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THE CSMS POORBOY DEPLOYMENT: SEISMIC RECORDING IN PINEDALE, WYOMING, OF THE BULLION NTS NUCLEAR TEST UNDER THE VERIFICATION PROVISIONS OF THE NEW TTBT PROTOCOL

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Abstract

The Configurable Seismic Monitoring System (CSMS), developed at the Lawrence Livermore National Laboratory (LLNL) was deployed in a 13-m deep vault on the AFTAC facility at Pinedale, Wyoming to record the Bullion nuclear test. The purpose of the exercise was to meet all provisions of the new TTBT protocol on in-country seismic recording at a Designated Seismic Station (DSS). The CSMS successfully recorded the Bullion event consistent with and meeting all requirements in the new treaty protocol. In addition, desirable seismic system features not specified in the treaty protocol were determined; treaty protocol ambiguities were identified, and useful background noise recordings at the Pinedale site were obtained.

Introduction

The re-negotiated treaty between the U.S. and the U.S.S.R. on the limitation of underground nuclear weapon tests provides for in-country verification of compliance with the 150-kt test yield limit. The verification technologies include in-country seismic recording of the nuclear test at three designated seismic stations (DSS) located at a regional distance from the nuclear test site when certain testing intervals and/or certain projected yield limits are exceeded. The seismic equipment that the U.S. will deploy at the designated seismic stations in the Soviet Union and what U.S. equipment, if any, will remain at the designated seismic stations has not been decided. The equipment must, however, conform to and meet all requirements in the treaty protocol. In addition to the treaty protocol requirements, there are many other advantageous seismic monitoring equipment capabilities.

The Lawrence Livermore National Laboratory (LLNL) has been developing a portable seismic recording system in anticipation of the seismic verification equipment requirements of the treaty protocol. This system is called the Configurable Seismic Monitoring System (CSMS). The system meets all requirements of the treaty protocol and has many other desirable capabilities. Although the CSMS has been extensively tested and fielded, it had not been deployed in accordance with the treaty protocol to record a nuclear test.

The Poorboy exercise was conducted to evaluate the capability of CSMS and other seismic recording systems to meet treaty protocol requirements by recording an actual nuclear test in accordance with protocol requirements. The deployment site was chosen to be a 13-m deep seismic vault at the Air Force Technical Applications Center (AFTAC) facility near Pinedale, Wyoming. The exercise recorded the nuclear test named Bullion, conducted at the Nevada Test Site (NTS). This report documents the results of the CSMS deployment at the Pinedale site to record the Bullion test in accordance with the treaty protocol requirements. We will begin with a short overview of the CSMS system followed by a discussion of the protocol requirements relevant to the Poorboy exercise. The specifics of the deployment and the measured background noise are discussed next and followed by the results of the Bullion event recording. We conclude with a summary of the CSMS ability to meet the protocol requirements, other CSMS features demonstrated in the Poorboy exercise and the planned developments of CSMS.

CSMS Overview

The CSMS deployed at Pinedale consisted of two distinct systems: the data acquisition system and the control, data archival and analysis system. The data acquisition system was located in the 13-m deep vault; the control, data archival and analysis system was located in a shallow walk-in vault about 50 m from the 13-m deep vault. The systems were connected by underground cable.

The data acquisition system consisted of a Guralp 3-component broadband seismometer, a Reftek 97-01 digital data acquisition system, a small seismometer control box, two large gel-cell batteries for power, and connecting cables.

The control, data archival, and analysis system consisted of a Masscomp 5400 central computer, an Omega time clock, two terminals and keyboards, two small 9-track tape archival units, a laser printer, an uninterruptable power supply (UPS), and connecting cables. The central computer internal disk drive was loaded with all control and analysis software. The block diagram of the entire system is shown in Figure 1. The vault subsystem is powered by batteries only (providing at least 10 days of continous operation without recharge), and all critical components of the central subsystem are on an UPS.

Protocol Requirements and Other Capabilities

The new TTBT protocol requirements applicable to verification using the seismic method in surface vaults directly state or imply that the following must be met with any seismic monitoring system:

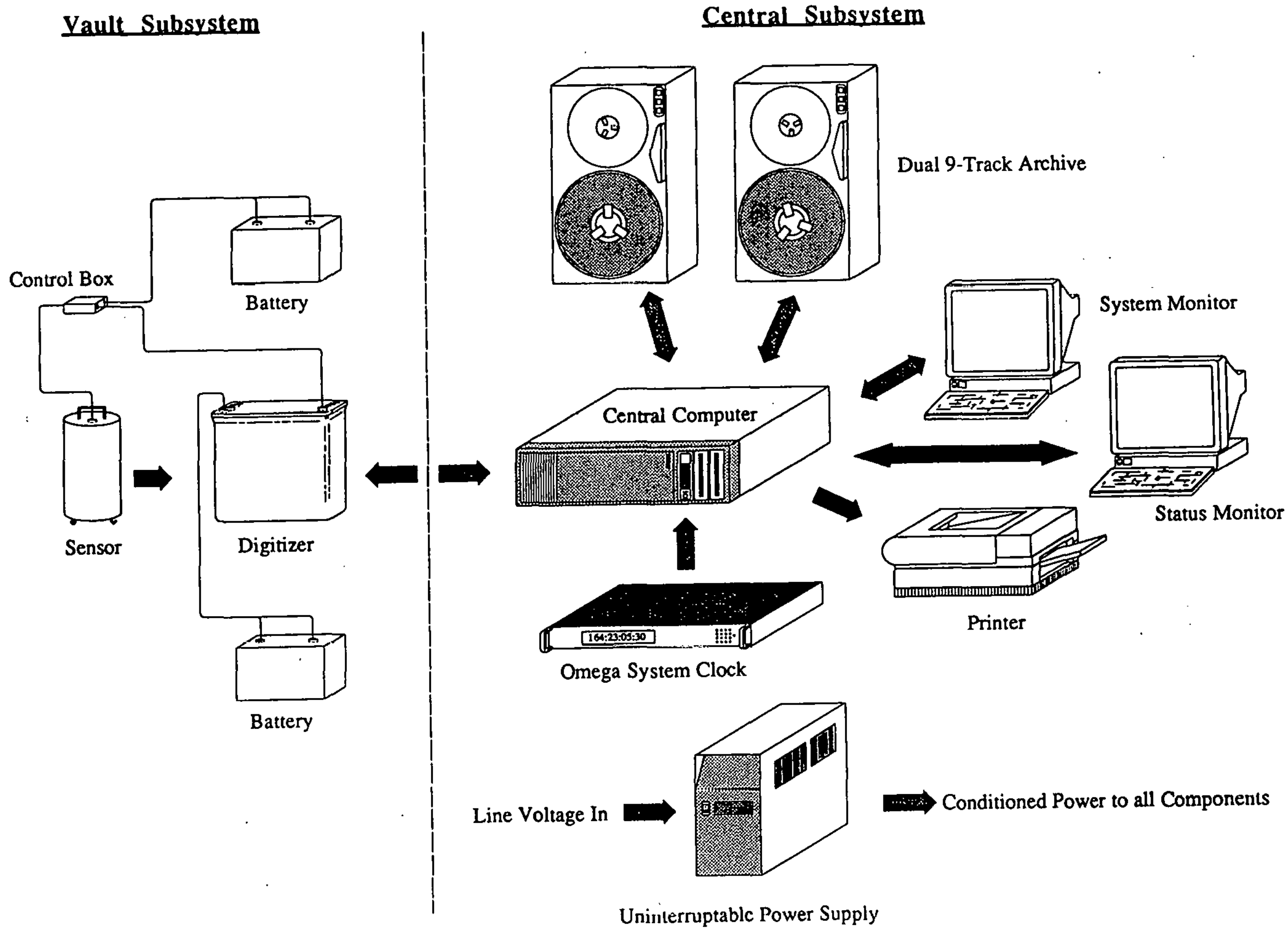

Figure 1. The CSMS consists of two subsystems: the vault subsystem where data acquisition and digitization occurs and the central subsystem where data control, archival and analysis occurs.

1) The seismic system can be made fully operational within 72 hours of arrival at the deployment site.

2) The seismic sensors measure three components in the 0.1 to 10 Hz band.

3) The seismic monitoring system have equipment for amplifying, filtering, and digitizing seismic sensor output; equipment for recording seismic data with interconnect cables; equipment for controlling sensors, recorders, and for calibrating equipment; equipment to monitor quality of recorded data and display, store and copy the data; and analysis programs for assessing the validity of recorded seismic data.

4) Means of recording Universal Time Coordinated and referencing the recorded seismic data to it.

5) Provide continuous seismic recording from 1 minute before the test until 30 minutes after the test.

6) The seismic system must be decommissioned and personnel off-site within 48 hours after the test.

7) Hardcopy capability.

In addition to the protocol requirements it is in the US interest to deploy a seismic system that has many of the following features:

1) Minimize the vault surface area required by seismometers because the vault pier dimensions are not specified.

2) Record continuous seismic data from the earliest possible opportunity until two hours after the test to maximize the amount of data obtainable on background noise and other site characteristics.

3) Provide independent backup power for vault and recording room.

4) Capability to produce dual copies of digital data.

5) A system dynamic range that can resolve the lowest background noise up to 10 Hz and record a well-coupled 150-kt test without clipping.

6) A powerful signal analysis capability to allow redundant determinations of data quality and background noise features.

7) Data authentication and physical security.

8) Fiber optic link between computer room and vault to eliminate grounding and shielding concerns.

The Poorboy Deployment

The CSMS system was shipped via air freight to Salt Lake City, Utah, from Livermore, California, and consisted of 17 shipping cases with a total weight of just under 1000 lbs. The CSMS system, as shipped, consisted of some spare parts and components as well as tools, etc.

We transported the CSMS from Salt Lake City to Pinedale, Wyoming, by rental truck and arrived at Pinedale on the evening of 6/8/90. The following morning the equipment setup began at the deployment site. Setup was complete in about 5 working hours and data were being recorded at about 3 p.m. local time.

The vault subsystem Guralp seismometer and the Reftek data acquisition unit were each powered by a large battery capable of at least 8 days of continous operation without a recharge. The Guralp seismometer was foam insulated to aid in temperature stabilization. The initial temperature stabilization of the seismometer took many hours. The vault subsystem required less than 1 sq. m of pier area.

The central subsystem includes redundant video monitors and 9-track tape drive units. The redundancy provides component backup and increases use efficiency since the dual moniters allow one user to check instrument status, etc., while another user analyzes data to determine quality. The dual tape drives provide two identical copies of all data archived and thereby avoid all the issues associated with data copying procedures to provide the Soviets with an identical copy of archived data.

The system gain setting in the data acquisition unit was chosen so that the quiet periods of background noise could be resolved up to at least 10 Hz. This was accomplished by recording background noise during a quiet period at 4 gain settings: 24, 36, 48 and 60 Db. The resulting vertical component velocity power density spectra for the 24, 36 and 48 Db (the 60-Db spectra was identical to the 48-Db spectra) are shown in Figure 2. All spectra presented in this paper were calculated for a 200-sec file using a non-overlapping 5-sec analysis window. The expected general decrease in spectral power with increasing frequency as observed at 48-Db gain does not occur at 36 and 24-Db gain. The flattening of these spectra indicates that quantization noise dominates earth noise. This flattening occurs above about 7 Hz at 36-Db gain and above about 1 Hz at 24-Db gain. Since the 48-Db gain spectra and 60-Db gain spectra are identical, we concluded 48-Db gain is the minimal gain setting that will resolve quiet Pinedale earth noise up to 10 Hz.

The Bullion event was recorded, and graphical representations of the data per the treaty protocol were produced. Recording continued until two hours after the event shot time. A complete copy of all data recorded and the required graphical representations of the event recording were available within 10 minutes of system shutdown. The system was packed and driven off-site within 2 hours.

Background Seismic Noise Measurements

The CSMS recorded continous data from about 3 p.m. local time on Fri., June 8, 1990 until about 2 p.m. local time on Wed., June 13, 1990. We selected the quietest time during the recording period to conduct some background seismic noise analyses. This quiet time period was the night of the 11th and the early morning of the 12th during which the weather was calm and the cultural noise was minimal. The vertical velocity power density spectra for four 200-sec time windows taken at midnight, 2 a.m., 4 a.m., and 6 a.m., respectively, are shown in Figure 3. The spectra are remarkably similar. Only the 2 a.m. spectra is significantly different with increased high-frequency noise, probably associated with a car or truck. We picked the quietest of the four spectra for further analysis: the 4 a.m. noise window.

The north-south component velocity power density spectra was calculated from the same 200-sec, 4 a.m. time window and compared to the vertical component spectra in this same time window. The comparison, shown in Figure 4, shows close similarity.

We converted the vertical component velocity spectra into an acceleration spectra and compared it to the Peterson low-noise model (Peterson, J., 1990, pending Open-File Report in preparation, Albuquerque Seismic Lab, USGS, Albuquerque, NM) in the 0.4 to 10-Hz frequency band. The comparison is shown in Figure 5. From 0.4 to 1-Hz, the Pinedale low-noise recording is very close to the low-noise model. Above about 1 Hz, the

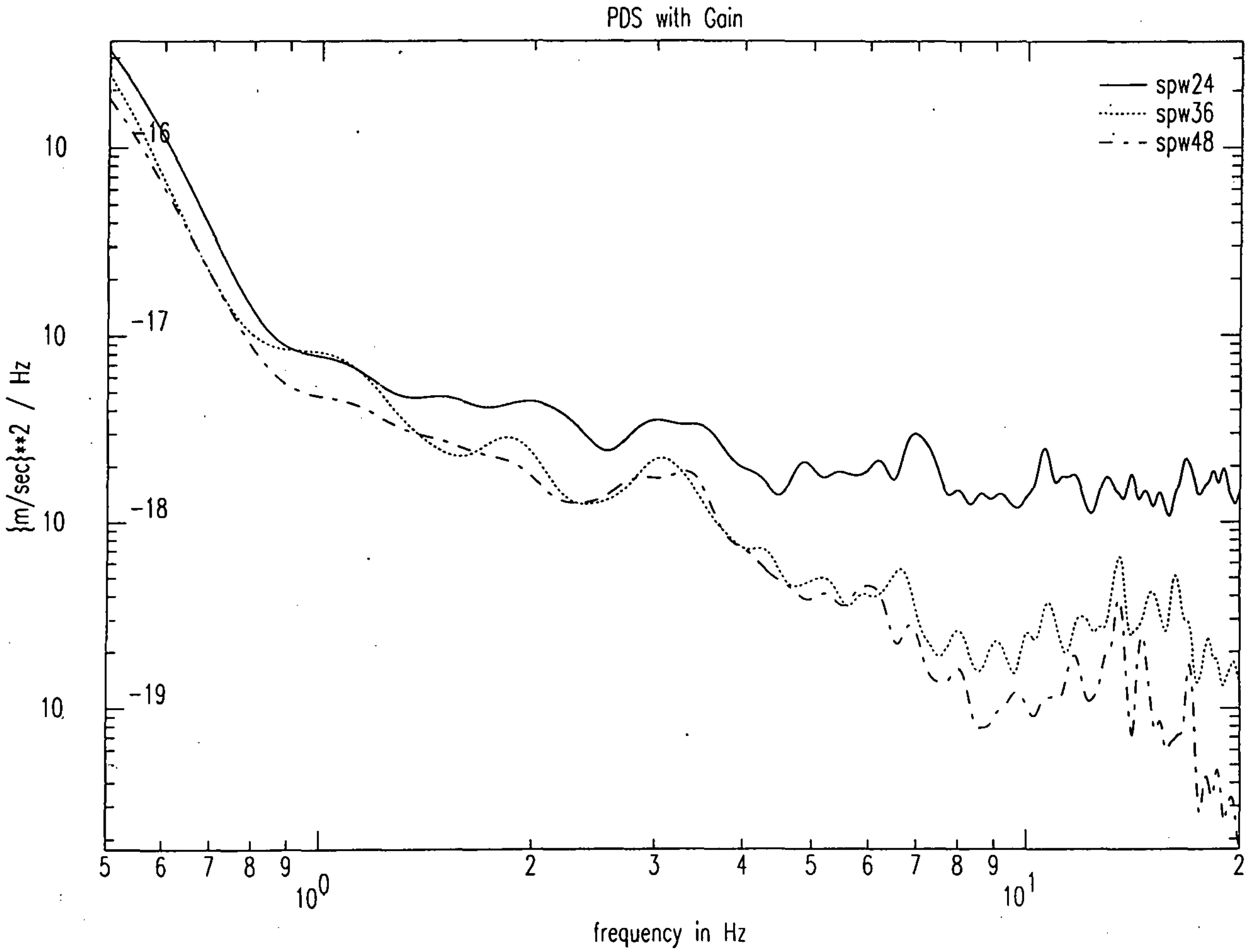

Figure 2. The velocity power density spectra are shown for three gain settings: 24, 36 and 48 Db. When quantization noise dominates, the spectra flatten and fail to exhibit a further decrease in power with frequency. At 24 Db this starts at about 1 Hz, at 36 Db it is closer to 7 Hz.

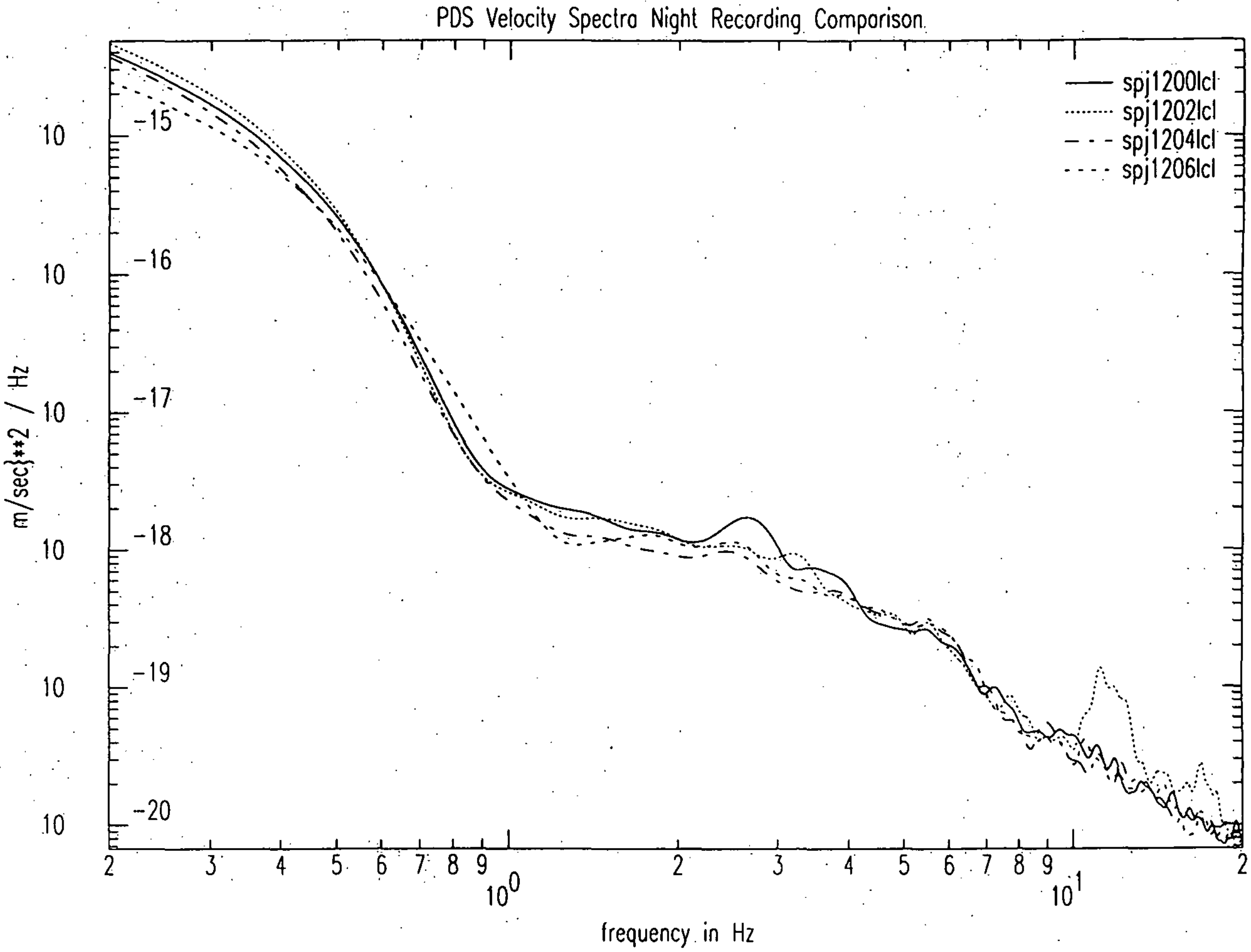

Figure 3. A comparison of quiet noise velocity power density spectra taken every two hours during the late night and early morning shows remarkable similarity. Only the 1202 (2 a.m.) spectra shows increased high-frequency noise, probably associated with a car or truck.

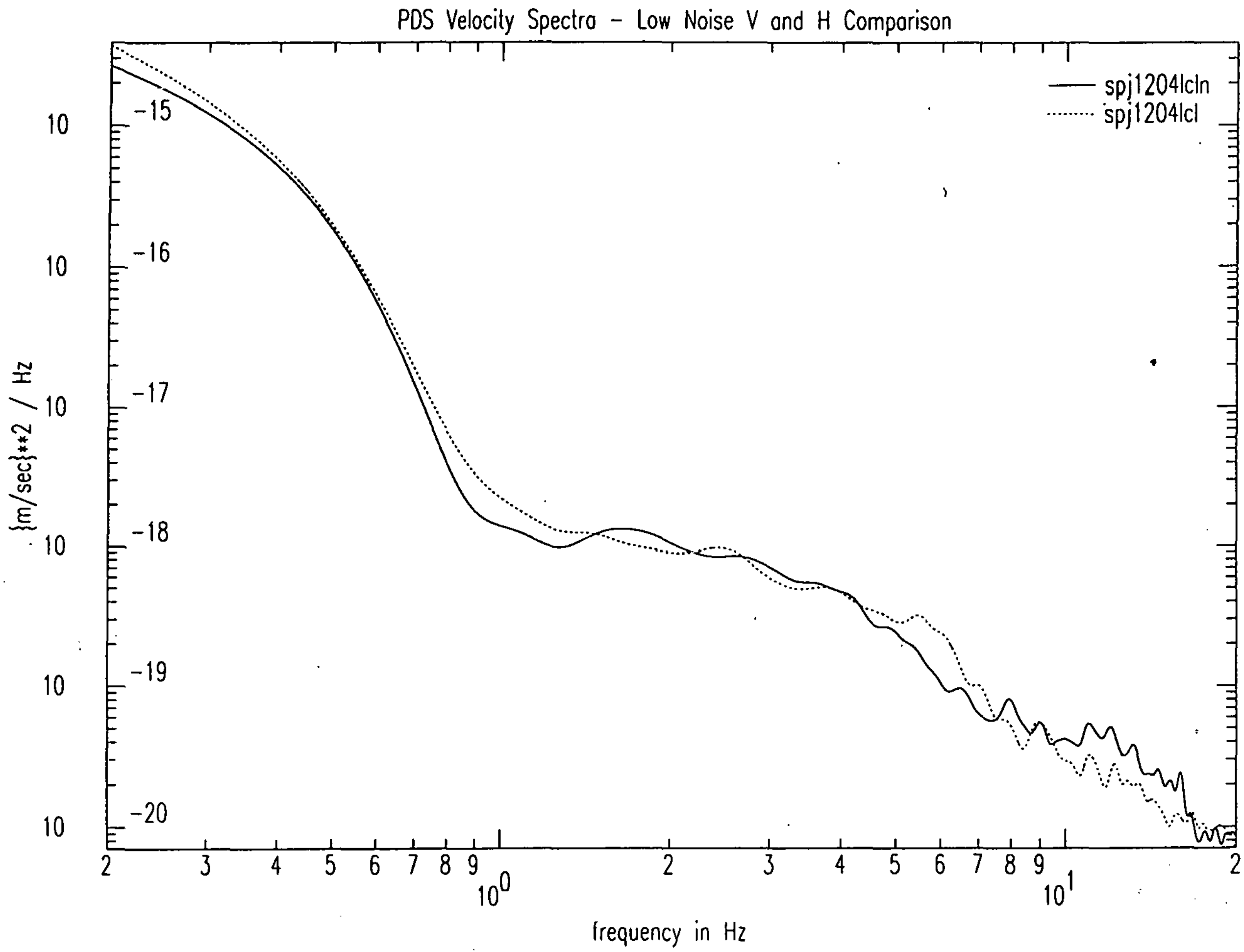

Figure 4. The lowest noise velocity power density spectra (taken at 4 a.m.) vertical component (dashed line) is compared to the N-S horizontal component (solid line). The spectra are similar.

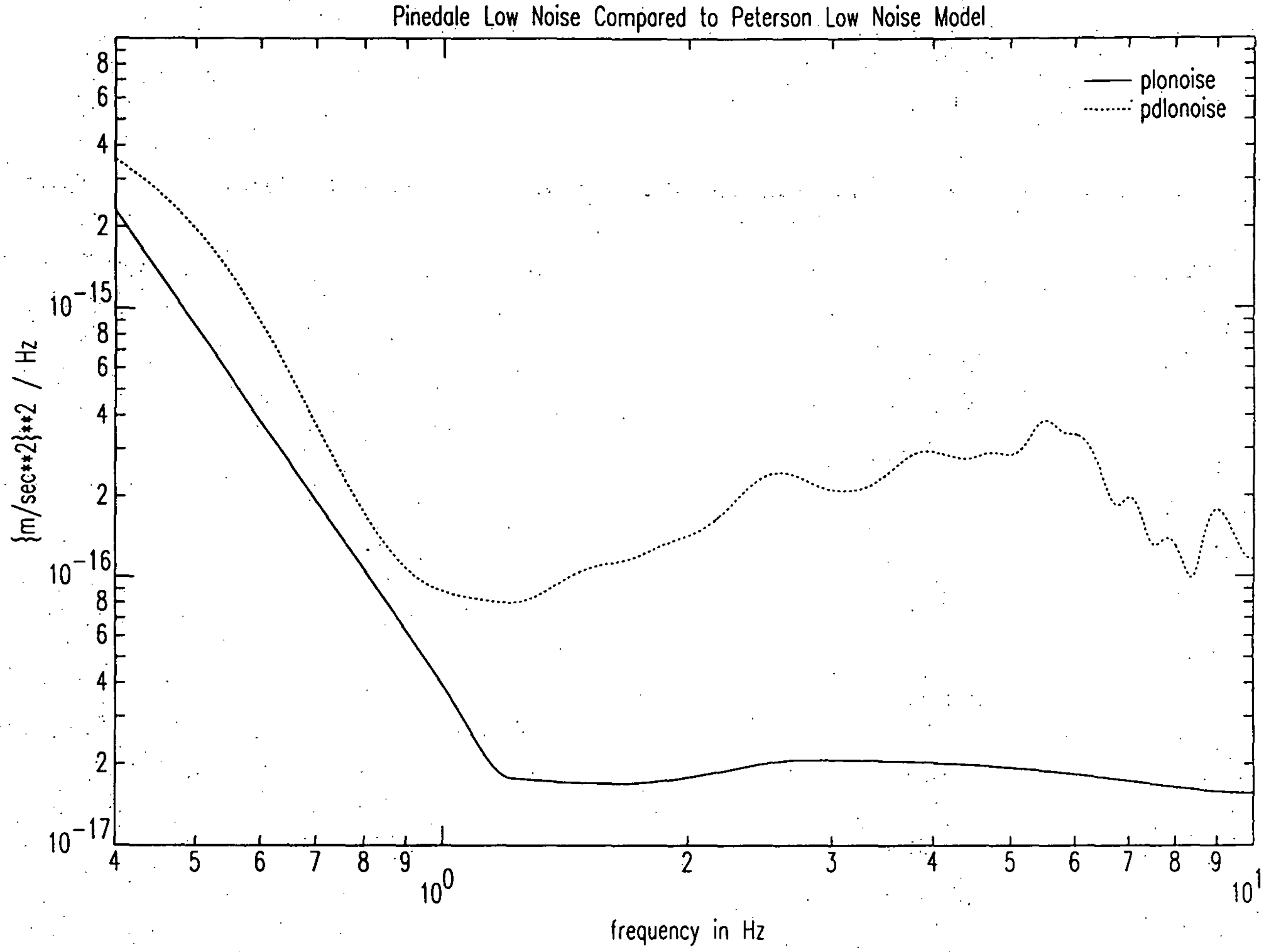

Figure 5. The lowest noise acceleration power density spectra recorded at Pinedale is compared with Peterson's low-noise model. From 0.4 to 1 Hz, the Pinedale low noise is very close to the low-noise model.

Pinedale low-noise power spectra is between about 10 to 20 Db above the Peterson low-noise model.

Bullion Event Recording

The Bullion event was detonated on June 13 at 10 a.m. local time with an announced yield of between 40 and 150 kt. The seismic signal from this event was recorded by the CSMS at Pinedale about two minutes later. Although the gain we determined was necessary to resolve the lowest background noise up to 10 Hz at Pinedale was 48 Db, we decided to turn the gain down to 36 Db for the shot recording to be sure the seismometer would not clip while recording the event. We determined later from the test recording that the maximum zero-to-peak voltage output from the seismometer at 48-Db gain would have been 2.5 V; the zero-to-peak clipping voltage of the CSMS recording system is 8 V. Consequently, with 48-Db gain at the Pinedale deployment site, the CSMS system had the dynamic range to resolve the quietest background noise at 10 Hz and the Bullion event signal without clipping.

We produced a hardcopy graphical representation of the shot recording per the provisions of the treaty protocol from 1 min before shot time to 30 min after shot time for each recorded component. These are shown in Figures 6, 7 and 8 for the vertical component, north-south component, and east-west component, respectively. The plots are de-sampled by a factor of 18 since including all samples over such a long time span will produce a solid black record that is not visually pleasing and takes a very long time to print on a laser printer. Figure 9 shows the Bullion event vertical recording without desampling from 100 to 600 sec (referenced from 1 minute before shot time) and includes all significant wave phases.

As an exercise in interpreting the protocol, we calculated the signal-to-noise ratio (SNR) per the protocol requirements for meeting Designated Seismic Station (DSS) specifications. This DSS specification calls for an SNR not less than 9 for an Lg phase recorded from a 150-kt shot. The noise is defined as the root-mean-square (RMS) value of at least 1 minute of pre-event noise in the frequency range typical of Lg waves recorded at the site. Since the typical Lg-phase frequency range at Pinedale was not well known, we calculated the RMS value in a typical Lg passband (0.1 to 2 Hz using a 4-pole low-pass filter with a corner at 2 Hz) and the full 0.1 to 10 Hz passband. The noise values differed by less than 1%.

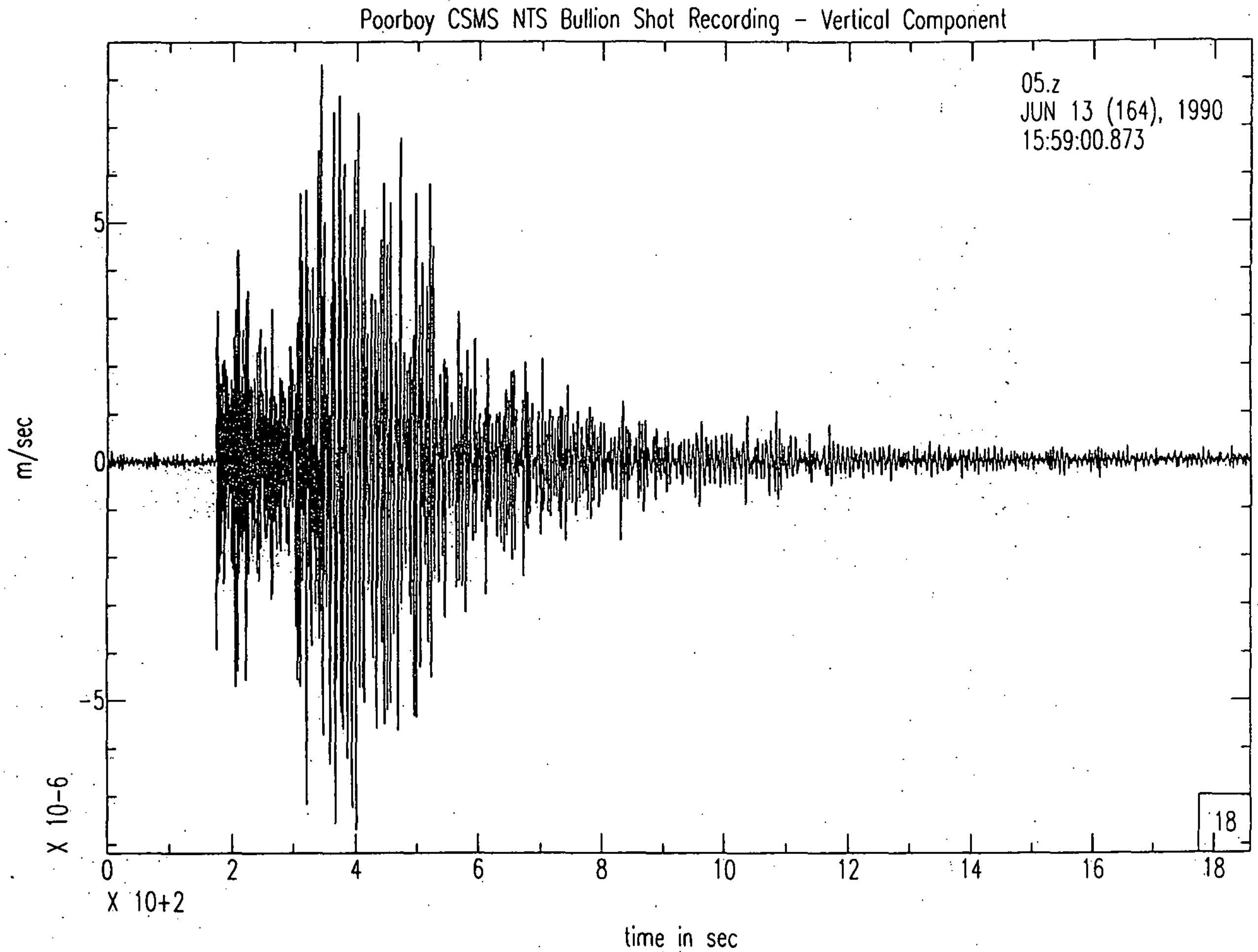

Figure 6. The vertical component of the Bullion nuclear test event recorded at Pinedale. The plotting window length is as specified in the TTBT protocol.

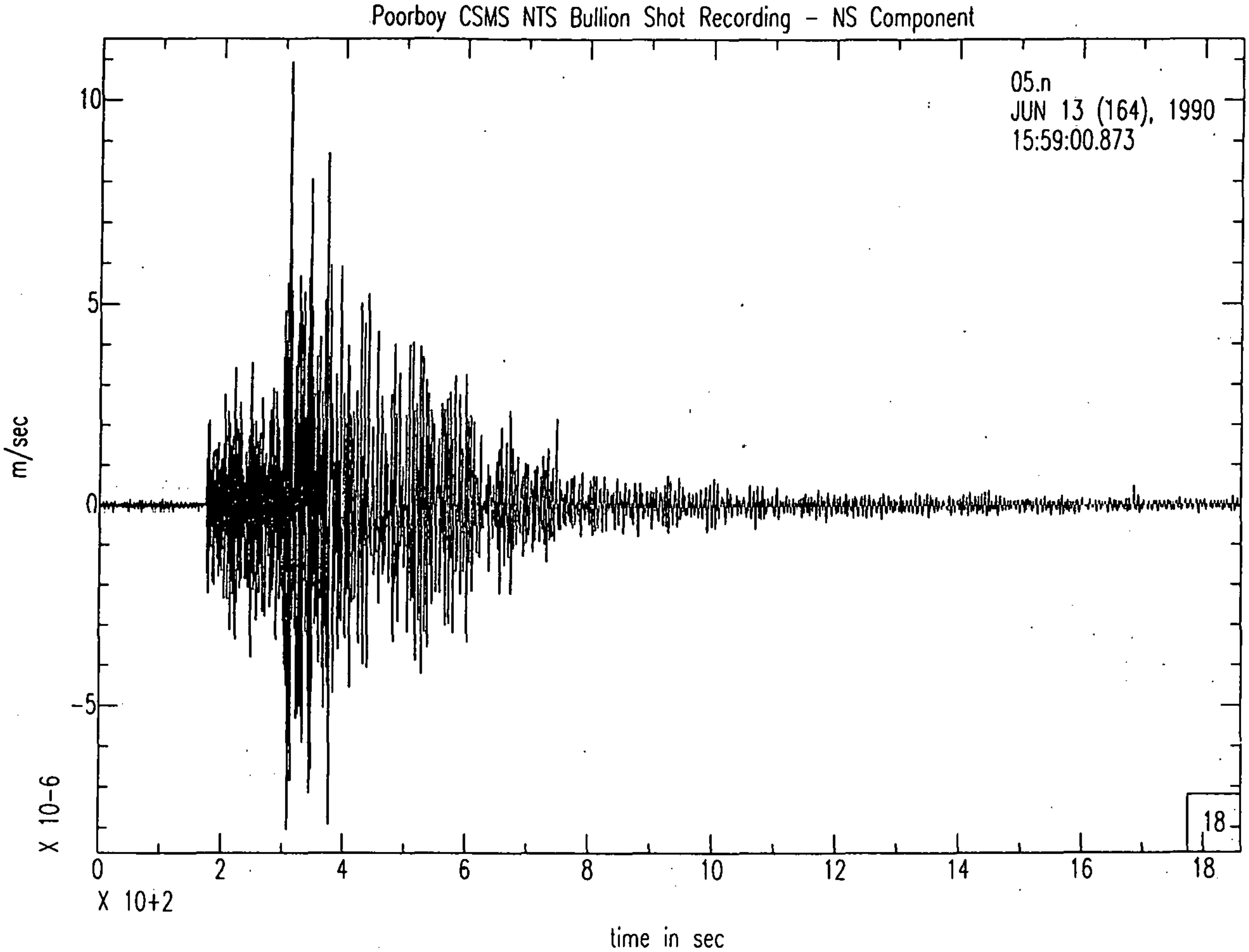

Figure 7. The horizontal N-S component of the Bullion nuclear test event recorded at Pinedale. The plotting window length is as specified in the TTBT protocol.

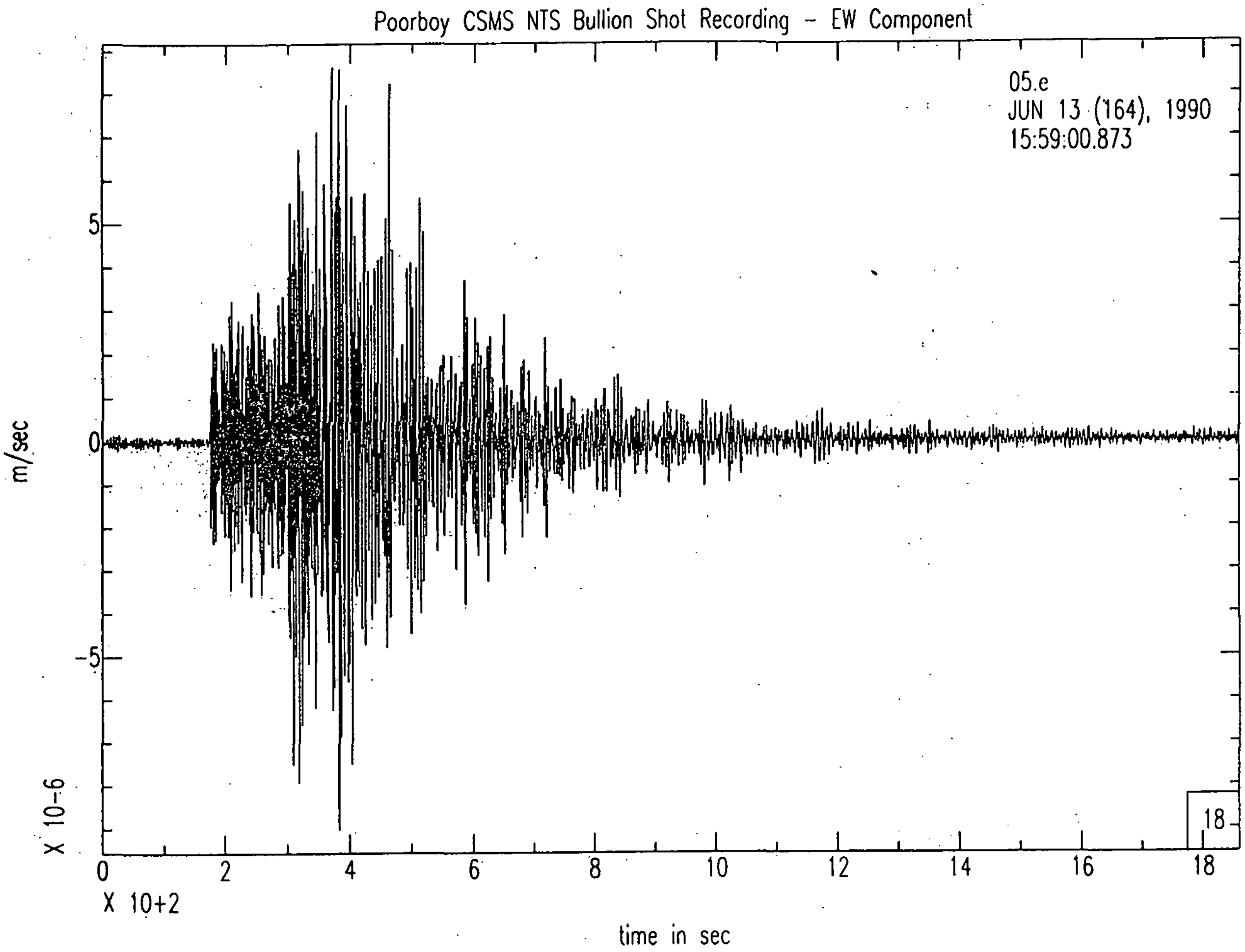

Figure 8. The horizontal E-W component of the Bullion nuclear test event recorded at Pinedale. The plotting window length is as specified in the TTBT protocol.

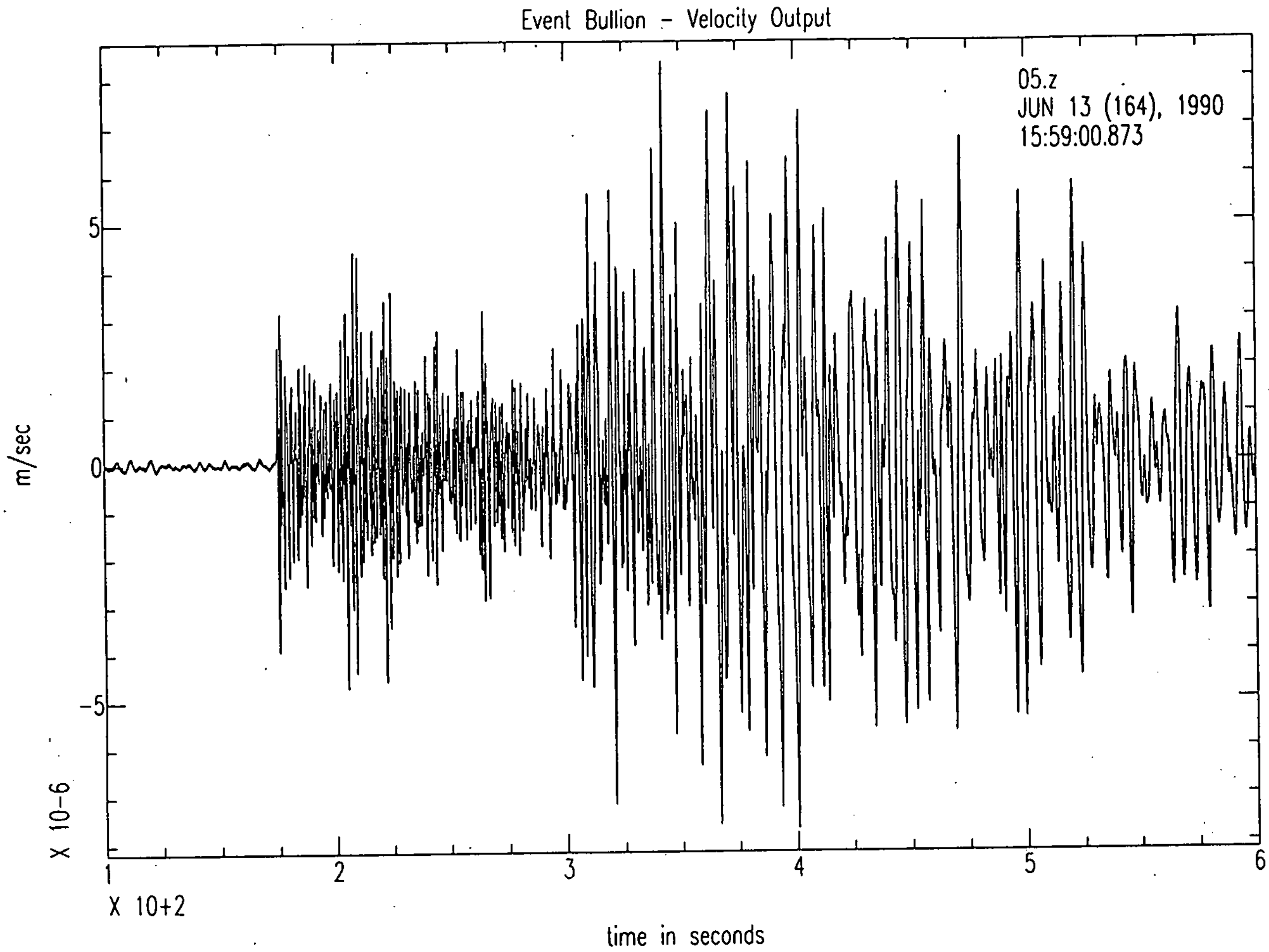

Figure 9. The vertical component of the Bullion test is shown plotted in a shorter time window. The plot has no desampling and clearly shows the P and Lg phase arrivals.

The signal is defined as one-half of the maximum peak amplitude of the Lg-wave signal. To be consistent with the RMS noise calculation, the signal should be defined as one-half the maximum peak-to-peak ampli-tude of Lg. Using peak amplitude, the SNR is 72.5. Using peak-to-peak am-plitude, it is 145. In either case, Pinedale is far above the SNR of 9; conse-quently, meets this DSS specification. The factor of 2 discrepancy in SNR, depending on interpretation, may be significant in other potential DSS sites.

A calculation of the SNR as a function of frequency was determined for two general phases: P, and Lg. A pre-event one-minute noise spectra was calculated, and spectra for the P and Lg event phases were also determined. The signal spectra and noise spectra were divided; the square root was taken of the resulting spectras to give amplitude SNR, consistent with the protocol-defined SNR. The results are shown in Fig. 10. This plot shows the SNR is highest at Pinedale for Lg in the 0.3 - 2 Hz band and for P in the 0.7 - 2.5 Hz band.

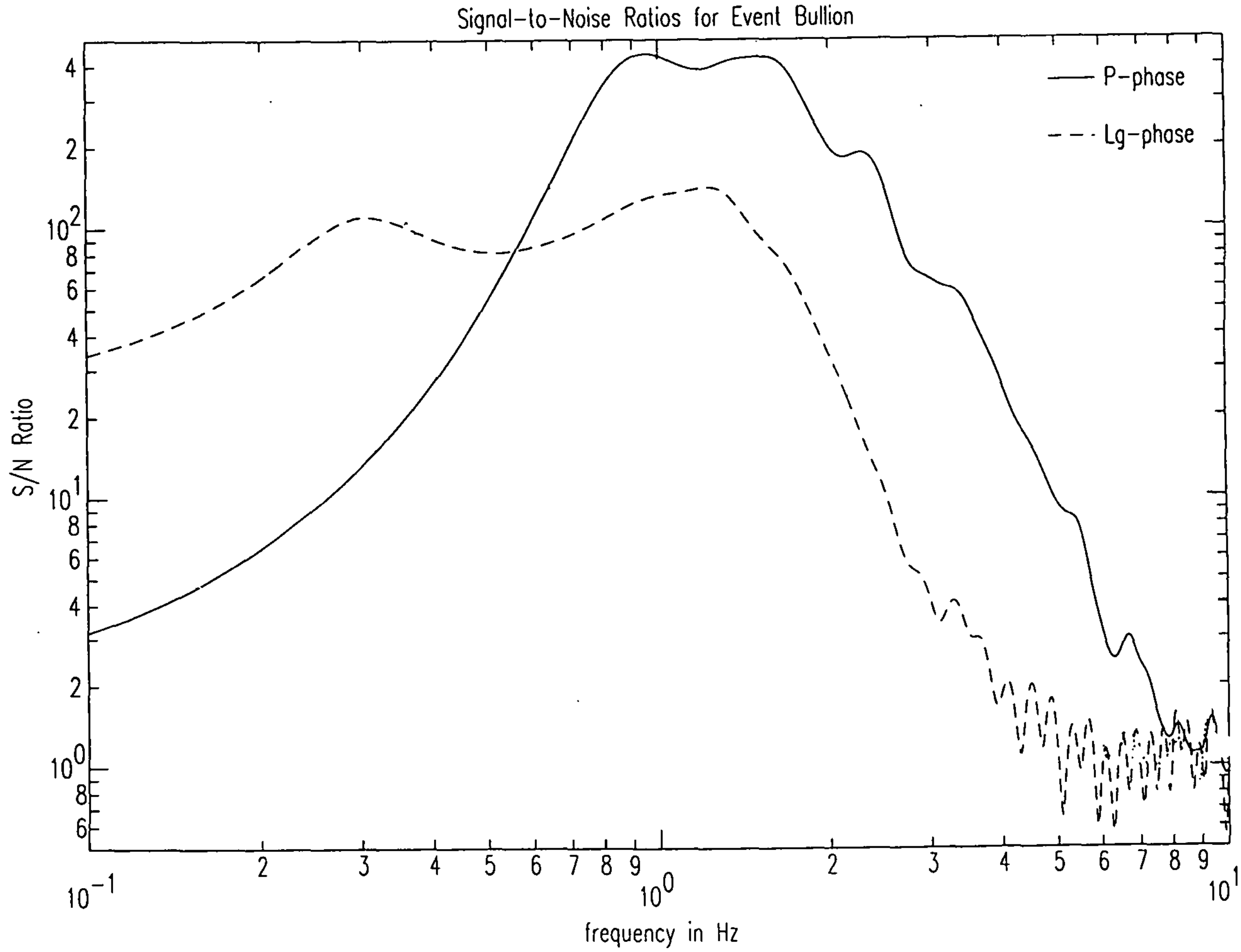

Figure 10. Amplitude SNRs are shown as a function of frequency for the P and Lg phases of the Bullion event vertical component recording.

Conclusions and Recommendations

The CSMS system deployed at Pinedale, Wyoming, to record the NTS Bullion test met all specified and implied requirements in the new TTBT protocol. In addition, the CSMS system deployed at Pinedale had many important and useful features that are not required by the TTBT protocol:

1) Continuous recording during the entire deployment period.

2) On-line dual copies of all recorded data.

3) Powerful signal analysis capability to verify data quality.

4) Continuous battery-powered vault electronics.

5) Minimal vault area requirements for system.

The CSMS system deployed at Pinedale could be improved in three principal areas: 1) although the dynamic range of the present system was adequate at 48 Db gain to resolve the lowest noise periods at Pinedale and to record the Bullion event, it is easily conceivable that a granite-coupled large shot recorded at shorter range could well have clipped the system. The dynamic range must be greater to eliminate this possibility.
2) high frequency noise detected on the central-vault cable connection was eliminated but could be a more severe problem in the Soviet Union. A central-vault fiber optic link would eliminate any possibility of this kind of problem. 3) security and data authentication were not a concern at Pinedale but must form part of a system proposed for the Soviet Union if the data are to be generally accepted.

The present working system will be systematically upgraded to meet other interagency requirements, to add desirable features, and to simplify the setup and use of the system. Some of the upgrades currently underway or planned to be implemented in the near-term are:

1) Full 24-bit dynamic range.

2) Fiber optic link between vault and central.

3) Data authentication and instrument security sealing.

The Pinedale deployment exercise was useful in pointing out certain operational needs and requirements, and some protocol requirements that need interpretation. The operational needs and requirements that we believe are important include: expert personnel in the deployment crew, restricted access to the vault near shot-time, and some system redundancy. We found that the challenges of deploying a seismic recording system with CSMS capabilities at a new site requires a system expert and a geophysicist to assure correct installation and high data quality. This requirement could probably be relaxed after some experience is gained in operation at a particular site. We found that our broadband (0.01 - 50 Hz) Guralp seismometer required significant settling time. A "no vault access" requirement of 3 hours before shot-time would be a reasonable operational restriction.

To be reasonably confident of having a full working system at shot-time, duplicate components are required in case of breakdown. It is clear, however that a full duplicate system is probably not required since some components rarely fail (like interconnect cables and tools) and others are redundant in the system itself (dual tape drives and dual monitors). Since the high-cost components (central computer, data acquisition unit, and seismometer) require backup units, the cost savings in deploying a system without full duplication is probably small. The primary advantage is probably perception, since a single system, defined to include all backup components, will half the number of systems (from 12 to 6) required in the Soviet Union to monitor a nuclear test.

The protocol requirements that need further clarification include: the required graphical representation of the event, the definition of SNR, and filter rolloffs outside of the 0.1 to 10 Hz recording band. The required graphical representation should require all sample points in the 31-minute recording period be plotted so that data glitches, i.e., bad data points, can be identified. If this is specified or agreed, then the time period displayed on each 8 1/2 x 11 page should be shorter, say 500 sec, to produce a visually pleasing and more useful plot. Finally, a de-glitched version of the same plot should be a requirement so that general data quality features can be observed.

The definition of SNR needs clarification in the treaty protocol. The particular item requiring clarification is if the Lg signal calculation uses the zero-to-peak or the peak-to-peak Lg amplitude. The two interpretations result in a factor of 2 SNR discrepancy. The peak-to-peak amplitude interpretation is the interpretation consistent with the noise calculation specified in the treaty protocol.

Finally, the filter rolloffs required to pass the 0.1- to 10-Hz frequency band and reject other seismic frequencies are not specified in the treaty protocol. We used a 0.1 Hz highpass 1-pole filter and a 16 Hz lowpass 6-pole filter to restrict recording to the 0.1 - 10 Hz band. Useful data outside of the 0.1- to 10-Hz band is recorded with the filter corners and rolloffs we used. It is, therefore, important that some general filter rolloff guideline characteristics are developed that are consistent with the intent of the treaty protocol passband restriction.

Acknowledgements

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