The Standardized CAV (SCAV) is a modified version of the CAV that does not include contributions from accelerations less than 0.025 g.

OBE Exceedance Criterion

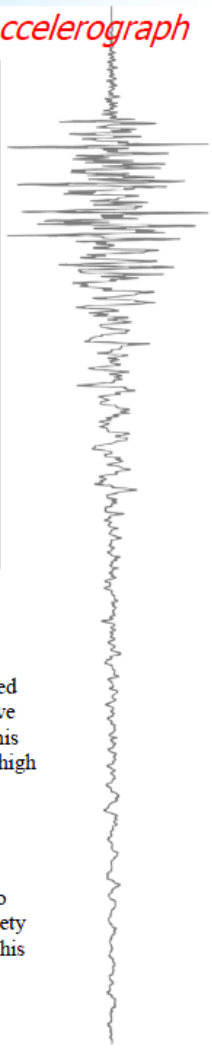
The combined conditions under which the OBE is considered to be exceeded.

Appendix B. Kinemetrics' Data Sheets for LLNL Seismic Instruments

KINEMETRICS

K2

High Dynamic Range Strong Motion Accelerograph



KEY BENEFITS

- Dynamic range greater than 114 dB
- Modular design that allows multi-channel expansion to 6 or 12 channels
- Multi-tasking operating system that allows simultaneous data acquisition and interrogation
- Timing accuracy to ±0.5 ms due to synchronized sampling with optional GPS timing system
- Zero Channel Skew through the utilization of individual A/D converters for each channel
- Remote alerting capability for system event or auto-diagnostic failure
- Remote data acquisition with real time digital data output
- Interconnectivity with other Altus Family recorders for common triggering and shared GPS (option)
- Common user interface, file format, and support tools with other Altus family recorders

INTRODUCTION

The ***K2*** is a full-featured Recorder or Accelerograph designed with the end user in mind. Technical advances and innovative engineering have increased performance and flexibility of this recorder to offer a dynamic range greater than 114 dB. The high dynamic range and superior resolution offer significant advantages for applications where signal fidelity and data integrity are vital.

In order to provide the greatest flexibility in data storage, retrieval and communications, Kinemetrics has included two fully compliant PCMCIA card slots that support a wide variety of nonproprietary memory cards, hard disks and modems. This allows users to easily configure the ***K2*** for their specific applications.

Developed for Microsoft Windows™, our QuickTalk® and QuickLook® software provide a user-friendly environment, making system setup, communications and rapid data analysis quick and easy.

MAJOR APPLICATIONS

- Structural monitoring arrays
- Dense arrays, two and three dimensional
- Aftershock study arrays
- Local, regional and national seismic networks and arrays

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Input Channels

Sensor channels:	3 standard (+1); 6-12 optional
Input level:	Standard ± 2.5V

Sensor

Type:	Triaxal EpiSensor Force Balance Accelerometer, Orthogonally Oriented, Internal (Std), External (Opt)
Full scale range:	User selectable at ±0.25g, ±0.5g, ±1g, ±2g or ±4g
Bandwidth:	DC to 200 Hz
Dynamic range:	155 dB+
Calibration & test:	Calibration Coil Functional Test Calibration Coil Response Test

Data Acquisition

Type:	Over-sampled Delta Sigma system with 24-bit DSP
Anti-alias filter:	Brickwall FIR filter. Cut-off at 80 % of output Nyquist; 120 dB down at output Nyquist
Dynamic range:	~114 dB (200 sps 0-50Hz BW RMS noise/RMS clip
Frequency response:	DC to 80 Hz @ 200 sps
Sampling rates:	20, 40, 50, 100, 200, 250 sps
Chan.-chan. skew:	None – simultaneous sampling of all channels
Acquisition modes:	Continuous, trigger
Output data format:	24 bit signed (3 bytes)
Parameter calculations:	Calculations of key parameters in real-time
Real time digital output:	RS-232 output of digital stream (contact factory for available formats)

Trigger

Type:	IIR bandpass filter (three types available)
Trigger selection:	Independently selected for each channel
Threshold trigger:	Selectable from 0.01% to 100% of full scale
Trigger voting:	Internal, external trigger votes with arithmetic combination
Additional trigger:	STA/LTA

Storage

Type:	Fully compliant PCMCIA storage system (two slots)
Compatibility:	PCMCIA standard 2.1; sockets accept Type I, II, III card formats Type I or II modem
Storage primary slot:	32 MB Memory Card (minimum) Optional larger cards available.
Storage 2nd slot:	Same as primary slot
Parallel 2nd slot:	Accepts Type I or II modem with connectors
Recording capacity:	Approximately 42 kB per channel per minute on Memory Card, of 24-bit data @ 200sps.
Recording format:	Data is stored in DOS file system allowing cards to be read directly by PC.

Firmware

Type:	Multi-tasking operating system supports simultaneous acquisition and interrogation; boot loader allows remote firmware upgrades
System control:	Configure sample rate, filter type, trigger type and voting, maintains communications and event storage
User interface:	Packetized protocol and simple terminal loop control and data retrieval via RS-232 interface
Intelligent alerting:	System can be configured to initiate communications when an event is detected or if an auto-diagnostic failure occurs
Auto-diagnostics:	System can be configured to continuously check system voltages, temperature, RAM and code integrity, timing system integrity
Rapid setup:	Unit can be configured from parameter file stored in PCMCIA memory card

Timing

Type:	Free running disciplined oscillator (standard); GPS
GPS option:	Integrates completely with system, providing timing, internal oscillator correction and position information
Shared GPS:	Allows a group of interconnected Altus recorders to share one GPS module (option)
Timing accuracy:	5 microseconds of UTC with GPS
Power:	Power cycling is software controlled
Power consumption:	110 mA at 12V (active)

I/O and Display

Display:	Matrix of 8 LEDs. Display indicates acquisition mode, event, recording, battery voltage, memory capacity used
Power input:	Mil-style connector for 24 Vdc charge input, external battery, standby power
RS-232 input:	Full RS-232C interface with modem control
Aux. input:	Mil-style connector for 4th channel input, IRIG out, IRIG in, clock sync., 1 pps out, trigger in, trigger out, alarm out, real time digital output (tx & rx), ext 12V out. Interface for interconnection of multiple units
EMI/RFI protection:	All I/O lines are protected from both EMI/RFI emission and susceptibility problems by ferrite filters and transient suppressors

Power Supply

Type:	High efficiency switched power supply and charger system
Input:	Nominal 24 Vdc from charger
Operating range:	10.5V to 15V
Ext. charger voltage:	100-250 Vac 50/60 Hz
Charging voltages:	Temperature compensated for lead acid gel cell, 2 outputs with separate protection circuitry allows unit to recharge flat battery and work with reversed or damaged battery in multi battery system
Fuses:	Four 2 amp fuses for charger and batteries
Batteries:	Internal battery 12V 12 Ah (standard); external battery (opt)
Current drain:	390 mA @12V (standard configuration)
Power autonomy:	>36 hours with internal battery

Housing

Type:	Lexan structural foam housing internally coated with EMI/RFI shielding material, 5/16" aluminum base support for mounting
Mounting:	Single hole for 1/4" stud
Size:	10.1" (256 mm) W x 15.0" (381 mm) L x 7" (178 mm) H
Weight:	10.9 kg (24 lbs) including battery

Communications

RS-232 interface: Parameter setup, real-time telemetry and event retrieval.
PCMCIA modem: Remote access, initiated by user or by the K2. Optional
Ethernet interface: Connect the K2 directly to your IP based Wide Area Network (WAN). Optional
FTP via Modem: FTP transmission of events via dial-up ISP. Optional

Support Software

QuickTalk®*:	Windows-based control and data retrieval program for easy setup and data retrieval by direct connection or modem.
QuickLook®*:	Windows-based data retrieval program for rapid review of waveforms and event information. Also operates with DOS communication software
Antelope:	Comprehensive commercial network operational and mgmt system for medium and large networks
Earthworm:	Comprehensive public domain network operational and management system for medium and large networks
NMS:	Commercial PC-based network management system for small to medium sized networks via modem or real-time data
SMARTS:	Commercial open architecture user-extensible real-time data collection and processing software that runs on a variety of computers
PSD:	Commercial Pseudo Spectral Density software for earthquake data analysis
SMA:	Commercial Strong Motion Analyst software for earthquake data analysis and processing
*K2COSMOS**:	Conversion software from Altus EVT file format to COSMOS v1.20 format
Format Converters*:	Provides option to convert and store data in ASCII and other formats. Contact Kinemetrics for other options.

*No charge

Environment

Operating temp.:	-20° to 70°C
Humidity:	0-100% RH

9/04

KINEMETRICS

Etna

High Dynamic Range Strong Motion Accelerograph

KEY BENEFITS

- 18 bits of resolution with 108 dB dynamic range
- Cost-effective solution that can satisfy today's most demanding applications
- Multitasking operating system that allows simultaneous data acquisition and interrogation
- Timing accuracy to 0.5 milliseconds due to synchronized sampling with optional GPS timing system
- Remote alerting capability for system event or auto-diagnostic failure
- Interconnectivity with other Altus family recorders for common triggering and shared GPS (option)
- Common user interface, file format, and support tools with other *Altus* family recorders.

MAJOR APPLICATIONS

- Structural monitoring arrays
- Dense arrays two and three dimensional
- Aftershock study arrays
- Regional arrays

INTRODUCTION

The *Etna* is a cost-effective Strong Motion Accelerograph designed to meet a wide range of earthquake monitoring applications. Based on Kinemetrics' *Altus* technology, the *Etna* provides superior resolution to meet customer needs in high dynamic range applications, where signal fidelity and data integrity are vital.

The *Etna* was designed to be easy on your budget while still providing those features most requested by end-users. The standard instrument comes equipped with 3 channels, an internal EpiSensor Force Balance Accelerometer and one Flash memory card. In addition, the *Etna* offers several optional features including: PCMCIA storage and communications, networking and GPS timing.

Developed for Microsoft Windows™, our QuickTalk® and QuickLook® software provide a user-friendly environment, making system setup, communications and rapid data analysis quick and easy. With the *Etna*, you can be assured of not only getting high quality, cost-effective instrumentation, but also of receiving Kinemetrics' commitment to the success of your projects for decades to come.

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Data Acquisition

Type:	Over sampled Delta Sigma system with 24 bit Digital Signal Processor
Number of channels:	3 Channels
Dynamic range:	108 dB @ 200 sps
Frequency response:	DC to 80 Hz @ 200 sps
Resolution:	18-bit resolution @ 200 sps
Noise:	Less than 8µV RMS
Sampling rate:	100, 200, 250 sps
Input range:	± 2.5V
Chan./chan. skew:	None – Simultaneous Sampling of all Channels
Anti-alias filter:	Brickwall FIR filter. Cut-off at 80% of output Nyquist. 120 dB down at output Nyquist
Real time digital output (Opt):	RS-232 output of digital stream
Calibration type:	Kinemetrics test sequence

Sensor

Type:	Triaxal EpiSensor Force Balance Accelerometer, Orthogonally Oriented, Internal (Std), External (Opt)
Full scale range:	User selectable at ±0.25g, ±0.5g, ±1g, ±2g or ±4g
Bandwidth:	DC to 200 Hz
Dynamic range:	155 dB+
Calibration & test:	Calibration Coil Functional Test Calibration Coil Response Test

Trigger

Type:	IIR Bandpass filter
Trigger bandwidth:	0.1 Hz – 12.5 Hz
Channel triggering:	
Trigger, De-trigger:	Independent threshold for all channels
Alarm thresholds:	Selectable from 0.01% to 100% of full scale
Trigger voting:	Internal, external trigger votes with arithmetic combination
Pre-event memory:	60 sec. max for 3 channels @ 200 sps Software selectable in 1 sec. increments
Post-event time:	Software selectable, specified in seconds, 0 to 65,000 sec.

Storage

Type:	2 Fully compliant PCMCIA storage slots (Opt) PCMCIA standard 2.1. Sockets accept Type I, II, III card formats. Type I or II modem
Primary slot:	32 MB Memory Card (minimum). Optional larger cards available
Secondary slot (Opt):	Same options as primary slot for storage media. Accepts Type I or II modem with connectors
Recording capacity:	Approx. 8 minutes per MB on Memory Card, 3 channels 0f 24-bit data @ 200 sps

Firmware

Type:	Multitasking operating system supports simultaneous acquisition & interrogation. Boot loader allows remote firmware upgrades
System control:	Configure sample rate, filter type, trigger type and voting, maintains communications and event storage
User interface:	Packetized protocol and simple terminal loop control and data retrieval, via RS-232 interface
Intelligent alerting:	Can initiate communications when an event is detected or if an auto-diagnostic failure occurs
Auto-diagnostics:	System can be configured to continuously check system voltage, temperature, RAM and code integrity and timing system integrity

Timing

Type:	Free running disciplined oscillator (Std); GPS (Opt)
Shared GPS:	Allows a group of interconnected Altus recorders to share one GPS module (option)
GPS (Opt):	Integrates completely with system, providing timing, internal oscillator correction and position information
Timing accuracy:	5 microseconds of UTC. GPS receiver better than 1 millisecond data synchronization of UTC. Power cycling is software controlled
Power consumption:	110mA at 12V (active)

I/O and Display

Type:	I/O Connectors, EMI/RFI and transient protection, I/O drivers and display are provided on a single front panel board
Display:	3 LEDs. Display indicates: Run/Fault, charge, event
Power input:	Mil-Style connector for charge input and external battery
RS-232 interface:	Full RS-232 interface with modem control
Interconnect input (Opt):	Mil-Style connector for IRIG out, IRIG in, Clock sync., 1 pps out, trigger in, trigger out, alarm out, real time digital output (Tx & Rx), ext. 12V out, Relay 1
EMI/RFI protection:	All I/O lines are protected from both EMI/RFI emission and susceptibility problems by ferrite filters and transient suppressors

Communications

RS-232 interface:	Parameter setup, real-time telemetry and event retrieval. Standard.
PCMCIA modem:	Remote access, initiated by the user or by the K2. Optional
FTP via Modem:	FTP transmission of events via dial-up ISP. Optional

Power Supply

Supplied external charger voltage:	100-250 Vac 50/60 Hz
Charging voltages:	14.9V @ fast charge, 13.8V @ float charge. Temperature compensated for sealed lead acid, gel type batteries
Battery operating range:	11V to 15V
Batteries:	Internal 12V, 6.5Ah battery (Std), 12V, 12Ah battery (Opt), external batter (Opt)
Current drain:	185mA @ 12V (standard configuration)
Power autonomy:	>36 hours (Std), >72 hours with optional internal battery

Housing

Type:	Lexan structural foam housing internally coated with EMI/RFI shielding material, 5/16" aluminum base support for mounting and coupling to sensors
Mounting and leveling:	Single hole for 1/4" stud and three adjustable feet for leveling
Size:	10.1" (256 mm) W x 15.0" (381 mm) L x 7" (178 mm) H
Weight:	20 lbs. (9 Kg) including battery

Support Software

QuickTalk®*:	Windows-based control and data retrieval program for easy setup and data retrieval by direct connection or modem.
QuickLook®*:	Windows-based data retrieval program for rapid review of waveforms and event information. Also operates with DOS communication software
Antelope:	Comprehensive commercial network operational and mgmt system for medium and large networks
Earthworm:	Comprehensive public domain network operational and management system for medium and large networks
NMS:	Commercial PC-based network management system for small to medium sized networks via modem or real-time data
SMARTS:	Commercial Open architecture user-extensible real-time data collection and processing software that runs on a variety of computers
PSD:	Commercial Pseudo Spectral Density software for earthquake data analysis
SMA:	Commercial Strong Motion Analyst software for earthquake data analysis and processing
*K2COSMOS**:	Conversion software from Altus EVT file format to COSMOS v1.20 format
Format Converters*:	Provides option to convert and store data in ASCII and other formats. Contact Kinemetrics for other options.

*No charge

Environment

Operating temperature:	-20° to 70°C
Humidity:	0-100% RH

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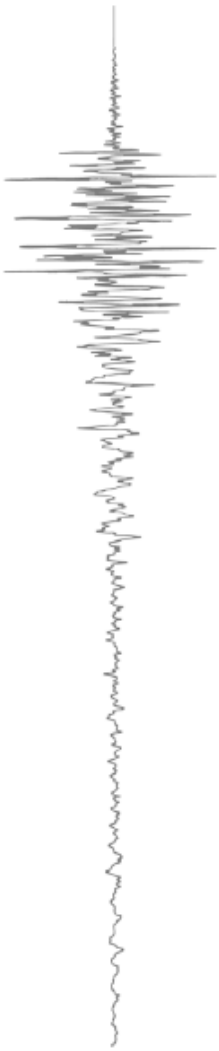
03/03

KINEMETRICS

Basalt

High Dynamic Range, IP Aware, Communication Centric Accelerograph



Basalt represents the next evolution in Kinemetrics Strong Motion Instrumentation. Offering exceptional high dynamic range, matched to Kinemetrics outstanding ***EpiSensor*** accelerometer performance, and with exemplary timing accuracy, and spectral purity the ***Basalt*** again advances the standards of strong motion data recording. Complementing this outstanding data fidelity is a new suite of communication capabilities offering multiple real time data streams to multiple clients.

As a member of Kinemetrics ***Rock*** platform, the ***Basalt*** is easy to integrate with other ***Rock*** and Quanterra instruments allowing users to develop highly flexible earthquake monitoring solutions.

The ***Basalt*** offers greatly enhanced ease of use over existing instruments as only a web browser is required to modify operation parameters, change recording and telemetry modes and formats, view or retrieve recorded files. Functions can be accessed worldwide via a WAN, or via a local wireless interface with the optional Bluetooth interface.

Features

- 3 +1 sensor channels digital recorder w/internal Episensor Triaxial Deck
- 24-bit Delta Sigma converter per channel
- Built-in GPS
- Record and communicate multiple sample rates
- Multiple data formats and telemetry protocols
- Power Management for ultra-low power operation
- Rugged aluminum extruded case designed for 1m drop and 1m temporary immersion (IP67)
- Extensive state-of-health monitoring, including input and system voltages, internal temperature, humidity, communication link diagnostics
- Transient and EMI/RFI protection on all connections
- System Status LEDs
- Designed for RoHS Compliance and easy re-cycling
- Designed for low total cost of ownership

Specifications subject to change without notice

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Channels

Basalt:	3 +1 sensor channels digital recorder w/internal triaxial Episensor accelerometer
Input level:	5Vpp, 10Vpp, 40Vpp Differential Input

Data Acquisition

Type:	Individual 24-bit Delta Sigma converter per channel with Black Fin DSP
Anti-alias filter:	Double Precision FIR Filter Causal/Acausal; >140 dB attenuation at output Nyquist
Dynamic range:	200 sps ~127 dB (RMS noise to RMS clip - Typical) 100 sps ~130 dB (RMS noise to RMS clip - Typical)
Frequency response:	DC to 80 Hz @ 200 sps
Sampling rates:	1, 10, 50, 100, 200, 250, 500, 1000, 2000 sps
Channel skew:	None – simultaneous sampling of all channels
Acquisition modes:	Continuous, triggered, time windows
Output data format:	24 bit signed (3 bytes) in user selectable format
Parameter calculations:	Calculations of key parameters in real-time
Real time digital output:	Ethernet or RS-232 output of digital stream (contact factory for available formats)

Sensor

Type:	Triaxal EpiSensor Force Balance Accelerometer, Orthogonally oriented, Internal
Full scale range:	User selectable at ±2g or ±4g
Bandwidth:	DC to 200 Hz
Dynamic range:	155 dB+
Calibration & test:	Calibr. Coil Functional Test; Calibr.Coil Response Test

Trigger

Type:	IIR bandpass filter (three types available)
Trigger selection:	Independently selected for each channel
Threshold trigger:	Selectable from 0.01% to 100% of full scale
Trigger voting:	Internal, external and network trigger votes with arithmetic combination
Additional trigger:	STA/LTA, Time Window

Storage

Primary slot:	Internal Compact Flash Slot, standard 4 Gb up to 64 Gb
Secondary slot:	Internal SD Card Slot
Storage Module: (Option)	Additional User Accessible Compact Flash Slot Accessible SD Card Slot (Replaces internal slot) Hard Drive (Additional Option)
Recording capacity:	Approximately 42 kB per channel per minute on Memory Card of 24-bit data @ 200 sps.
Recording format:	Main CF Card Linux EXT3 Removable Media DOS File System

Firmware

Type:	Multi-tasking operating system supports simultaneous acquisition and interrogation; boot loader allows remote and optionally automatic firmware upgrades
System control:	Configure sample rate, filter type, trigger type and voting, maintains communications and event storage
Supported File Formats:	Kinemetrics EVT, MiniSEED, SAC, COSMOS, MATLAB, SUDS, SEISAN, ASCII
User interface:	1 10BaseT Ethernet Port 3 RS-232 1 USB 1.1 Device 2 USB 2.0 Ports (1 OTG/1 Host) (optional in Storage Module) 1 Bluetooth Interface (optional)
Intelligent alerting:	System can be configured to initiate communications when an event is detected or if an auto-diagnostic failure occurs
Auto-diagnostics:	System can be configured to continuously check system voltages, temperature, humidity, and timing system integrity
Rapid setup:	Unit can be configured from parameter file stored on Compact Flash

Timing

Type:	Oscillator digitally locked to GPS or *RockNet*
GPS:	Integrates completely with system, providing timing, internal oscillator correction and position information.
RockNet:	Shared timing for two units over CAT-5 cable
Timing:	Accuracy: <1 microseconds of UTC with GPS
Power:	Power consumption: <100mW (active)

I/O and Display

Power input:	Mil-style connector for DC power input, external battery connection, 1-W power LAN
RS-232/USB input:	Mil-style connector with full RS-232C interface with modem control, USB 1.1 Device connection, RS232 Console connector
Ethernet Connection:	10 Base-T Ethernet Interface
EMI/RFI protection:	All I/O lines EMI/RFI and transient protected
LEDS:	System, power and event status, Ethernet Link & Data

Power Supply

Type:	Internal high efficiency switched power supply and battery charger system
Input:	8-18 VDC
Int. Charger Operation:	15.5VDC Required
Ext. Power Module:	Input 100-250 VAC 50/60 Hz Output 15.5 VDC
Internal Battery Charger:	Digitally temperature compensated output for VRLA battery with reverse protection and deep discharge recovery.
Fuses:	None uses resettable Polyswitch protection
Batteries:	External Valve Regulated Lead Acid (VRLA) Battery Optional battery housing.
Curent drain:	~145ma @12V (w/o sensors)

Communications

Ethernet interface:	Real Time Telemetry (Multiple destinations TCP/IP Protocol), Parameter set up, and event retrieval (FTP/SFTP)
RS-232 interface:	Real Time Telemetry (over modem, radio, etc.), Parameter set up, and event retrieval
Modem:	Built in modem, Remote access, initiated by user or by the Basalt

Support Software

*Altus File Viewer**:	Multiplatform program for rapid review of waveforms and event information.
Antelope:	Comprehensive commercial network operational and mgmt system for medium and large networks
Earthworm:	Comprehensive public domain network operational and management system for medium and large networks
NMS:	Commercial PC-based network management system for small to medium sized networks via modem or real-time data
*RockTalk**:	Multiplatform program for command and control
Rockhound:	Commercial open architecture user-extensible real-time data collection and processing software that runs on a variety of computers
PSD:	Commercial Pseudo Spectral Density software for earthquake data analysis
SMA:	Commercial Strong Motion Analyst software for earthquake data analysis and processing
*K2COSMOS**:	Conversion software from Altus EVT file format to COSMOS v1.20 format (COSMOS format can also be produced natively from the Granite)
Miscellaneous:	Format converters to ASCII other formats. Web Server for command and control, Optional Software Development Kit and Compilers. Contact Kinemetrics for other options.

*No charge

Environment

Operating temperature:	-20° to 70°C Operation
Humidity:	0-100% RH (Non-condensing)

Physical

Size & Weight:	Basalt: 13.25" (L) x 7.25" (D) x 6.8" (H), 16.5 lbs
Enclosure Rating:	IP67 Equivalent
Environmental:	RoHS Compliant Unit

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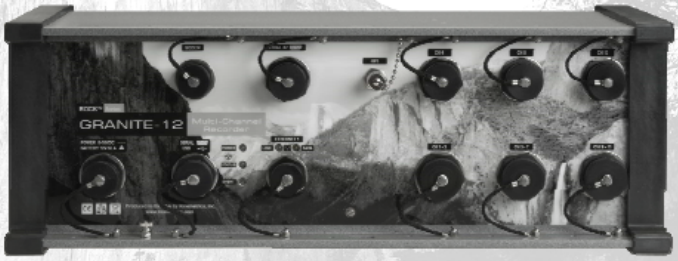
KINEMETRICS

Granite®

High Dynamic Range, IP Aware, Communication Centric Multi-channel Recorder!

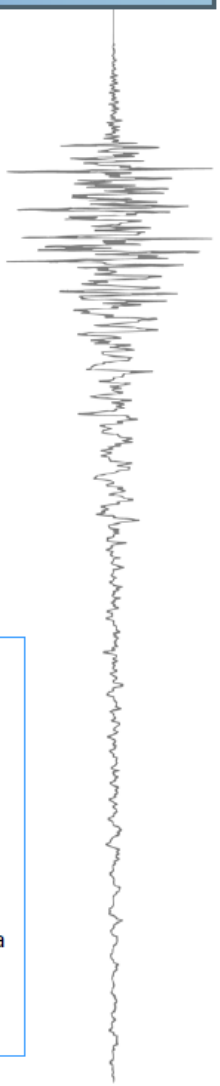


Granite represents the next generation of Kinemetrics multi-channel recorders. Offering high dynamic range on up to 36 channels and with exemplary timing accuracy and spectral purity, the ***Granite*** again advances the standards of seismic data recording.

Complementing the outstanding data fidelity of this unit is a very low power operation and a new suite of communication capabilities offering multiple real time data streams to multiple clients. Built on Kinemetrics' new ***Rock*** platform ***Granite*** is easy to integrate with other ***Rock*** & ***Quanterra*** instruments allowing users to develop highly flexible monitoring solutions.

Since only a web browser is required to modify the parameters, ***Granite*** offers greatly enhanced ease of use over existing instruments to change operation parameters, change recording and telemetry modes & formats, view or retrieve recorded files. Functions can be accessed worldwide via a WAN, or via local wireless interface with the optional Bluetooth interface.

As with all Kinemetrics instrumentation the Granite is designed and tested to ensure ultra-reliable operation in rugged field conditions.



Features

- Up to 36 channels at ~130dB dynamic range
- Record and communicate multiple sample rates
- Multiple data formats and telemetry protocols
- Power Management for ultra-low power operation
- Designed for low total cost of ownership
- Extensive state-of-health monitoring, including input and system voltages, internal temperature, humidity, communication link diagnostics
- Rugged aluminum extruded case designed for 1m drop and 1m temporary immersion (IP67)
- Optional Terminal strips for easy sensor connection
- Designed for RoHS Compliance and easy re-cycling
- Transient and EMI/RFI protection on all connections
- System Status LEDs

ROCK Family Granite® Digital Recorder Specifications

Input Channels

Sensor channels:	12, 24 or 36 (Other configurations available)
Input level:	5Vpp, 10Vpp, 40Vpp Differential Input

Data Acquisition

Type:	Individual 24-bit Delta Sigma converter per channel with Black Fin DSP on each 4 Channel board
Anti-alias filter:	Double Precision FIR Filter Causal/Acausal; >140 dB attenuation at output Nyquist
Dynamic range:	200 sps ~127 dB (RMS noise to RMS clip - Typical) 100 sps ~130 dB (RMS noise to RMS clip - Typical)
Frequency response:	DC to 80 Hz @ 200 sps
Sampling rates:	1, 10, 20, 50, 100, 200, 250, 500, 1000 sps (2000 sps available depending on output format)
Channel skew:	None – simultaneous sampling of all channels
Acquisition modes:	Continuous, triggered, time windows
Output data format:	24 bit signed (3 bytes) in user selectable format
Parameter calculations:	Calculations of key parameters in real-time
Real time digital output:	Ethernet or RS-232 output of digital stream (contact factory for available formats)

Trigger

Type:	IIR bandpass filter (three types available)
Trigger selection:	Independently selected for each channel
Threshold trigger:	Selectable from 0.01% to 100% of full scale
Trigger voting:	Internal, external and network trigger votes with arithmetic combination
Additional trigger:	STA/LTA, Time Window

Storage

Primary slot:	Internal Compact Flash Slot, std 4Gb up to 64Gb
Secondary slot:	Internal SD Card Slot
Storage Module: (Option)	Additional User Accessible Compact Flash Slot Accessible SD Card Slot (Replaces internal slot) Hard Drive (Additional Option)
Recording capacity:	Approximately 42 kB per channel per minute on Memory Card of 24-bit data @ 200 sps.
Recording format:	Main CF Card Linux EXT3 Removable Media DOS File System

Firmware

Type:	Multi-tasking operating system supports simultaneous acquisition and interrogation; boot loader allows remote and optionally automatic firmware upgrades
System control:	Configure sample rate, filter type, trigger type and voting, maintains communications and event storage
Supported File Formats:	Kinemetrics EVT, MiniSEED, SAC, COSMOS, MATLAB, SUDS, SEISAN, ASCII
User interface:	1 10BaseT Ethernet Ports 1 RS232 (2nd Port/Modem Optional) 1 USB 1.1 Device 2 USB 2.0 Ports (1 OTG/1 Host) (optional in Storage Module) 1 Bluetooth Interface (optional)
Intelligent alerting:	System can be configured to initiate communications when an event is detected or if an auto-diagnostic failure occurs
Auto-diagnostics:	System can be configured to continuously check system voltages, temperature, humidity, and timing system integrity
Rapid setup:	Unit can be configured from parameter file stored on Compact Flash

Timing

Type:	Oscillator digitally locked to GPS or *RockNet*
GPS:	Integrates completely with system, providing timing, internal oscillator correction and position information, optional power cycling.
RockNet:	Shared timing for two units over CAT-5 cable
Timing:	Accuracy: <1 microseconds of UTC with GPS

Specifications subject to change without notice

Power:	Power consumption: <100mW (active)

I/O and Display

Power input:	Mil-style connector for DC power input, external battery connection, 1-W power LAN
RS-232/USB input:	Mil-style connector with full RS-232C interface with modem control, USB 1.1 Device connection, RS232 Console connector
Ethernet Connection:	10 Base-T Ethernet Interface
EMI/RFI protection:	All I/O lines EMI/RFI and transient protected
LEDS:	System, power and event status, Ethernet Link & Data

Power Supply

Type:	Internal high efficiency switched power supply and battery charger system
Input:	8-18 VDC 4W (typical) for 12 channels
Int. Charger Operation:	15.5VDC Required
Ext. Power Module:	Input 100-250 VAC 50/60 Hz Output 15.5 VDC
Internal Battery Charger:	Digitally temperature compensated output for VRLA battery with reverse protection and deep discharge recovery.
Fuses:	None uses resettable Polyswitch protection
Batteries:	External Valve Regulated Lead Acid (VRLA) Battery Optional battery housing.
Curent drain:	~335ma @12V (12 Channel System)

Communications

Ethernet interface: Real Time Telemetry (Multiple destinations TCP/IP Protocol), Parameter set up, and event retrieval (FTP/SFTP)

RS-232 interface: Real Time Telemetry (Multiple destinations TCP/IP Protocol), Parameter set up, and event retrieval

Modem: Remote access, initiated by user or by the Granite. Optional

Support Software

*Altus File Viewer**:	Multiplatform program for rapid review of waveforms and event information.
Antelope:	Comprehensive commercial network operational and mgmt system for medium and large networks
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Miscellaneous:	Format converters to ASCII other formats. Web Server for command and control, Optional Software Development Kit and Compilers. Contact Kinemetrics for other options.

*No charge

Environment

Operating temperature:	-20° to 70°C Operation
Humidity:	0-100% RH (Non-condensing)

Physical

Size & Weight:	Granite 12 ~ 19"(L) x 7.5"(D) x 6.8"(H) 16lbs Granite 24, 36 ~19"(L) x 7.5"(D) x 13.6"(H) 32lbs
Enclosure Rating:	IP67 Equivalent
Environmental:	RoHS Compliant Unit

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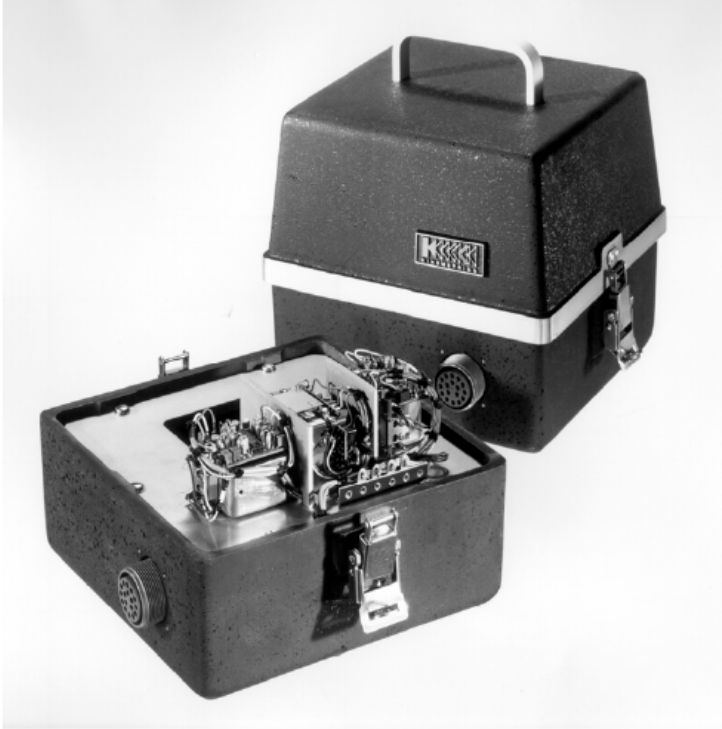
KINEMETRICS

FBA-3

Force Balance Accelerometer



The FBA-3 Force Balance Accelerometer is a high-sensitivity, low-frequency triaxial device suitable for a variety of seismic and structural applications. It is an economical instrument characterized by high reliability, ruggedness and low current drain.

Designed to meet the stringent requirements of USNRC Regulatory Guide 1.12 for nuclear power plants, the FBA-3 is deployed in over 100 nuclear power plants in the United States and abroad. Frequency response is flat from DC to 50 Hz. Nominal full-scale range is ±1 g, but optional full-scale ranges are available.

The FBA-3 is packaged in a cast aluminum base and cover, sealed to prevent the entrance of moisture and dirt. The three accelerometers are orthogonally mounted on an internal deck plate.

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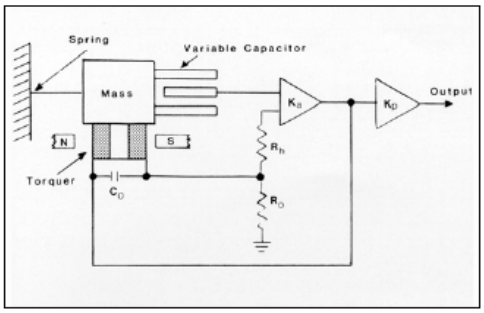
TECHNICAL DESCRIPTION

The FBA-3 is a spring-mass device which uses variable capacitance transduction, as shown in the schematic below. The output is fed back to the parallel combination of capacitor C_0 and the torquer coil, which



is an integral part of the mass. From the coil the feedback loop is completed through resistors R_0 and R_h. This has the effect of stiffening the system, thus increasing the natural frequency to 50 Hz. Resistor R_0 (with C_0) controls the damping, which normally is adjusted to 70% critical. The acceleration sensitivity is controlled by the gain K_p of the post-amplifier.

TECHNICAL SPECIFICATIONS

Full-scale range
±1.0g, (¼, ½ & 2 g optional)
Natural frequency
50 Hz*
Bandwidth
DC to 50 Hz (3 dB point)
Damping
70% critical*
Operating temperature range
-20° to 70°C (0° to 160°F)
Output (full-scale)
±2.5V* into 50,000 Ω
Zero offset
Less than 25 mV*
Cross-axis sensitivity
Less than .03 g/g*
Linearity
Less than 1% of full-scale
Noise (0 to 50 Hz)
Less than ±25 μV*
Noise (0 to 10,000 Hz)
Less than ±2.5 mV*
Dynamic Range (0 to 50 Hz)
100 dB
Temperature effects (zero drift and sensitivity)
Less than 2% of full-scale
Supply voltage
± 12 Vdc
Turn-on time
Operational within 0.1 second after power applied
Calibration
Electrical commands can be applied to produce damping and natural frequency outputs
*Measured values furnished with each sensor.

SEISMIC QUALIFICATION

Kinemetrics/Systems has provided strong motion accelerograph systems to over 100 nuclear power plants throughout the world for over 30 years. Kinemetrics products have been carefully tested for generic qualification to meet most existing and future requirements.

Kinemetrics seismic test characteristics for the FBA-3 accelerator have the following general characteristics:

1. Biaxial: horizontal and vertical rotated, and repeated at 90 degrees.
2. Five OBE's (Operating Base Earthquake) in each direction.
3. Random excitation controlled at 1/3 octave intervals with incoherent phasing between axes, over the range 1 to 40 Hz.
4. Test duration of thirty seconds minimum.
5. Minimum SSE RRS ZPA (Required Response Spectrum Zero Period Acceleration) of 2 g with 3% damped response accelerations exceeding 6 g in the range 2 to 20 Hz.
6. Sensor SSE RRS ZPA of 6 g with 1% damped response accelerations exceeding 14 g in the range 2 to 30 Hz.
7. Functional testing conducted on devices prior to, during and following seismic tests.

In addition, Kinemetrics has performed RIM (Required Input Motion) testing of pipe-mounted sensors. The FBA-3 accelerometer has been qualified as follows:

1. Biaxial: horizontal and vertical rotated, and repeated at 50 degrees.
2. Steady-state sinusoidal dwell tests at ½ octave intervals from 1 to 45 Hz.
3. Dwell duration of 30 seconds at each frequency.
4. 0-Peak input acceleration at each frequency of 4.5 g except limited by displacement (below 5 Hz)
5. Functional tests conducted on devices prior to, during and following seismic tests.

PHYSICAL CHARACTERISTICS
Dimension
200mm × 200mm × 200mm water tight closure (8" cube)
Weight
7 kg (15 pounds)

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KINEMETRICS

EpiSensor ES-T

Force Balance Accelerometer

Features

- Low noise
- Extended bandwidth – DC to 200 Hz
- User-selectable full-scale range
- Calibration coil (standard)
- Single-end or differential output (user selectable)
- Double-stage transient protection

The EpiSensor ES-T – A Flexible, Versatile Value

Kinemetrics announces its latest line of earthquake sensors – EpiSensor force balance accelerometers. Model FBA ES-T is a triaxial surface package useful for many types of earthquake recording applications. The unit consists of three EpiSensor force balance accelerometer modules mounted orthogonally in one small convenient package. With full-scale recording ranges of ± 0.25 to ± 4g (user selectable) the EpiSensor provides on-scale recording of earthquake motions even at near-fault locations and in a wide variety of structure types.

The significantly improved bandwidth of DC to 200 Hz allows engineers and scientists to study motions at higher frequencies while maintaining the very important DC response that allows simple field calibration and reduces post-processing confusion.

Output circuitry is also significantly enhanced. Several types of outputs can be field-selected by the user: ± 2.5V single-ended output for use with traditional Kinemetrics earthquake recording instruments: ± 10V single-ended or ± 20V differential output for use with Kinemetrics digital recorders and other 24-bit digital recorders currently on the market.

EpiSensor force balance accelerometers are also available in uniaxial (the FBA ES-U) and borehole (the FBA ES-SB shallow and FBA ES-DH deep) packages.

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EpiSensor ES-T Specifications

Dynamic range:	155 dB+
Bandwidth	DC to 200 Hz
Calibration coil:	Standard
Full-scale range:	User selectable at ± 0.25g, ± 0.5g, ± 1g, ± 2g or ± 4g
Outputs:	User selectable at: ± 2.5V single-ended ± 10V single-ended ± 5V differential ± 20V differential
Zero adjust	Three user-friendly access holes for simple, safe, efficient adjustment
Linearity:	< 1000 µg/g^2
Hysteresis:	< 0.1% of full scale
Cross-axis sensitivity:	< 1% (including misalignment)
Zero point thermal drift:	< 500 µg/°C (1g sensor)
ESD, RF, EMI protection:	Double stage transient protection with gas arrester elements
Power consumption:	12mA from +/- 12V (Standard Amp) 35mA from +/- 12V (Low Noise Amp) Single supply option available
Physical size:	13.3 cm diameter (cylinder), 6.2 cm high
Mounting:	Single bolt mounting, three adjustable leveling feet and bubble level
Connection:	Single military-style metal connector
Operating Temperature:	-20° to 70°C (0° to 160°F)
Housing:	Watertight enclosure

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Appendix C. LLNL Seismic Instrument Information

Table 3. Free-field instruments.

Site/Power	SMIP Station Number	Instrument/ (Sensor) Phone Type	DOE Number	Serial Number	Phone Number
Buffer Zone (LLBZ) Solar Power and Batteries	57252	K2-4 (EpiSensor) Cellular	*	2387	Voice (916) 612-1464 Data (916) 606-5209 +X is east +Y is north +Z is up
East Gate (LLEG) Solar Power and Batteries	57253	ETNA (EpiSensor) Cellular	*	4862	Voice (916) 612-1465 Data (916) 601-7980 +X is east +Y is north +Z is up
Sandia (CSA) Solar Power and Batteries	57254	K2-4 (EpiSensor) Cellular	*	2388	Voice (916) 832-5983 Data (916) 494-9417 +X is east +Y is north +Z is up
Site 300 (CST) AC Power and Batteries	57202	K2-4 (Force Balance) Landline	*	0191	Voice (925) 422-7553 +X is east +Y is north +Z is up
Patterson Pass (CPP) Solar Power and Batteries	57201	K2-4 (Force Balance) Cellular	*	0228	Voice (916) 612-1470 Data (916) 340-4351 +X is east +Y is north +Z is up
SW Gate (LLSG) AC Power and Batteries	57227	ETNA (EpiSensor) Landline	*	3473	Voice (925) 422-7671 +X is east +Y is north +Z is up
NIF Slab at Central Plant (NIF SM10) AC Power and Battery	–	ETNA (EpiSensor) No Phone	8607049**	4102	– +X is east +Y is North +Z is up

* Instrument is owned by Strong Motion Instrumentation Program, CGS, State of California.

** Bob Swanson is the LLNL custodian of the NIF-owned instrument.

Table 4. Building instruments.

Building/Power	Station Identifier	Instrument (Kinemetrics)	DOE Number	Serial Number	IP Address or Phone Number
111 AC Power with UPS	Appendix C.1.1.1 11	Appendix C.1.1. ranite	Appendix C. 309911*	Appendix 77	Appendix C.1.1.5 *IP Address* 128.115.193.242 Appendix C.1.1.6 *Sub net Mask* 255.255.255.0 Appendix C.1.1.7 *Gat eway* 128.115.193.254 Appendix C.1.1.8 *DNS Name* seismic 2 Appendix C.1.1.9 (see Ref 1)
313 AC Power with UPS	313	Basalt	9309935*	1555	*IP Address* 128.115.221.2 *Subnet Mask* 255.255.255.0 *Gateway* 128.115.221.254 *DNS Name* seismic 1 +Z is up
332 AC Power with UPS	332	Granite	9309928*	389	*IP Address* 134.9.139.239 *Subnet Mask* 255.255.255.0 *Gateway* 134.9.139.254 *DNS Name* seismic 3 (see Ref 1)
170 AC Power with Battery	B170-1 (SM8)	ETNA	8606967*	4098	(925) 423-3026 +Z is up
170 AC Power with Battery	B170-2 (SM9)	ETNA	8607032*	4094	(925) 424-3140 +Z is up
453 AC Power with Battery	B453-1 (SM3)	ETNA	8607056*	4095	(925) 423-2243 +Z is up

Building/Power	Station Identifier	Instrument (Kinemetrics)	DOE Number	Serial Number	IP Address or Phone Number
453 AC Power with Battery	B453-4 (SM4)	ETNA	8606998*	4097	(925) 423-2306 +Z is up
NIF	Tool Crib (SM1)	ETNA	8607025**	4101	
NIF	Tool Crib (SM2)	ETNA	8607001**	4096	
NIF AC Power with Battery	SY2 Level 2 (SM5)	ETNA	8606981**	4100	+Z is up
NIF AC Power with Battery	SY2 Level 5 (SM6)	ETNA	8607018**	4099	+Z is up
NIF	Tool Crib (SM7)	ETNA	8606974**	4103	

*Robert C. Murray is the LLNL custodian of all LLNL-owned instruments (except for NIF).

**Bob Swanson is the LLNL custodian of the NIF instruments (1 free-field, 4 building, 1 spare).