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Title: PRACTICAL OBSERVATIONS OF US MINING PRACTICES AND IMPLICATIONS FOR CTBT MONITORING

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PRACTICAL OBSERVATIONS OF US MINING PRACTICES AND IMPLICATIONS FOR CTBT MONITORING

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ABSTRACT

Man made and man induced seismic events associated with surface and underground mining operations produce seismic signals that might have to be identified when monitoring a Comprehensive Test Ban Treaty (CTBT). The importance of these sources to the monitoring process depend on the size of the seismic signal they generate and the degree of similarity these signals have to that expected from a contained nuclear explosion. Under the CTBT Research and Development Program sponsored by the DOE, an experimental task has been developed with the goal of identifying the seismological characteristics of sources associated with mining operations. The complete experimental program consists of four distinct components that include: (1) Characterization of mining explosions in hard and soft rock; (2) Quantification of decoupling effects; (3) Investigation of source depth of burial effects; and (4) Characterization of rockbursts and collapses. Items 1 and 4 in this list relate directly to signals generated by mining and compose the topic of this review. Currently, seven experiments are planned under this program with initial results from a number of these reported in other presentations at this meeting (Pearson *et al.*, 1995; Stump *et al.*, 1995). This paper will focus on mining operations in one of the largest coal producing basins in the US, The Powder River Basin. This review is intended to illustrate the magnitude and complexity of mining operations that might produce seismic signals of large enough magnitude to be of interest to CTBT verification.

OBJECTIVE

Explosions associated with mining operations produce signals that will be detected by a world wide seismological monitoring system such as that currently being tested under GSETT-3. This point is illustrated in Figure 1 which is a summary of one of three explosions from the Powder River Basin that was detected on 11 Feb 95 and later located. The location (actual and calculated) of the largest event is illustrated in the figure with the associated error ellipse (which does not include the actual event location). This example demonstrates that to some degree these events will trigger the monitoring system and as such must be identified. This figure also illustrates that these types of events can provide useful practical information for calibration of the location capabilities of the monitoring system if we have ground truth.

Under the DOE CTBT Research and Development Program an experimental task has been designed for quantifying and characterizing seismic signals that are generated by mining operations. This program is being conducted jointly by LLNL and LANL. The complete experimental program is more comprehensive including experiments associated with; (1) Mining explosions; (2) Decoupling; (3) Depth of burial effects; and (4) Rockbursts/collapses. During FY95 seven experiments have been planned and are in various stages of implementation (Pearson *et al.*, 1995; Stump *et al.*, 1995; Jarpe *et al.*, 1995). Data developed and cataloged under this program will provide the foundation for quantifying seismological effects from these different sources.

Implementation of this program has resulted in the development of close cooperative ties with the US mining industry. This cooperation has included input from companies such as The Thunder Basin Coal Company (ARCO), Newmont Gold Company, Cypress Amax Coal Company and Blasting Analysis International. As a result of this cooperation, much practical information has been gathered about US blasting practices and their contribution to the resulting seismic waves. This information can be used to assess the types of seismic signals expected from foreign mines.

The goal of this paper is to document some of the things learned in the initial phases of this program and indicate the direction of planned and ongoing experiments. The primary focus of this paper will be on blasting activities associated with the Powder River Basin for illustration.

RESEARCH ACCOMPLISHED

BASIN/MINE DESCRIPTION: The Powder River Basin is located in northeast Wyoming (Figure 1). It is a rich source of coal as well as oil and gas deposits. Within the Basin, which is approximately 60 km from east to west and 160 km from north to south, there are 22 active coal mines with an annual production each of over 5 million tons of coal (Jones, 1991). Figure 2 illustrates these mines, possible sites of explosive sources that one might have to monitor. The total coal production for the Basin in 1994 was estimated to be 225 million tons (Glass, 1995). Surface mining accounts for nearly all of the coal recovery in this area because of the shallow depth of the coal. There are over 1 trillion tons of reserves that have been identified (Jones, 1991 and Glass, 1995). It is estimated by the local blasting community that between 300,000-400,000 tons of explosives are used annually in excavating the coal.

The Black Thunder Coal Mine is the largest in the region and is cooperating in the DOE field program. It provides an example of the types of blasting practices one might expect to find in a single mine. The southern portion of the mine with a dimension of 3.9 by 5.2 kilometers is displayed in Figure 3. Three of the four active pits in the mine are visible in this figure. The largest has a length of nearly 4 kilometers. The strike of the pits vary from east-west to north-south to northeast-southwest thus changing the orientation of the sources in these different pits to a fixed regional station. The coal seam that is mined in this region is buried at a depth between 33 and 49 m by weathered shales and sandstones and has a thickness of 18 m. The Pinedale Seismic Research Facility (PSRF) is 360 km to the southwest of the mine (Figure 1) and the US National Network Station, RSSD, is 150 km to the northeast.

***BLASTING PRACTICES*:** Cast blasting is employed to remove a significant portion of the overburden above the coal. This process is followed by a drag line and bucket operation for coal recovery. The casting operation typically involves the largest explosions in the mine. Cast blasts with millisecond delays can contain between 2,000,000-5,400,000 lb. of explosives. These large explosions occur on the order of once every two to four weeks in this mine. Explosive emplacement holes for the cast blasting are as deep as 49 m and 27 cm in diameter. Each hole is loaded with ANFO/emulsion blends varying from 70/30 to 30/70 with approximately 5,000 lb. of explosives per hole. The holes are both top and bottom detonated.

As an example of a cast blast, a shot in the south pit is illustrated (Figure 3) that was recorded by the experimental program. In this case a total of nine rows were drilled in the pattern, each at 20 degrees from vertical which aids in free face stability. Blasting was completed with a non-electric system. The initiation of the system began on the west side of the front row and propagated to the east, front to back. Over 700 holes were detonated giving a total explosive weight of 3,500,000 lb.(1.75 ktons). The burden on the first row was 6.7 m with burdens between intervening rows as large as 11 m. The spacing between holes in a row was 9.8 m. The delays along one diagonal of the pattern were 125, 300, 500, 700, 900, 1000, 1200 and 1400 ms. Delays between individual charges in a row were 35 ms yielding a total source duration of over 4 seconds.

Coal shots, in contrast, are designed to fracture the coal after the overburden has been removed. These explosions as a result have shorter delay times, smaller total explosives and thus much shorter source duration. The coal shots occur on a daily basis within the mine with total explosive yield between 50,000 to 700,000 lb. With cast shots, coal shots and multiple pits a single mine can produce several different types of signals that can be observed at regional distances and thus must be identified. Both cast and coal shots are observed at the Pinedale Seismic Research Facility (personal communication Vindell Hsu).

SEISMOLOGICAL IMPLICATIONS: An example of possible implications of shooting practices on spectral amplitudes is given in Figure 4. The theoretical amplitude spectra of the impulse time series (design) for the example cast shot of 3,500,000 lb. (recorded during the experimental program) is displayed along with amplitude spectra for two theoretical shots, each with the same nine row pattern and 35 ms delay between charges in a row but with the total number of shots in each row halved (1,750,000 lb.) and halved again (875,000 lb.). The effect of total charge size is easily identified at the long period spectral levels below 0.2 Hz. It is interesting to focus on frequencies around 1 Hz where teleseismic body wave magnitude measurements are made. In this frequency band, the peak spectral amplitudes between the three shots of 1.75, 0.875 and 0.438 kilotons are nearly identical. This effect is a result of the shooting pattern used at the mine. With nine rows, very large delays are used in order to remove the burden prior to detonation of the later rows (the last row has a delay of 1400 ms). As the total number of explosions in a row are reduced, the total duration of the source does not decrease linearly but begins to be dominated by the large delays in the last row. This effect is illustrated by the total durations of the three shots in Figure 4 decreasing from 4320 to 2780 to 2010 ms.

The Non-Proliferation Experiment (NPE) was a fully contained (390 m depth of burial) single detonation of 2,850,000 lb. of an ANFO/emulsion mixture conducted at the Nevada Test Site (Denny and Zucca, 1994). The regional m_b for this event was 4.1, about a factor of 10 greater amplitude than typical Black Thunder cast blasts at regional stations if the observations were made along the same propagation path. Near-source observations like those made at the Black Thunder Mine were made for the NPE explosion as well. The expected surface velocities in the shales and weathered sandstones (~1800 m/sec) at Black Thunder are not significantly different from those where the surface measurements were made of the NPE. The NPE and the large Black Thunder Cast Shot provide observational data for making a qualitative comparison of a singly detonated, contained explosion representative of a nuclear shot and a typical cast shot.

Comparison of vertical acceleration time series and spectra is made in Figure 5. Near source observation from the cast shot was 450 m from the closest of the individual 5,000 lb. explosions and as far as 700 m. The near-source data from the NPE chosen for comparison is at a free surface range of 690 m (NPE at a much greater depth of burial). The four second duration of the cast shot is apparent in a comparison of the two time series. The effects of individual charges are seen in the waveform when the cast shot time series is expanded. The NPE waveform is quite impulsive and short in duration. The peak amplitude from the well coupled NPE explosion is slightly smaller than the peak amplitude recorded at later times in the cast shot when superposition and constructive interference of the individual charges begins to boost the amplitudes. The spectra from the two observations are compared in the bottom of Figure 5. The NPE has nearly an order of magnitude greater spectral amplitudes in the frequency band of 0.5 to 2 Hz, consistent with the regional m_b

differences. At the highest frequencies the mining shot has larger amplitudes. At the longest periods the two spectra converge although this is the region where the signal to noise ratio in the acceleration data for both data sets is decreasing. The convergence at the longest periods is consistent with the theoretical impulse spectra displayed in Figure 4 which argues that only periods longer than the total duration of the source will reflect the total charge size.

RECOMMENDATIONS AND FUTURE PLANS

Results from analysis of The Powder River Basin and The Black Thunder Mine illustrate the different types of explosive sources one might expect from a large cast blasting operation. The GSETT-3 detections on 11 Feb 95 indicates that in some circumstances, these sources will be detected in a monitoring regime. Comparison of cast blast waveforms with single shot data indicates that these cast blasts are deficient in long period energy resulting in reduced magnitudes relative to concentrated charges. The variety of blasting practices within the Black Thunder Mine indicates that multiple source types can be expected from a single mine. Within the Powder River Basin there are an additional 21 mines, many of which are also using explosives, complicating the identification process. Cooperative work with AFTAC is attempting to quantify relationships between the blasting practices in the mine and the resulting regional signals.

Additional experimental work associated with mine related seismicity includes blasting in hard rock as well as collapse events associated with underground operations. These parallel efforts will relate equivalent near-source physical processes in these other environments to the resulting regional seismic signals. This process will allow the assessment of monitoring challenges imposed by man made or man induced events.

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- Three Events Located by GSETT3 on 11 Feb
- Largest Recorded Teleseismically
- Error Ellipse Does Not Include the Mine
- Explosion was 5,340,290 lb

No Magnitude Declared

Station	Dist	Phase(s)
PDAR	3.16	Pn,Lg
WALA	7.38	Pn
ULM	8.98	Pn,Lg
FCC	16.18	P
YKA	18.97	P,tx
WHY	23.87	P

Location error of ~75 km covering 1192 km^2.

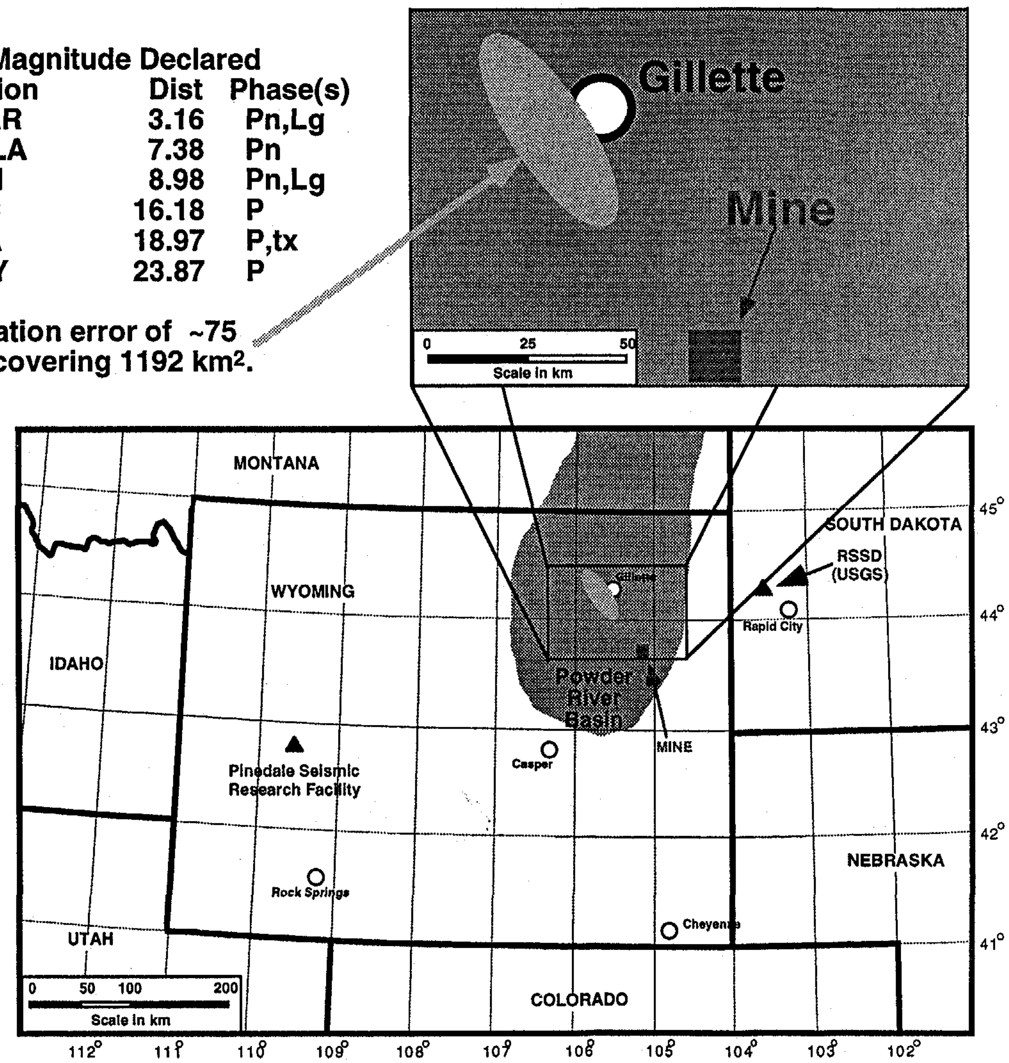
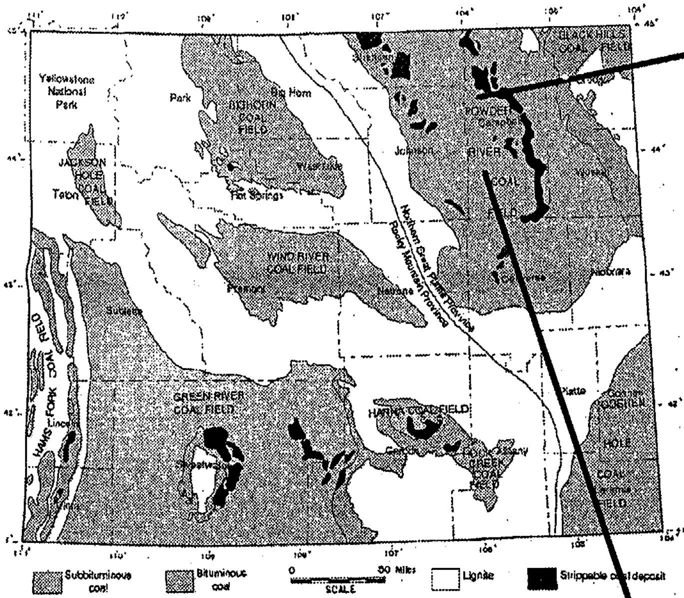
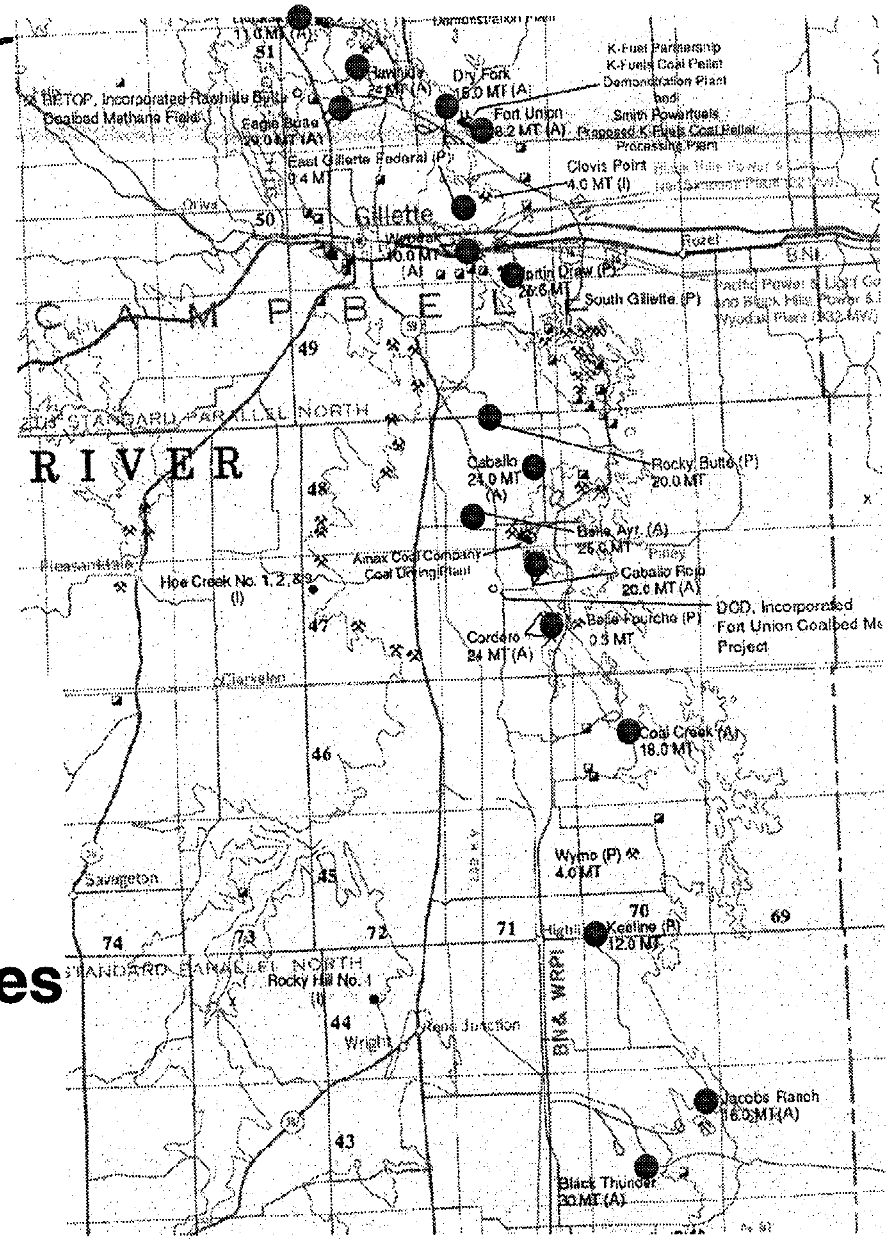


Figure 1: Powder River Basin with location of 11 Feb 95 GSETT-3 Event

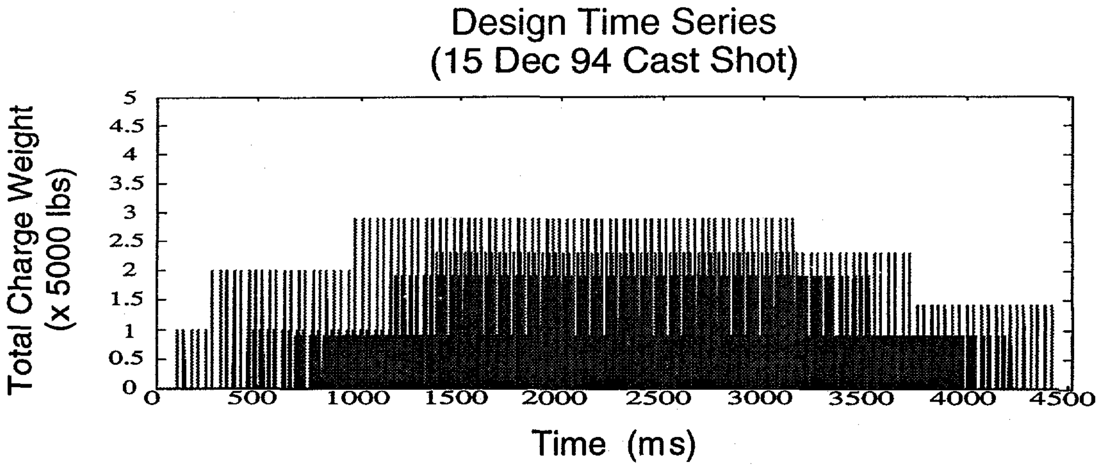




- ○ 225 MTons Coal in 94
- ○ 22 Mines > 5 MTons
- ○ 300-400,000 Tons Explosives
- ○ 99% SURFACE MINING
- ○ 1.46 Trillion Tons Reserve

Figure 2: Surface Coal Mining Operations in the Powder River Basin

Figure 3: Overhead image of the southern portion of the Black Thunder Mine.



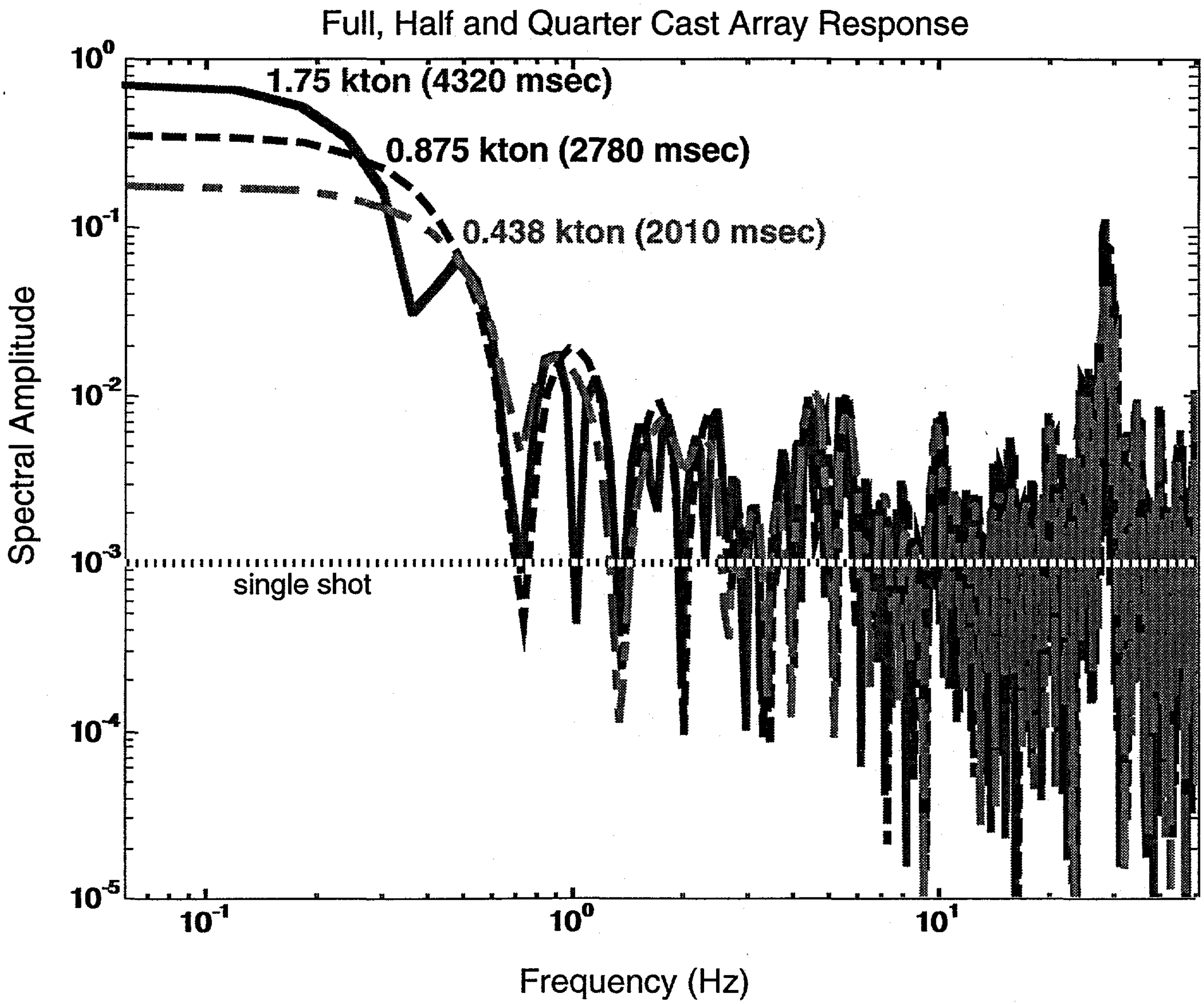


Figure 4: Impulse time series for the 1.75 kton cast blast (top) and spectra for this explosion (bottom) and two others each half the size.

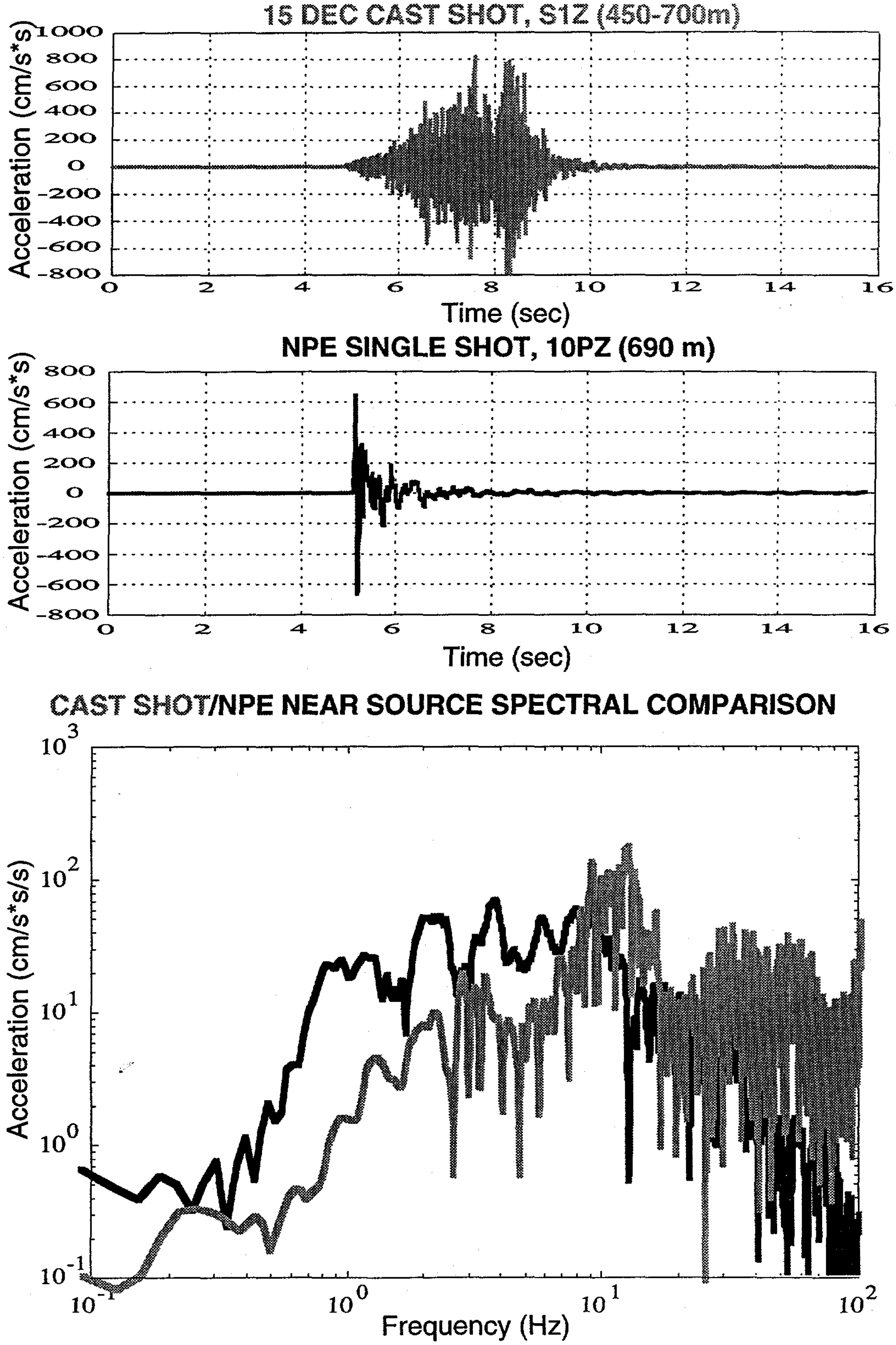


Figure 5: Comparison of near-source accelerations from a Cast Blast (top) and the NPE (bottom).