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NOISE AND GROUND VIBRATION MONITORING RELATED TO DRAGLINE OPERATIONS IN PHOSPHATE MINING

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NOISE AND GROUND VIBRATION MONITORING RELATED TO DRAGLINE OPERATIONS IN PHOSPHATE MINING

FINAL REPORT
FIPR # 92-05-039

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PERSPECTIVE

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Florida Institute of Phosphate Research

A prime mission of the Florida Institute of Phosphate Research is to sponsor or conduct research that will determine the magnitude of the effects of phosphate mining and processing on public health and the environment, and to devise programs that would minimize these effects. Over the years, these programs have very often dealt with naturally occurring radiation, but a number of other areas also have been addressed. This report deals with environmental noise and vibration from mining activities, and resulting exposures to, and acceptability by, the public living in the vicinity of mining operations.

Several years ago the Institute was approached by the Chairperson of the Polk County Board of County Commissioners for information about noise levels associated with phosphate mining. Polk County had a nuisance statute dealing with noise, but not a quantitative rule limiting community exposure to industrial noise, such as exists in several counties, including Hillsborough and Manatee. Polk County does have "set-back" rules governing how close mining activities may come to property lines, but these were not established on noise or vibration control. Any numerical standards that would be considered by Polk should be both protective of community well-being and yet feasible for industry implementation. First, however, a knowledge of actual noise (and vibration) levels from mining activities as a function of distance from the source would be needed. Other than some anecdotal information, data were virtually non-existent as to noise and its acceptability in the mining region, or as to factors that affect the two, such as type of source, time of day, nature of the noise, land use by the receiver, and others. Thus a measurements project was developed and submitted by the joint FAMU/FSU College of Engineering. The goal was to establish a reliable and quantitative data base for noise and vibration for use by industry, local government, and the public, so that for future understanding and potential regulation, less reliance would need to be placed on subjective measures such as annoyance and perceived loudness.

During the mining of phosphate, heavy machinery including large electric draglines, earth-moving vehicles trucks and hydraulic equipment produce noise and vibration: often for 24 hours a day and 7 days a week. Noise is generally an annoyance, but sometimes interferes with well-being or lifestyle, and can even contribute to hearing loss. Vibration is generally considered a nuisance, but in extreme cases can lead to structural damage. In this project, noise and vibration levels were measured at four different mining sites, during all four seasons of the year, and throughout the 24-hour day. Additionally, an assessment of the acceptability of levels was developed from the literature, and a range of distances found projected from each mine site where noise could be considered as acceptable versus unacceptable. In summary, this project has examined what noise and vibration levels exist as a result of mining activities, what levels are reasonable to expect as acceptable, measured data as opposed to subjective estimates, and realistic guidelines for any future regulation.

ACKNOWLEDGEMENTS

This research study was funded by the Florida Institute of Phosphate Research (FIPR) (Grant # 92-05-039). This study would not have been possible without assistance from FIPR and IMC-Agrico. Dr. Gordon Nifong, Research Director, provided strong support and coordinated this study. Mr. Jon Harris with FIPR, assisted in every phase of the field monitoring program. Mr. Dennis Adams with IMC-Agrico provided logistics and field support. Mr. Jay Allen and Mr. Ross Franklin, both with IMC-Agrico, provided needed information and assistance. Dr. Roger Wayson with the University of Central Florida assisted in the initial phase of the research study. Special thanks are extended to Sinjon Bradberry and Sean McDonald for providing their Fortran programming expertise.

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NOISE AND GROUND VIBRATION MONITORING RELATED TO DRAGLINE OPERATIONS IN PHOSPHATE MINING

PROJECT SUMMARY

The primary objective of this study was to determine levels of noise and ground vibration as a function of distance from draglines operating under various meteorological conditions. The goal was to provide a reliable, statistically sound data base of dragline noise and ground vibration for future reference. To accomplish the goal, noise and ground vibration readings were taken from four distinct draglines mining in Polk and Hardee counties. The draglines monitored were the Bucyrus Erie #1150B (at Noralyn), Bucyrus Erie #1250B (at Phosphoria), Bucyrus Erie #1260 (at Clear Springs), and Page Model 752 #16 (at Fort Green).

Field monitoring was conducted during each of the four seasons of the year with the last measurement concluding in December 1994. Noise monitoring was conducted using a Type I precision 2236A (Bruel & Kjaer) integrating sound level meter while the vibration monitoring was conducted using a piezoelectric accelerometer Type 4378 (B & K). Both the noise and ground vibration signals were recorded in real-time using a portable, digital audiotape recorder (Sony PC 204A) via the sound level meter and charge amplifier respectively. Noise and ground vibration readings were collected continuously and simultaneously over a duration of approximately two minutes for each increment of distance from the dragline. The measurements were collected two times by day and two by night during each site visit with one reading taken between midnight and 6 a.m..

Immediately, after completion of the field monitoring program, equivalent continuous sound levels, both L_{AV5} and L_{eq}, were read directly from the sound level

meter. The L_{10}, L_{90}, and the sound exposure level presented in this report were also taken directly from the sound level meter. Regression analysis performed on the L_{eq} readings revealed a discernible gap between the average sound levels of the different draglines. Specifically, the average sound levels resulting from the 1260W dragline at Clear Springs were noticeably higher than the sound levels from the other monitored draglines.

In the laboratory, the ground vibration signals were transferred from the recorded tapes to a PC computer whereby a FORTRAN program was utilized to calculate peak particle velocities. All of the measured peak particle velocities were below 0.106 inch per second which is classified by NAVFAC DM 7.3 (1983) as easily noticeable to persons. Comparison amongst the different draglines revealed that the 1250B dragline at Phosphoria produced the highest peak particle velocities.

After the noise parameters and the peak particle velocities were determined, the recorded noise and vibration signals from the tapes were further analyzed by the FORTRAN program. Fast Fourier Transform (FFT) analysis was applied to the noise signals to show how the sound pressure level varied as a function of frequency. The analysis revealed that the frequency distribution of the prominent sound pressure levels occurred within the 0 to 2000 Hertz range. It was also found that the 1250B and the 1150B has consistent dominant frequencies of approximately 1617 and 1400 Hz respectively.

FFT analysis was also applied to selected vibration measurements to show how particle velocity varied as a function of frequency. The resulting vibration spectrograms showed that the frequency ranges of the ground vibrations extended from 0 to just over 60 Hz. Most of the significant spectral energy, however, was contained between approximately 5 to 25 Hz.

The noise results were further analyzed to determine the influence of various factors on the sound levels. Since the operations of the draglines were not controlled in any manner, it was difficult to differentiate between the causes of the variability in the measured dragline noise. Thus, no definite conclusions could be drawn as to the effect of seasonal variations in the weather or the time of day, on the measured sound levels. However, background noise levels during the early morning measurements did seem slightly lower than other times of day.

In addition, an assessment of the dragline noise was made, and acceptable noise levels were determined from the literature. Finally, a range of distances from each dragline where mining noise is considered as acceptable or unacceptable was established.

In summary, field monitoring and laboratory analysis of noise and vibration measurements were successfully carried out to achieve the project objectives. A reliable data base of noise and ground vibration levels was established to provide a better understanding of dragline effects on the physical environment. This study may provide industry and the public with: (1) a quantitative measure of sound and ground vibration levels caused by dragline mining; (2) an indication of what noise levels are reasonable and can be expected; and (3) actual measured sound levels instead of subjective estimates of loudness. The study may also provide local officials with a better understanding of reasonable noise levels, so that any future regulations to be considered may be realistic.

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The phosphate industry is one of the larger industries in Florida. The phosphate mining process used in central Florida is open-pit operation. Phosphates are derived from phosphate rock which is a naturally occurring sediment located several feet below surface soils. During open-pit mining, a dragline is used to remove the overburden surface soils and then extract the phosphate rock from the ground. Noise and ground vibration are two public concerns associated with open-pit dragline operations.

1.2 STATEMENT OF PROBLEM

In several counties of central Florida, local authorities have established noise regulations to protect the public from the environmental hazard of excessive noise. These may be nuisance oriented, as in Sarasota County, or may contain numerical limits applicable at the receiver's property line, as in Hillsborough and Manatee counties. These would apply to dragline noise, but their application is not universal. All mining areas also have "set-back" rules governing how close to a property line mining may approach, but these vary and were not established solely for noise control.

In addition, concern has been expressed over ground vibration around draglines. An ordinance prohibiting excessive ground vibration due to mining exists in Manatee County. However, this is somewhat arbitrary and there is little data available for evaluation. There is also doubt as to what level ground vibration will affect human feeling.

1.3 SCOPE OF STUDY

This research study was undertaken to monitor the noise and vibration levels related to dragline operations. The primary objective of the research study was to determine levels of noise and ground vibration as a function of distance from operating draglines at various times of day, seasons of year, and under various meteorological conditions. The goal would be to provide a reliable, statistically sound data base for future reference.

1.4 REPORT CONTENT

This report, entitled "Noise and Ground Vibration Monitoring Related to Dragline Operations in Phosphate Mining," documents the work effort and results of the noise and ground vibration study carried out by the researchers. More specifically, this report includes: a field monitoring program summary, presentation of field results, laboratory analysis methods and results, and conclusions and recommendations. Also, included in the appendices, are a brief review of basic sound characteristics, and field and laboratory data summary.

CHAPTER 2: FIELD MONITORING PROGRAM

2.1 GENERAL

The primary objective of this study was to conduct field measurements of noise and ground vibration from mining draglines at various environmental conditions. To achieve the objective, a series of noise and vibration field measurements were conducted on four different walking draglines (Figure 2.1) mining under various meteorological conditions. The draglines were operating in Polk and Hardee counties in central Florida. Noise and vibration levels were monitored at various seasons between February 15, 1994 and December 15, 1994. The field monitoring program was jointly carried out by the Florida Institute of Phosphate Research (FIPR), IMC-Agrico, and the research team. This chapter describes the field monitoring program, including: test site selection, site locations, site geology, instrumentation, field operational procedures, and weather considerations.

2.2 TEST SITE SELECTION

Test sites were selected through coordination between IMC-Agrico and the FIPR. Originally, three sites were chosen and one dragline was monitored from each of the sites. The goal was to collect data from these same draglines for the duration of the field measurements. However, at the request of IMC-Agrico, another site was selected during the second phase of field monitoring. As shown in Table 2.1, four phases of measurements, representing four different seasons, were conducted during the period of February 15, 1994 to December 15, 1994.

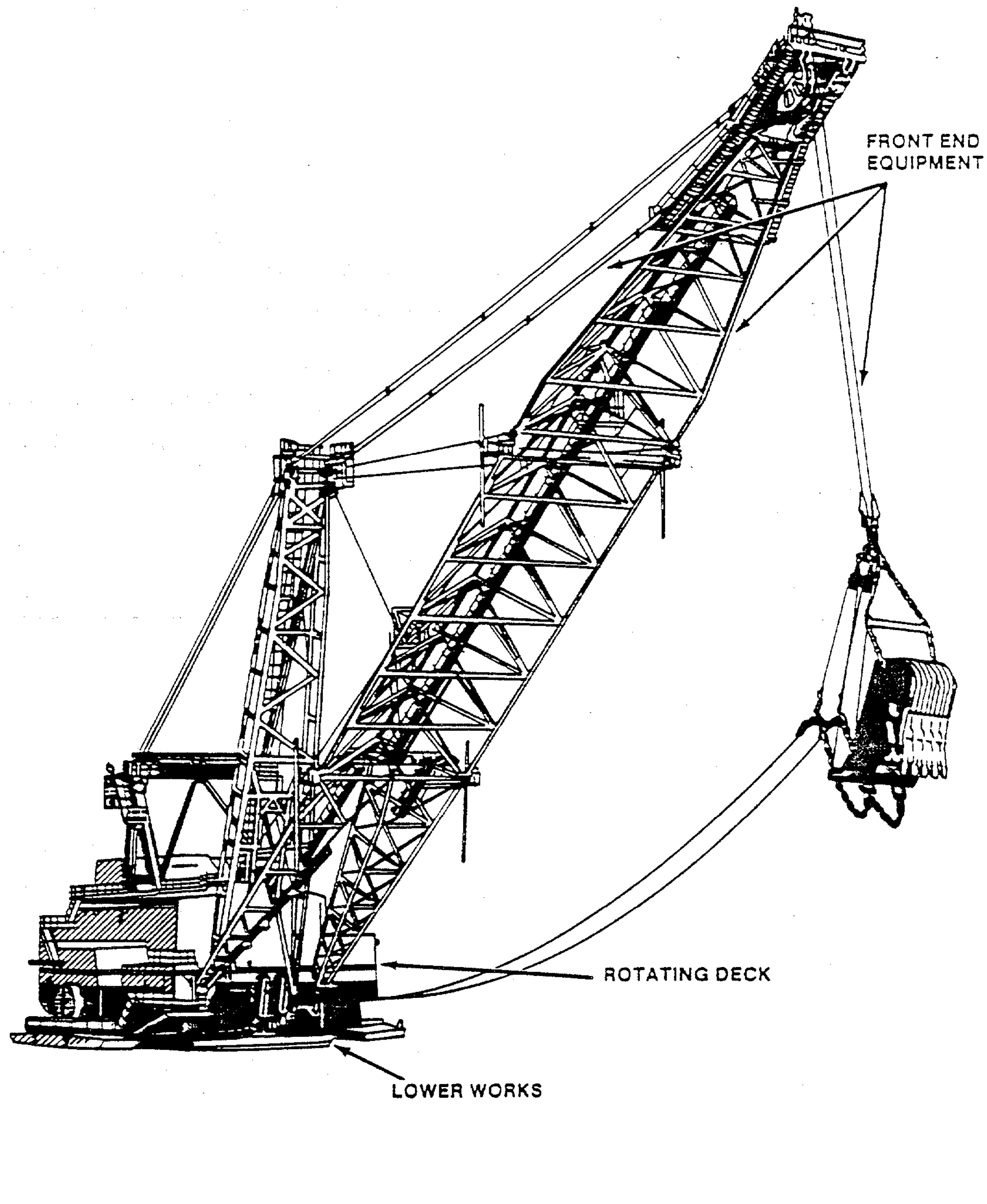


Figure 2.1 Walking dragline

Table 2.1 List of Monitored Draglines

Phase I Feb. 15-18, 1994	Phase II May 11-13, 1994	Phase III Aug. 23-25, 1994	Phase IV Dec. 13-15, 1994
Bucyrus Erie 1150B (Noralyn) Bucyrus Erie 1250B (Phosphoria) 752 Page #16 (Fort Green)	Bucyrus Erie 1260W (Clear Springs) Bucyrus Erie 1250B (Phosphoria) 752 Page #16 (Fort Green)	Bucyrus Erie 1260W (Clear Springs) Bucyrus Erie 1250B (Phosphoria) 752 Page #16 (Fort Green)	Bucyrus Erie 1260W (Clear Springs) Bucyrus Erie 1150B (Noralyn) 752 Page #16 (Fort Green)

*For a more detailed summary of the field monitoring schedule, refer to Appendix B.

2.3 DRAGLINE POWER SPECIFICATIONS

All of the draglines monitored for this study are powered by a 4160 volt line (electrical power). Table 2.2 lists the electrical equipment present in each dragline during the field monitoring program. The information contained in the table came from IMC-Agrico's specification manuals for each dragline.

2.4 TEST SITE LOCATIONS

Of the four test sites (draglines) monitored for the purpose of this study, three were located in the southwest corner of Polk County. The other dragline at Fort Green was mining in northwestern Hardee County during the field measurements. A location map is shown in Figure 2.2. The collection of the noise and vibration data took place during 1994. During the year, the draglines moved periodically to dredge unmined land. The position of each dragline during the field monitoring program is shown below and is also depicted in Figure 2.3.

Phase	Site/Dragline	Position
I	Noralyn/1150-B	T30S-R24E-SEC. 21
	Phosphoria/1250-B	T30S-R23E-SEC. 35
	Clear Springs/1260 W	T30S-R25E-SEC. 03
II	Fort Green/752 #16	T33S-R23E-SEC. 05
	Phosphoria/1250-B	T30S-R23E-SEC. 25
	Clear Springs/1260W	T30S-R25E-SEC. 03

III	Fort Green/752 #16	T33S-R23E-SEC. 08
	Phosphoria/1250-B	T30S-R23E-SEC. 36
	Clear Springs/1260W	T30S-R25E-SEC. 03
IV	Fort Green/752 #16	T33S-R23E-SEC. 03
	Noralyn/1150B	T30S-R24E-SEC. 20
	Clear Springs/1260W	T30S-R25E-SEC. 03

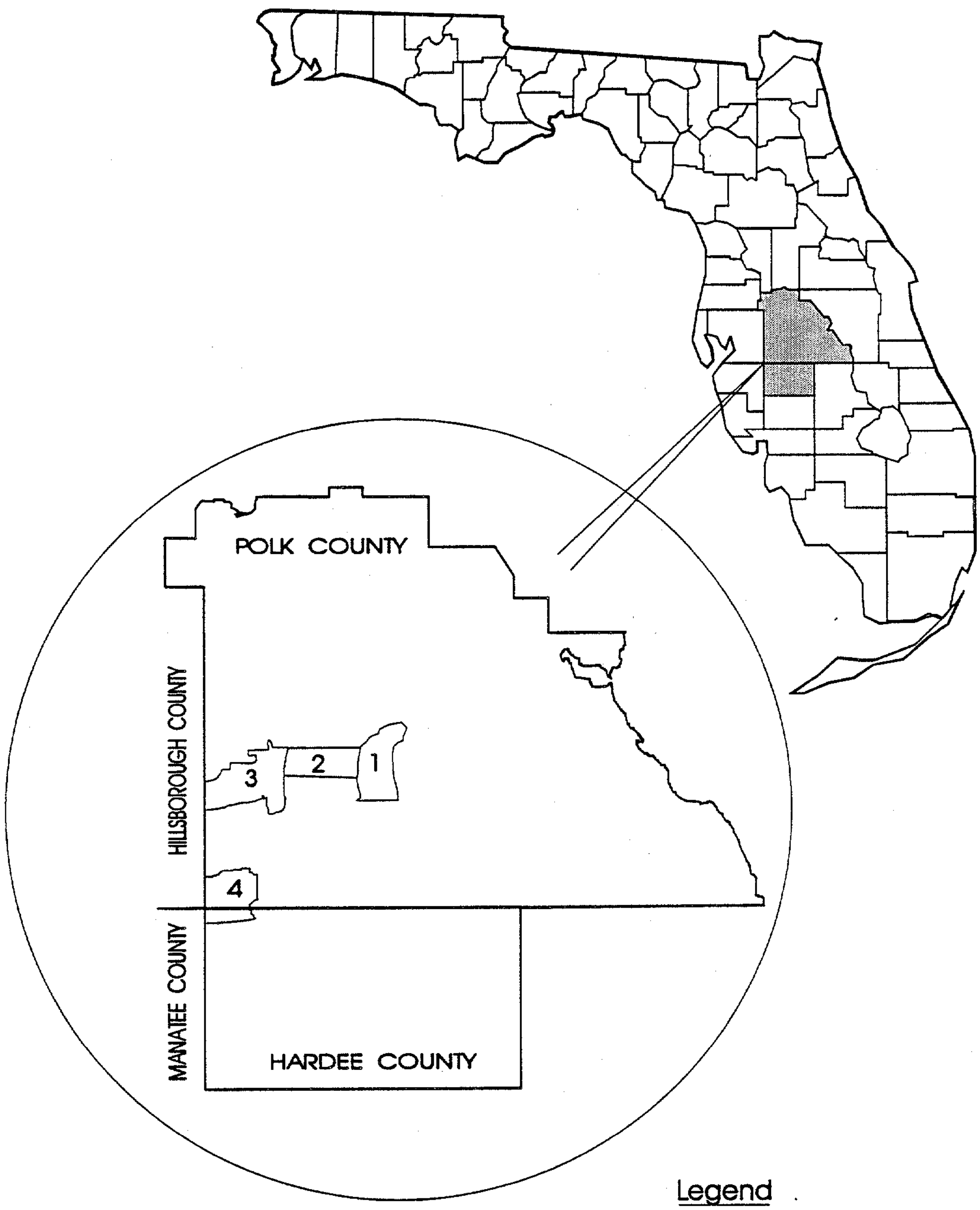
Table 2.2 Dragline Electrical Equipment

Electrical Equipment	Noralyn 1150B	Clear Springs 1260W	Phosphoria 1250B	Fort Green 752 Page#16
Synchronous motor	1 @ 1250 HP*	1 @ 1750 HP	1 @ 1250 HP	1 @ 2000 HP
Swing motor	3 @ 125 HP	4 @ 137.5 HP	4 @ 137.5 HP	4 @ 137.5 HP
Induction motor	1 @ 500 HP	1 @ 700 HP	1 @ 600 HP	1 @ 700 HP
Hoist/Drag motor	4 @ 425 HP	4 @ 1000 HP	4 @ 425 HP	4 @ 625 HP
Propel motor	------------	2 @ 150 HP	2 @ 100 HP	1 @ 625 HP
Swing generator	3 @ 112.5 KW**	4 @ 125 KW	4 @ 124 KW	4 @ 124 KW
Hoist/Drag generator	4 @ 375 KW	4 @ 450 KW	4 @ 375 KW	4 @ 560 KW
House exciter	------------	1 @ 40 KW	1 @ 40 KW	1 @ 50 KW
Hoist/Drag exciter	------------	------------	------------	2 @ 21 KW
Induction motor (exciter drive)	------------	------------	------------	1 @ 125 HP

*HP - horsepower
**KW - kilowatt

2.5 SITE GEOLOGY

Polk County lies within the Central Highlands physiographic province. The vast majority of the county lies within the Polk and Lake uplands. The major topographic features of the county are three long, irregular, north-south trending ridges which are separated and bounded by relatively flat land. Northern Hardee County also lies in the Polk Upland range (Wilson, 1977).



Legend

1 Clear Springs site - Dragline #1260W
2 Noralyn site - Dragline #1150B
3 Phosphoria site - Dragline #1250B
4 Fort Green site - Dragline 752 #16

Figure 2.2 Site location map

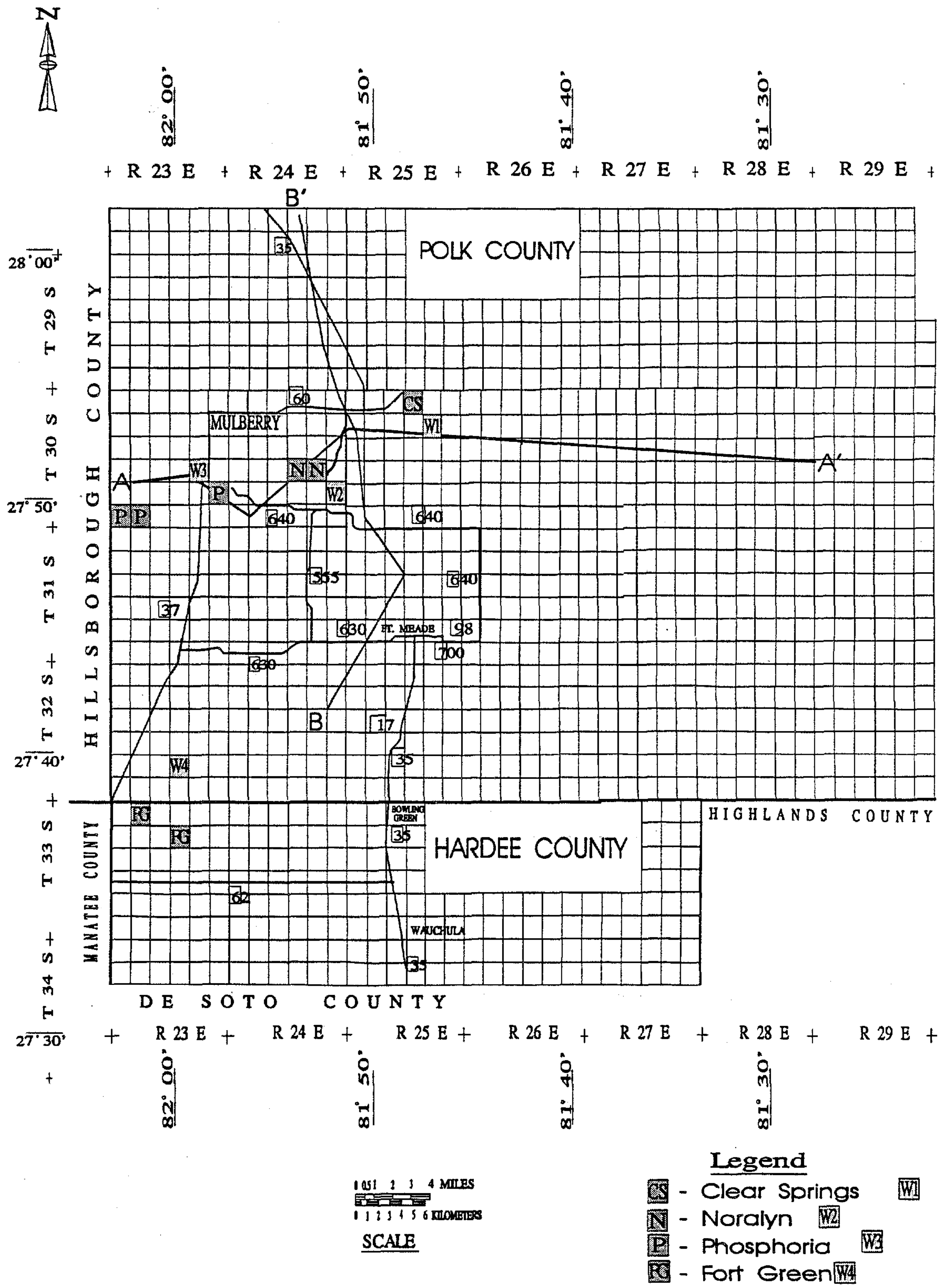


Figure 2.3 Location map showing position of each dragline during the field monitoring program

As previously discussed, during the field measurements, three of the four draglines monitored were located in the southwestern section of Polk County, while the fourth dragline (at Fort Green) was mining in the far northwestern section of Hardee County (see Figure 2.3). Thus, all four draglines were mining in the Polk uplands. With the exception of the ridges, the surface elevations in the Polk Upland vary from 100 to 130 feet above Mean Sea Level (Cambell, 1986).

Litho-Stratigraphy

Sediments located within a few hundred feet of the surface in Polk County and in northern Hardee County generally consist of quartz sand, clay, phosphorite, limestone, and dolomite. These sediments range in age from Late Eocene to Holocene (40 million years ago to present). Figures 2.4 (a) and (b) depict two general geologic sections revealing the formations penetrated by wells in the Polk County area. These sections were constructed from electric and sample logs. Data for the cased sections in wells were interpreted from drillers' logs (Stewart, 1966).

For the purposes of this study, four wells were selected to represent the lithology of the four dragline sites monitored during the course of the noise and vibration field monitoring program. The position of the wells in reference to the draglines can be seen in Figure 2.3. In the figure, W1, W2, W3, and W4 are the locations of the wells selected to represent the sites. Figures 2.5 through 2.8 depict the lithology and stratigraphy for each well. The information contained in the figures was obtained from drillers' logs and lithologic well logs extracted from the Florida Geological Survey, Tallahassee, Florida.

2.6 INSTRUMENTATION

After careful research into current noise and vibration measurement standards and after consideration of the type of field conditions that would be encountered, primary equipment was purchased from Bruel and Kjaer (B & K) meeting all of the specifications necessary to complete this research study. A list of the major equipment employed during the field monitoring program is shown in Table 2.3.

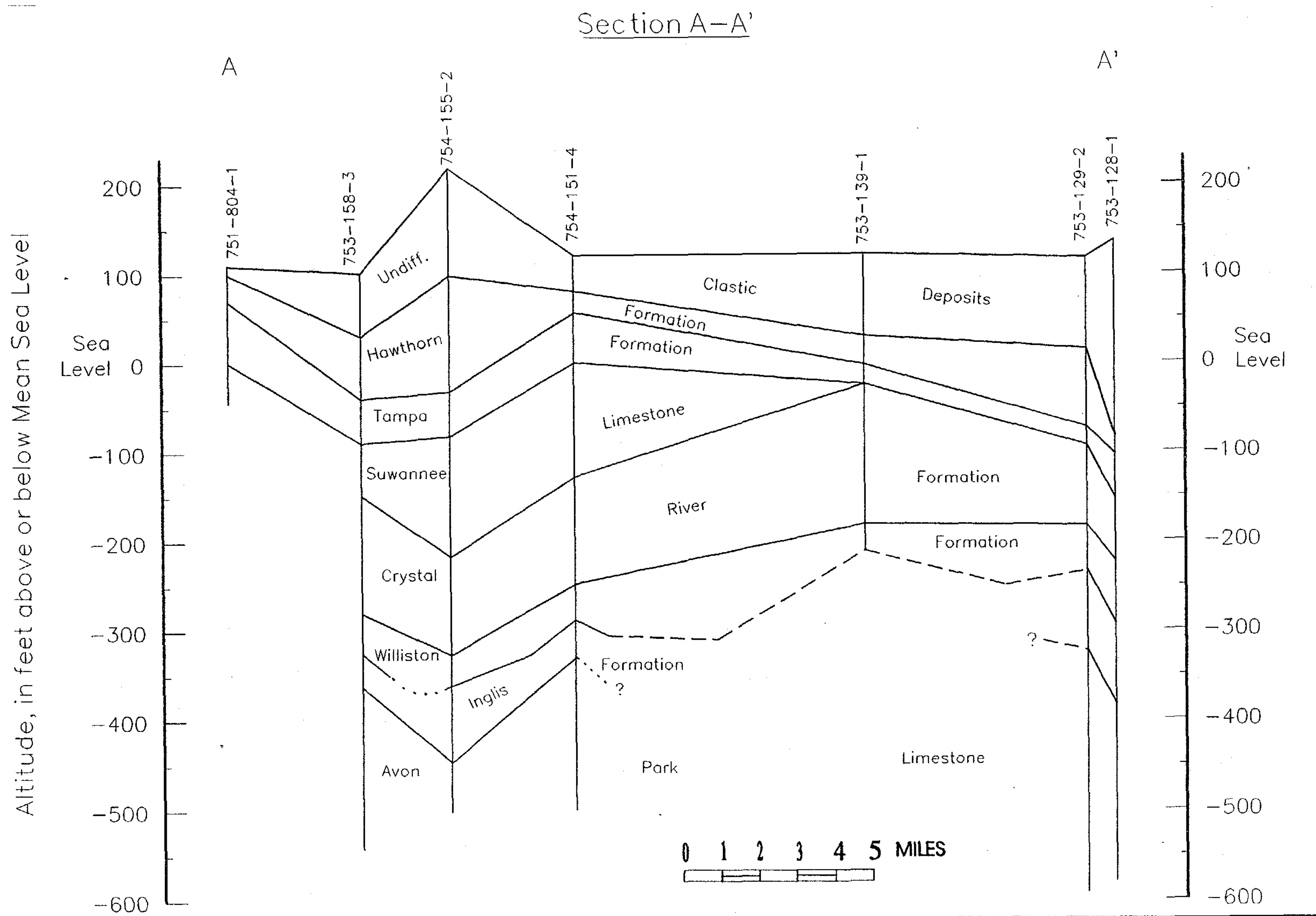


Figure 2.4a Geologic sections along line A-A'. Sections located on Figure 2.3.

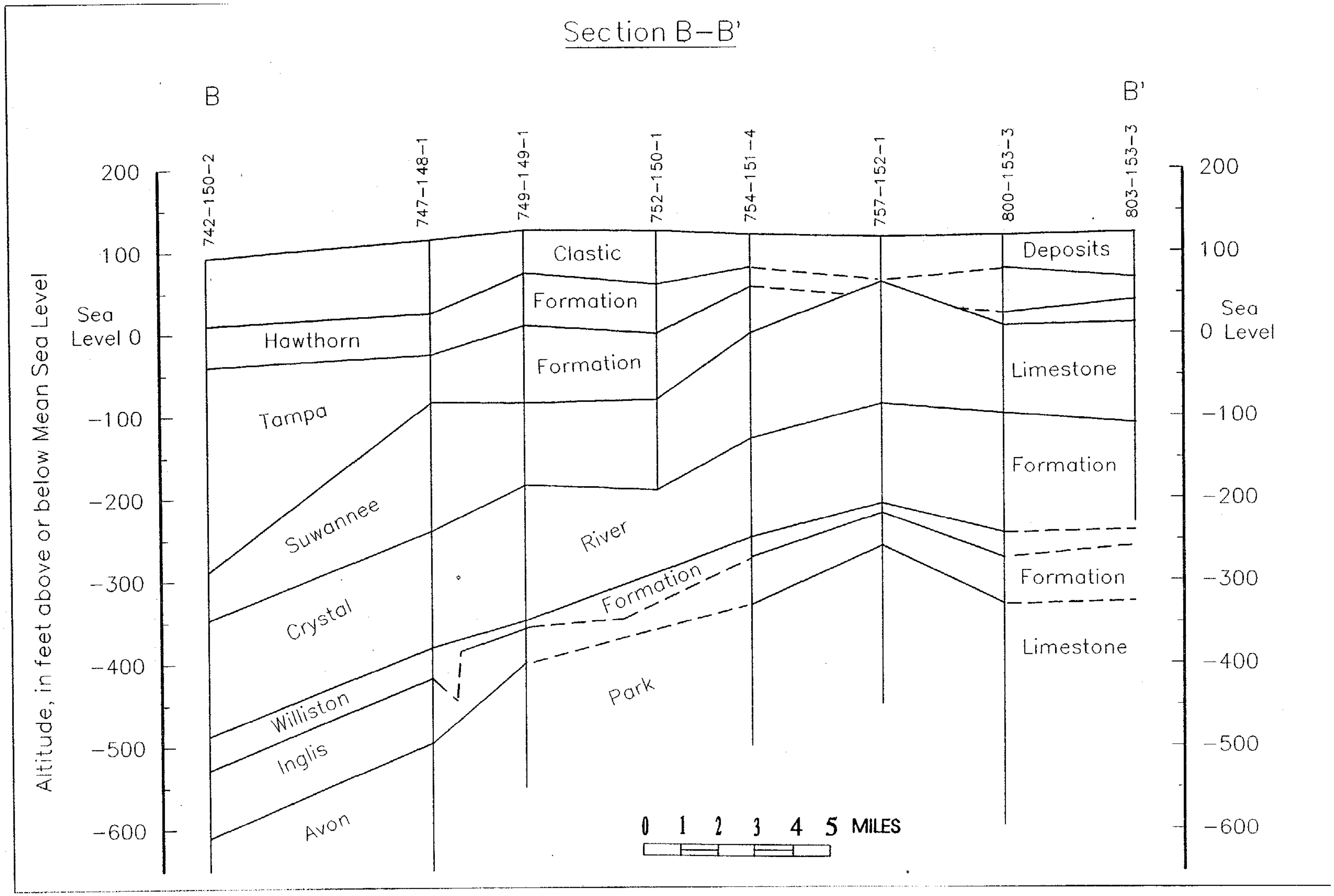


Figure 2.4b Geologic sections along line B-B'. Sections located on Figure 2.3.

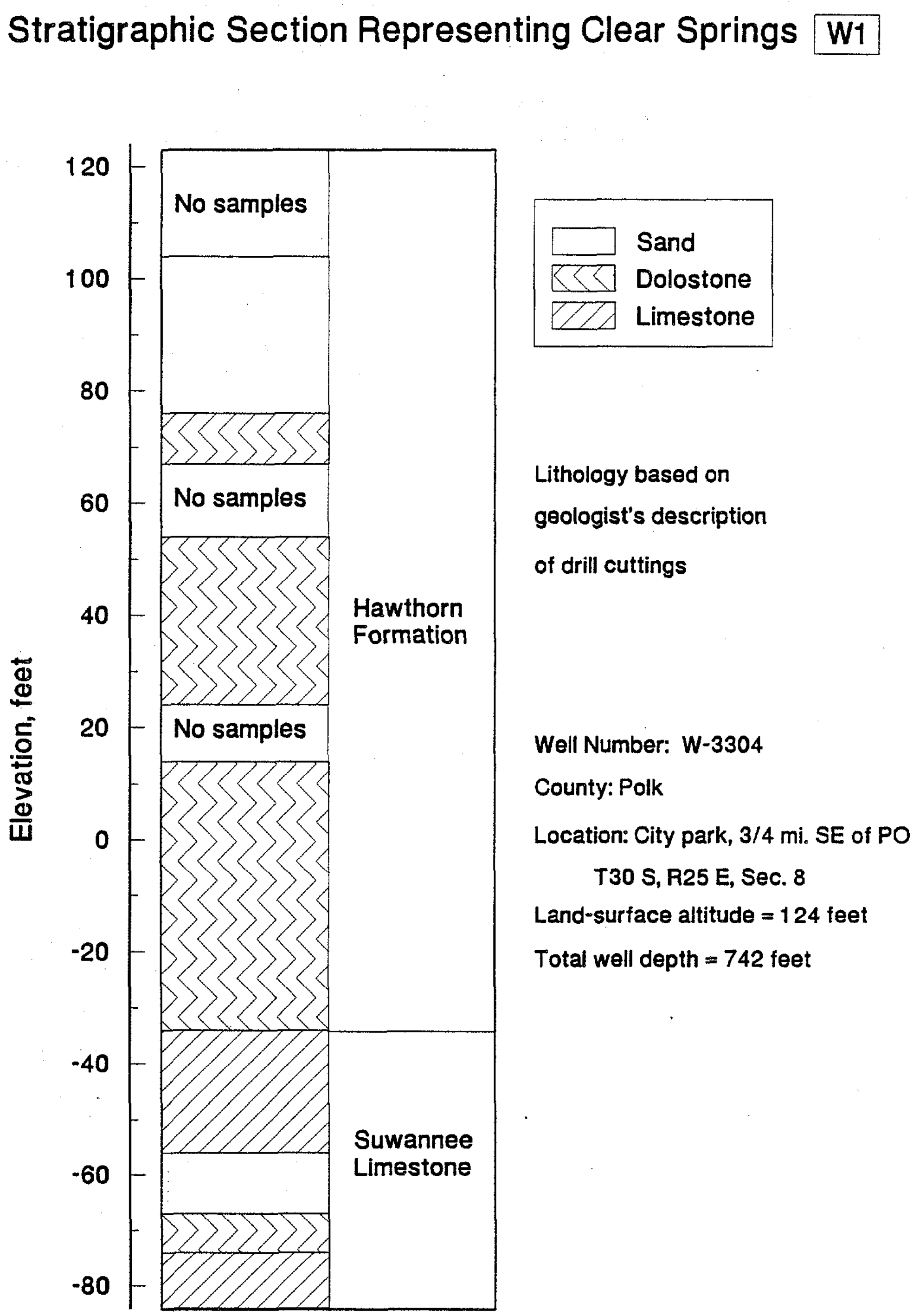


Figure 2.5 Stratigraphic section representing Clear Springs site, W1.

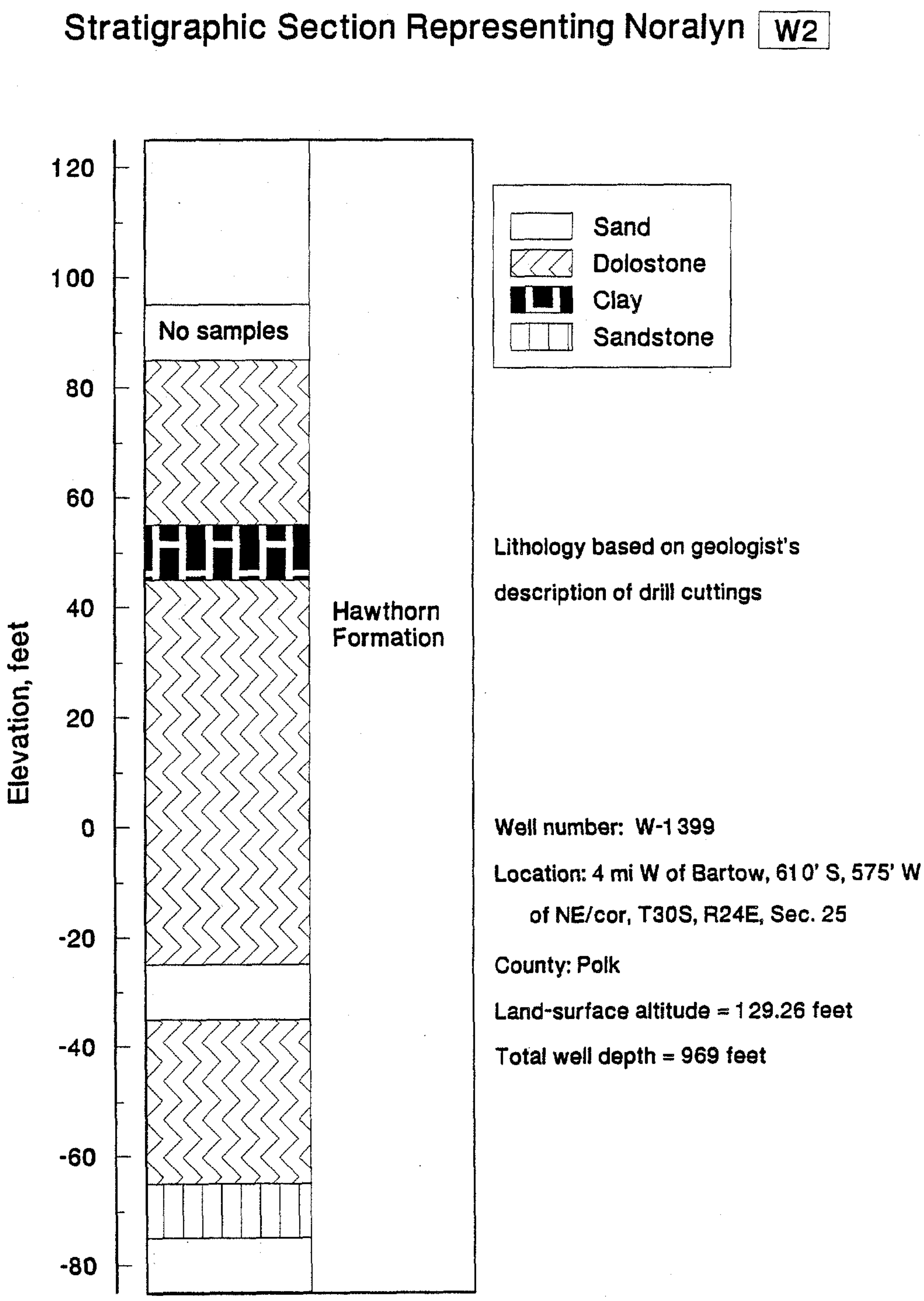


Figure 2.6 Stratigraphic section representing Noralyn site, W2.

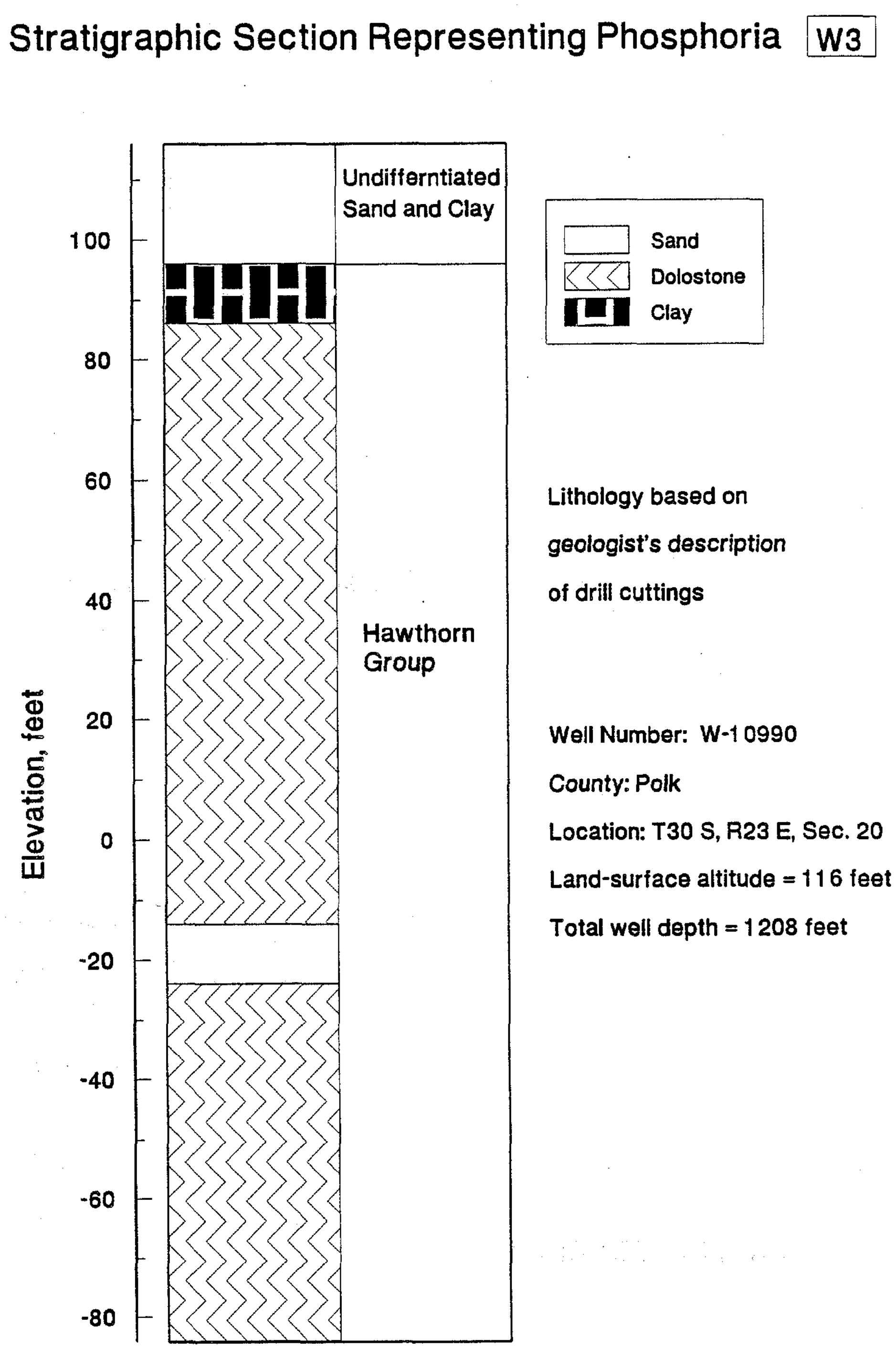


Figure 2.7 Stratigraphic section representing Phosphoria site, W3.

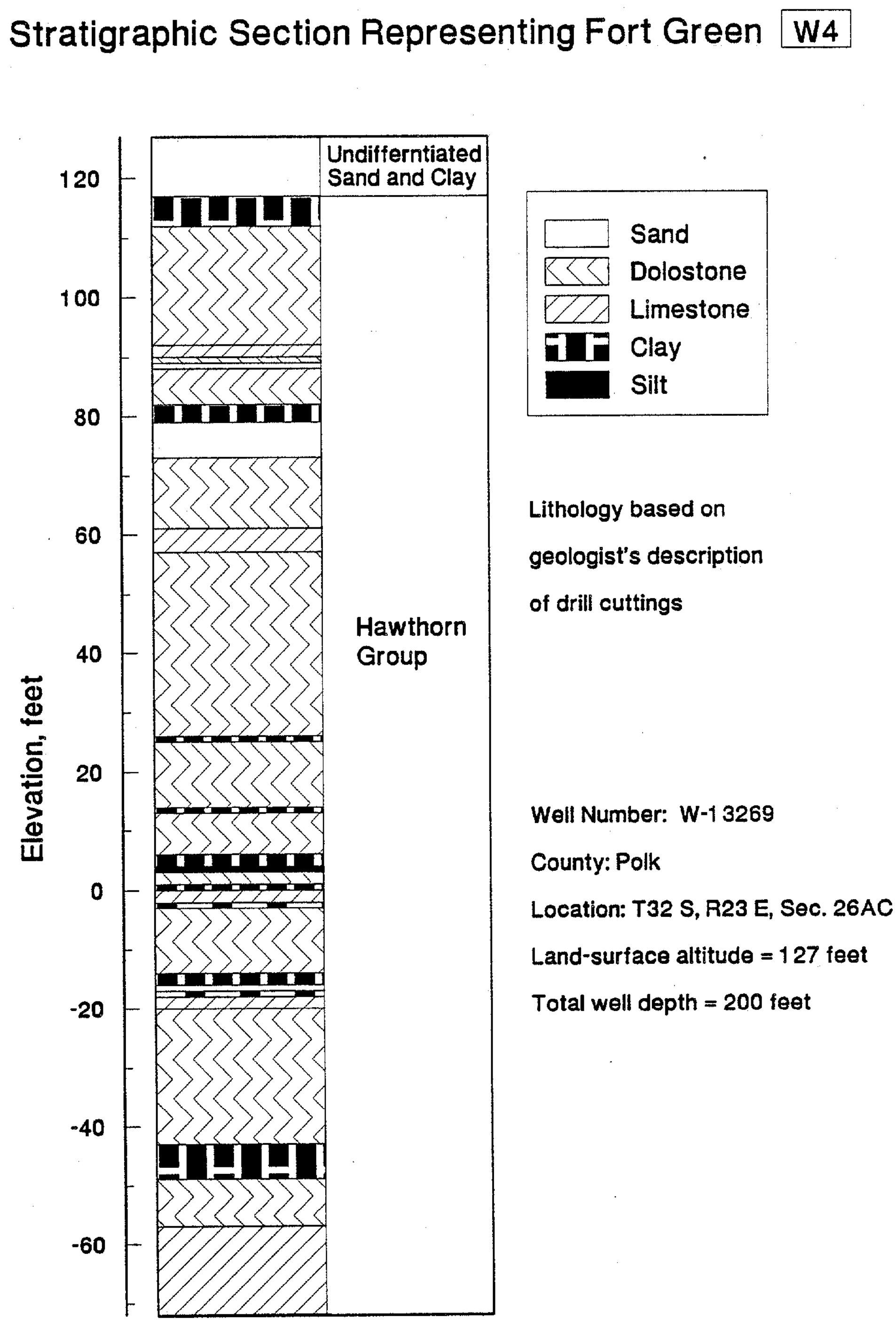


Figure 2.8 Stratigraphic section representing Fort Green site, W4.

Table 2.3 List of Major Instruments for Noise and Vibration Field Measurements

NAME	MAKE	MODEL	SERIAL#
DAT Recorder	Sony	PC204A	U3432
Precision Integrating Sound Level Meter	Brüel & Kjaer	2236A-007	1763709
Delta Sheer Accelerometer	Brüel & Kjaer	4378X	1716422
Charge Amplifier	Brüel & Kjaer	2635A	1742795
Sound Level Calibrator	Brüel & Kjaer	4321A	1761671
Sling psychrometer	Fisher Scientific	NA	NA
Optical Range Finder	Lengemann of Florida	6-100 ft	NA
Optical Range Finder	Lengemann of Florida	50-1000 yds	NA
Temperature & Humidity Indicator	Bacharach	22-7056	YF0509
Windscope Speed & Direction Indicator	Ward's Natural Science	23 E 1300	NA

The noise monitoring was conducted using a Type I (precision) 2236A integrating Sound Level Meter (SLM) which complies with ANSI S 1.4-1983, IEC 651 (1979) and 804 (1985). Vibration monitoring was conducted using a piezoelectric accelerometer Type 4378 (specifications in accordance with ANSI S2.11-1969) which can measure peak particle velocities as low as 0.0006 inches per second. A charge amplifier Type 2635 was used to amplify the signal from the accelerometer. Relevant specifications for the sound level meter and accelerometer are listed in Appendix E.

Field noise and vibration signals were recorded using a portable, digital audiotape (DAT) recorder, Sony PC 204A, via the charge amplifier and SLM 2236A. The sound level measurements were recorded in real time and the vibration measurements were recorded in terms of velocity (m/s). Later, in the laboratory, the digital data were transferred from the PC 204A to a computer using Sony's PCscan real-time, high speed data transfer system.

Environmental conditions at each site, such as the air temperature, humidity, wind speed, and wind direction were also measured. During Phase I and Phase II, an anemometer system (Model#1072, Serial# 251, Meteorology Research Inc.) provided a stripchart readout of the wind speed and direction at each site. However, this unit was extremely heavy and therefore, inconvenient to transport from site to site in the field. Hence, a smaller, portable wind speed and direction indicator was utilized for the last two field measurements. Likewise, the temperature and humidity measurements were taken from a sling psychrometer for the first two phases of the field testing program then was replaced with a more sophisticated temperature and humidity indicator (See Table 2.3).

Calibration

Calibration of the accelerometer was performed by Bruel and Kjaer and is traceable to the National Bureau of Standards, Washington D.C. The charge amplifier was calibrated according to the instructions provided in the instruction manual. Prior to each field noise measurement, calibration of the sound level meter was accomplished by using a sound level calibrator with a known steady reference sound.

2.7 OPERATIONAL PROCEDURES

Field Monitoring Schedules

Noise and vibration measurements were recorded during each of the four seasons of the year as follows:

--Phase I (winter season) - February 15-18, 1994
--Phase II (spring season) - May 11-13, 1994
--Phase III (summer season) - August 23-25, 1994
--Phase IV (fall season) - December 13-15, 1994

During each phase and for each site, one set of noise and vibration measurements were taken during each time period below.

--Late morning - between 6:00 a.m. and 12:00 p.m.
--Afternoon - between 12:00 p.m. and 6:00 p.m.
--Night - between 6:00 p.m. and 12:00 a.m.
--Early morning - between 12:00 a.m. and 6:00 a.m.

Therefore, each dragline was monitored two times by day and two times by night as planned (see Appendix B for detailed field monitoring schedules).

Field Monitoring Stations

For each site, measurements were targeted at incremental distances of 50, 100, 200, 400 and 800 feet from the base of the dragline, whenever possible. Occasionally the physical characteristics of a site made it impossible to take measurements at each pre-determined distance. In this case, measurements were taken as close as possible to the desired distance.

Sound level measurements were also taken at three different property lines as follows:

Phase	Dragline/Site	Property Line Location
(1)Phase I	1250B/Phosphoria	IMC property line in line with other stations (636 & 586 feet from dragline)
(2) Phase III	1250B/Phosphoria	Pebbledale road located 200 feet due south of 800 foot station
(3) Phase III	1260W/Clear Springs	Connersville road located roughly 756 feet due east of dragline

Distances from the dragline base were measured with 100-foot long surveyor steel tape. After the distances were measured, the bearings of the distances (stations) were recorded and documented. Most of the noise and vibration measurements were monitored from distances directly behind the dragline as illustrated in Figure 2.9. Occasionally, measurements were taken to the side of the dragline because of the layout of the site. The field monitoring stations are shown in Figures 2.10, 2.11, 2.12, and 2.13, for phase I, phase II, phase III, and phase IV, respectively.

Field Monitoring Setup

Sound and vibration instrumentation was deployed at each of the predetermined stations for each dragline site. For each measurement, the SLM free-field microphone

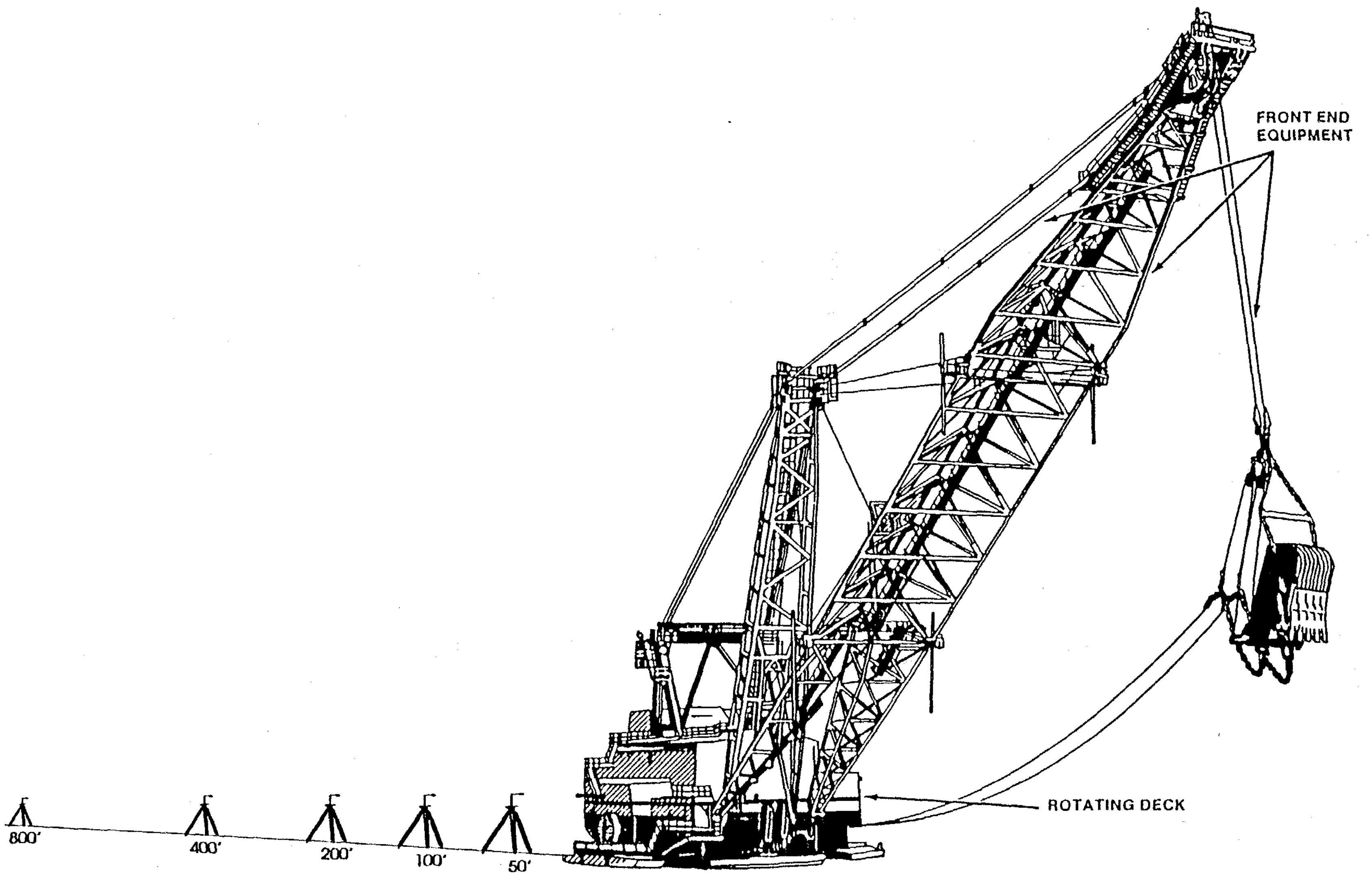


Figure 2.9 Schematic illustration showing station positions

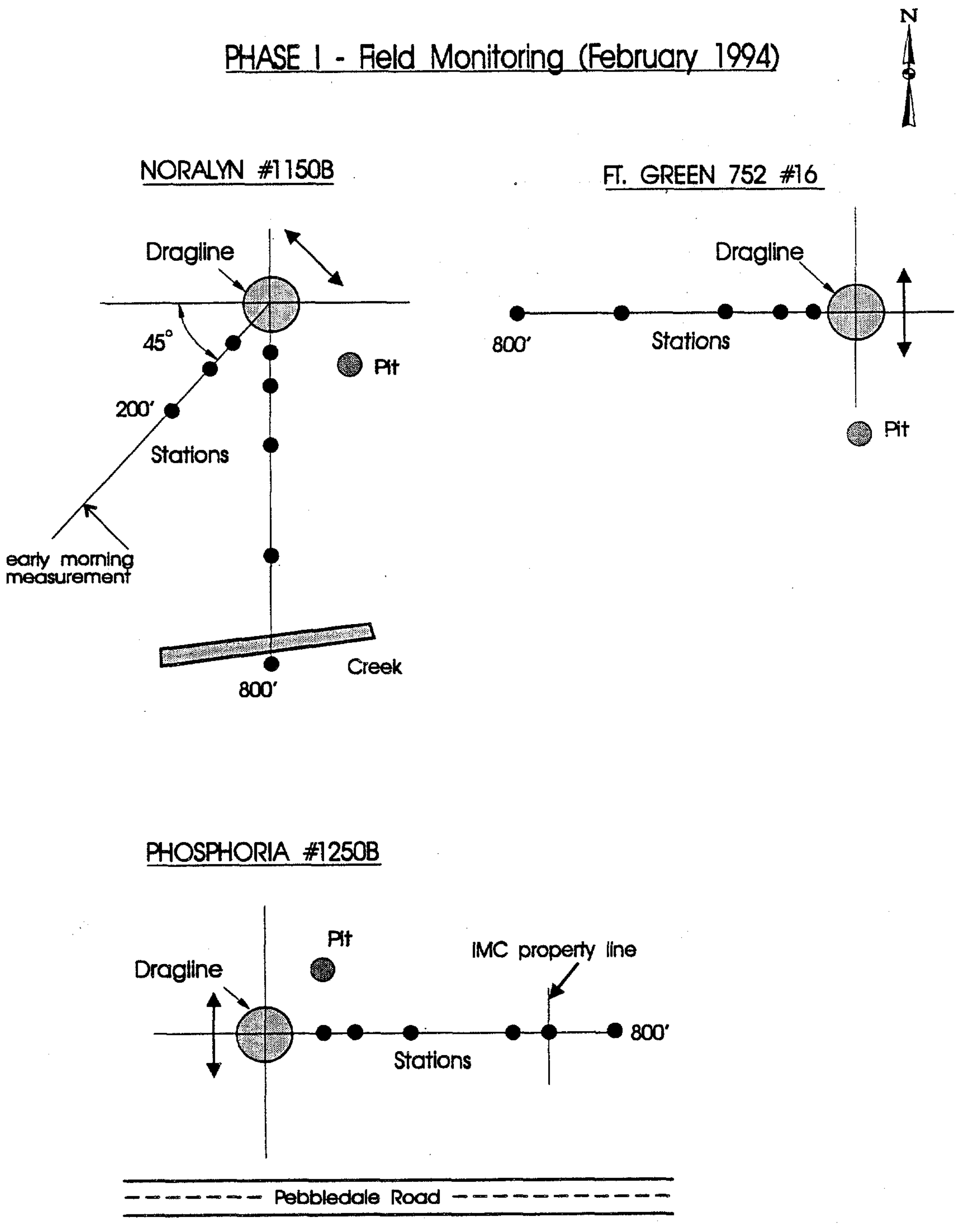


Figure 2.10 Station positions in field during Phase I.

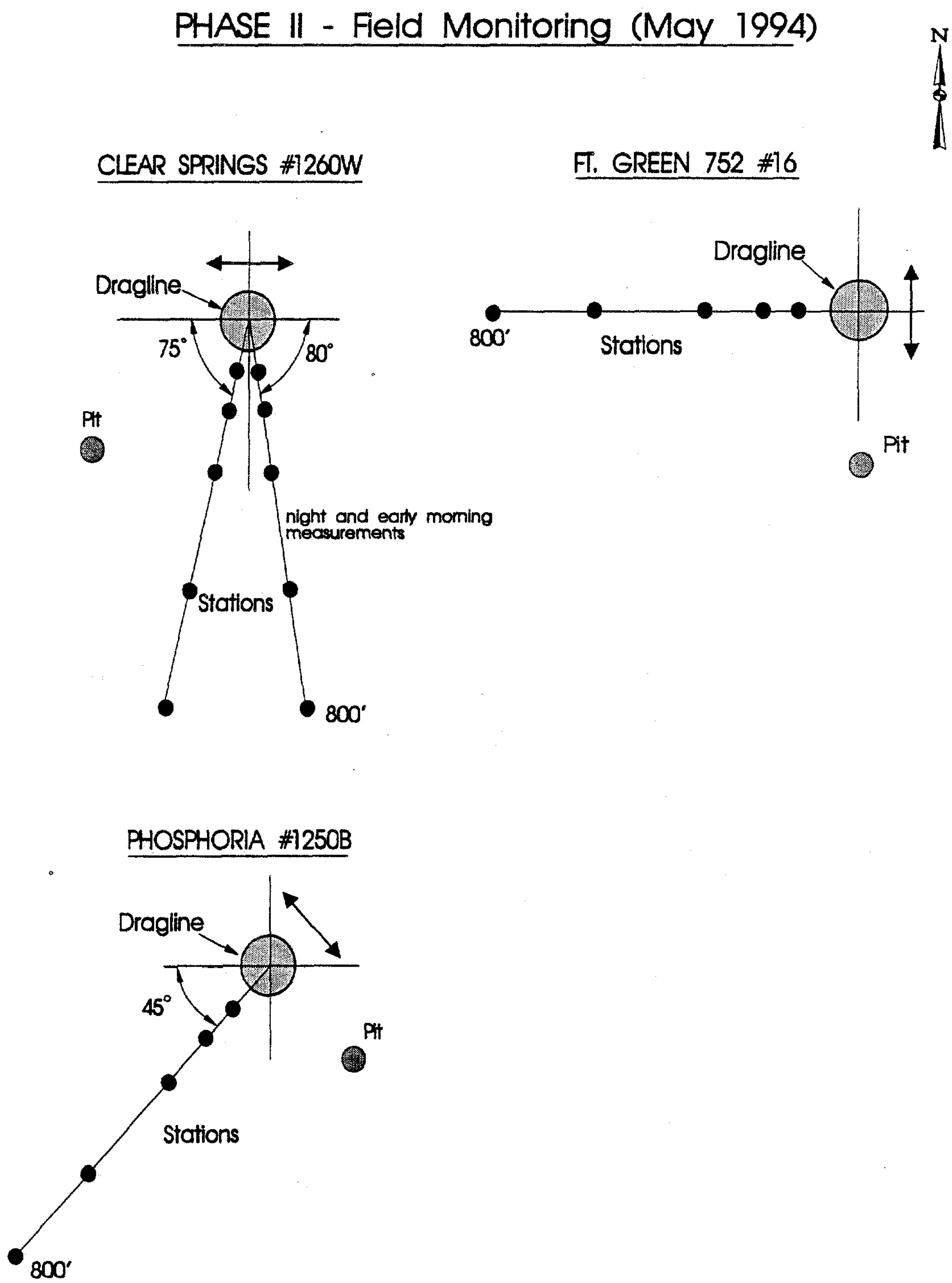


Figure 2.11 Station positions in field during Phase II.

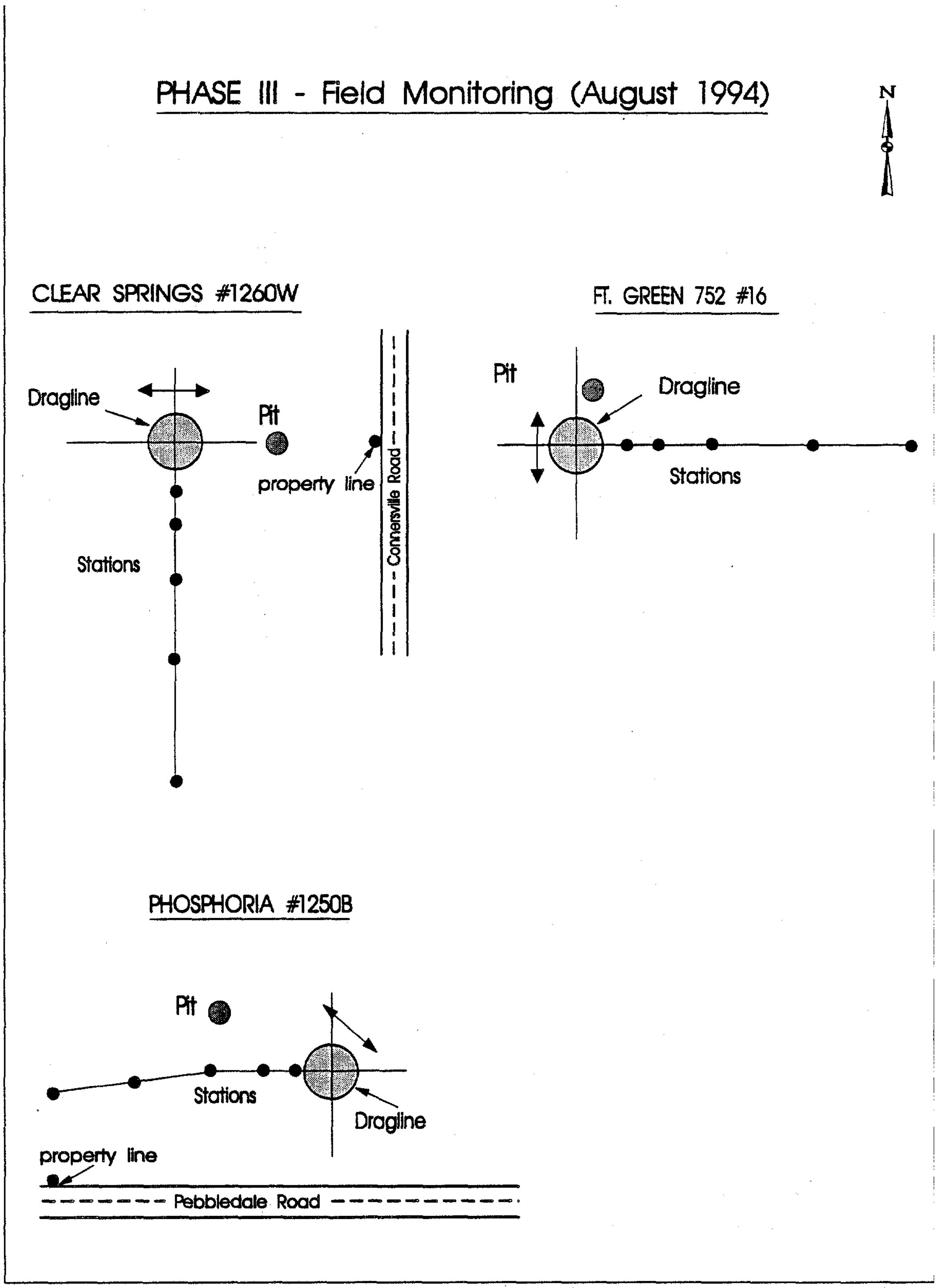


Figure 2.12 Station positions in field during Phase III.

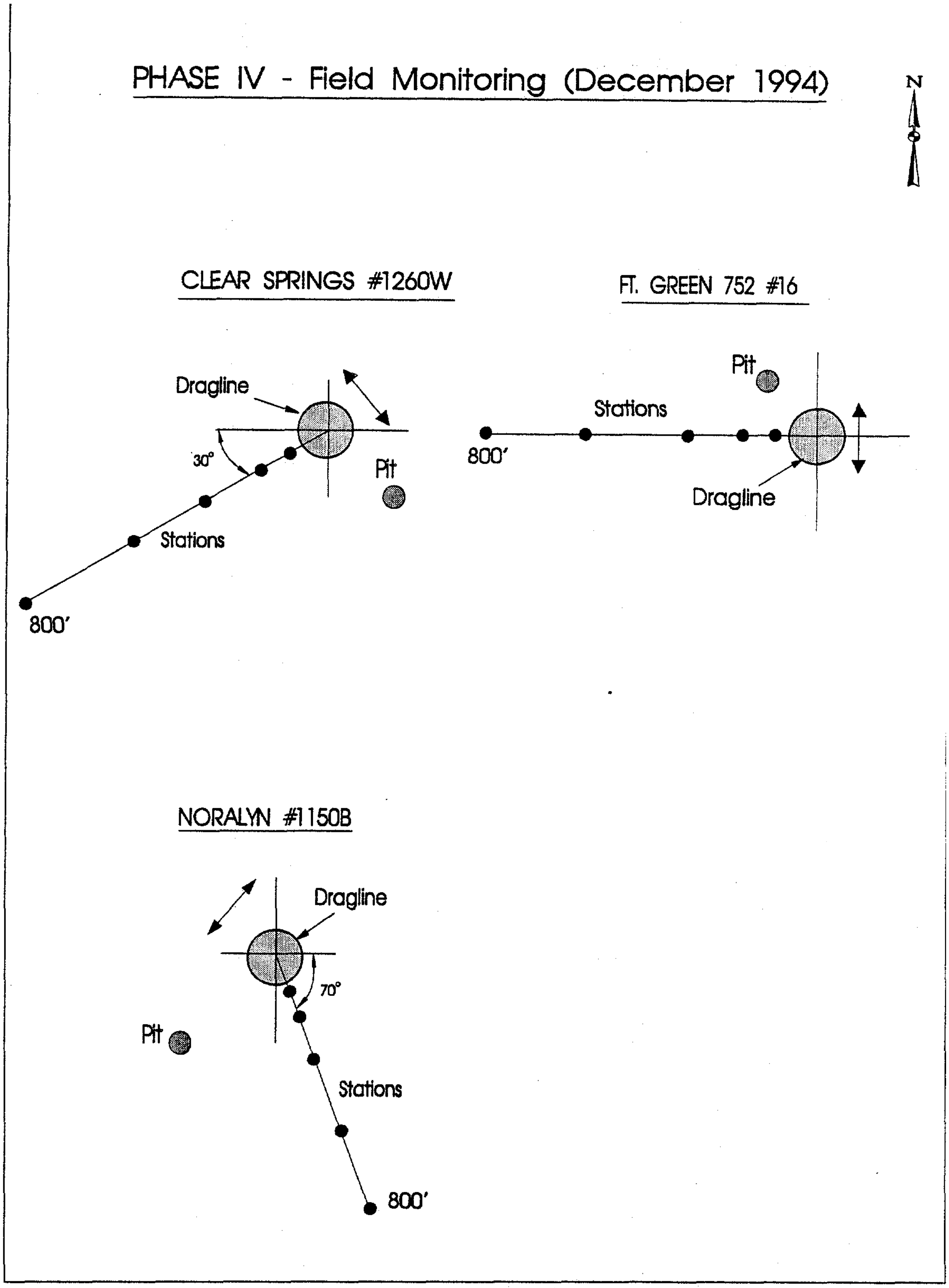


Figure 2.13 Station positions in field during Phase IV.

(with windscreen) was mounted, parallel to the ground surface with the microphone pointing directly toward the dragline, on a tripod approximately four feet above the ground surface. A low noise, 100 foot microphone extension cable extended from the microphone to the SLM and then to the Sony DAT recorder. For the vibration measurements, a low noise, 100 foot extension cable connected the accelerometer to the charge amplifier, which, in turn, was connected to the Sony DAT recorder (see Figure 2.14 for illustration).

The DAT recorder, charge amplifier, and SLM were housed in a van that was parked as far away as possible to. avoid interference with the field measurements. All observers also kept as far away as possible or sat in the van. At each incremental distance from the dragline, noise and vibration measurements were recorded simultaneously and continuously for a duration of approximately two minutes to cover several full cycles of dragline mining operation.

Vibration Measurement. Vibration measurements were taken in both the vertical (V_z) and the horizontal (V_x) directions (see Figure 2.15). For field measurements during Phase I and Phase II, the Bruel & Kjaer accelerometer was mounted on a wooden block which was spiked into the ground with three screws. The wooden block was replaced by a 5" x 5" x 5" aluminum box for Phases III and IV. Both the accelerometer block and box were placed on top of the ground surface near the tripod.

Weather Station. The anemometer, which was utilized during the first two phases to determine wind speed and direction, was placed within each site so as not to interfere with the microphone or any other piece of equipment. The anemometer was mounted on a tripod at approximately the height of the microphone above the ground (four feet).

2.8 WEATHER CONSIDERATIONS

Environmental conditions at each site, such as ambient air temperature, humidity, wind speed, and wind direction, were measured and recorded (see Table 2.4). The effects of these weather conditions on the sound generated by the dragline, as well as on the performance of all instruments, are discussed in Chapter 4.

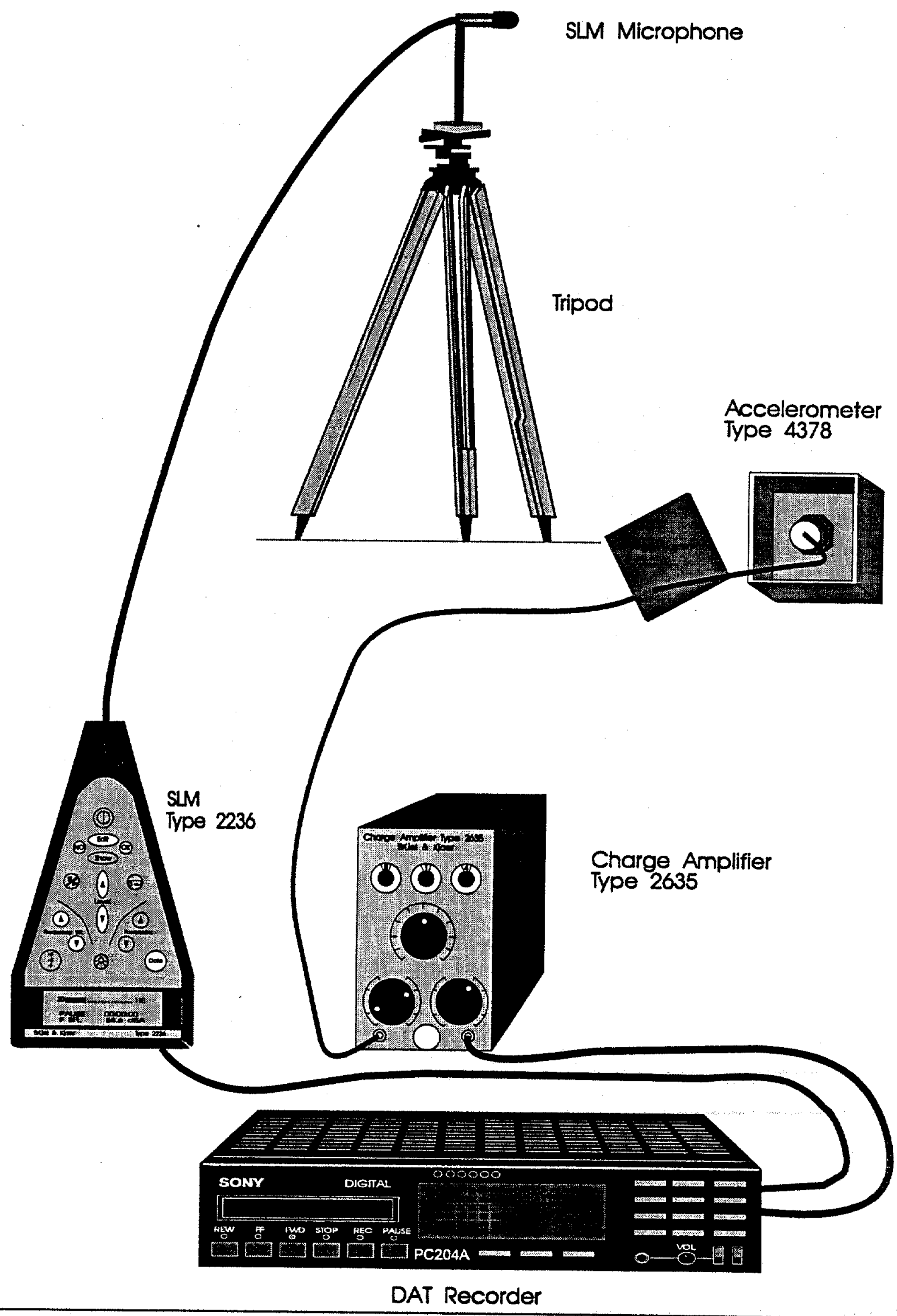


Figure 2.14 Schematic illustration of field instrumentation setup

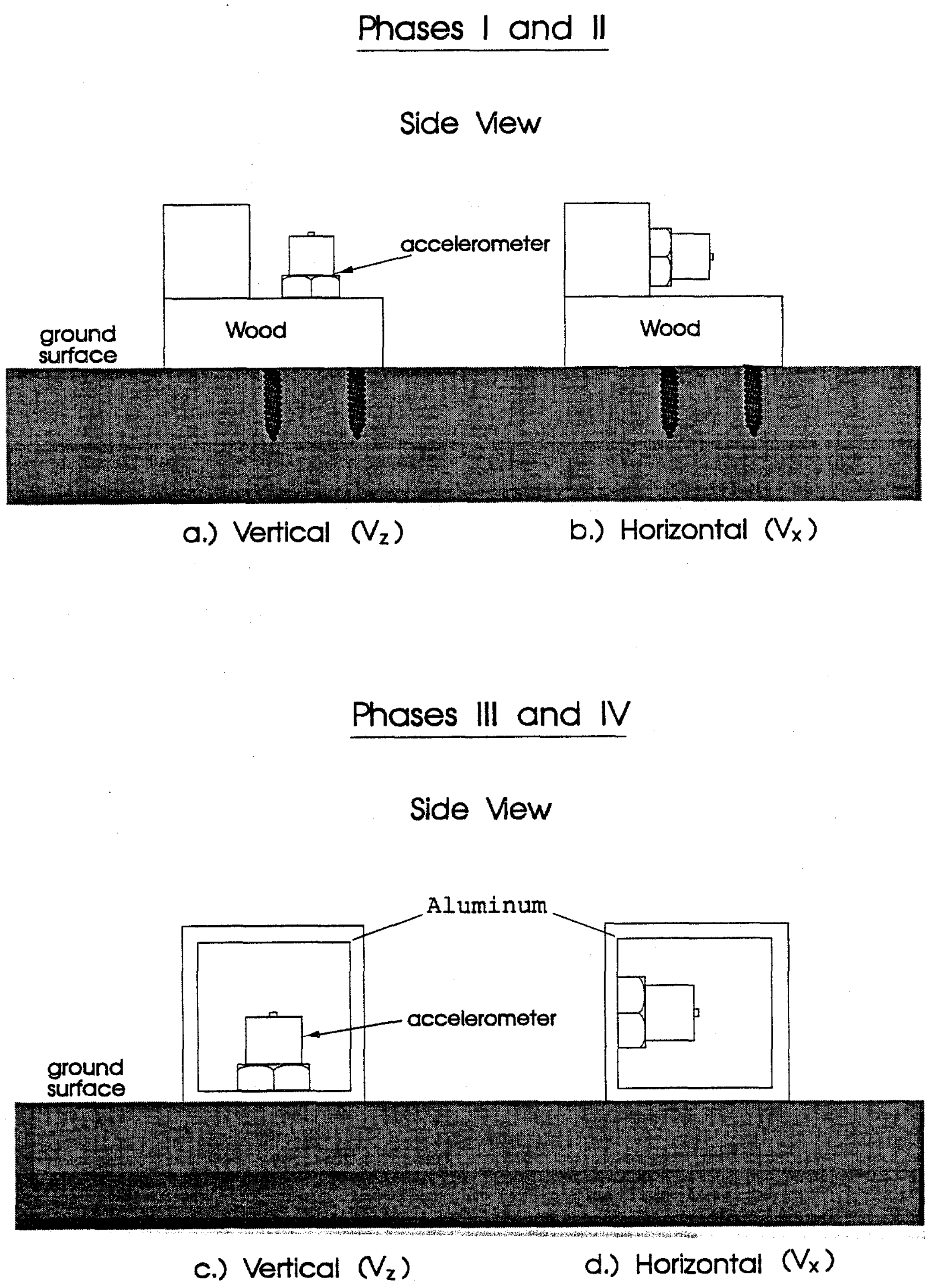


Figure 2.15 Schematic illustration of accelerometer setup in the field

Table 2.4a: Weather Conditions in the Field During Phases I and II

Phase I - February 1994

Site/Time	Temperature °F	Relative Humidity	Windspeed (mph)	Wind Direction
Noralyn (Early Morning)	62	90%	5.3	SW
Noralyn (Late Morning)	64	76%	6.3	NE
Noralyn (Afternoon)	72	68%	5.2	NE
Noralyn (Night)	62	86%	3.6	E
Phosphoria (Early Morning)	64	100%	6.7	NE
Phosphoria (Late Morning)	71	76%	8.0	NE
Phosphoria (Afternoon)	76	48%	6.7	NE
Phosphoria (Night)	64	78%	4.8	E
Ft. Green (Early Morning)	61	94%	5.5	SW
Ft. Green (Late Morning)	61	94%	5.0	S
Ft. Green (Afternoon)	73	68%	7.1	E
Ft. Green (Night)	68	80%	9.0	SW

Phase II - May 1994

Site/Time	Temperature °F	Relative Humidity	Windspeed (mph)	Wind Direction
Clear Springs (Early Morning)	70	100%	2.0	S
Clear Springs (Late Morning)	79	84%	5.0	S
Clear Springs (Afternoon)	87	72%	3.6	W
Clear Springs (Night)	82	64%	5.5	SW
Phosphoria (Early Morning)	72	92%	0.0	SW
Phosphoria (Late Morning)	74	94%	2.0	S
Phosphoria (Afternoon)	92	54%	5.9	SSE
Phosphoria (Night)	84	70%	4.7	E
Ft. Green (Early Morning)	74	92%	1.0	NW
Ft. Green (Late Morning)	73	92%	1.0	NNW
Ft. Green (Afternoon)	90	48%	3.6	SE
Ft. Green (Night)	80	56%	2.5	SE

Table 2.4b: Weather Conditions in the Field During Phases III and IV

Phase III - August 1994

Site/Time	Temperature °F	Relative Humidity	Windspeed (mph)	Wind Direction
Clear Springs (Early Morning)	87	95%	3-5	E
Clear Springs (Late Morning)	92	90%	2	NE
Clear Springs (Afternoon)	100	90%	2	NE
Clear Springs (Night)	84	90%	5-6	E
Phosphoria (Early Morning)	80	95%	1	SE
Phosphoria (Late Morning)	82	97%	1	SE
Phosphoria (Afternoon)	94	90%	3-4	NW
Phosphoria (Night)	84	100%	1	SW
Ft. Green (Early Morning)	78	95%	3-5	SE
Ft. Green (Late Morning)	89	90%	5	NE
Ft. Green (Afternoon)	94	90%	5-6	NNE
Ft. Green (Night)	84	100%	5-6	W

Phase IV - December 1994

Site/Time	Temperature °F	Relative Humidity	Windspeed (mph)	Wind Direction
Clear Springs (Early Morning)	56	95%	2-3	NW
Clear Springs (Late Morning)	60	95%	3-4	N
Clear Springs (Afternoon)	71	86%	5-7	NW
Clear Springs (Night)	62	93%	5-7	NW
Noralyn (Early Morning)	56	95%	3-5	NNW
Noralyn (Late Morning)	55	98%	4-6	NW
Noralyn (Afternoon)	74	80%	5-7	NW
Noralyn (Night)	61	94%	5-7	NW
Ft. Green (Early Morning)	54	100%	0-1	N
Ft. Green (Late Morning)	58	95%	3-5	NNW
Ft. Green (Afternoon)	69	78%	3-6	N
Ft. Green (Night)	64	88%	3-5	N

CHAPTER 3: PRESENTATION OF NOISE PARAMETERS

3.1 GENERAL

The field monitoring program was undertaken to collect, the noise and vibration data needed to achieve the objectives of this research study. In the field, the sound level meter automatically calculated and stored, at one-second intervals, the equivalent continuous sound levels with an exchange rate of 5, or L_{AV5} (in dBA), in its memory. The SLM also stored the statistical parameters L_{10} and L_{90}, in dBA, corresponding to the L_{AV5}. These parameters were downloaded from the SLM to a portable notebook computer in the field.

The equivalent continuous sound level with an exchange rate of 3, or L_{eq}, and the parameters associated with L_{eq}, however, were determined in the office by playing the original data, on the magnetic tapes, back through the SLM with it set to calculate and record these values at one-second, intervals.

Included in this chapter are the following: (1) a summary of the sound level meter settings in the field, (2) a discussion on noise parameters, such as L_{AV5}, SEL, L_{eq}, L_{10}, and L_{90}, (3) a presentation of the measured noise parameters in tabular form, (4) a graphical representation of L_{eq} versus distance for each dragline, and (5) a discussion of field observations.

3.2 SOUND LEVEL METER SETUP

The sound level meter employed during the field measurements meets the Type I requirements of *American National Standard Specification for Sound Level Meters*, S1.4-1983. For storage of results, the Brüel & Kjaer 2236 SLM has three types of memory: Buffer, Log, and Memory. All of the results for the current measurement are stored in the Buffer. The Log contains the automatically logged results: L_{eq} (L_{AV5}), L_{10}, L_{90}, and the measurement time of results. The Memory contains the overall results that are manually stored in a record together with the setup. Examples of the information contained in the Log and the Memory are shown in Figure 3.1.

During all four phases of the field measurements, the SLM was set to the A-frequency-weighting network and the "slow" meter response. The meter automatically logged the A-weighted parameters, L_{AV5}, L_{10}, and L_{90} and stored these values at one second intervals in the Log. The "average" L_{AV5}, L_{10}, and L_{90} values over the duration of each measurement (usually two minutes) were calculated by the SLM and stored in a record.

3.3 EXPLANATION OF NOISE PARAMETERS

Equivalent Continuous Sound Level (L_{eq})

When measuring noise for the evaluation of hearing risk, the time factor has an important influence. It is generally assumed that doubling the noise energy also doubles the hearing risk. Hence, if the noise energy is doubled (i.e., it increases by 3 dB) the allowed exposure time should be halved in order to keep the same hearing risk. Thus, as the equal energy concept requires a halving of the exposure time for a 3 dB increase in level, it is said to have an exchange rate of 3 dB (Bruel & Kjaer, 1993). This is known as the equivalent continuous sound level, or L_{eq} and is standardized by the International Organization for Standardization (ISO). The L_{eq} value for a sampling period has the same energy content as the actual time-varying sound level. The true L_{eq} of a sound measured over a time period T is given by

$$L_{eq} = 10\log_{10} \frac{1}{T} \int_0^T \frac{p^2}{p_o^2}\, dt \qquad (3.1)$$

where:

p = instantaneous sound pressure

p_o = 20 µ Pascals

LOG MEMORY

S
RMS:A Peak:L
20-100 dB

Time	Lav5	L10	L90	Pause	Ovl
12:12:54	61.5	62	61		
12:12:55	60.5	60.5	60		
12:12:56	60.3	60	60		
12:12:57	60.2	60	60		
12:12:58	60.5	60.5	60		
12:12:59	60.5	60.5	60		
12:13:00	60.1	60	60		
12:13:01	60	60	59.5		
12:13:02	59.6	59.5	59		
12:13:03	59	59	58.5		
12:13:04	58.9	58.5	58.5		
12:13:05	58.5	58.5	58		
12:13:06	58	58	57.5		
12:13:07	58	58	57.5		
12:13:08	57.8	57.5	57.5		
12:13:09	57.6	57.5	57		
12:13:10	57.3	57.5	57		
12:13:11	58.2	58.5	57.5		
12:13:12	58.9	59	58.5		
12:13:13	59.2	59	59		
12:13:14	59.3	59.5	59		
12:13:15	60.1	60.5	59.5		
12:13:16	61.1	61	60.5		
12:13:17	61.8	62	61.5		
12:13:18	62.9	63	62		
12:13:19	64.3	64.5	63.5		
12:13:20	65.8	66	65		
12:13:21	66.3	66	66		
12:13:22	66.7	66.5	66.5		
12:13:23	66.8	66.5	66.5		

MEMORY

SETTINGS:

S 20-100 dB
RMS: A Peak: L

RECORD NO.: 10

8/23/94 12:12:53 PM

Elapsed Time	0000:02:07
Pauses	0
Overload	0.0 %
MaxP	97.4 dB
MaxL	68.8 dB
MinL	56.9 dB
Lav5	65.3 dB
SEL	N.A. dB
LEPd (Te= 7h30)	N.A. dB
L10	67.5 dB
L50	66.0 dB
L90	58.0 dB

Figure 3.1 Example of SLM 2236 Log and memory printout

The A-weighted equivalent continuous sound level, L_{Aeq}, is given by

$$L_{Aeq} = 10\log_{10}[\frac{1}{100}\Sigma f_i \cdot 10^{\frac{L_i}{10}}] \qquad (3.2)$$

where:

L_{Aeq} = the A-weighted equivalent continuous sound level

L_i = the sound level corresponding to the class midpoint of the class i

f_i = the time interval expressed as a percentage of the relevant time period for which the sound level is within the limits of class i

All of the L_{eq}s for this study were determined in the office by playing the original data from the Sony DAT recorder back into the SLM with the A-weighting network. The "average" L_{eq} value for each measurement was calculated by the SLM and stored in the record memory. All of the records and logs were then transferred from the SLM to a computer and Microsoft EXCEL was used to view each record and log. The "average" L_{eq}s, the L_{10}s, and the L_{90}s were copied into tables. Maximum L_{eq}s for each measurement were also found. These values are presented by dragline in Section 3.4.

Equivalent Continuous Sound Level (5dB Exchange Rate) L_{AV5}

In the United States, the Occupational Safety and Health Administration (OSHA) regulation allows a 5 dB increase in noise level for each halving of the exposure time (i.e. the exchange rate is 5 dB). This is known as L_{AV5} and is called the equivalent continuous sound level with an exchange rate of 5 decibels. The L_{AV5} has a different relationship between sound level and time than the L_{eq} standardized by ISO. Figure 3.2 shows the effect of using an exchange rate of 3 or 5 dB. The "average" L_{AV5}, as well as the L_{10} and L_{90} values for each field measurement were taken directly from the Bruel & Kjaer 2236 sound level meter.

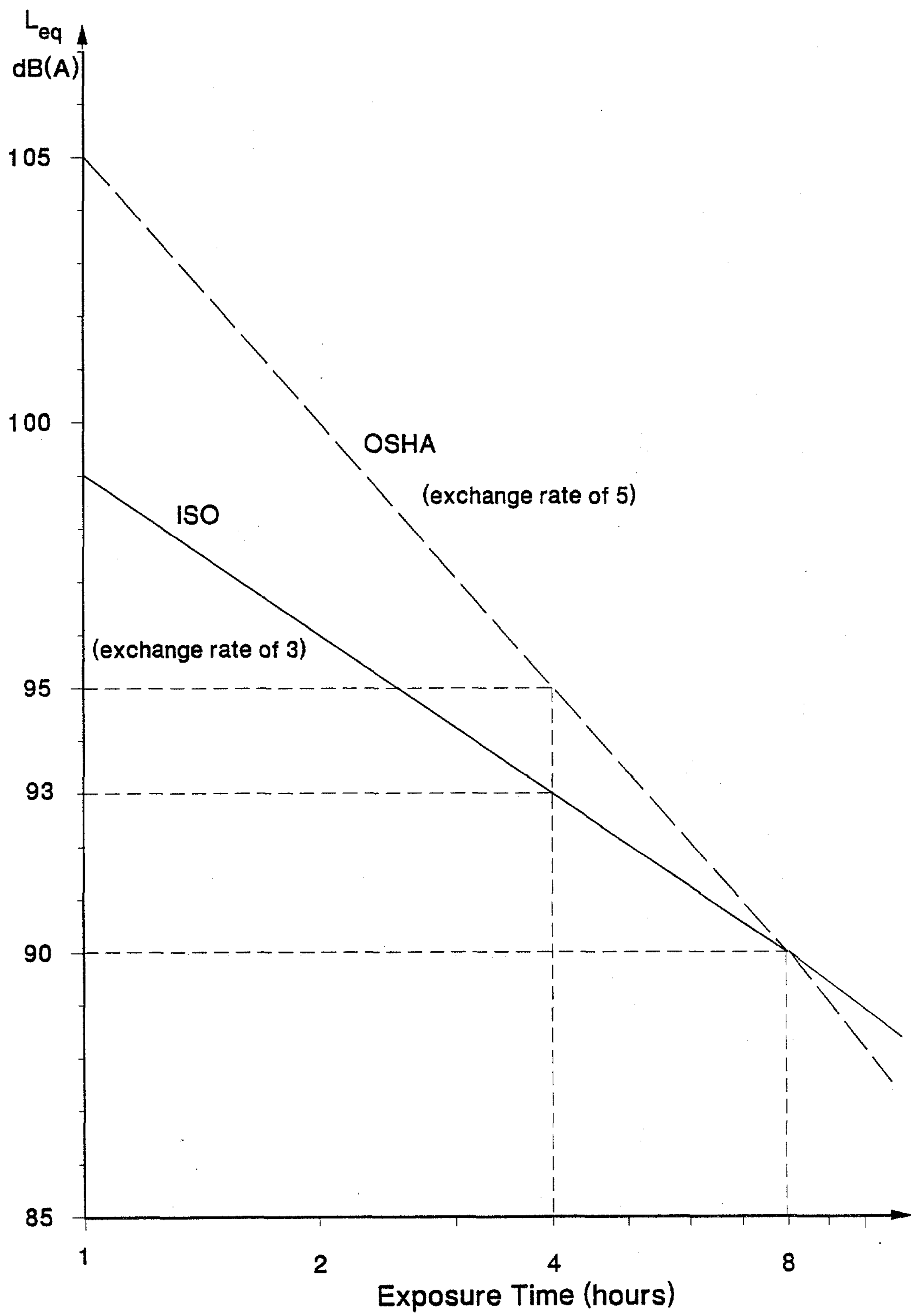


Figure 3.2 The effect of an exchange rate of 3 or 5 dB on sound level. (redrawn from Brüel & Kjaer, 1993)

Sound Exposure Level SEL

The Sound Exposure Level, or SEL, is another useful energy parameter. The SEL is defined as the constant sound level in decibels acting for one second which has the same amount of acoustic energy as the original time-varying sound. A-weighted sound exposure level ASEL, in decibels, is given by:

$$ASEL = 10 \log_{10} (E_A/E_o) \qquad \textbf{(3.3)}$$

where:

E_A = A-weighted sound exposure in Pascal-squared seconds

E_o = $p_o^2 t_o$ reference sound exposure in Pascal-squared seconds where

P_o = 20 μPa and t_o = 1 second.

As all SEL measurements are normalized to a one second time interval, the energy content of different types of noise sources can be compared by using SEL measurements. Figure 3.3 depicts the SEL compared to the time-varying RMS signal and L_{eq} (Bruel & Kjaer, 1993).

Statistical Parameters: L_{10} and L_{90}

L_{10} and L_{90} are statistical quantities representing the noise levels exceeded for 10 percent and 90 percent of the time period respectively. L_{90} is a measure of the residual noise level while L_{10} is a measure of the peak noise levels observed during a given time period.

3.4 TABULAR PRESENTATION OF NOISE PARAMETERS

All of the noise parameters collected during the field monitoring program and in the office, are presented in tabular form in this chapter. The noise parameters are presented in Tables 3.1 through 3.3 for the first phase measurement, Tables 3.4 through 3.6 for the second phase measurement, Tables 3.7 through 3.9 for the third phase measurement, and Tables 3 . 10 through 3.12 for the fourth phase measurement.

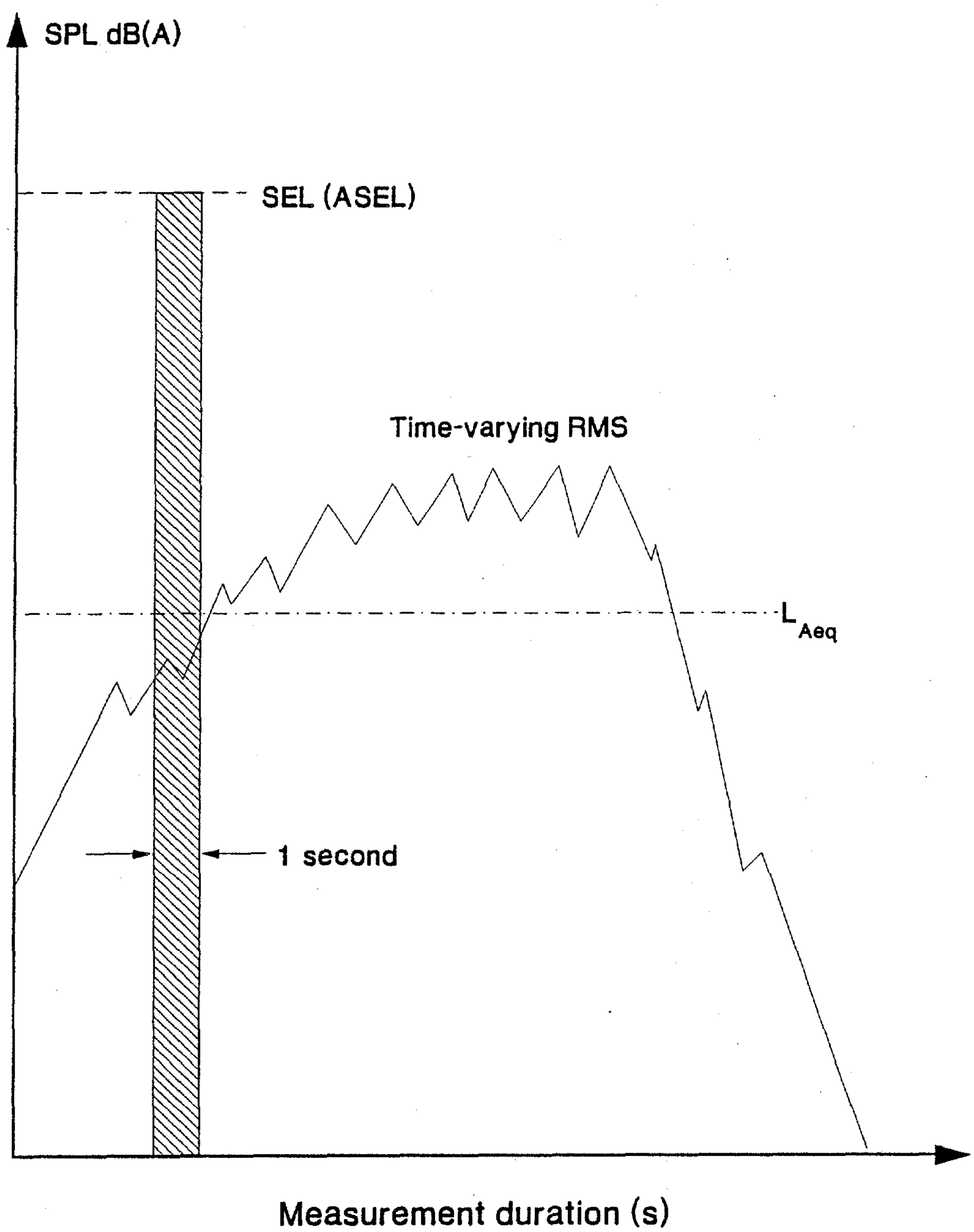


Figure 3.3 SEL compared to L_{eq} and time-varying RMS signal

Table 3.1 Noise parameters for 1150B Phase I, (dBA)

Noralyn - 1150B (February 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	81.9	76.9	81.3	70.3	97.9	82.0	76.1	81.2	70.2
100	75.6	70.4	73.3	65.8	92.1	75.5	70.0	73.2	65.7
200	68.6	63.6	65.2	60.2	85.6	68.6	63.5	65.7	60.2
400	63.0	57.4	58.7	54.2	79.1	63.0	57.2	58.7	54.2
800	53.4	48.6	51.2	45.2	70.1	54.9	49.2	52.2	45.2

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
40	83.3	78.4	81.8	71.3	101.0	83.1	77.5	81.6	71.1
90	80.5	74.0	75.8	68.8	96.2	80.6	73.4	75.6	68.6
190	71.8	65.8	69.2	62.7	87.7	71.7	65.4	69.1	62.6
390	64.3	58.6	59.7	56.2	80.6	64.1	58.3	59.6	56.1
790	58.4	52.6	54.2	50.7	75.2	57.8	52.5	54.6	50.6

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
40	84.5	81.4	82.8	74.8	102.7	84.6	81.2	83.2	74.7
90	76.6	73.6	75.3	69.3	94.3	76.5	73.4	75.2	69.7
190	69.2	65.8	67.2	63.7	87.1	69.3	65.9	67.7	63.7
390	65.3	63.1	64.2	61.2	84.5	65.4	63.1	64.2	61.2
790	58.2	53.6	55.2	51.7	75.6	58.2	53.5	54.7	51.7

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	82.7	77.9	81.3	71.8	100.3	82.7	77.1	81.1	71.6
100	76.1	71.9	73.8	67.3	94.6	76.9	71.7	73.6	67.1
200	68.5	63.3	65.7	59.7	86.1	69.4	63.3	66.1	59.6
400	61.7	57.4	59.7	53.2	78.7	64.7	59.1	62.1	55.6
800	53.6	49.5	50.7	46.7	71.1	53.6	49.5	51.1	46.6

Table 3.2 Noise parameters for 1250B Phase I, (dBA)

Phosphoria - 1250B (February 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	78.8	75.5	77.7	72.7	97.6	78.9	75.6	77.6	72.6
100	73.5	68.4	70.7	64.7	90.1	73.6	68.2	71.1	65.1
200	65.5	61.5	63.7	57.7	83.3	65.4	61.1	63.1	58.1
400	*62.5	*59.9	*59.7	*54.2	*81	*64.2	*58.6	*60.1	*53.6
636-PL	55.9	51.3	53.2	48.2	72.4	55.7	51.3	53.6	48.1
800	50.4	44.8	47.2	40.2	66.4	50.4	44.7	47.6	40.6

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	75.8	73.3	74.3	71.3	94.8	75.8	73.3	74.6	71.1
100	73.5	67.4	68.3	65.8	89.3	73.3	67.2	68.1	65.5
200	69.8	61.4	62.7	58.7	83.4	69.2	61.2	62.6	58.6
400	60.9	55.7	57.2	53.2	77.2	60.9	55.6	57.1	53.1
636-PL	54.6	49.5	51.4	45.7	70.9	54.6	49.2	51.6	45.6
800	51.6	45.4	47.7	42.2	67.1	51.6	45.1	47.6	42.1

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	77.9	75.2	76.3	73.3	96.6	77.9	75.1	76.7	73.2
100	71.8	68.5	70.2	66.2	90.0	72.1	68.6	70.2	66.2
200	65.3	60.4	63.2	55.7	82.5	65.5	59.8	63.2	56.2
370	64.3	57.7	60.7	53.2	79.6	64.4	57.3	60.7	53.2
770	57.3	52.4	54.2	49.7	73.7	57.3	52.3	54.2	49.7

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	75.7	70.9	72.8	67.3	92.8	78.4	70.7	72.7	67.2
150	70.6	64.9	65.8	62.3	86.7	70.4	64.7	66.2	62.2
350	**71.0	**63.1	**67.7	**56.2	**85.3	**71.1	**61.9	**67.7	**56.2
586-PL	58.6	51.2	53.2	46.7	73.7	58.8	51.0	53.7	46.7
750	58.4	52.7	54.7	49.2	74.4	58.5	52.4	54.7	49.2

* includes traffic
** includes jets
PL - property line

Table 3.3 Noise parameters for 752 #16 Phase I, (dBA)

Ft. Green - 752 #16 (February 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	81.3	75.2	78.3	70.3	95.6	81.4	74.6	78.7	68.7
100	70.7	66.5	67.8	63.8	88.5	73.3	66.4	68.2	63.7
200	68.2	59.8	61.7	56.7	80.7	68.9	59.4	61.7	56.7
370	60.6	55.1	57.2	50.7	77.0	60.7	54.8	57.2	51.2
770	59.3	51.5	55.7	45.2	73.5	59.3	51.0	55.7	44.7

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
70	77.9	71.1	75.8	60.3	91.8	77.8	69.2	75.7	59.7
170	69.7	64.1	67.2	59.2	85.9	69.9	63.5	67.2	59.2
370	56.5	51.1	52.2	49.7	72.9	56.6	51.0	51.7	49.7
770	52.7	45.8	49.7	41.2	68.2	52.7	45.1	49.7	41.2

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
60	81.1	76.4	79.7	71.2	98.4	81.2	76.1	79.7	71.2
160	73.0	67.6	71.2	60.2	89.5	73.1	66.8	71.2	60.2
360	73.4	64.4	68.7	53.7	84.0	73.5	61.1	65.2	53.2
760	56.1	51.4	54.7	46.2	73.4	56.2	50.9	54.2	46.2

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
60	79.0	71.9	75.3	67.3	93.9	79.0	71.3	74.7	66.7
160	70.7	66.8	69.2	61.2	88.5	73.0	66.4	69.2	61.2
360	65.2	58.8	60.7	53.2	80.8	65.4	58.4	60.7	52.7
760	62.4	52.3	53.7	47.7	74.1	58.0	51.8	53.7	47.7

Table 3.4 Noise parameters for 1260W Phase II, (dBA)

Clear Springs - 1260W (May 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
70	82.5	77.6	81.3	71.8	99.2	84.1	77.3	81.5	71.5
170	70.5	68.6	69.7	67.2	90.3	*ND	68.7	70.0	67.0
200	Bad DAT Recorder					73.0	71.7	72.5	70.5
400	68.3	65.2	67.7	60.2	85.1	68.5	64.9	68.0	60.5
800	56.8	55.7	56.2	54.7	71.5	58.2	55.7	57.5	53.5

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
70	83.4	77.2	81.3	70.3	99.4	83.7	76.7	81.5	70.5
170	73.0	69.8	72.2	66.2	90.0	ND	70.0	ND	ND
370	66.9	63.5	65.7	60.2	84.7	66.9	63.4	66.0	60.5
770	60.7	57.0	64.7	60.2	84.7	60.1	57.0	59.0	54.5

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
85	88.9	85.9	88.3	81.8	106.6	89.0	85.7	88.0	82.0
165	78.8	77.2	78.2	76.2	97.5	78.9	77.3	78.5	76.5
365	70.4	69.5	70.2	68.2	90.3	70.6	69.7	70.0	68.5
765	64.1	62.8	63.2	61.7	83.8	64.2	62.9	63.5	62.0

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	91.6	88.0	90.8	82.8	110.5	91.6	87.9	91.0	83.0
100	85.4	81.1	82.7	79.2	102.2	83.7	81.3	83.0	79.5
200	73.7	72.0	72.2	71.2	103.3	ND	72.1	72.5	71.0
400	68.1	65.5	66.2	63.7	88.1	68.3	65.6	66.5	64.0
800	62.4	58.5	60.2	54.7	79.3	62.3	58.4	60.5	55.0

*ND - No data.

Table 3.5 Noise parameters for 1250B Phase II, (dBA)

Phosphoria - 1250B (May 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	78.9	76.1	77.8	73.3	96.9	78.9	76.0	78.0	73.5
100	73.2	70.2	71.2	68.2	90.6	73.5	70.4	71.5	68.5
200	70.7	64.2	65.2	62.2	84.9	70.4	64.2	65.5	62.0
400	64.4	60.8	62.2	59.2	80.0	64.6	60.9	62.0	59.5
800	55.4	49.8	53.7	46.2	69.9	55.6	49.6	53.5	46.0

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
90	72.5	69.8	71.2	67.7	90.3	72.5	69.9	71.5	68.0
190	68.5	64.4	67.2	61.2	84.6	68.8	64.3	67.5	61.0
390	62.3	59.6	61.2	57.7	80.1	62.4	59.6	61.5	58.0
790	50.9	47.0	48.7	44.7	67.0	51.8	48.4	50.0	45.5

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
30	83.6	79.4	82.3	74.3	95.7	83.6	78.7	82.0	74.0
130	70.6	66.8	68.7	64.2	87.8	70.8	66.7	69.0	64.0
330	65.2	61.9	62.7	60.2	82.8	65.2	61.9	63.0	60.0
730	58.5	51.7	54.2	47.2	71.9	58.7	51.2	54.0	47.5

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	81.2	75.8	78.7	69.7	96.6	81.3	75.7	79.0	70.0
100	74.6	70.7	73.2	67.2	91.3	75.3	70.8	73.5	67.5
200	67.7	63.0	65.2	59.7	83.1	67.8	62.8	65.5	59.5
400	62.2	55.9	57.7	53.2	76.6	63.0	55.7	57.5	53.5
800	53.7	50.3	51.7	48.2	71.9	53.8	50.1	51.5	48.0

Table 3.6 Noise parameters for 752 #16 Phase II, (dBA)

Ft. Green - 752 #16 (May 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	80.4	75.0	78.7	68.2	94.3	80.6	74.2	79.0	68.0
100	73.5	67.4	71.7	61.7	85.3	73.8	66.4	72.0	62.0
200	65.7	62.1	64.2	57.2	82.3	65.8	62.0	64.5	57.5
400	59.3	56.1	56.7	54.7	76.4	59.4	56.2	57.0	55.0
700	55.6	53.3	54.7	51.2	74.0	55.6	53.3	54.5	51.5

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
67	68.4	66.7	67.7	65.7	86.9	68.6	66.8	67.5	65.5
200	68.1	61.6	65.7	55.2	82.8	68.2	61.2	66.0	55.5
400	58.8	53.4	55.2	50.2	73.9	59.0	53.2	55.5	50.0
700	57.6	54.5	55.7	52.2	71.4	58.8	54.9	56.5	52.5

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	81.5	75.3	78.3	67.3	95.8	81.8	74.7	78.0	67.5
150	66.8	64.5	65.8	62.3	80.4	67.0	64.5	65.5	62.5
350	63.3	58.7	60.7	56.7	79.4	63.4	58.9	61.5	56.5
750	58.9	55.8	57.2	53.2	76.2	58.8	55.8	57.5	53.5

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
100	74.6	66.1	69.2	61.2	86.3	74.8	65.6	69.0	61.5
300	63.3	58.7	61.2	54.7	79.7	66.1	58.4	61.5	54.5
600	58.7	55.0	56.2	52.2	74.5	58.7	54.6	56.0	52.0

Table 3.7 Noise parameters for 1260W Phase III, (dBA)

Clear Springs - 1260W (August 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	93.7	91.6	93.2	88.2	111.8	93.9	91.5	93.5	88.0
100	84.7	83.1	84.2	80.7	111.9	86.0	83.0	84.5	79.5
200	77.1	74.6	76.2	72.7	94.6	77.2	74.7	76.0	72.5
400	68.5	65.7	67.2	58.2	86.6	68.7	65.3	67.5	58.0
800	59.0	56.7	57.7	52.7	77.4	59.1	56.6	58.0	52.5
756-PL	ND	ND	ND	ND	ND	54.5	46.7	48.0	44.5

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	91.1	86.3	90.3	73.8	107.0	91.1	85.2	90.5	74.0
100	84.8	82.3	84.2	72.7	103.1	84.9	81.8	84.0	73.0
200	76.6	72.4	74.7	67.2	93.2	75.9	72.1	75.0	67.0
400	67.4	65.3	66.7	60.2	86.0	68.2	65.1	67.0	60.0
800	72.4	59.0	59.7	53.7	79.8	61.7	58.0	60.0	53.5

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
200	76.3	74.5	75.7	71.7	95.5	76.3	74.7	76.0	72.5
400	71.1	69.2	70.2	68.2	89.9	71.3	69.5	70.0	68.0
800	59.6	57.9	59.0	56.5	78.7	59.7	57.7	58.5	56.5

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	90.8	85.9	90.3	72.8	110.0	93.8	86.5	92.5	75.0
100	86.2	82.2	85.2	72.2	103.0	86.3	81.9	85.0	72.5
200	77.1	73.7	76.2	67.2	94.1	77.3	73.5	76.5	67.0
400	68.9	66.2	67.7	57.7	86.3	69.0	66.0	68.0	58.0
800	58.4	55.0	56.7	49.2	75.0	58.5	54.7	57.0	49.0

PL - property line
ND - no data

Table 3.8 Noise parameters for 1250B Phase III, (dBA)

Phosphoria - 1250B (August 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	78.0	74.6	76.2	71.7	95.5	78.3	74.6	76.5	71.5
100	75.8	70.6	72.2	68.2	91.3	76.0	70.6	72.5	68.5
200	68.8	65.0	66.7	62.7	86.2	68.9	65.1	67.0	63.0
400	62.3	59.2	60.7	56.7	79.9	62.4	59.2	61.0	57.0
800	59.0	52.3	55.2	46.7	73.0	59.0	51.7	55.5	47.0

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	80.6	74.2	76.7	65.7	92.0	78.8	73.2	76.5	65.0
100	70.7	68.4	69.7	65.2	89.1	70.7	68.4	70.0	65.5
200	68.6	63.8	65.7	61.7	84.2	69.1	63.8	65.5	61.5
400	66.3	59.5	61.2	57.2	80.3	65.9	59.5	62.0	57.0
800	53.9	50.5	51.7	48.7	71.2	53.9	50.4	51.5	48.5

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	77.1	73.4	75.2	68.2	94.1	77.4	73.3	75.5	68.5
100	71.3	68.5	70.2	65.7	89.2	71.4	68.5	70.5	65.5
200	63.5	61.9	63.2	59.7	77.9	66.4	62.4	64.5	59.5
400	61.4	57.5	59.7	54.2	77.9	61.4	57.4	59.5	54.0
800	52.1	48.6	50.7	45.7	69.1	52.1	48.5	50.5	46.0

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	77.4	74.0	76.2	69.7	94.5	77.6	73.6	76.0	67.5
100	*74.3	*69.8	*72.2	*66.2	*89.3	*74.5	*70.0	*72.5	*67.0
200	*74.2	*70.5	*72.2	*66.7	*90.0	*73.4	*69.4	*72.0	*65.0
400	*64.5	*59.7	*62.2	*55.7	*80.4	*64.5	*59.6	*62.5	*56.0
800	59.3	55.6	57.7	52.7	76.4	59.4	55.3	58.0	52.5
800-PL	ND	ND	ND	ND	ND	75.6	62.7	64.5	56.0

* includes bulldozer
PL - property line
ND - no data

Table 3.9 Noise parameters for 752 #16 Phase III, (dBA)

Ft. Green - 752 #16 (August 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
135	73.2	66.5	68.2	64.2	87.5	73.4	66.5	68.5	64.0
335	63.3	58.7	60.7	55.7	79.3	63.9	58.6	60.5	56.0
735	52.8	47.8	50.2	45.7	67.6	53.0	47.9	51.0	45.5

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	78.3	74.4	76.2	72.7	95.1	78.5	74.4	76.0	73.0
135	67.7	64.7	65.7	62.7	85.4	67.7	64.8	65.5	63.0
335	61.6	57.9	59.7	55.5	78.5	61.8	57.8	60.0	55.0
735	63.6	53.4	55.2	47.7	75.5	60.0	52.4	55.0	47.5

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
78	75.0	70.2	71.7	68.2	91.2	74.7	70.2	71.5	68.0
278	67.2	61.9	63.7	59.2	79.5	68.1	61.5	64.0	58.0
678	52.1	48.4	49.2	46.7	68.7	53.8	49.5	51.5	47.0

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	78.7	73.4	76.2	69.2	94.2	78.9	73.3	76.0	69.5
100	71.5	68.3	69.7	66.2	88.9	71.4	68.4	69.5	66.0
200	66.9	62.3	63.7	60.7	83.4	66.8	62.3	63.5	60.5
400	61.9	55.6	57.5	52.7	76.3	62.0	55.5	58.0	52.5
800	54.7	51.7	53.2	49.7	72.6	55.0	53.0	51.0	50.0

Table 3.10 Noise parameters for 1260W Phase IV, (dBA)

Clear Springs - 1260W (December 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
40	94.9	91.0	94.3	82.8	111.3	94.4	89.6	94.0	82.5
90	88.5	84.0	86.7	81.7	106.5	88.5	84.0	87.0	82.0
190	79.1	76.2	77.7	72.2	96.6	79.3	76.3	78.0	72.0
390	71.7	68.7	70.2	66.2	89.4	71.7	68.6	70.0	65.5
790	61.9	56.5	58.2	52.2	75.8	64.6	60.0	61.5	57.5

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
43	95.6	94.0	94.8	90.3	115.0	95.6	93.8	95.0	90.5
93	88.6	87.1	88.3	84.3	107.9	88.6	87.1	88.0	84.5
193	79.1	76.6	78.7	67.7	97.2	79.4	76.4	78.5	67.5
393	72.2	70.2	71.2	69.2	91.4	72.2	70.1	71.0	69.0
793	61.4	57.8	60.2	55.2	78.5	61.4	57.5		

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
32	96.8	92.5	95.8	86.8	113.3	96.9	91.9	96.0	87.0
132	83.9	79.9	82.2	70.7	100.7	83.9	79.5	82.5	70.5
332	70.3	67.6	69.7	61.2	88.5	70.2	67.0	69.5	60.5
732	63.0	59.3	61.7	55.2	79.9	62.3	57.6	61.0	51.5

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	93.4	89.6	92.3	86.8	110.9	93.3	89.4	92.0	87.0
100	87.0	83.3	86.7	69.2	103.1	87.1	82.4	86.5	69.0
200	78.8	77.1	77.7	75.7	97.9	79.0	77.3	78.0	76.0
400	72.8	71.2	72.2	69.7	92.0	72.9	71.2	72.0	69.5
800	63.4	61.1	62.2	59.2	81.9	63.3	61.0	62.0	59.0

Table 3.11 Noise parameters for 1150B Phase IV, (dBA)

Noralyn - 1150B (December 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	85.8	81.7	83.3	78.3	102.5	85.8	81.6	83.0	78.5
100	75.6	71.1	73.7	67.2	92.4	75.8	70.9	73.5	67.5
200	71.1	67.2	69.2	65.2	87.9	71.2	67.0	69.0	65.0
400	60.8	58.2	60.2	55.7	77.0	58.8	57.1	58.5	53.5
770	55.8	52.7	54.2	50.2	73.5	55.6	52.1	54.0	49.5

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	85.0	79.5	82.3	75.8	100.3	85.0	79.3	82.5	76.0
100	76.5	73.5	75.2	70.7	94.2	76.7	73.4	75.5	70.5
200	70.2	66.1	68.2	63.7	85.7	69.8	65.9	68.0	63.5
400	63.0	59.7	61.2	57.7	80.3	66.6	59.6	61.5	57.5
800	57.2	52.8	54.7	49.7	74.1	57.0	52.3	54.5	49.0

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	82.6	80.4	81.8	72.3	101.1	82.6	79.9	82.0	72.0
100	76.6	73.1	74.7	68.2	93.9	76.8	72.9	74.5	68.0
200	67.8	65.2	66.2	62.7	86.0	67.8	65.0	66.5	62.5
400	64.4	60.9	62.2	58.7	81.7	64.4	60.7	62.0	58.5
800	59.7	55.8	58.2	53.2	76.9	59.9	55.4	58.0	53.0

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	82.4	77.7	81.7	72.7	99.0	82.4	77.1	81.5	72.0
100	74.2	71.8	69.7	63.7	88.6	74.3	71.6	74.0	67.5
200	67.1	65.5	66.7	63.2	86.4	67.1	65.4	66.5	63.0
400	64.8	61.3	62.7	58.7	82.2	64.9	61.2	63.0	59.0
800	58.7	53.3	54.7	50.7	73.9	60.1	52.7	55.0	50.0

Table 3.12 Noise parameters for 752 #16 Phase IV, (dBA)

Ft. Green - 752 #16 (December 1994)

Afternoon									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	76.0	71.9	74.2	68.7	92.7	76.1	72.1	74.5	69.0
100	69.5	65.2	67.2	62.7	86.1	69.7	65.2	67.0	62.5
200	66.8	63.3	65.7	57.2	80.8	67.6	62.4	65.0	58.5
400	59.5	56.9	58.7	53.7	74.5	60.9	55.9	58.0	53.0
800	54.5	48.7	49.7	46.7	69.3	54.5	48.0	49.5	46.0

Night									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	79.7	73.1	76.7	65.7	93.8	79.8	72.8	77.0	65.5
100	70.5	66.8	69.2	62.2	87.6	70.7	66.6	69.5	62.0
200	65.1	61.5	63.7	55.7	82.3	65.0	61.3	63.5	56.0
400	57.8	55.1	56.7	52.7	75.9	57.8	54.9	56.5	52.0
800	55.1	50.5	51.7	48.2	71.2	54.6	50.0	51.5	48.0

Early Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
57	73.5	68.3	70.7	64.2	89.2	73.5	68.2	71.0	65.0
107	68.4	64.8	67.2	62.7	85.6	68.6	64.8	67.0	62.5
207	64.7	59.6	61.7	57.2	80.4	64.7	59.6	62.0	57.5
407	59.0	54.3	55.7	51.7	74.6	58.8	53.8	55.5	51.5
807	51.2	48.1	49.7	45.7	68.7	50.8	47.0	49.0	44.5

Late Morning									
Dist. (ft)	Max L_{eq}	L_{eq}	L_{10}	L_{90}	SEL	Max L_{AV5}	L_{AV5}	L_{10}	L_{90}
50	74.8	68.8	71.2	64.7	89.6	74.9	68.5	71.0	64.5
100	69.8	65.3	67.7	60.7	86.0	71.4	65.1	68.0	61.0
200	62.8	59.0	60.7	56.7	79.6	62.9	58.8	60.5	56.5
400	64.5	55.9	57.7	50.7	76.6	64.5	55.1	58.0	51.0
800	54.4	48.7	50.7	45.2	69.3	54.4	48.3	51.0	45.0

3.5 L_{eq} VERSUS DISTANCE FROM DRAGLINE

The L_{eq}s are also presented as a function of distance from the base of dragline in Figures 3.4 through 3.6 for the first phase measurement, Figures 3.7 through 3.9 for the second phase measurement, Figures 3.10 through 3.12 for the third phase measurement, and Figures 3.13 through 3.15 for the fourth phase measurement. Variations among the L_{eq}s measured at daytimes and at night are not significant. Therefore, the L_{eq}s are grouped together for analysis.

Regression Analysis

The solid lines in Figures 3.4 through 3.15 contain the results of the ordinary least-squares analysis (OLS) for all measurements (i.e., afternoon, night, early morning, and late morning). The linear regression line is the line that has the smallest sum of squared vertical differences from the noise measurements to the line. The equation of each regression line is provided on each graph for prediction purposes. R-squared values are also calculated and presented on the figures.

3.6 FIELD MONITORING OBSERVATIONS

During the field monitoring study, the draglines were under normal production operations. It was not intended to be a controlled field study. Thus, sounds from sources other than the dragline were present throughout field monitoring, especially as the distance from the dragline increased. These sounds, from such sources as, pit guns, bulldozers, irrigation pumps, traffic, and airplanes, were occasionally included in the measurements. Every effort was made to discard the unwanted sounds other than the dragline noise in the office. However, the effort was not successful every time, and as such, the high unwanted sounds are labeled on the tables and the figures.

While conducting the noise and vibration, monitoring at the sites, the dragline operators were aware of the noise measurements. Thus, it is felt that some of the data does not reflect noise and vibration values concurrent with full-scale dragline operations. In some cases, the dragline was "swinging empty," meaning the operator was swinging the bucket from side to side without stripping overburden or mining.

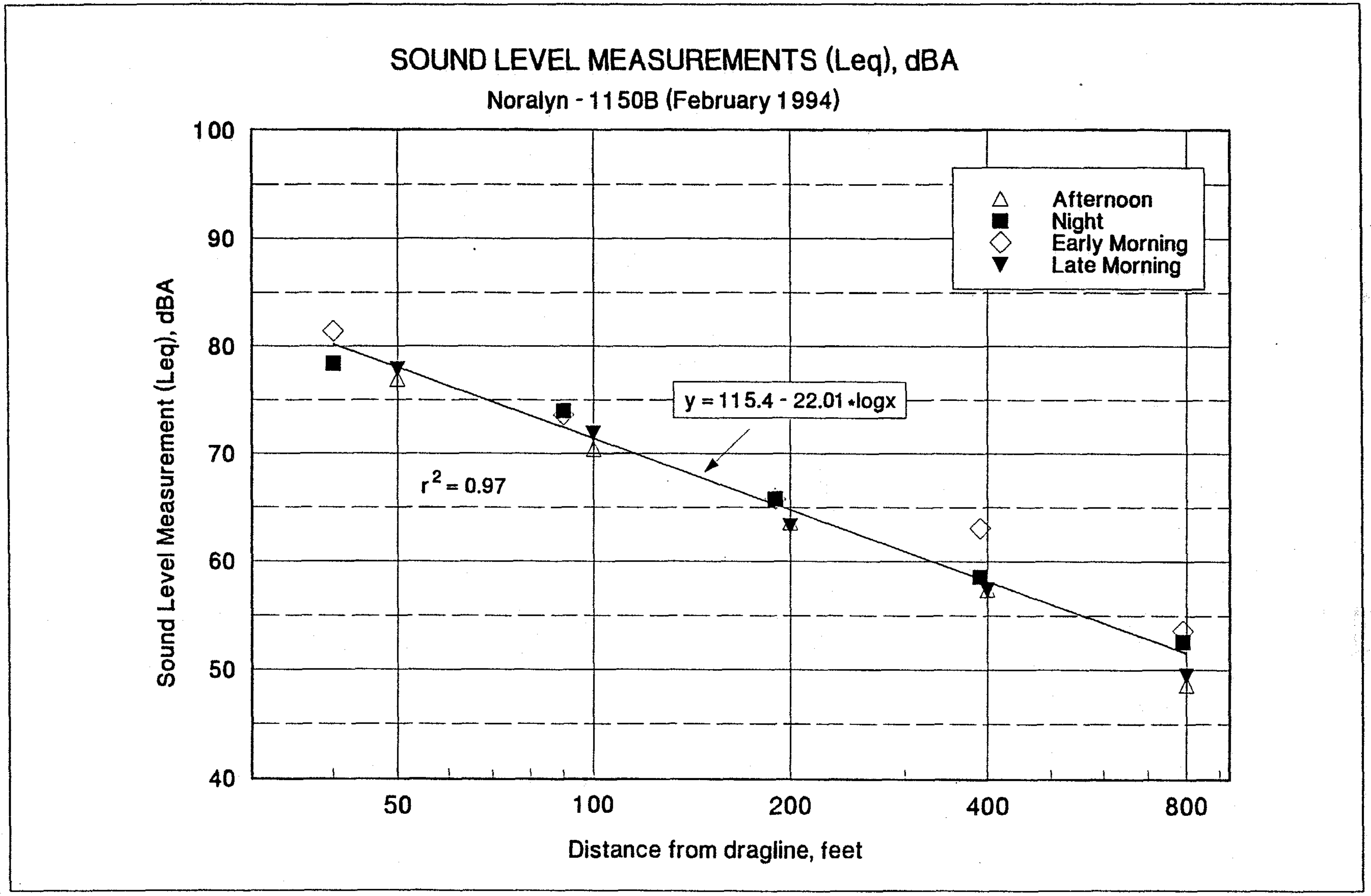


Figure 3.4 Sound level measurements (L_{eq}), dBA - 1150B Phase I

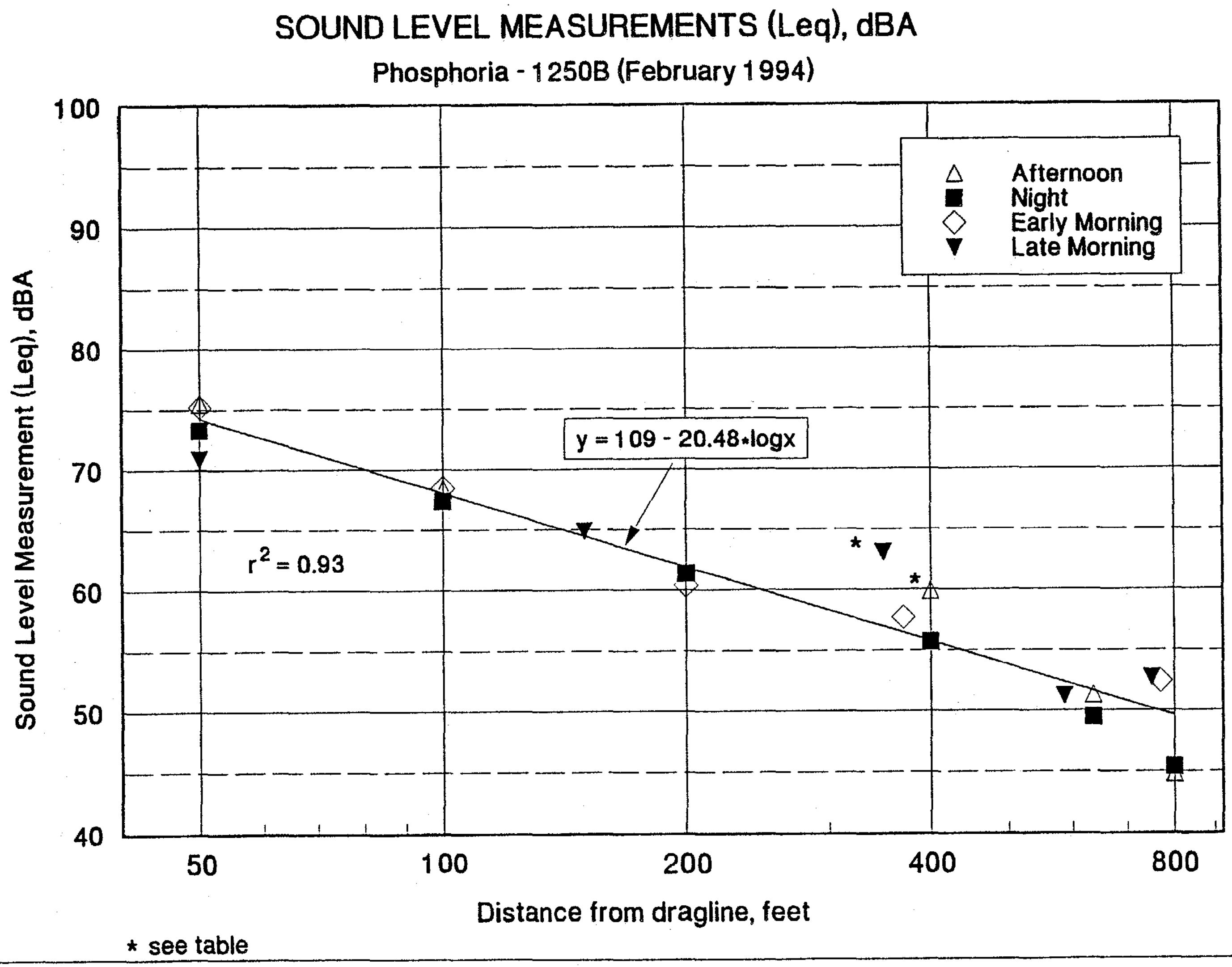


Figure 3.5 Sound level measurements (L_{eq}), dBA - 1250B Phase I

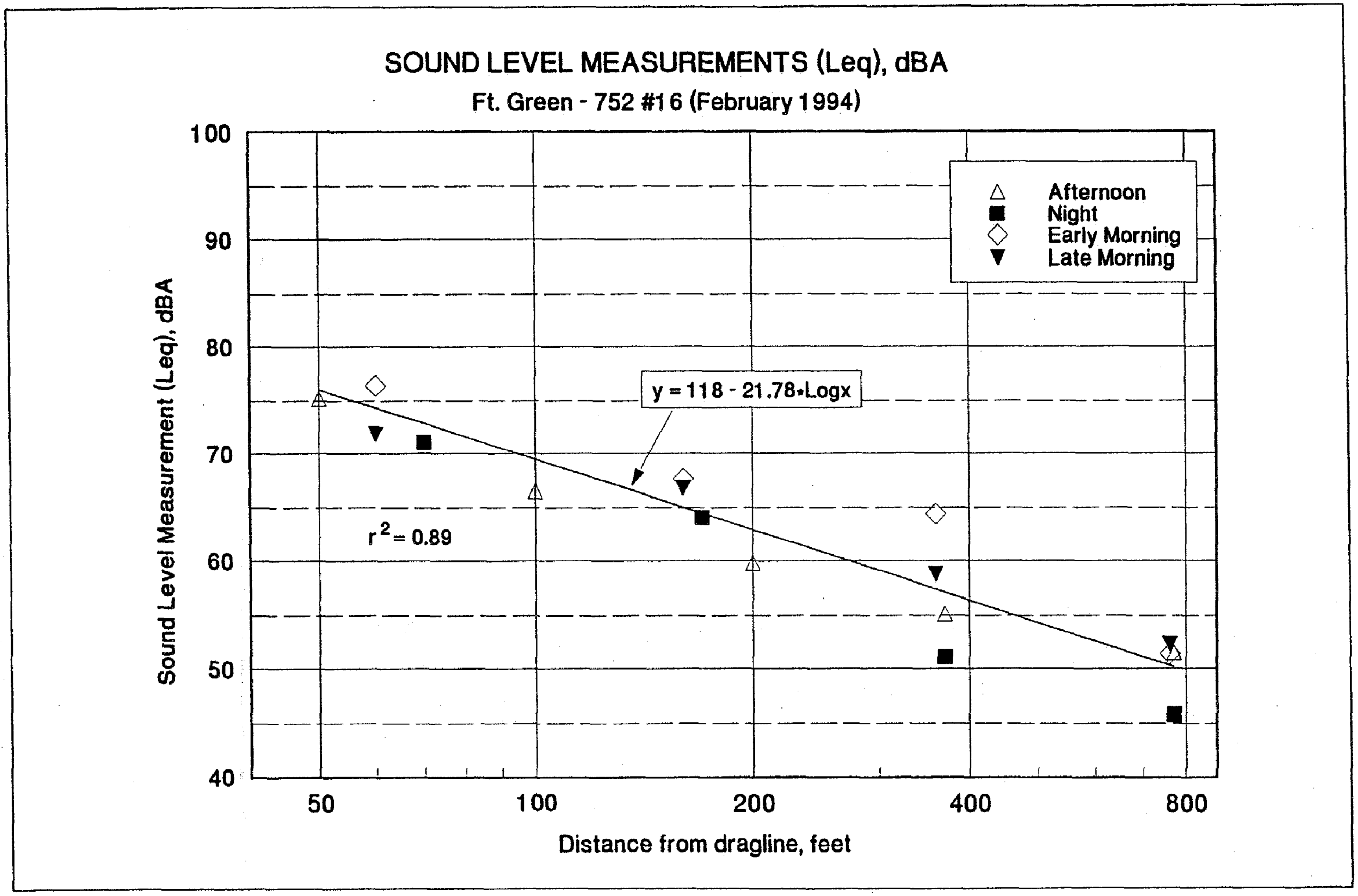


Figure 3.6 Sound level measurements (L_{eq}), dBA - 752 #16 Phase I

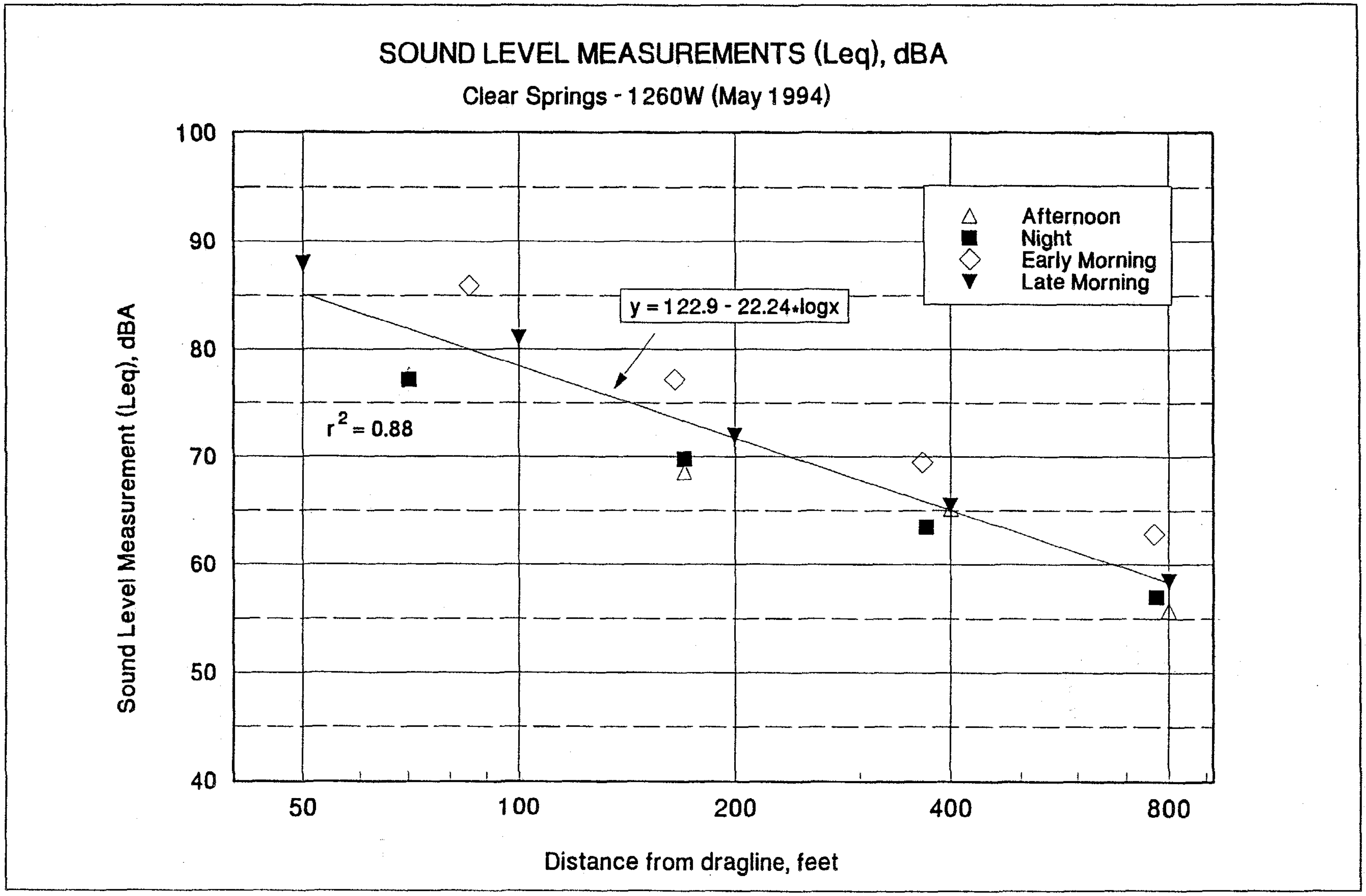


Figure 3.7 Sound level measurements (L_{eq}), dBA - 1260W Phase II

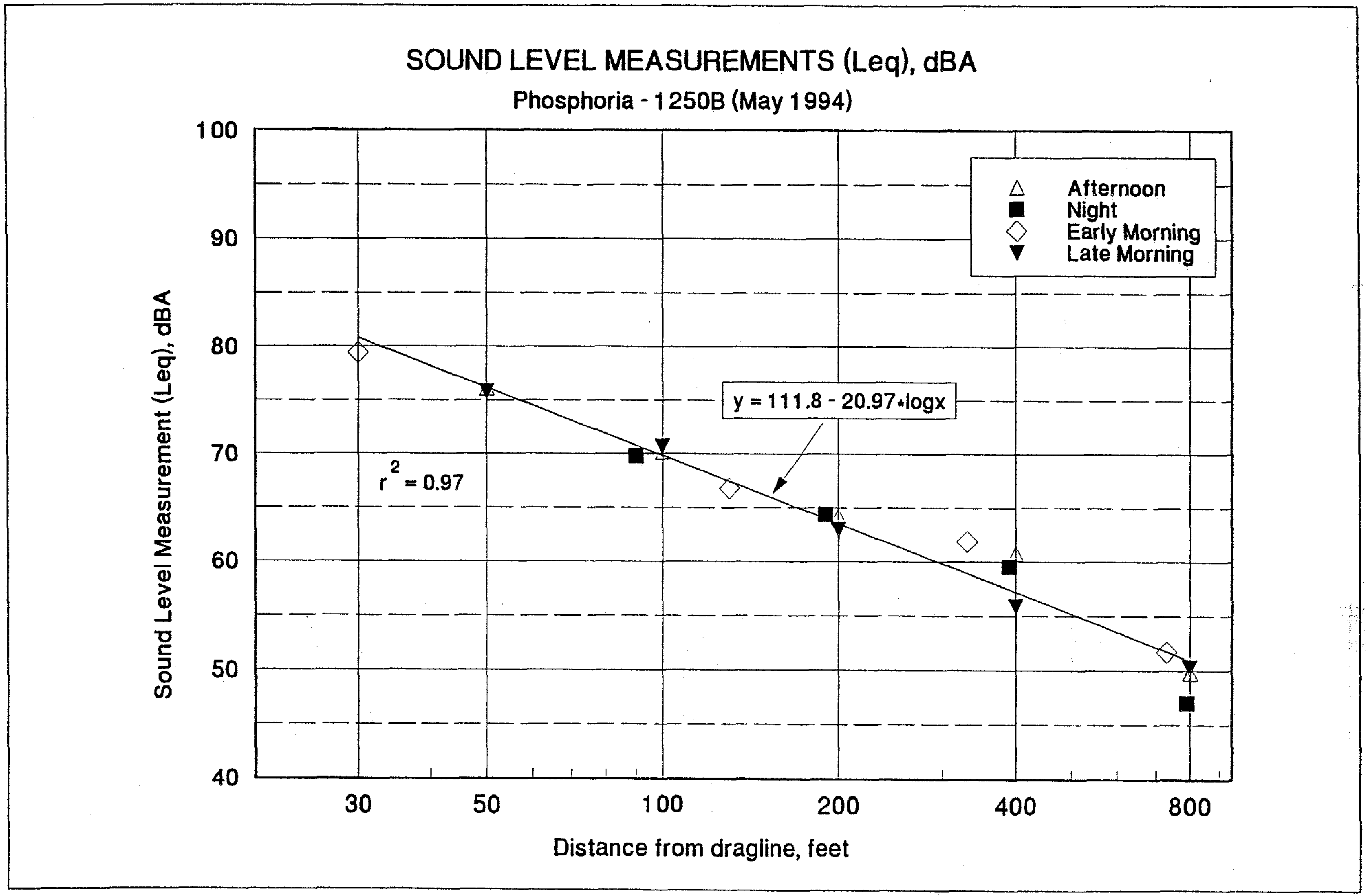


Figure 3.8 Sound level measurements (L_{eq}), dBA - 1250B Phase II

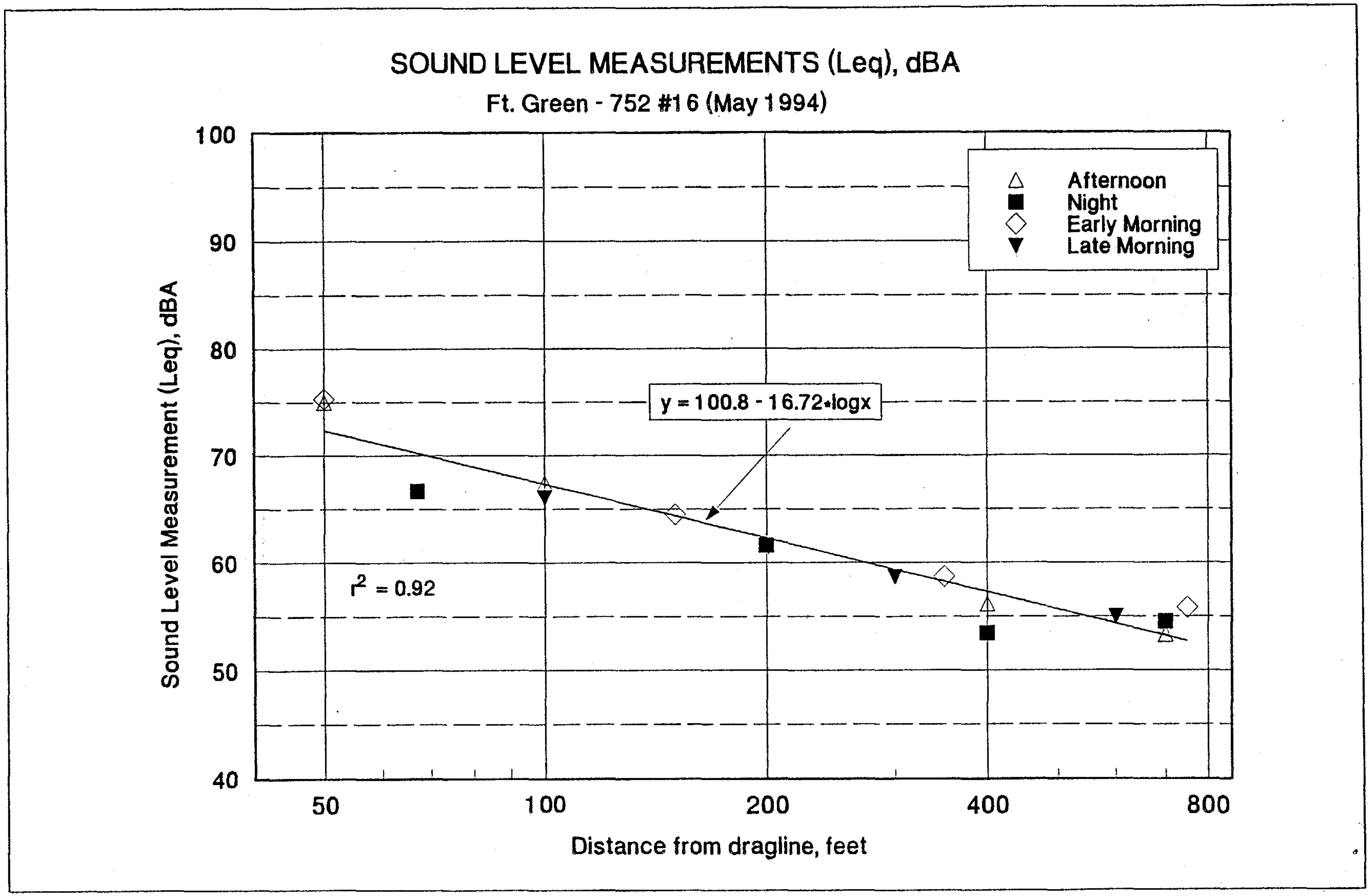


Figure 3.9 Sound level measurements (L_{eq}), dBA - 752 #16 Phase II

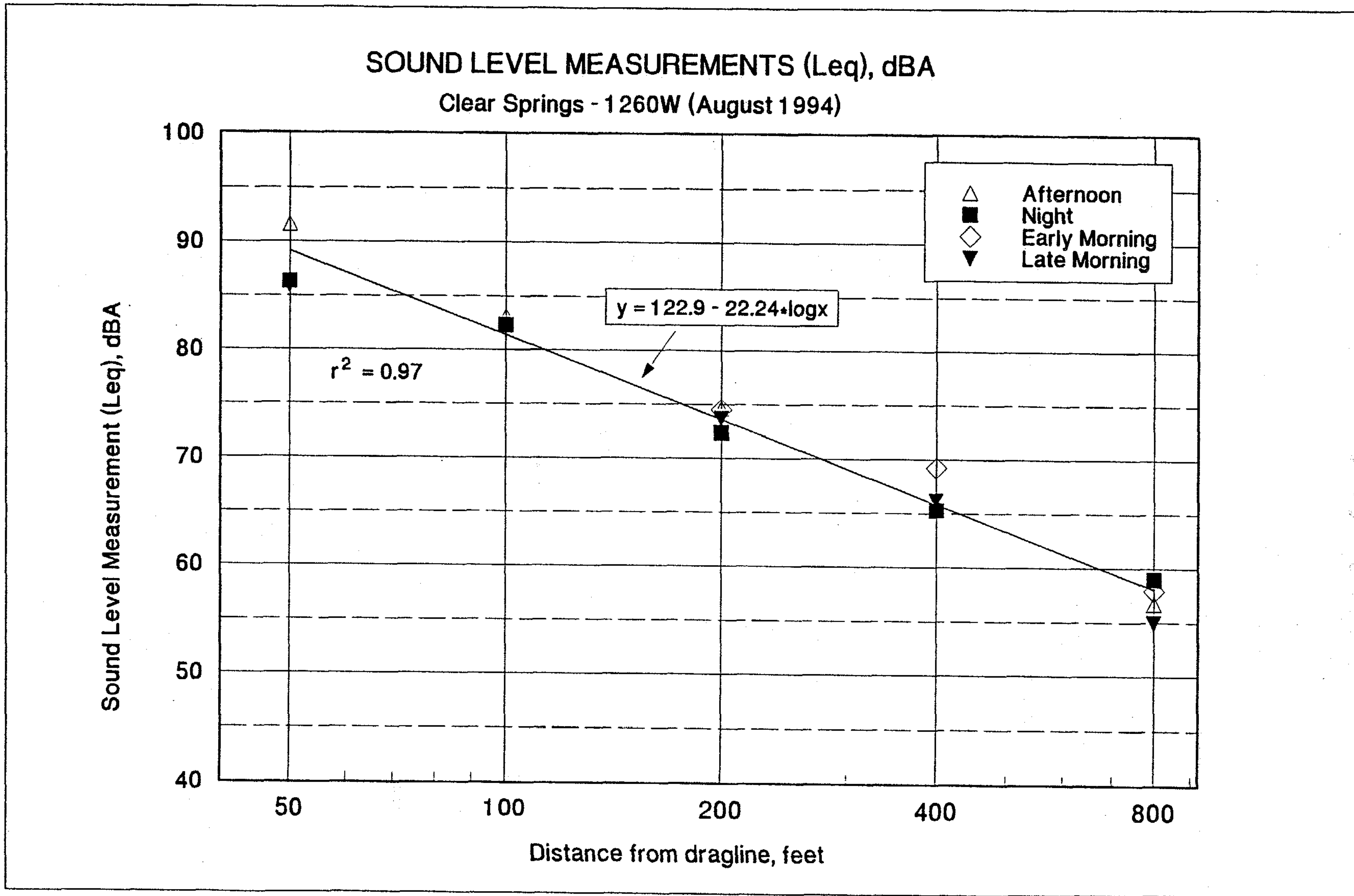


Figure 3.10 Sound level measurements (L_{eq}), dBA - 1260W Phase III

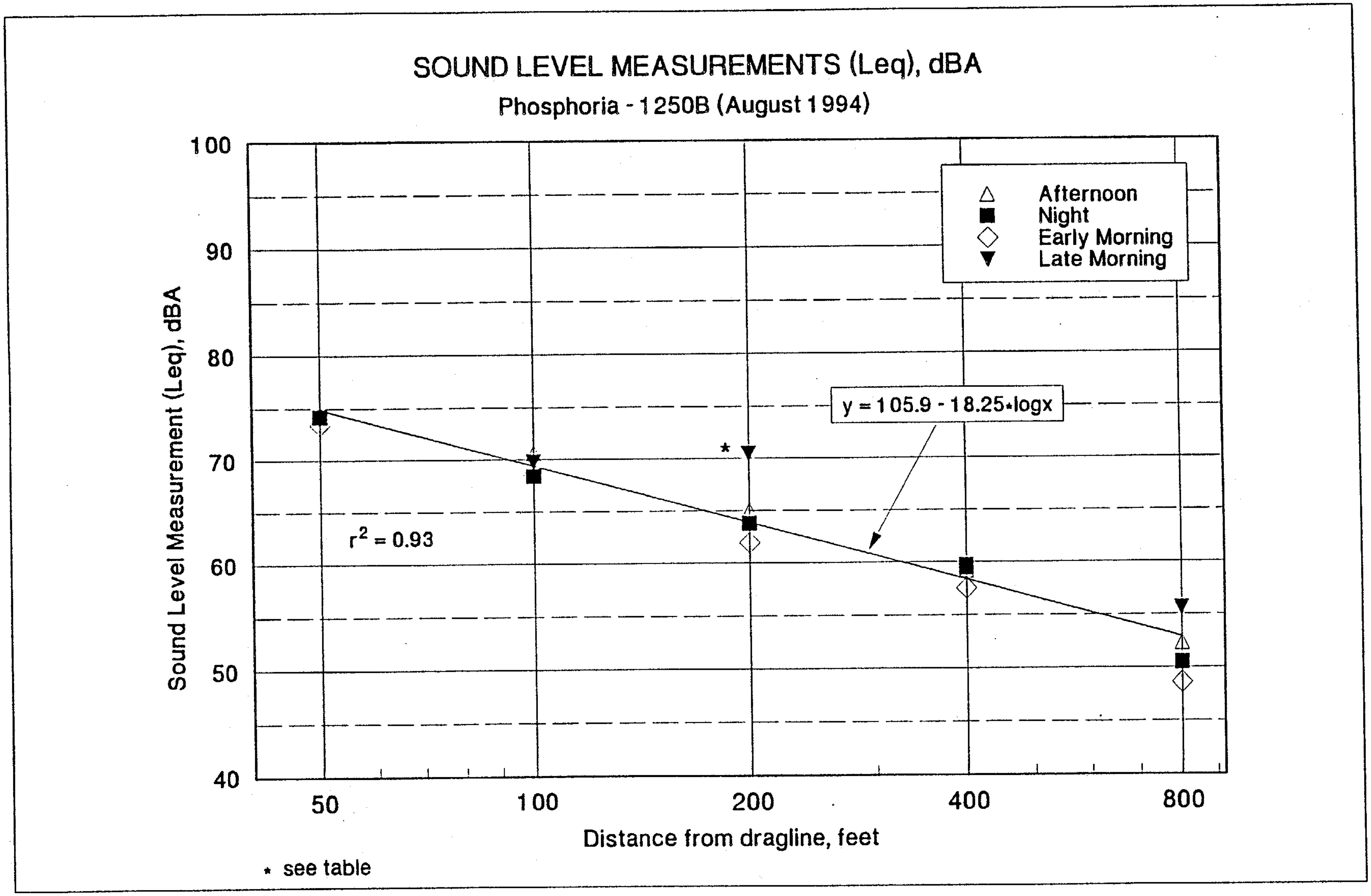


Figure 3.11 Sound level measurements (L_{eq}), dBA - 1250B Phase III

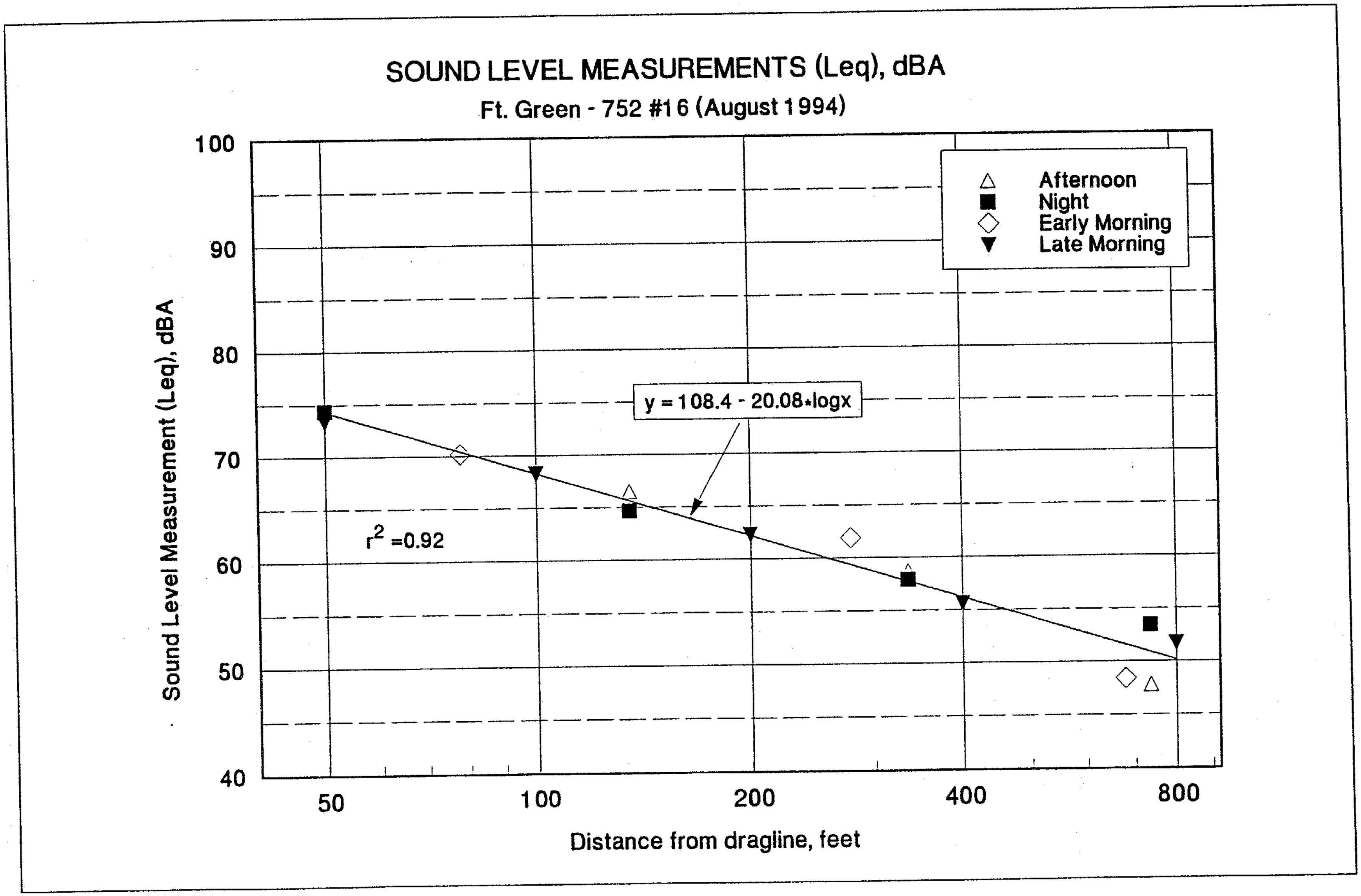


Figure 3.12 Sound level measurements (L_{eq}), dBA - 752 #16 Phase III

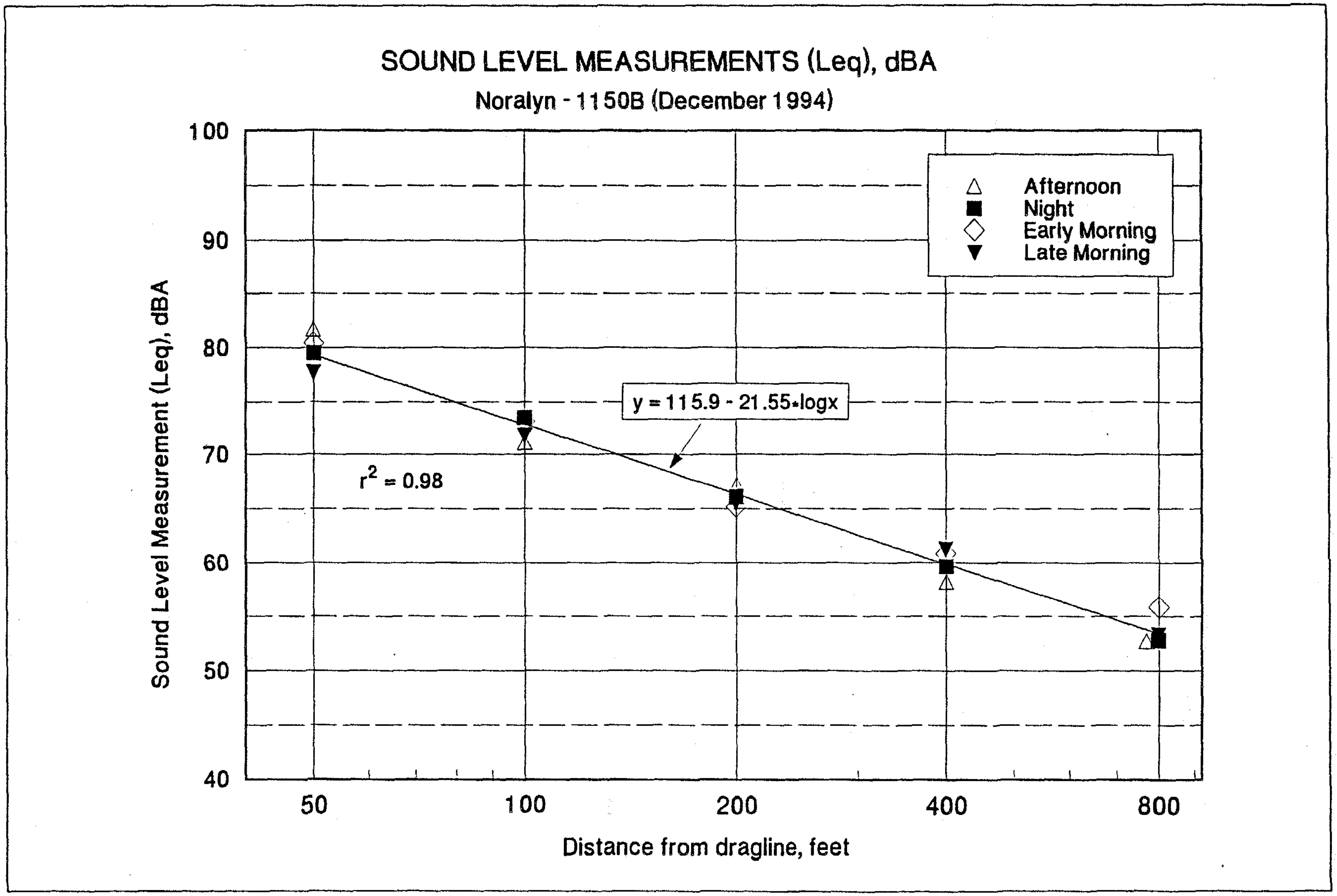


Figure 3.13 Sound level measurements (L_{eq}), dBA - 1150B Phase IV

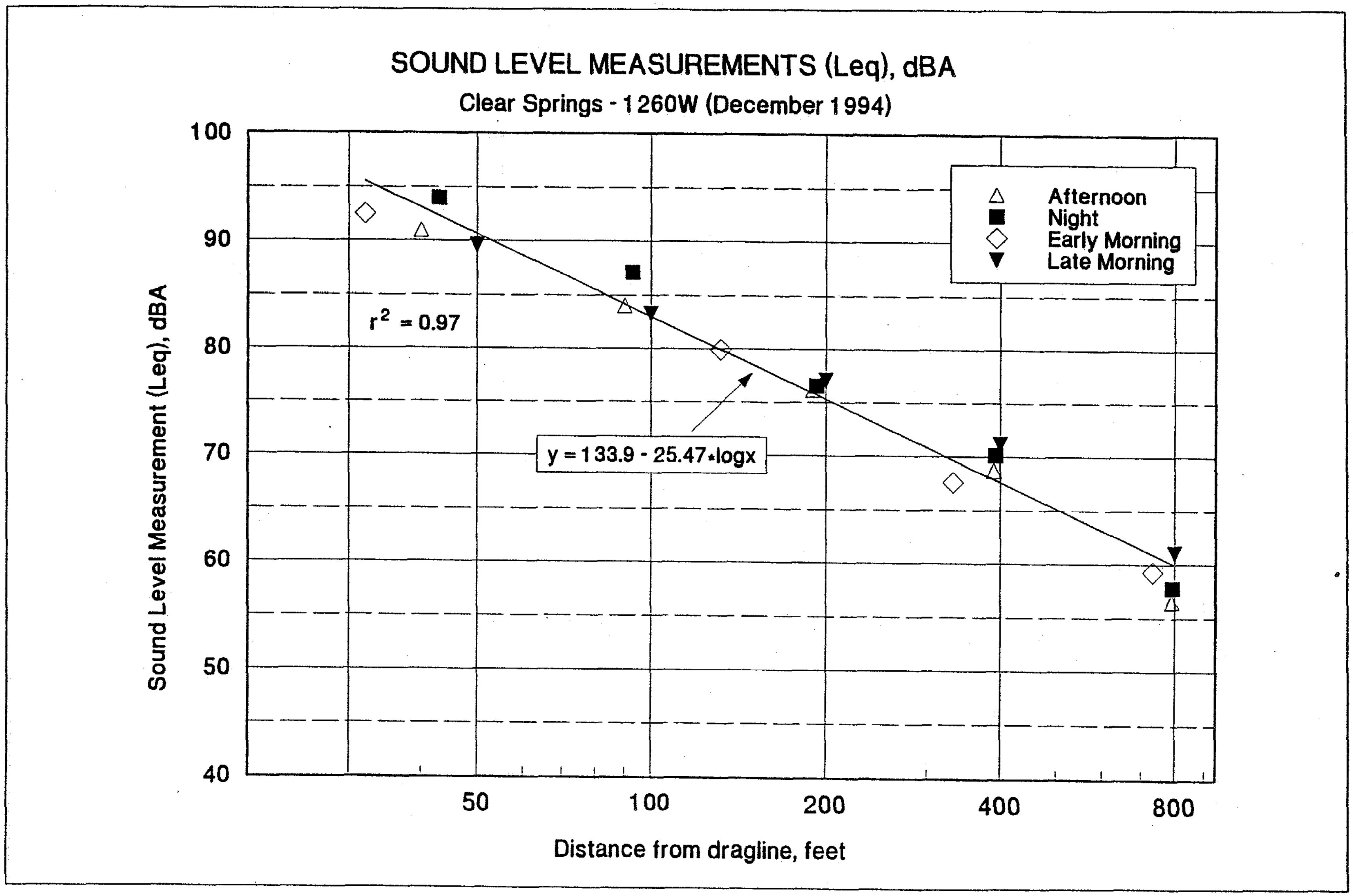


Figure 3.14 Sound level measurements (L_{eq}), dBA - 1260W Phase IV

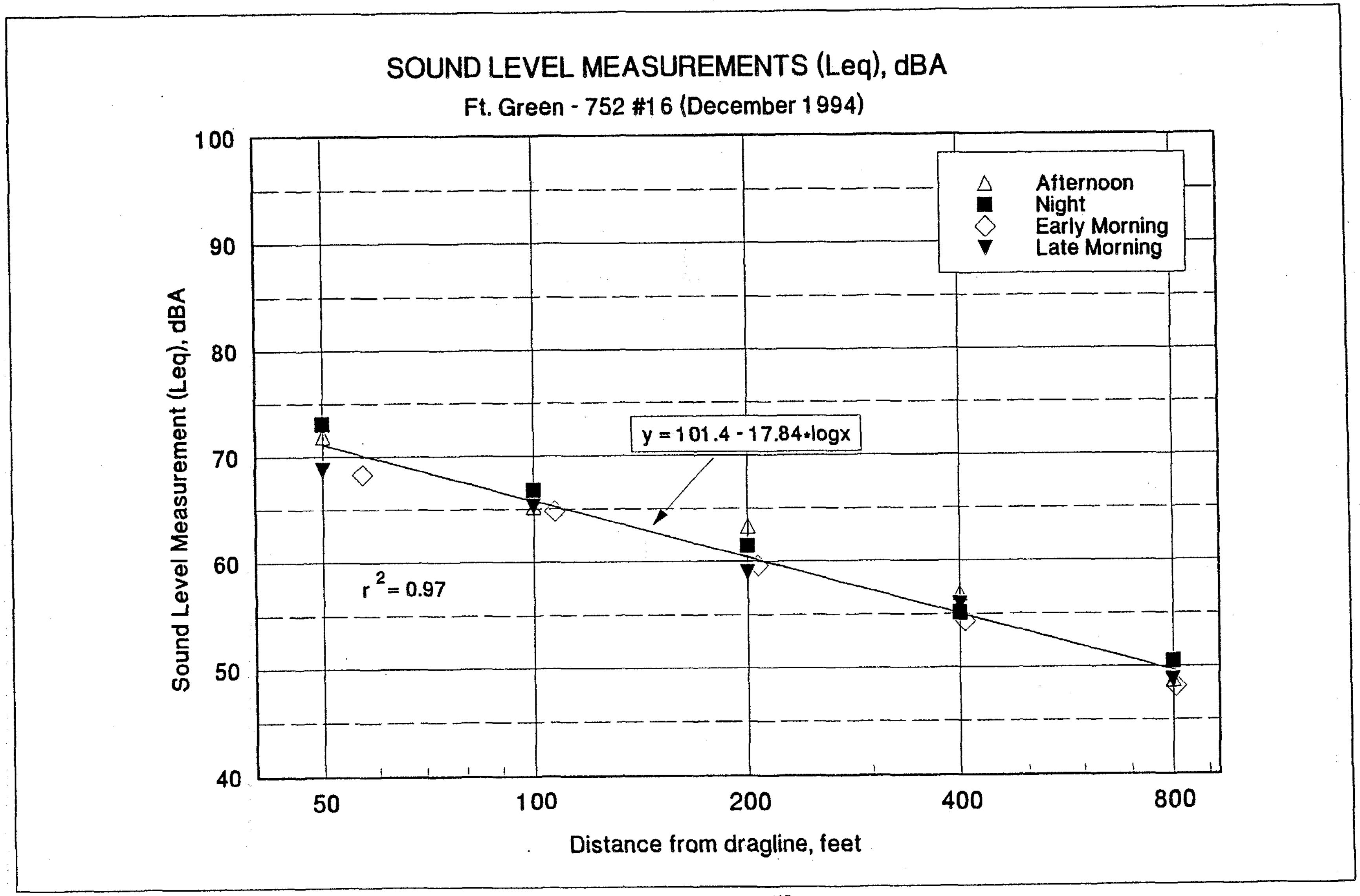


Figure 3.15 Sound level measurements (L_{eq}), dBA - 752 #16 Phase IV

CHAPTER 4: LABORATORY ANALYSIS

4.1 GENERAL

Data analysis of the recorded noise and vibration signals was performed in the laboratory. The analysis consisted of determining the following:

1. Peak (and rms) particle velocity in inches per second,
2. Spectrum analysis of the noise data,
3. Overall sound pressure level of the noise data, and
4. Spectrum analysis of selected vibration data.

The following are addressed in this chapter: (1) An explanation of the data transfer process, (2) an overview of the analysis procedure (FORTRAN program), and (3) the methodology used to determine the peak particle velocity (PPV), frequency spectrum of the noise and vibration data, and overall sound pressure level (OASPL).

4.2 DATA TRANSFER PROCESS

Field noise and vibration measurements were recorded using a Sony digital tape recorder, PC 204A, via the charge amplifier and sound level meter. Both the noise and vibration signals were recorded digitally and in real time on magnetic tapes for laboratory analysis.

In the laboratory, the data were transferred from the digital tapes (at a 24000 Hz sampling rate) to a computer via a high-speed digital data transfer system, developed by Sony, called PCscan (see Figure 4.1). PCscan enables real time data transfer from

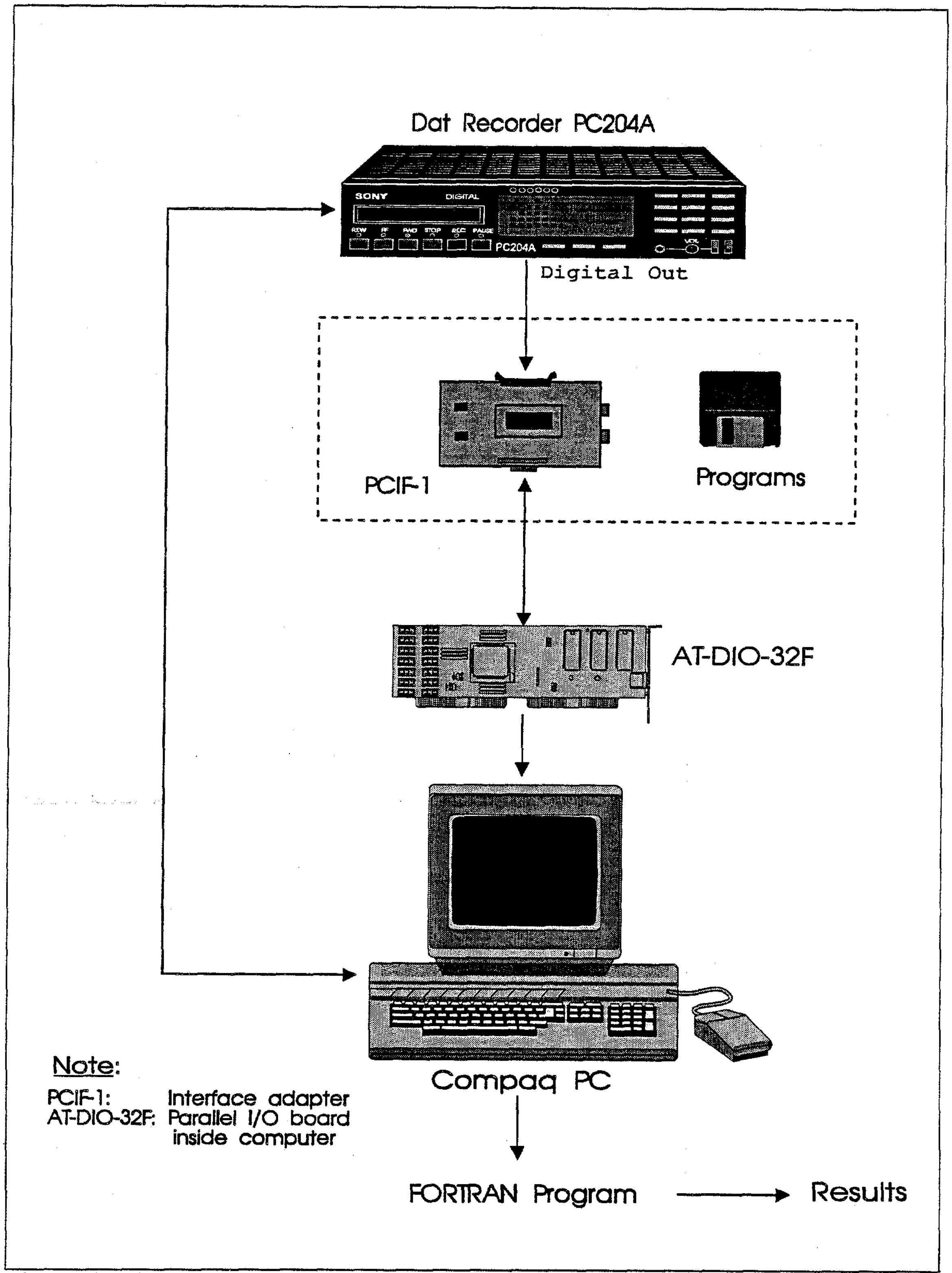


Figure 4.1 Schematic illustration of data transfer process

the Sony DAT recorder to a computer hard drive and also provides bar graph and waveform display monitors. The PCscan package consists of the following items (Figure 4.1):

1. Digital interface adapter (PCIF-1)
2. Parallel digital I/O board (AT-DIO-32F)
3. Cables
4. Program disks

4.3 ANALYSIS PROCEDURE

Before analysis, the data were carefully reviewed. The anemometer's strip chart data was tabulated, and the Windscope data was searched for conditions that violated the defined meteorological criteria of excessive wind turbulence or wind gusts greater than 13.42 mph (ANSI S1.13-1971 (R1976)). None of the data was influenced in this way. However, due to extremely high humidities and the sensitivity of the accelerometer, a number of vibration measurements were faulty and are shown as "Bad Data" in Tables 4.1 through 4.4. In addition, any noise from vehicles or airplanes that passed by during field data collection was recorded on tape and noted on paper.

Once the noise and vibration data were transferred from the digital tapes to the hard drive at a 24000 Hz sampling rate, the data were manipulated by a Microsoft FORTRAN program (see Appendix C). The program provided peak and root-mean-square (rms) particle velocity for the vibration data, performed frequency analysis on the noise data, and calculated the overall sound pressure level (OASPL) in decibels.

The original FORTRAN program was later modified to perform frequency analysis on eight selected vibration measurements, two for each dragline.

4.4 CALCULATION OF PARTICLE VELOCITY

The vibration amplitude is a characteristic that describes the severity of a vibration and can be quantified in several ways. For this report, the peak particle velocity and the root-mean-square (rms) particle velocity were determined.

Peak Particle Velocity

The peak particle velocity (measured in inches per second) of the ground vibration was determined by equation (4.1) below, which is included in Part I of the FORTRAN program (see Appendix C). The equation calculated the original analog values in volts (a), included a factor for the charge amplifier's calibration (b), and converted from meters per second (m/s) to inches per second (c). The equation is as follows:

$$PPV\ (inches\ per\ second) = \underbrace{\frac{(Peak\ Value - AVG) \times R2}{24576}}_{(a)} \times \underbrace{\frac{1}{1000}}_{(b)} \times \underbrace{\frac{100}{2.54}}_{(c)} \qquad (4.1)$$

where:

AVG = Sum of all velocity values during measurement time divided by the number of values

R2 = DAT recorder range setting (1, 2, 5, 10, or 20)

The vibration data stored in binary format do not have a direct correspondence with an analog value such as volts or amperes. According to the PCscan operation manual (Sony Magnescale Inc., 1994), the original analog vibration values in volts can be calculated by using the formula below which is represented as part (a) in equation (4.1):

$$original\ signal\ level\ (volts) = \frac{D}{24576} \times R2 \qquad (4.2)$$

where:

D = value of the binary word

R2 = range setting on DAT recorder

For the charge amplifier Type 2635, the instruction manual was consulted to determine the output sensitivity S_p. The following relationship was used (Bruel & Kjaer, 1986):

$$S_p = \frac{\textit{mV/UNIT OUT switch setting x exponent}}{\textit{Unit Out selected with ACC. -VEL.-DISPL. switch}} \qquad (4.3)$$

During the duration of the field monitoring program, the charge amplifier was set to 1000 mV/UNIT OUT, and the Unit Out selected with the ACC.-VEL.-DISPL. switch was set to 0.01 m/s. The exponent in equation (4.3) relates to the accelerometer's charge sensitivity which is 31.6 pC/ms^{-2}. On the charge amplifier, the setting could only be set for 3.16 pC/ms^{-2}. Therefore, the exponent is 10. Substituting these values in equation (4.3) yields 1000 V/m/s, or 0.001 m/s/V (this is part (b) in equation (4.1)). Finally, m/s is converted to in/s in part (c) in equation (4.1).

Tables 4.1 through 4.4 present the values of peak particle velocities, determined from equation (4.1), measured at various distances from the operating draglines. The data is also plotted on Figures 4.2 through 4.5 in the form of peak particle velocity versus distances from each dragline.

Root-Mean-Square Particle Velocity

The root-mean-square (rms) value is the most relevant measure of amplitude because it accounts for the time history of the wave and gives an amplitude value that is directly related to the energy content and, therefore, the destructive abilities of the ground vibration. For this reason, the rms particle velocity in inches per second was also determined for each vibration measurement by the Fortran program. The rms values are shown along with the peak particle velocities in Tables 4.1 through 4.4.

4.5 FREQUENCY ANALYSIS ON NOISE DATA

Part II of the FORTRAN program computes the sound pressure level in decibels as a function of frequency. Since the noise and vibration data were discretely sampled, the Fast Fourier Transform (FFT) method was employed in the program. The sampling rate of the Sony DAT recorder is 24000 Hertz (Hz); therefore, the Nyquist critical frequency is 12000 Hz (i.e., 24000/2). Thus, the program was written to analyze only those spectral components less than 12000 Hertz.

Table 4.1 Peak and RMS particle velocities for Phase I (February 1994)

NORALYN--FEBRUARY 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	4.11 E-02	4.77 E-03	50	2.59E-02	7.43E-03	40	3.36E-02	1.50E-02	40	1.66E-02	3.26E-03
100	2.01 E-02	6.06 E-03	100	2.78E-02	5.85E-03	90	2.31E-02	5.72E-03	90	2.56E-02	7.93E-03
200	4.41 E-02	3.34 E-03	200	2.11E-02	5.86E-03	190	3.95E-02	9.95E-03	190	2.05E-02	6.91E-03
400	2.17 E-02	2.36 E-03	400	8.61E-03	2.10E-03	390	1.86E-02	6.43E-03	390	3.08E-02	7.60E-03
800	6.15 E-03	1.35 E-03	800	7.28E-03	2.91E-03	790	1.28E-02	3.63E-03	790	9.11E-03	2.89E-03

FT. GREEN--FEBRUARY 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
60	2.80E-02	5.41E-03	50	2.18E-02	4.54E-03	70	1.43E-02	3.35E-03	60	2.22E-02	3.71E-03
160	1.59E-02	3.55E-03	100	1.76E-02	4.83E-03	170	1.09E-02	3.31E-03	160	1.84E-02	5.35E-03
360	8.95E-03	2.16E-03	200	1.05E-02	2.99E-03	370	8.01E-03	2.61E-03	360	2.04E-02	5.05E-03
760	5.31E-02	5.17E-03	370	8.86E-03	2.46E-03	770	5.77E-03	1.86E-03	760	1.17E-02	3.32E-03
			770	9.36E-03	3.29E-03						

PHOSPHORIA--FEBRUARY 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	7.39E-02	1.59E-02	50	5.08E-02	7.02E-03	50	3.82E-02	7.81E-03	50	Bad Data	Bad Data
150	1.42E-02	4.16E-03	100	2.39E-02	4.76E-03	100	4.01E-02	1.19E-02	100	Bad Data	Bad Data
350	1.92E-02	6.33E-03	200	1.52E-02	2.95E-03	200	2.03E-02	6.08E-03	200	Bad Data	Bad Data
586	2.69E-02	6.97E-03	400	8.19E-03	1.83E-03	400	1.30E-02	5.14E-03	370	5.10E-02	2.70E-02
750	2.15E-02	5.56E-03	636 PL	7.94E-03	2.34E-03	636 PL	1.12E-02	3.13E-03	770	4.93E-02	2.73E-02
			800	1.06E-02	3.28E-03	800	1.35E-02	6.51E-03			

Table 4.2 Peak and RMS particle velocities for Phase II (May 1994)

CLEAR SPRINGS--MAY 1994

LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	5.21E-02	7.90E-03	70	4.33E-02	6.52E-03	70	3.53E-02	6.22E-03	85	3.41E-02	5.47E-03
100	4.55E-02	7.91E-03	170	1.40E-02	3.36E-03	170	2.05E-02	6.42E-03	165	2.56E-02	4.39E-03
200	2.69E-02	5.99E-03	200	Bad Data	Bad Data	370	8.98E-03	1.09E-03	365	9.71E-03	2.56E-03
400	1.63E-02	4.09E-03	400	1.95E-02	3.02E-03	770	5.40E-03	1.36E-03	765	4.75E-03	1.41E-03
800	9.26E-03	2.84E-03	800	1.42E-02	7.11E-03						

FT. GREEN--MAY 1994

LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
100	1.36E-02	1.55E-03	50	3.24E-02	6.56E-03	67	1.79E-02	1.97E-03	50	2.86E-02	3.63E-03
300	9.34E-03	1.20E-03	100	2.41E-02	8.23E-03	200	2.11E-02	1.58E-03	150	1.46E-02	1.88E-03
600	3.22E-03	4.68E-04	200	2.69E-02	1.23E-02	400	1.83E-02	3.00E-03	350	4.87E-03	6.94E-04
			400	6.10E-03	1.94E-03	700	6.24E-03	2.63E-03	750	7.87E-03	9.16E-04
			700	9.14E-03	4.63E-03						

PHOSPHORIA-- MAY 1994

LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	5.77E-02	1.14E-02	50	6.91E-02	1.44E-02	90	3.00E-02	5.14E-03	30	3.69E-02	5.41E-03
100	4.06E-02	7.98E-03	100	5.96E-02	8.75E-03	190	1.80E-02	3.02E-03	130	2.81E-02	3.88E-03
200	2.49E-02	6.10E-03	200	3.43E-02	1.78E-03	390	3.13E-02	8.99E-03	330	6.34E-03	1.41E-03
400	2.50E-02	9.79E-03	400	2.53E-02	5.49E-03	790	1.29E-02	3.16E-03	730	1.26E-02	7.46E-03
800	1.21E-02	4.56E-03	800	2.46E-02	4.02E-03						

Table 4.3 Peak and RMS particle velocities Phase III (August 1994)

CLEAR SPRINGS--AUGUST 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	2.82E-02	5.13E-03	50	3.08E-02	8.01E-03	50	3.43E-02	3.24E-03	200	Bad Data	Bad Data
100	1.63E-02	3.23E-03	100	2.05E-02	3.51E-03	100	1.17E-02	1.80E-03	400	3.13E-02	1.03E-02
200	1.43E-02	5.06E-03	200	1.87E-02	6.04E-03	200	*1.19E-02	*2.64E-03	800	1.73E-02	4.83E-03
400	1.34E-02	4.36E-03	400	6.59E-03	2.00E-03	400	*8.79E-02	*1.65E-02			
800	1.03E-02	3.96E-03	800	9.26E-03	4.95E-03	800	5.59E-03	1.76E-03			

FT. GREEN--AUGUST 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	6.00E-02	9.42E-03	135	1.55E-02	2.89E-03	50	1.20E-02	1.97E-03	78	Bad Data	Bad Data
100	4.86E-02	7.56E-03	335	1.18E-02	4.15E-03	135	7.90E-03	1.84E-03	278	6.55E-02	1.99E-02
200	3.85E-02	1.34E-02	735	1.10E-02	2.38E-03	335	3.17E-03	6.74E-04	678	5.44E-02	1.50E-02
400	4.11E-02	1.35E-02				735	9.43E-03	5.26E-03			
800	1.70E-02	8.33E-03									

PHOSPHORIA-- AUGUST 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	4.03E-02	1.02E-02	50	4.84E-02	1.43E-02	50	1.36E-02	3.01E-03	50	1.87E-02	5.12E-03
100	**4.99E-02	**1.04E-02	100	2.73E-02	9.72E-03	100	1.01E-02	1.98E-03	100	1.13E-02	2.65E-03
200	**1.04E-01	**1.39E-02	200	1.45E-02	4.03E-03	200	1.43E-02	2.98E-03	200	9.54E-03	2.95E-03
400	**8.79E-02	**1.73E-02	400	8.42E-03	3.71E-03	400	2.61E-03	7.17E-04	400	Bad Data	Bad Data
800	3.72E-02	1.06E-02	800	2.40E-03	4.39E-04	800	3.19E-03	1.35E-03	800	Bad Data	Bad Data

* includes thunder

** includes bulldozer

Table 4.4 Peak and RMS particle velocities for Phase IV (December 1994)

CLEAR SPRINGS--DECEMBER 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	2.21E-02	1.89E-03	40	2.66E-02	7.92E-03	43	3.09E-02	2.86E-03	32	3.21E-02	5.69E-03
100	1.49E-02	3.05E-03	90	1.81E-02	3.81E-03	93	2.66E-02	3.25E-03	132	1.60E-02	3.47E-03
200	1.41E-02	3.39E-03	190	2.79E-02	6.92E-03	193	1.36E-02	3.84E-03	332	1.77E-02	4.25E-03
400	1.44E-02	5.55E-03	390	1.53E-02	6.10E-03	393	1.04E-02	2.41E-03	732	5.22E-03	1.49E-03
800	7.20E-03	2.20E-03	790	8.98E-03	2.22E-03	793	8.59E-03	2.65E-03			

FT. GREEN--DECEMBER 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	5.27E-02	4.76E-03	50	3.03E-02	5.12E-03	50	5.07E-02	9.25E-03	57	1.48E-02	2.23E-03
100	1.13E-02	2.67E-03	100	2.07E-02	6.16E-03	100	1.78E-02	3.68E-03	107	2.04E-02	4.23E-03
200	1.32E-02	2.23E-03	200	1.30E-02	2.50E-03	200	1.39E-02	6.11E-03	207	5.00E-03	8.44E-04
400	9.23E-03	3.10E-03	400	9.69E-03	1.93E-03	400	5.51E-03	1.36E-03	407	5.39E-03	2.03E-03
800	1.27E-02	1.35E-03	800	6.36E-03	8.01E-04	800	1.01E-02	5.90E-03	807	5.68E-03	3.08E-03

NORALYN--DECEMBER 1994											
LATE MORNING			AFTERNOON			NIGHT			EARLY MORNING		
Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s	Distance from dragline, feet	Peak Particle Velocity, in/s	RMS Velocity, in/s
50	2.04E-02	4.09E-03	50	1.85E-02	6.78E-03	50	2.61E-02	4.28E-03	50	1.95E-02	3.09E-03
100	1.51E-02	3.79E-03	100	1.25E-02	4.27E-03	100	1.63E-02	1.81E-03	100	1.60E-02	2.65E-03
200	1.21E-02	2.72E-03	200	8.89E-03	3.08E-03	200	2.62E-02	1.95E-03	200	1.20E-02	3.16E-03
400	1.13E-02	4.25E-03	400	9.38E-03	2.92E-03	400	1.17E-02	2.88E-03	400	1.21E-02	3.61E-03
800	1.18E-02	3.50E-03	770	9.13E-03	1.29E-03	800	7.54E-03	2.92E-03	800	9.42E-03	2.43E-03

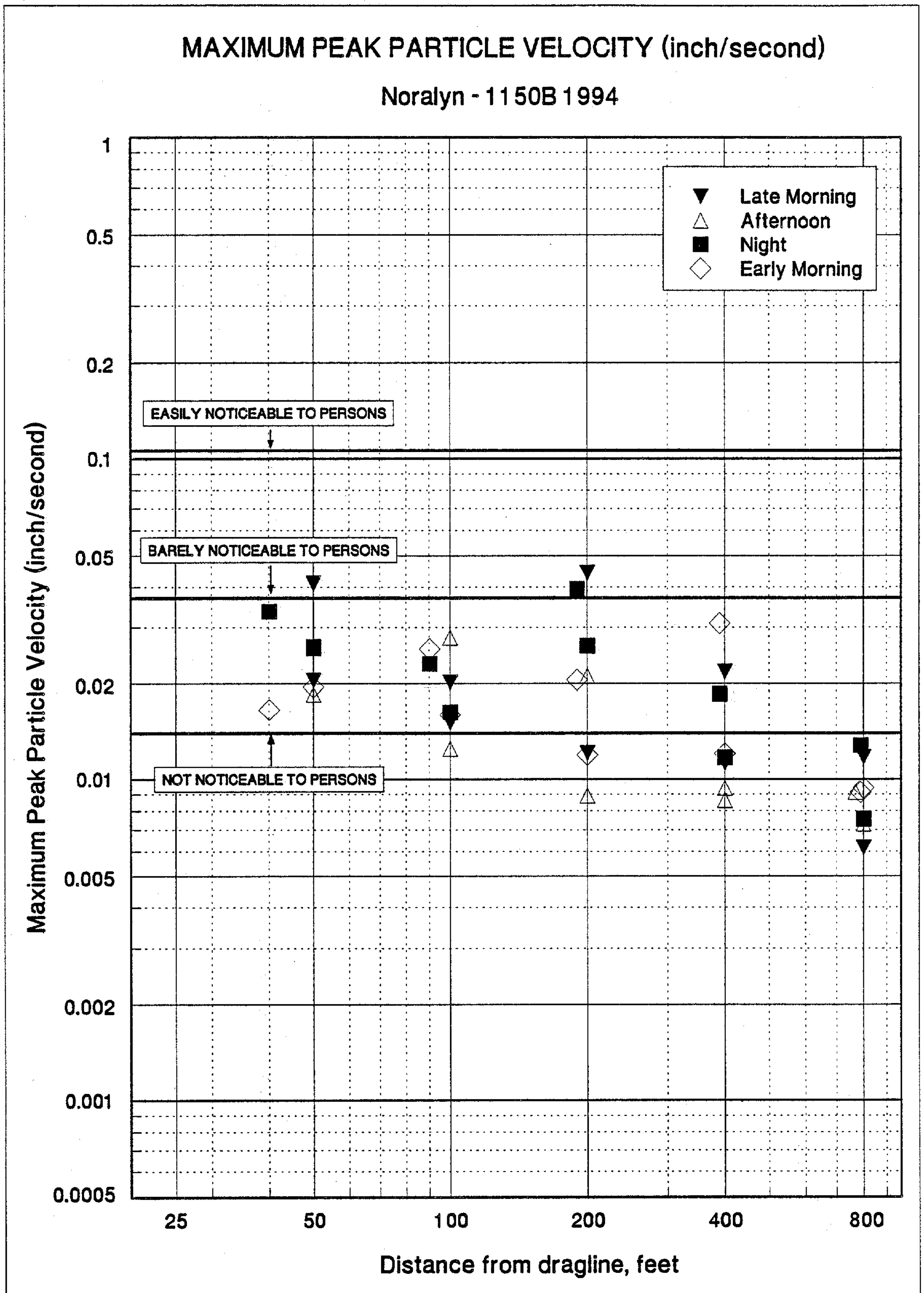


Figure 4.2 Peak particle velocity versus distance from dragline for 1150B

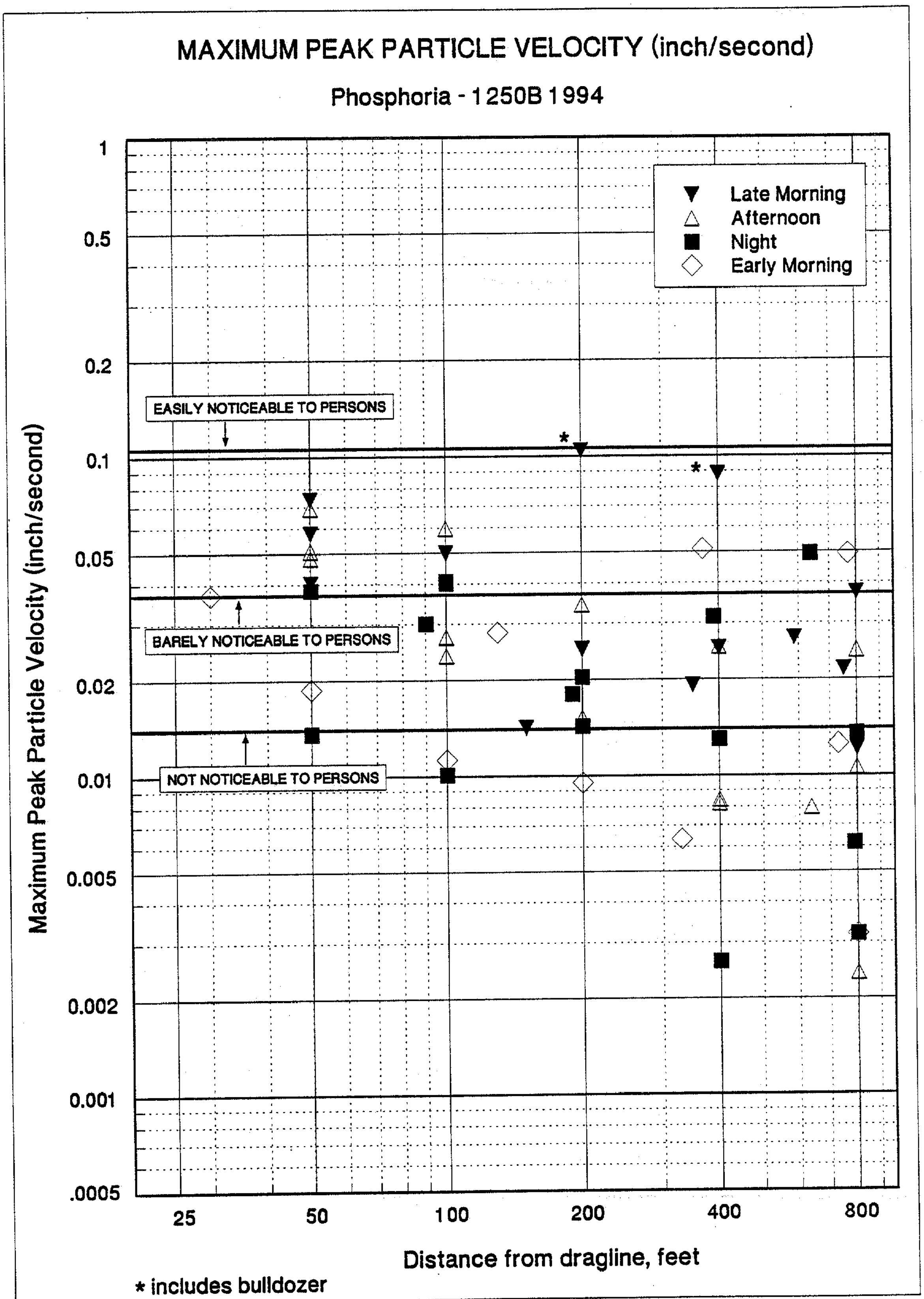


Figure 4.3 Peak particle velocity versus distance from dragline for 1250B

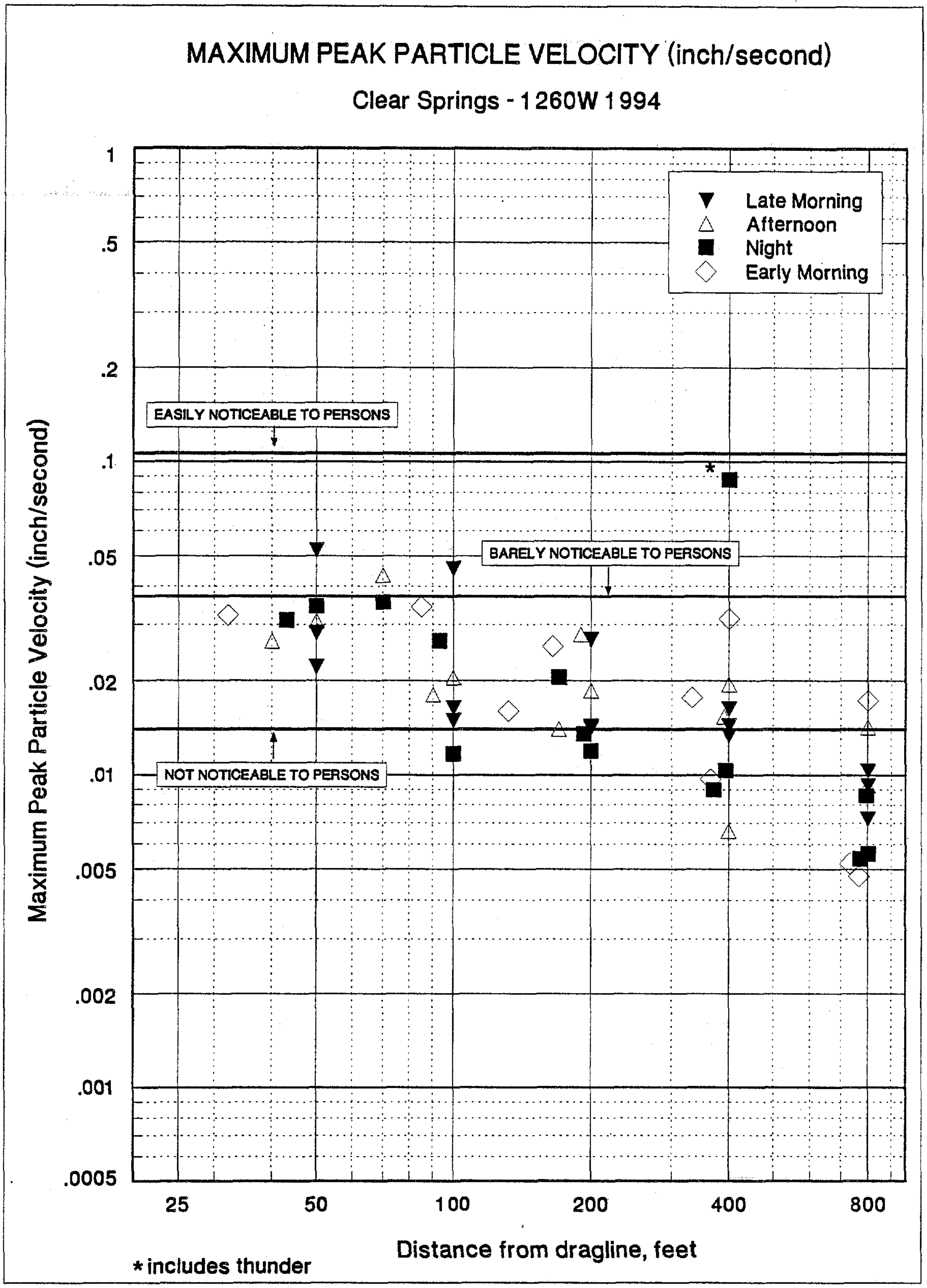


Figure 4.4 Peak particle velocity versus distance from dragline for 1260W

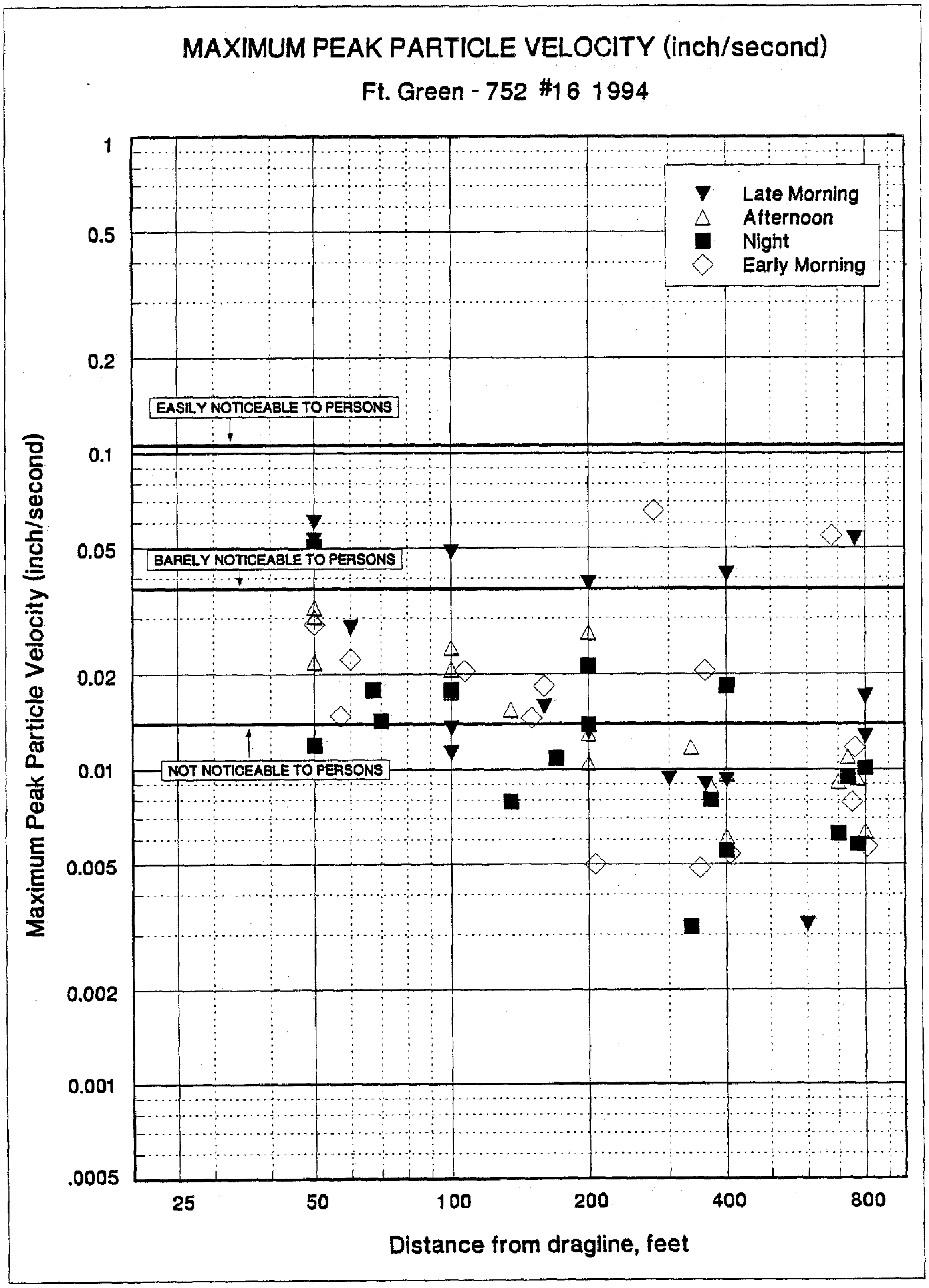


Figure 4.5 Peak particle velocity versus distance from dragline for 752 #16

In order to suppress what is known as leakage, or truncation errors resulting from the FFT algorithm, the Parzen window was utilized in the program. The Parzen window is simply one of many different data windows that may be utilized to counteract the leakage phenomenon.

For the estimation of the power spectral density, or PSD, in the frequency range of 0 to 12000 Hz, the original sound data for each distance were partitioned into 240 segments. Each segment contained 4096 consecutive sampled points and was separately FFT'd to produce a periodogram estimate. Finally, the 240 periodogram estimates were averaged at each frequency. The result of Part II in the program is a sound pressure spectrum of frequency (Δf = 5.859 Hz) versus sound pressure level in decibels. These sound pressure spectrums are graphically presented in Appendix D for each noise measurement to show how the sound pressure is distributed as a function of frequency. The spectrums are shown in the range of 0 to 2000 Hz since this is where the critical sound pressure levels occur. However, four noise spectrums, representing each dragline, are presented in the range of 0 to 12000 Hz at the beginning of Appendix D to show how the sound pressure level varies after 2000 Hz.

4.6 OVERALL SOUND PRESSURE LEVEL (OASPL)

The overall sound pressure level (OASPL) was also determined for each noise measurement by a formula in the Fortran program. OASPL is calculated by converting the sound pressure levels measured in a series of contiguous frequency bands into a single-band pressure level encompassing the same frequency range. Thus, the OASPL was determined by combining the sound pressure levels in the 0 to 12000 Hz frequency range. The overall sound pressure levels corresponding to the noise frequency spectrums are presented in Appendix D.

4.7 FREQUENCY ANALYSIS ON SELECTED VIBRATION DATA

Part II of the FORTRAN program was slightly modified to perform frequency analysis on eight selected ground vibration measurements. Figures showing the frequency versus the particle velocity for the selected vibration measurements are included at the end of Appendix D.

CHAPTER 5: ANALYSIS OF NOISE AND VIBRATION RESULTS

5.1 GENERAL

The noise and vibration results are further evaluated in this chapter. The effects of various factors on the sound level meter and on airborne sound are reviewed as related to the field monitoring program. Discussions are made on the sound level, peak particle velocity, and frequency analysis results obtained from the field data.

5.2 INFLUENCE OF VARIOUS FACTORS ON SOUND LEVEL METER

When making sound level measurements outdoors, it is essential to know the influence of the environment on the instruments and on the attenuation of airborne sound. Various factors such as, type of microphone, position of operator, temperature, humidity, and wind speed, will affect the sound level meter as well as the sound level readings. Moreover, the environmental conditions can also have an effect on the sound propagation or attenuation through the air.

Type of Micronhone

The type of microphone and its placement in the outdoor sound field influence the accuracy of the sound level measurements. The microphone used in the field during the field measurements was a type 4188 prepolarized, free-field, half-inch condenser microphone which complies with the International Electrotechnical Commission standard IEC 651 (1979). It should be noted that any microphone will disturb a sound field, but the free-field microphone will compensate for the interference it causes in the sound field. The microphone was mounted on top of a tripod and pointed directly at the dragline (0° incidence) during all field measurements.

Influence of Operator

When making noise measurements, it is important that the operator keep as far away from the sound level meter as possible. The operator's presence can cause reflections that may cause measurement errors, sometimes as high as 6 dB. In order to minimize reflections during the field monitoring program, the microphone was mounted on a tripod, and all persons kept as far away as possible.

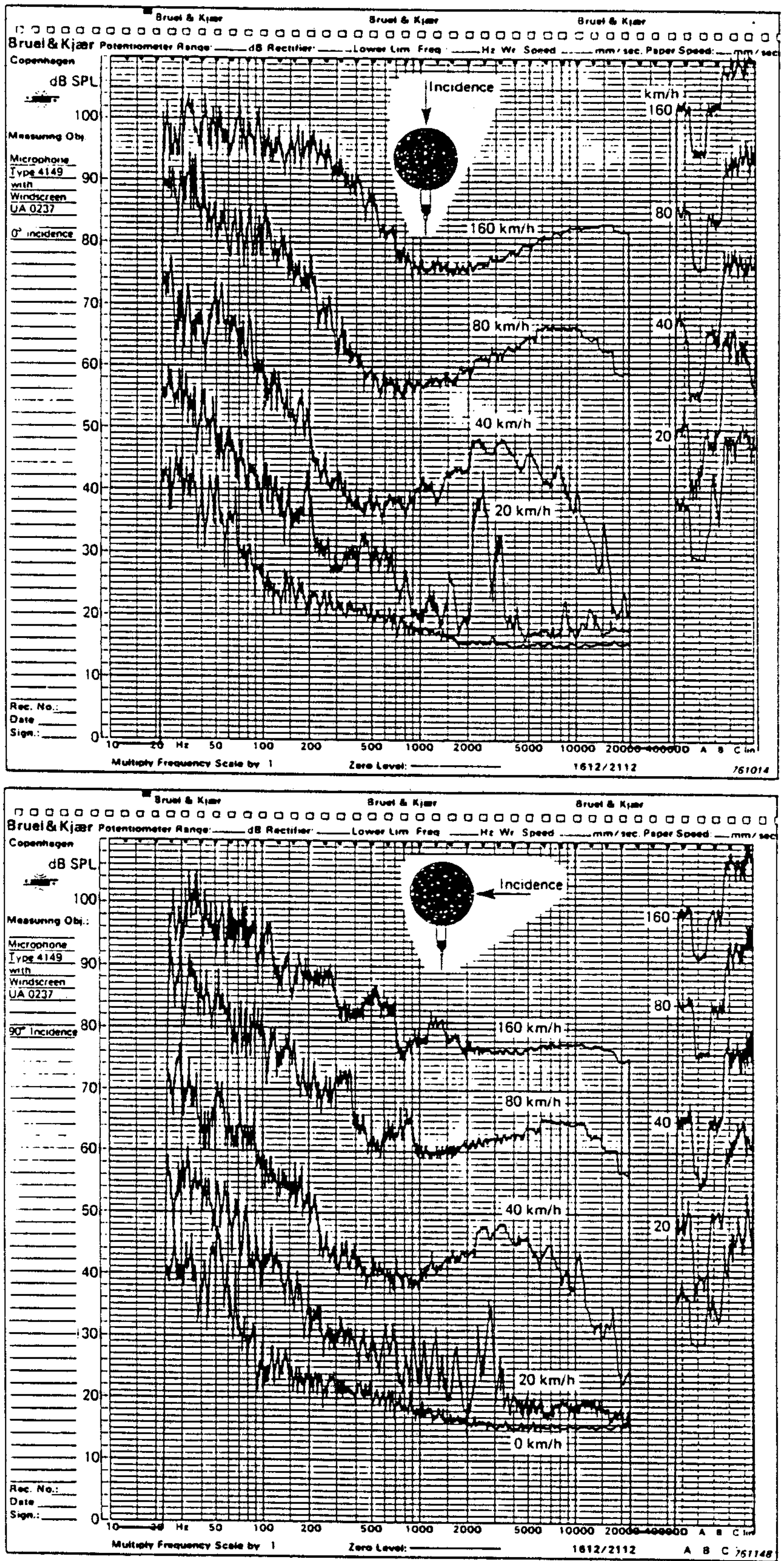
Influence of the Environment on Sound Level Meter

Environmental factors will affect the microphone as well as the sound level readings. Wind, humidity, and temperature are all enemies of a delicate sound level meter.

Wind. Wind blowing across the microphone introduces extraneous noise that can add to the overall sound pressure level. To minimize the effect of wind, a windscreen (Windscreen UA 0237 B&K) consisting of a ball of porous sponge was secured on the SLM microphone at all times during field monitoring. The wind screen did not have an appreciable effect on the readings other than to remove the extraneous noise due to wind. Therefore, the effect of the wind speed on the sound levels due to the microphone is negligible. Figure 5.1 shows wind induced noise levels for half-inch microphones fitted with Windscreen UA 0237.

The American National Standard (ANSI S1.13-1971 (R1976)) states that noise measurements should not be collected when the wind speed exceeds 13.42 mph (6 m/s). During the field measurements, the wind speed never exceeded nine miles per hour or 4.0 m/s (see Tables 2.4a & b), which is well within the ANSI limit.

Humidity. Relative humidity levels between 30 and 90 percent have less than a 0.5 dB effect on the sensitivity of the 2236 sound level meter (see Appendix E). Even in extremely humid environments, measurements are still accurate provided that the microphone is fitted with a windscreen (Bruel & Kjaer, 1984). During field monitoring, the 2236 SLM was fitted with the Windscreen 0237 for protection against the rain. Hence, the effect of the humidity on the sound levels was minimal.



a)

b)

Figure 5.1 Wind induced noise levels for half-inch microphones fitted with Windscreen UA 0237 (*source: Brüel & Kjaer, Sept. 1982*)

Temperature. All Bruel & Kjaer sound level meters are manufactured to operate accurately over the 14 to 122ºF (-10 to 50°C) range. In fact, the calibration of the 2236 SLM is not affected by more than 0.5 dB in that temperature range (see Appendix E). All sound level measurements were collected within this temperature range during the field monitoring program. Therefore, the influence of temperature on the 2236 SLM is negligible.

5.3 INFLUENCE OF THE ENVIRONMENT ON SOUND LEVELS

Sound propagating outdoors from a source to a receiver depends upon the properties of the atmosphere and the presence of any objects or barriers in the transmission path. Sound propagating through the air generally diminishes in level with increasing distance between the source and the receiver. This attenuation is the result of several mechanisms, principally geometrical divergence from the sound source (A_{div}), absorption of acoustic energy by the air (A_{air}), and the effect of propagation close to different ground surfaces (A_{ground}). The equation for total attenuation is thus:

$$A_{total} = A_{div} + A_{air} + A_{ground} \ dB \tag{5.1}$$

For the purposes of this research study, the following factors are reviewed: (1) the distance between source and receiver, A_{div}, and (2) the absorption of acoustic energy by the air, A_{air}. The influence of the type of ground surface (A_{ground}) is not considered for this study.

Geometrical Divergence (A_{div})

When sound is radiated from a source in a homogeneous and undisturbed atmosphere, far away from all reflecting or absorptive surfaces, the sound is radiated as spherical waves (like ripples in a pond). When the distance between the source and receiver doubles, the amplitude of the waves drops by half, which corresponds to a drop of 6 dB. Spherical spreading of acoustic energy in a free field from a source (A_{div}) is given by (Harris, 1991):

$$A_{div} = 20 \log_{10} r + 0.6 - C \ dB \qquad (5.2)$$

where:

r = the distance from the source to the receiver in feet

C = a small correction factor which may be obtained from Figure 5.2

The term $20*\log_{10}r$ in this equation signifies a sound level which decreases 6 dB per doubling of distance from the source. The correction term C depends on the temperature and atmospheric pressure, and is usually negligible except for temperatures and/or pressures which differ significantly from 20°C (68 ºF) and 1 atm, respectively (see Figure 5.2).

Attenuation from Air Absorption (A_{air})

As sound propagates through the atmosphere, its energy is gradually converted into heat, or the sound is absorbed, by a number of molecular processes in the air called air absorption. The attenuation of sound due to air absorption, A_{air}, during propagation, is as follows (Harris, 1991):

$$A_{air} = \frac{\alpha d}{1000} \qquad \textbf{(5.3)}$$

where:

α = the air attenuation coefficient in decibels per kilometer.

d = the distance between source and receiver in meters

The propagation of sound near the ground for horizontal distances less than about 300 feet (100 m) is basically independent of atmospheric conditions (Harris, 1991). Therefore, A_{air} can be neglected at short distances except for frequencies above 5000 Hz (see Table 5.1).

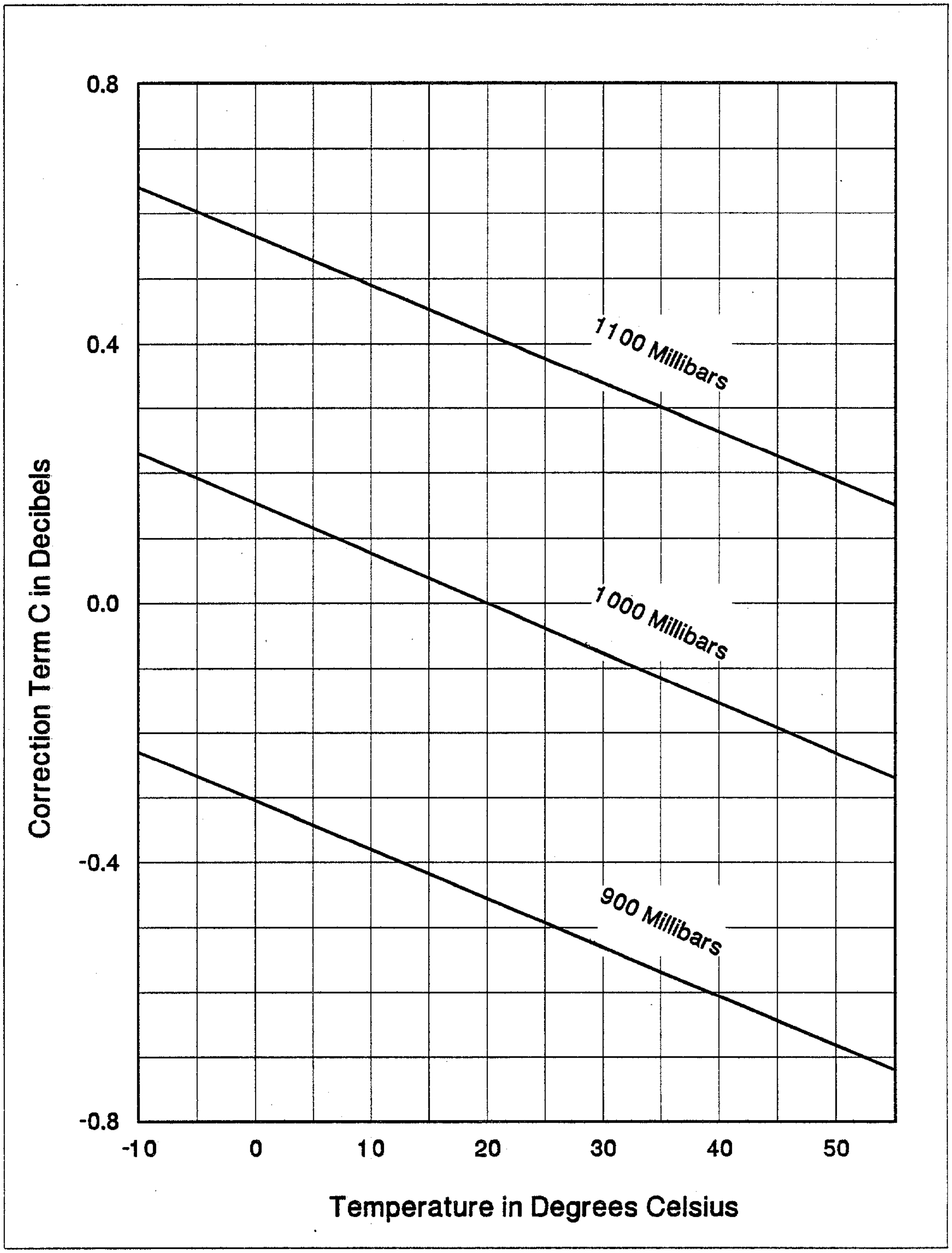


Figure 5.2 Correction term C as a function of temperature, for three values of atmospheric pressure (*source: Harris, 1991*)

Temperature. During the collection of sound level measurements in the field, the temperature ranged from 54°F to 100ºF (see Tables 2.3a and b). Table 5.1 shows that temperature has a substantial effect on the attenuation at high frequencies and long distances through air absorption. For example, to calculate A_{air} for the Phase I, Fort Green night measurement at a frequency of 1000 Hz, refer to Table 2.3a. The temperature was 68ºF, the relative humidity was 68 percent and, say the distance from the dragline was 800 feet (244m). Since a value for the absorption coefficient is not available for 80 percent humidity, interpolation is necessary. Interpolation yields 5.2 for α, the absorption coefficient. Substituting into equation (5.3) yields:

$$A_{air} = \frac{5.2(244)}{1000} = 1.27dB$$

Meaning, that 1.27 dB of sound was absorbed by the air under the given conditions.

Relative Humidity. The influence of relative humidity on sound propagation can be seen in Table 5.1. Generally, as the humidity increases, the attenuation of sound decreases (when temperature is constant). In other words, less sound energy is absorbed by the atmosphere when the humidity is high. The humidity ranged from 48 to 100 percent during field monitoring. Take, as an example, the Phase II, Fort Green night temperature and humidity values from Table 2.3a. The humidity obtained in the field was 56 percent, while the temperature was 80ºF. At a frequency of 1000 Hz and a distance of 800 feet (244m) from the dragline, the air absorption coefficient obtained by interpolation is 6.34. Now, substituting 6.34 for a into equation (5.3) yields:

$$A_{air} = \frac{6.34(244)}{1000} = 1.55\ dB$$

Meaning, that 1.55 dB of sound was absorbed by the air under the given conditions.

Frequency. Attenuation of sound due to air absorption also depends strongly on the frequency of the sound. For example, at 800 feet (244 m), 4000 Hz, 68 °F (20 °C), and 80% relative humidity, the air absorption coefficient of 21.5 yields:

$$A_{air} = \frac{21.5(244)}{1000} = 5.25 \quad dB$$

Table 5.1 Air Attenuation Coefficient (α), dB/km, for Ambient Pressure of 1 atm for Sound Propagation in Open Air (*source: Harris, 1991*)

Temperature	Relative humidity, %	Frequency, Hz					
		125	250	500	1000	2000	4000
30°C (86°F)	10	0.96	1.8	3.4	8.7	29	96
	20	0.73	1.9	3.4	6.0	15	47
	30	0.54	1.7	3.7	6.2	12	33
	50	0.35	1.3	3.6	7.0	12	25
	70	0.26	0.96	3.1	7.4	13	23
	90	0.20	0.78	2.7	7.3	14	24
20°C (68°F)	10	0.78	1.6	4.3	14	45	109
	20	0.71	1.4	2.6	6.5	22	74
	30	0.62	1.4	2.5	5.0	14	49
	50	0.45	1.3	2.7	4.7	9.9	29
	70	0.34	1.1	2.8	5.0	9.0	23
	90	0.27	0.97	2.7	5.3	9.1	20
10°C (50°F)	10	0.79	2.3	7.5	22	42	57
	20	0.58	1.2	3.3	11	36	92
	30	0.55	1.1	2.3	6.8	24	77
	50	0.49	1.1	1.9	4.3	13	47
	70	0.41	1.0	1.9	3.7	9.7	33
	90	0.35	1.0	2.0	3.5	8.1	26

Wind Speed and Direction

The wind speed and direction can also have a noticeable effect on sound level in open air. Of course, if a microphone is placed downwind from the noise source, the sound level will be higher than if it were placed upwind from the source (Bugliarello, et al., 1976). The wind speeds and directions during field monitoring for each dragline site measurement can be found in Tables 2.3a & b.

5.4 ANALYSIS OF NOISE AND VIBRATION DATA

Equivalent Continuous Sound Levels (L_{eq})

In Chapter 3, the regression line of L_{eq} versus distance was graphically presented for each dragline with respect to the time of day for each season The variability in the sound levels for each site measurement may have been caused by one or more of the following factors:

(1) different dragline operators
(2) dragline swinging empty or mining
(3) pit guns on or off during measurements
(4) shifts in weather conditions

Figures 5.3 through 5.6 show the regression line generated for each dragline including all L_{eq} measurements taken for each dragline during the field monitoring program. The equation for each regression line as well as the r-squared coefficient are also shown on each figure. The regression lines from Figures 5.3 through 5.6 are summarized in Table 5.2 and are presented in Figure 5.7 to show how the L_{eq} measurements for each dragline vary. The slope and x-intercept from the regression lines are also graphically presented in Figure 5.8. It is apparent from Figures 5.7 and 5.8 that the 1260W dragline at Clear Springs produced the highest L_{eq} levels, while the 752 #16 dragline at Fort Green created the lowest sound levels. In fact, the sound levels between the two machines differ by almost 15 dBA at 50 feet. However, the slopes of the regression lines are very similar for the four monitored draglines.

Property line measurements. During field monitoring, sound level measurements were performed at three different property lines (see Tables 3.2, 3.7 and, 3.8). Equivalent continuous sound levels were found for the property line measurements during Phase I. The two sound level measurements performed during Phase III, on the other hand, were recorded using the sound level meter only. Therefore, L_{eq} values were not attainable for these measurements. However, reasonably accurate L_{eq} values can be estimated by looking at the differences between L_{eq}s and L_{AV5}s in Tables 3.7 and 3.8.

Table 5.2: Regression line equations for each dragline--slope and x-intercept

Dragline/Site	Regression Equation	Slope (m) dBA/distance	X-intercept (b) dBA
1260W/Clear Springs	y = 131.2 - 25.00*logx	m_1 = -25.00	b_1 = 131.2
752 #16/Fort Green	y = 105.0 - 18.76*logx	m_2 = -18.88	b_2 = 105.3
1150B/Noralyn	y = 115.6 - 21.75*logx	m_3 = -21.75	b_3 = 115.6
1250B/Phosphoria	y = 109.2 - 20.05*logx	m_4 = -20.05	b_4 = 109.2

Peak Particle Velocity

Peak particle velocities (PPVs) obtained for the ground vibration (presented in Chapter 4) are on or below 0.106 inch per second which is classified as "easily noticeable to persons" according to the NAVFAC DM 7.3 Naval Facilities Design Manual (see Figure 5.9). The considerably high PPVs obtained for the 1250B and 1260W draglines were caused by a bulldozer and thunder respectively (see Figures 4.2 and 4.4). The peak particle velocities obtained, are consistent with previous research efforts (Ardaman and Associates, Inc., 1993).

Frequency Analysis - Noise

The results of the frequency analysis performed on the sound measurements can be found in Appendix D. Sound pressure level, in dB, was plotted against frequency between 0 and 2000 Hertz since the most prominent sound pressure levels occur within this frequency range.

Frequency Analysis - Vibration

Frequency analysis was also performed on selected ground vibration measurements to show how the peak particle velocity was distributed as a function of ground vibration frequency. The frequency spectrums for the eight selected vibration data are presented after the noise frequency spectrums in Appendix D.

Seasonal Effects

It is generally known that the weather in the state of Florida is not seasonal (i.e., there are not four distinct seasons). Figure 5.10 shows how the temperature, relative humidity, and wind speed varied for each season during the noise and ground vibration

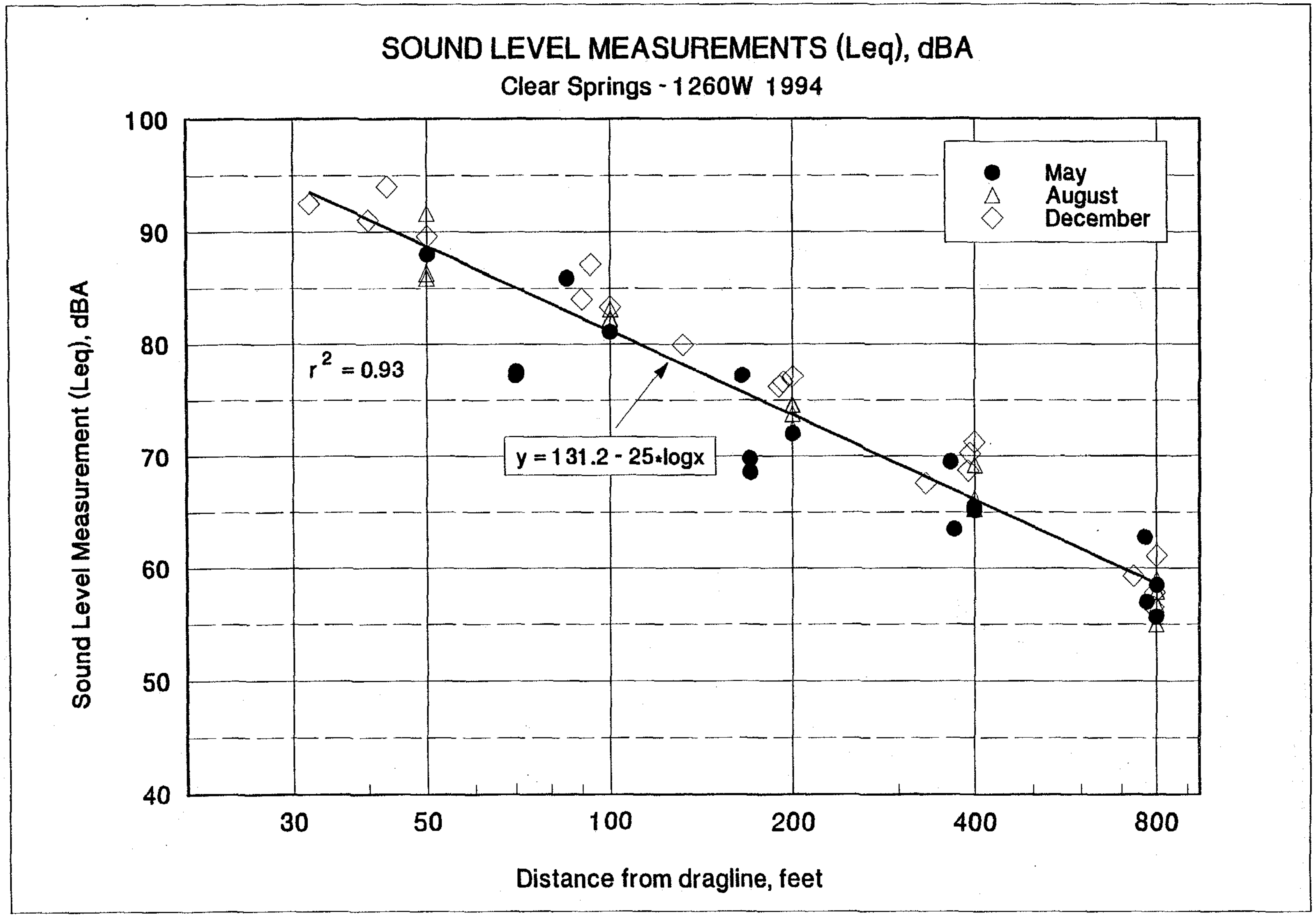


Figure 5.3 L_{eq} **versus distance from dragline including all measurements for 1260W - Clear Springs**

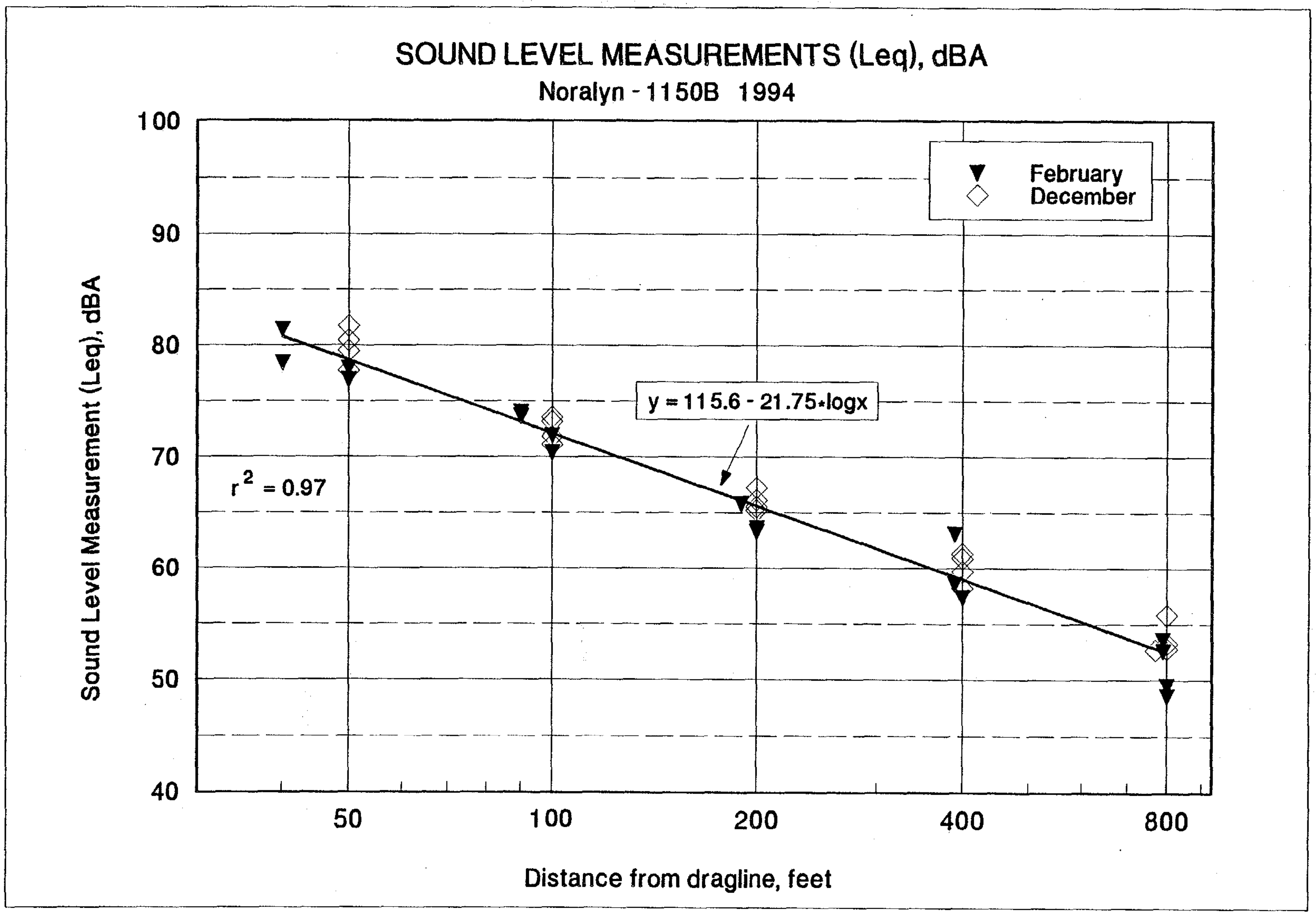


Figure 5.4 L_{eq} **versus distance from dragline including all measurements for 1150B - Noralyn**

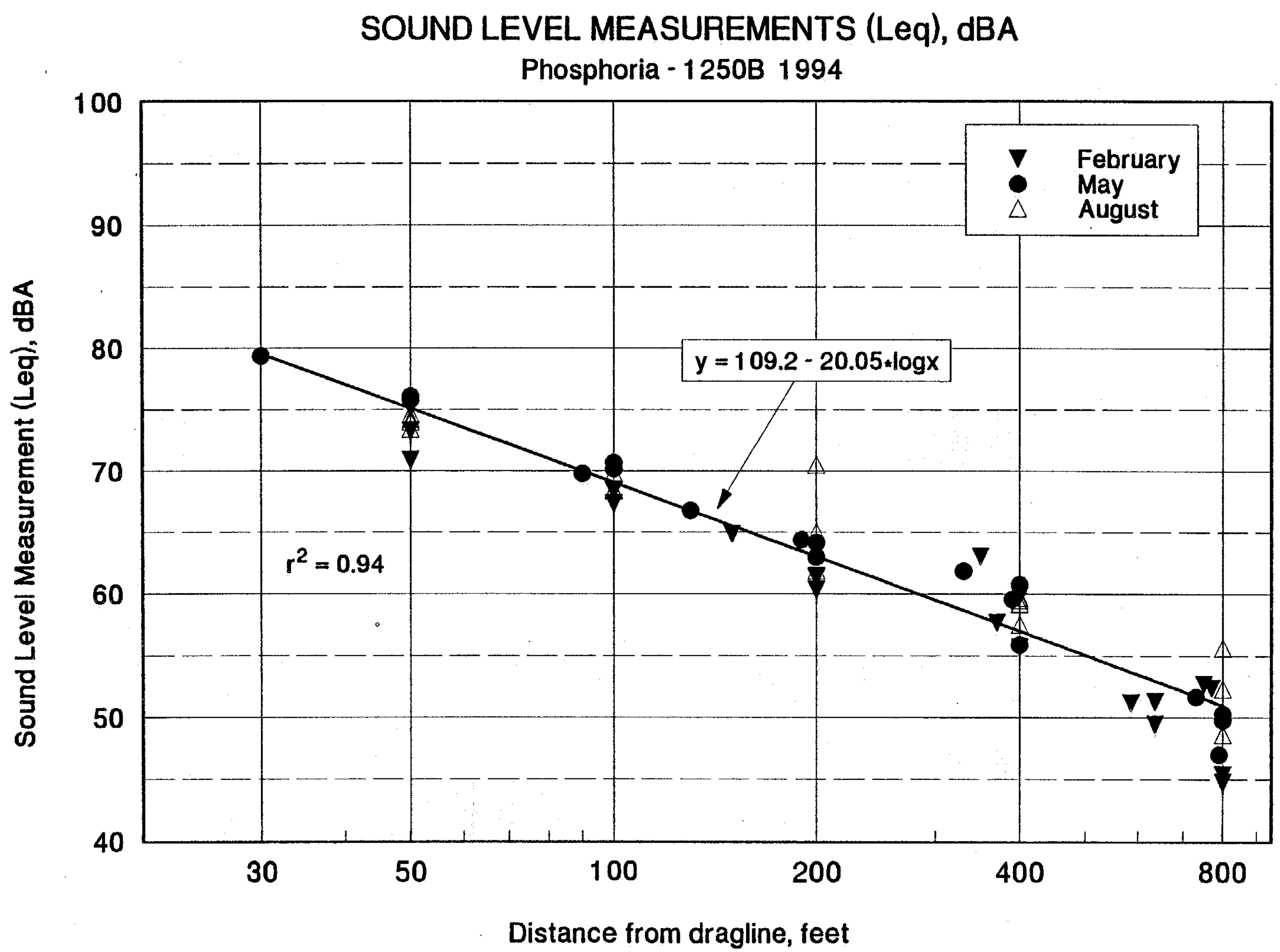


Figure 5.5 L_{eq} **versus distance from dragline including all measurements for 1250B - Phosphoria**

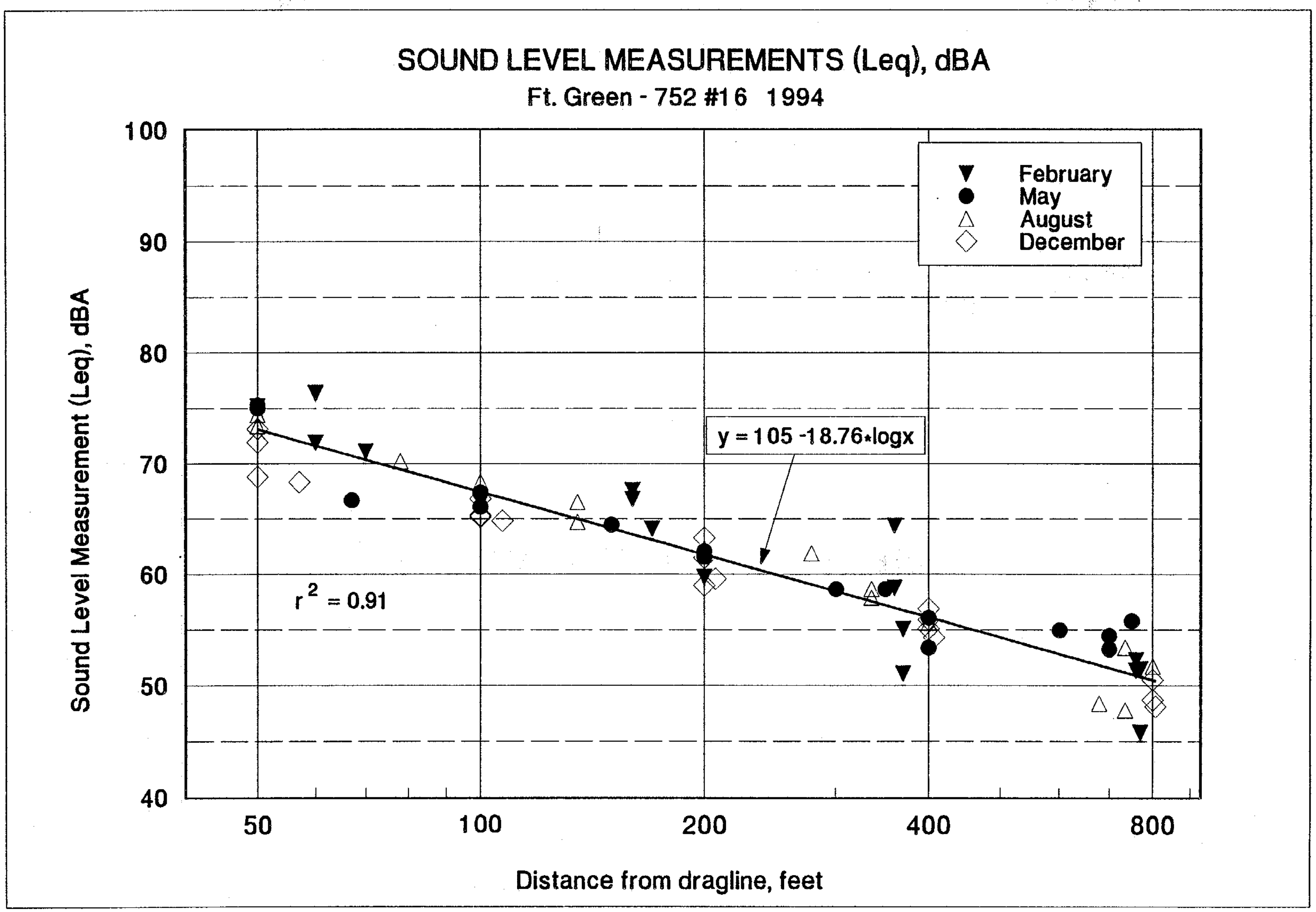


Figure 5.6 L_{eq} **versus distance from dragline including all measurements for 752 #16 - Fort Green**

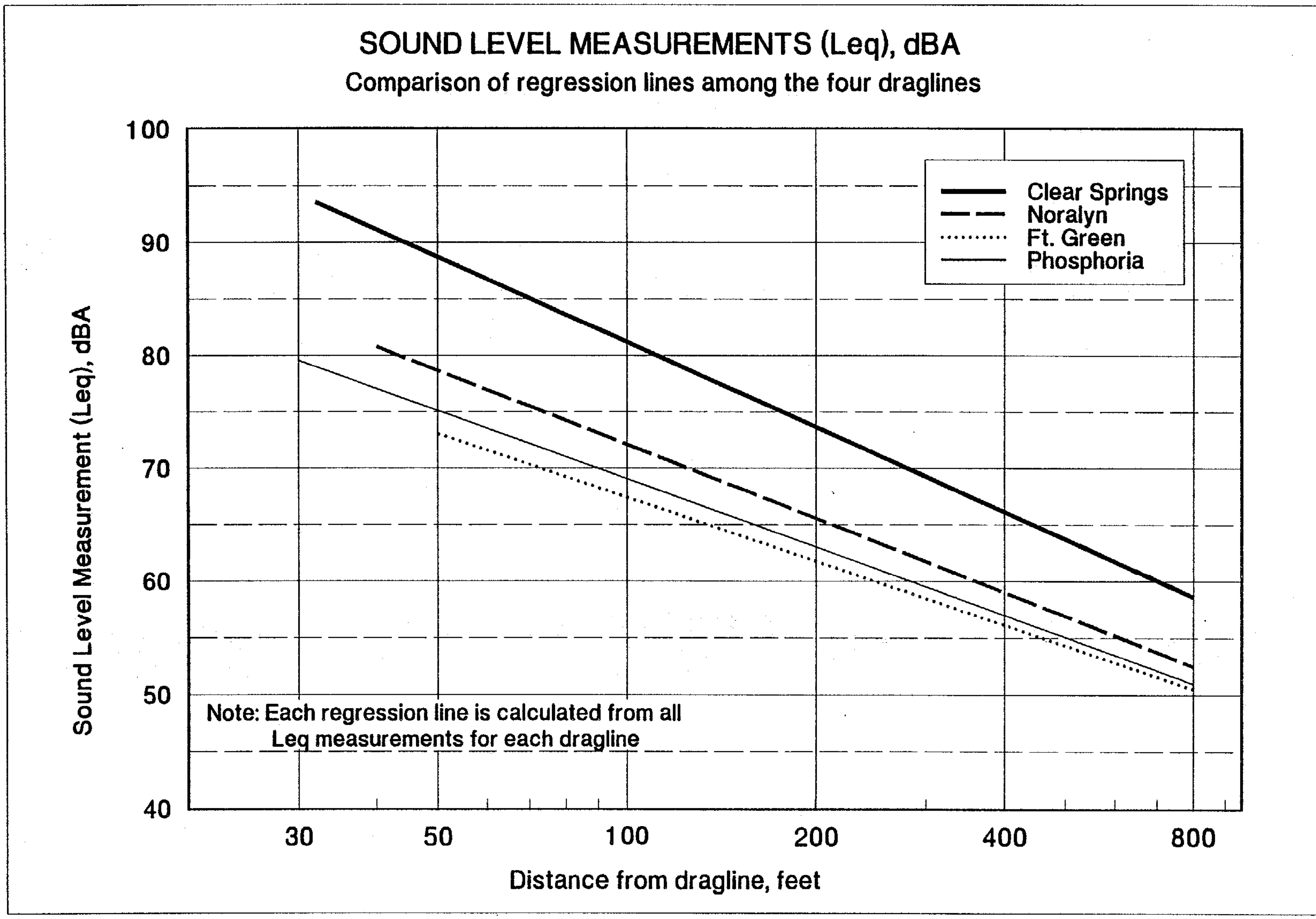
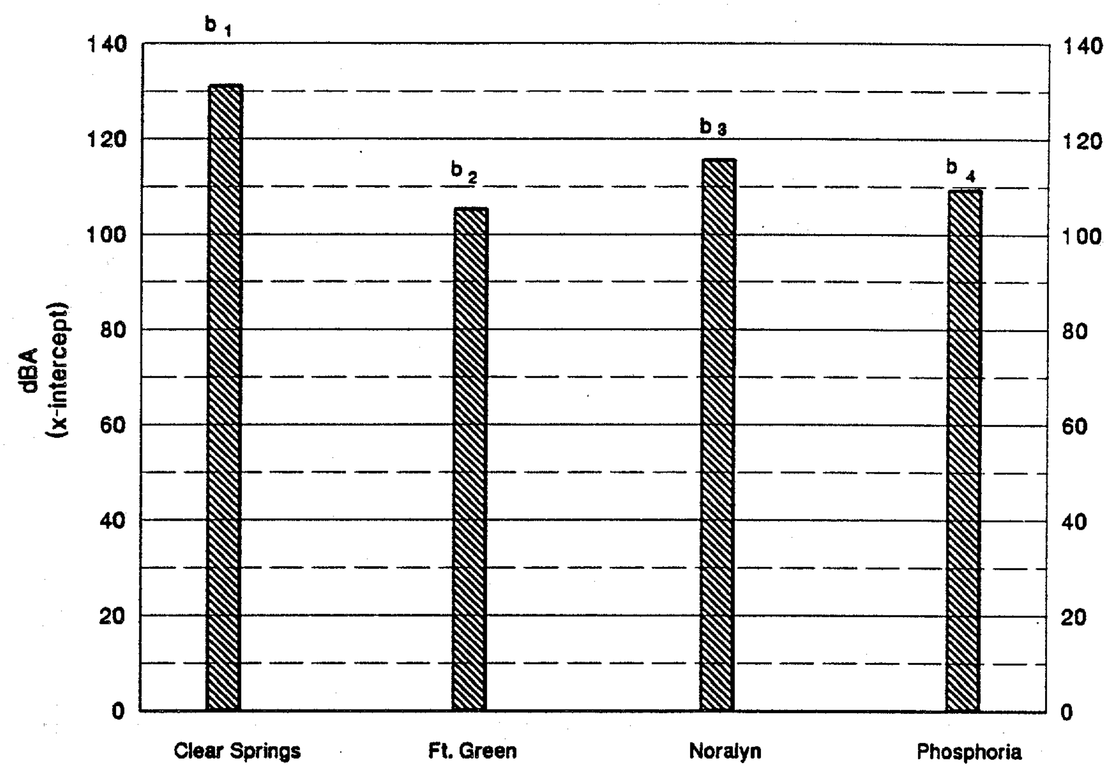


Figure 5.7 Comparison of L_{eq} versus distance from dragline for all four draglines



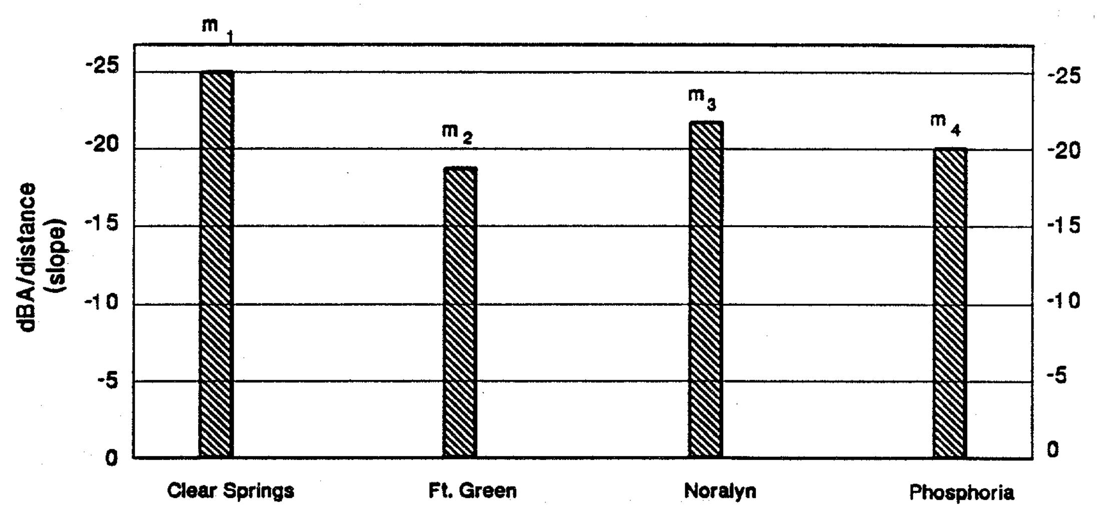


Figure 5.8 Graphical representation of x-intercept and slope from linear regression analysis of sound level measurements

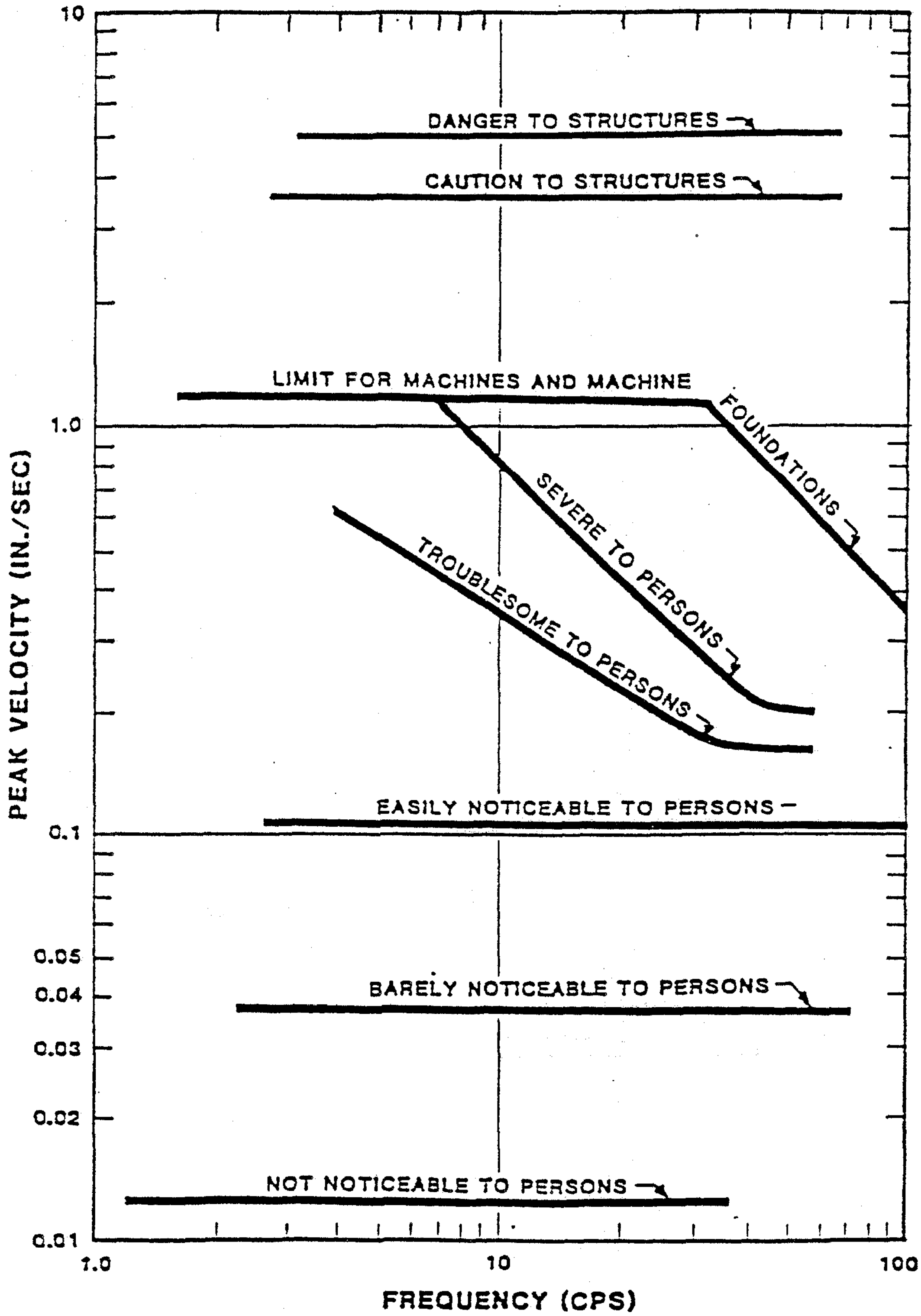


Figure 5.9 Allowable amplitude of ground vibrations (*redrawn from the NAVFAC DM 7.3 Naval Facilities Design Manual*)

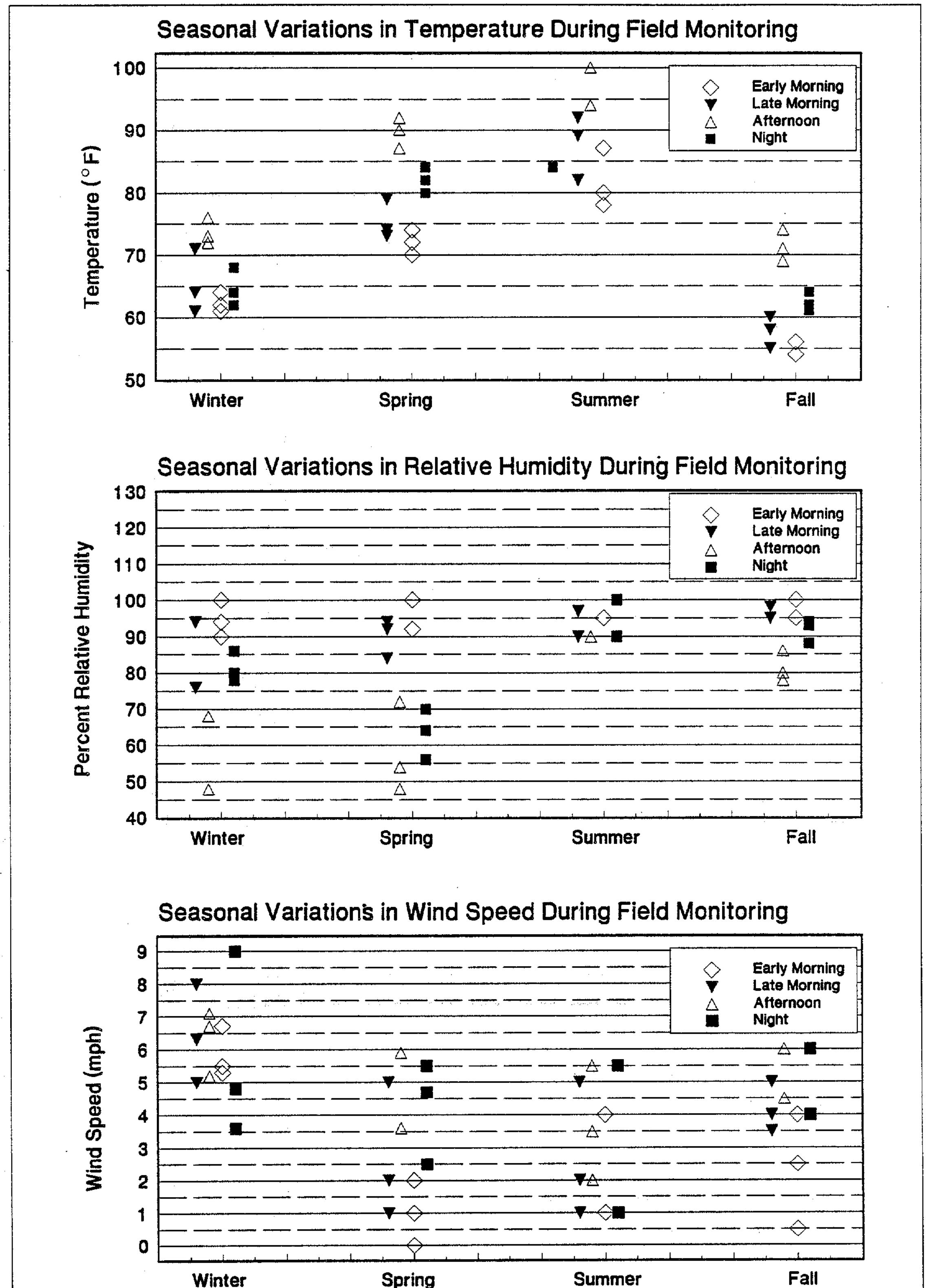


Figure 5.10 Seasonal variations in temperature, humidity, and wind speed during field monitoring

field monitoring. Noise and vibration measurements were recorded during every season, nonetheless, to examine what effect, if any, the different seasons (weather conditions) had on the sound level measurements. Notice from Figure 5.10 that the temperature in the summer was higher, on the average, than the other seasons, whilst the humidity in the winter and spring were the lowest. The wind speed was appreciably greater in the winter than during any other season.

To see the effect of the seasonal variability on the sound levels, a graph for each dragline of L_{eq} versus distance from the dragline was drawn with respect to the seasons (see Figures 5.11 through 5.14). From the figures, it is evident that no significant relationship between sound levels and seasons exist. However, the 752 #16 dragline was the only dragline in which four seasons of sound measurements were collected. Thus, it is felt that more data may be needed to determine if any significant conclusion can be drawn.

Since the dragline operations were not controlled during field monitoring, it is difficult to say if the variability in the sound levels arose from seasonal shifts in weather conditions or from other uncontrollable factors.

Effect of Time of Day

The time of day is an important factor in determining the acceptance of a noise source. For example, loud noise levels at night in residential areas are not acceptable because of sleep disturbance, while nighttime noise near professional buildings is not as important as noise during the working portion of the day. Thus, community noise ordinances specify different sound level limits for the daytime (7:00 a.m. to 10:00 p.m.) and the nighttime (10:00 p.m. to 7:00 a.m.). For this reason, two dragline sound level measurements were conducted between 6:00 a.m. and 6:00 p.m. and two measurements were taken between 6:00 p.m. and 6:00 a.m..

Figures 3.4 through 3.15 and Tables 3.1 through 3.12 in Chapter 3 present the L_{eq} levels obtained in the field with respect to the time of day. The tables and figures show that there was no noticeable difference between the daytime and nighttime L_{eq} readings. Based on field observations, however, background noise levels during the early

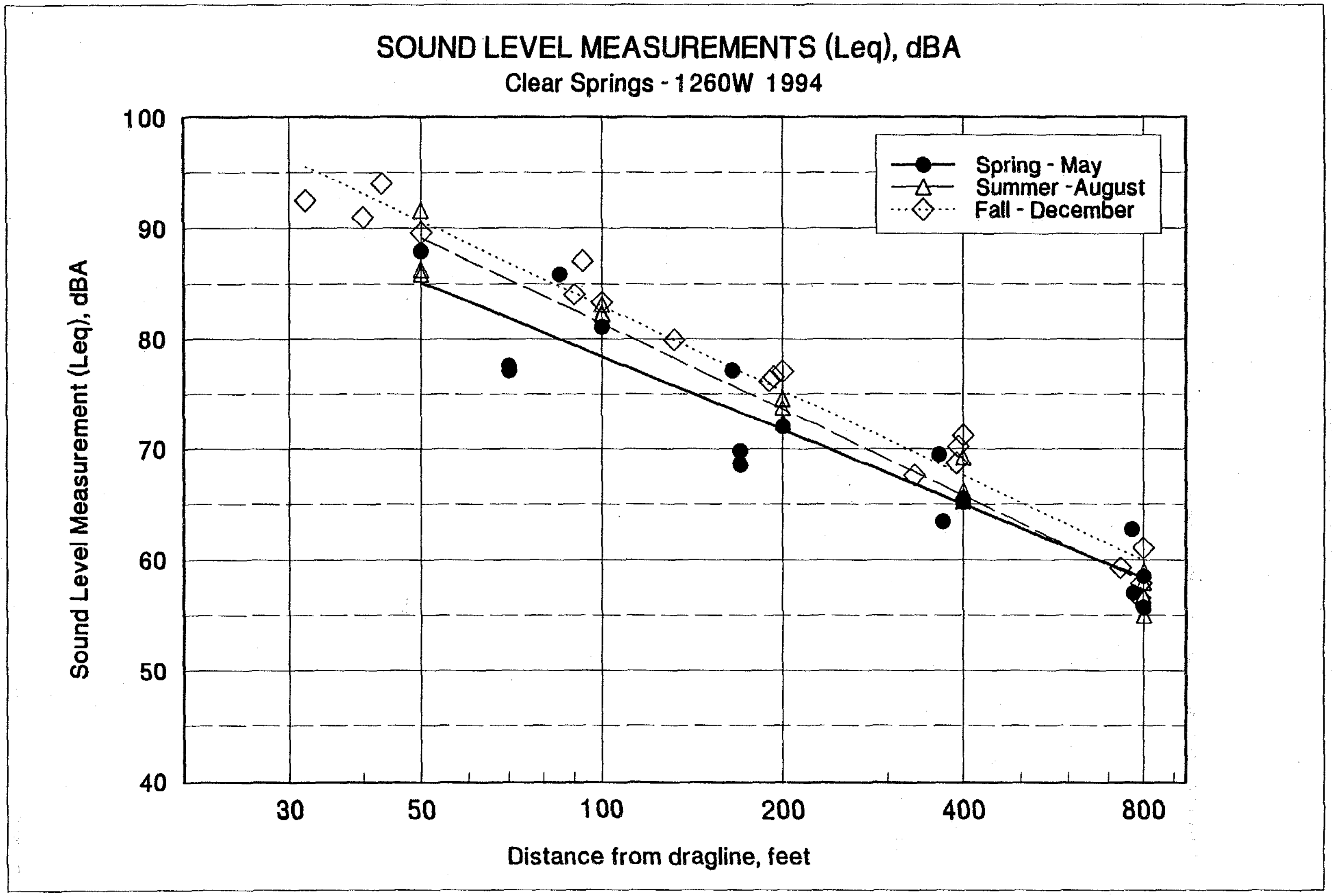


Figure 5.11 L_{eq} **versus distance from dragline with respect to seasons for 1260W - Clear Springs**

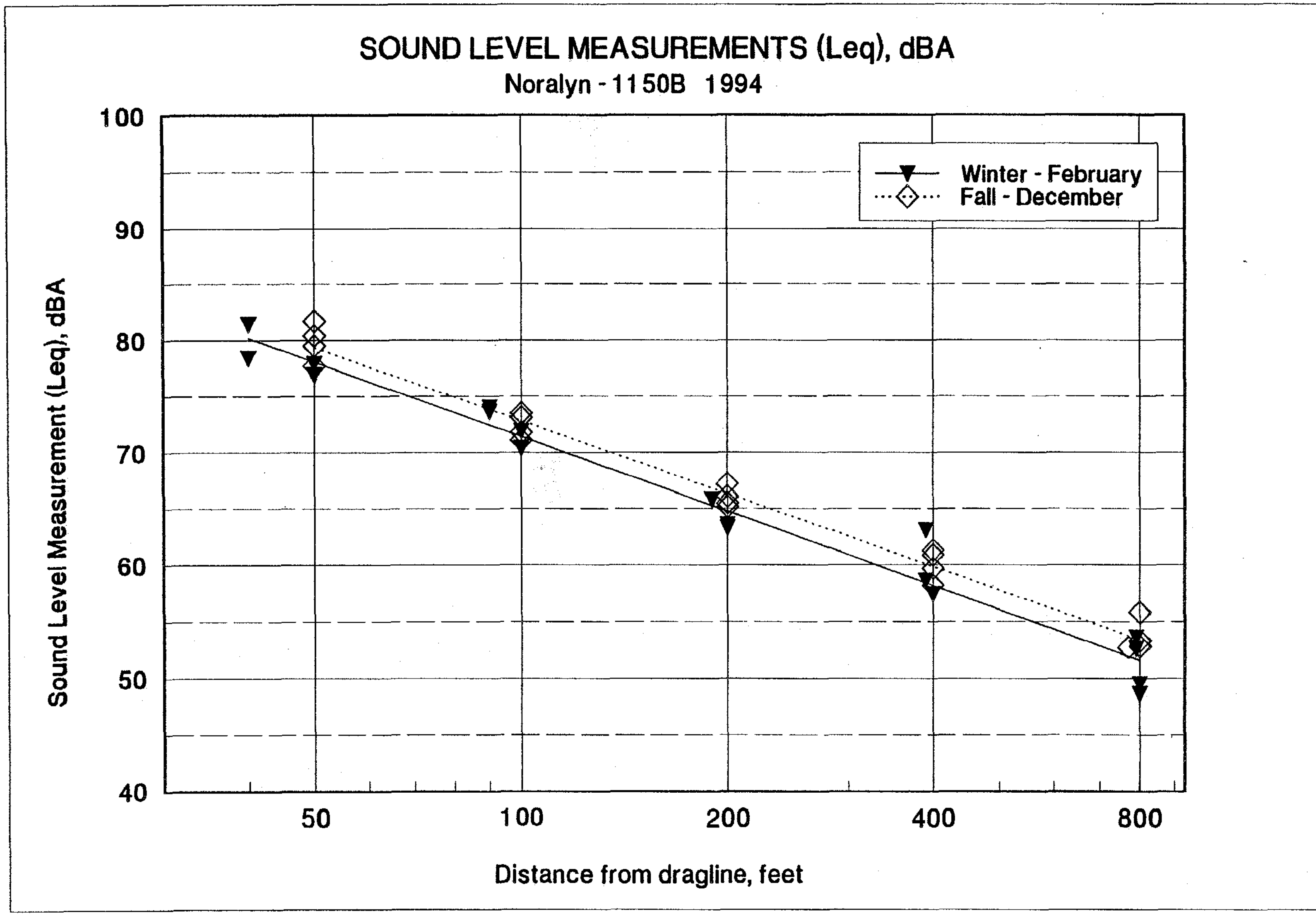


Figure 5.12 L_{eq} **versus distance from dragline with respect to seasons for 1150B - Noralyn**

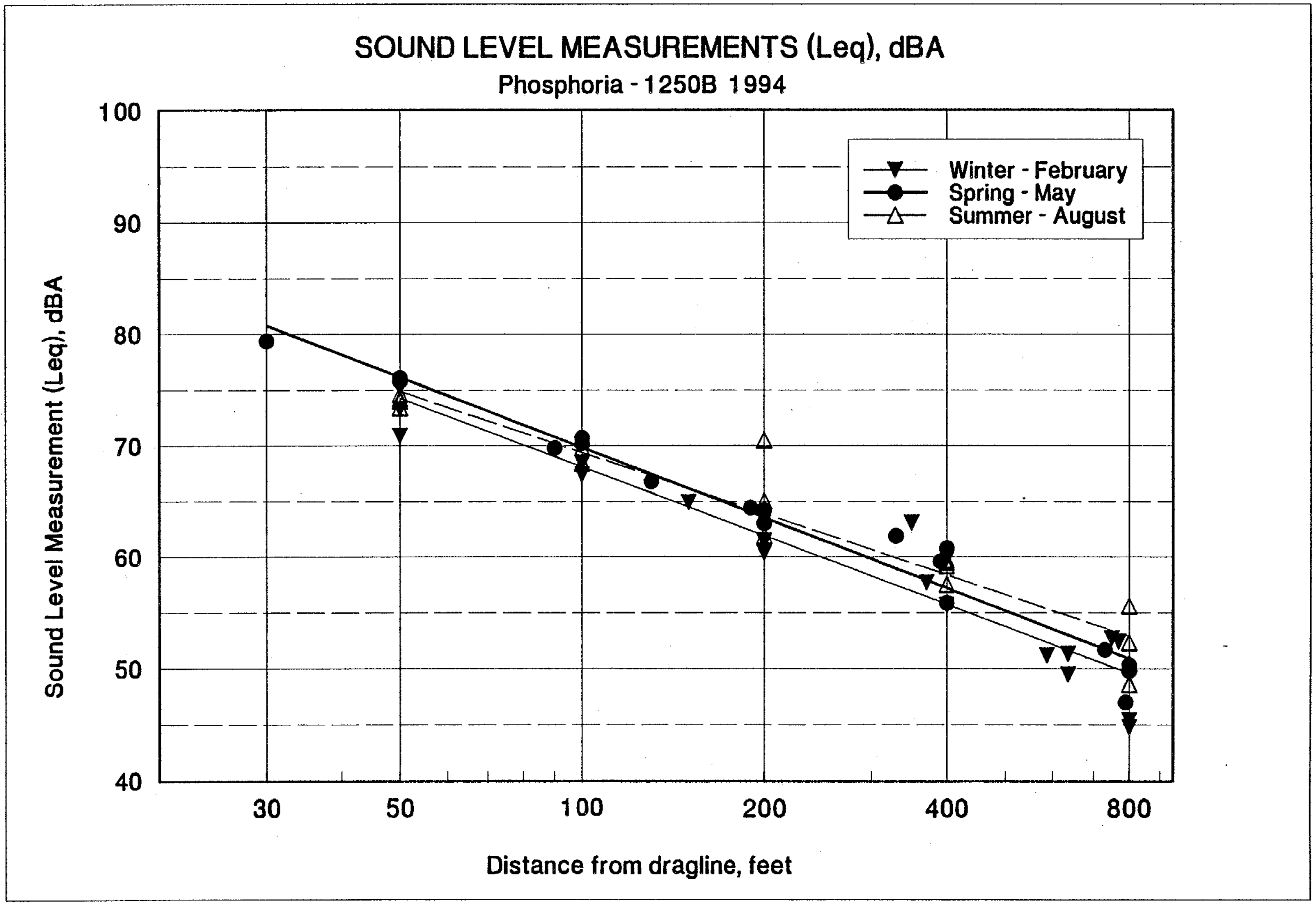


Figure 5.13 L_{eq} **versus distance from dragline with respect to seasons for 1250B - Phosphoria**

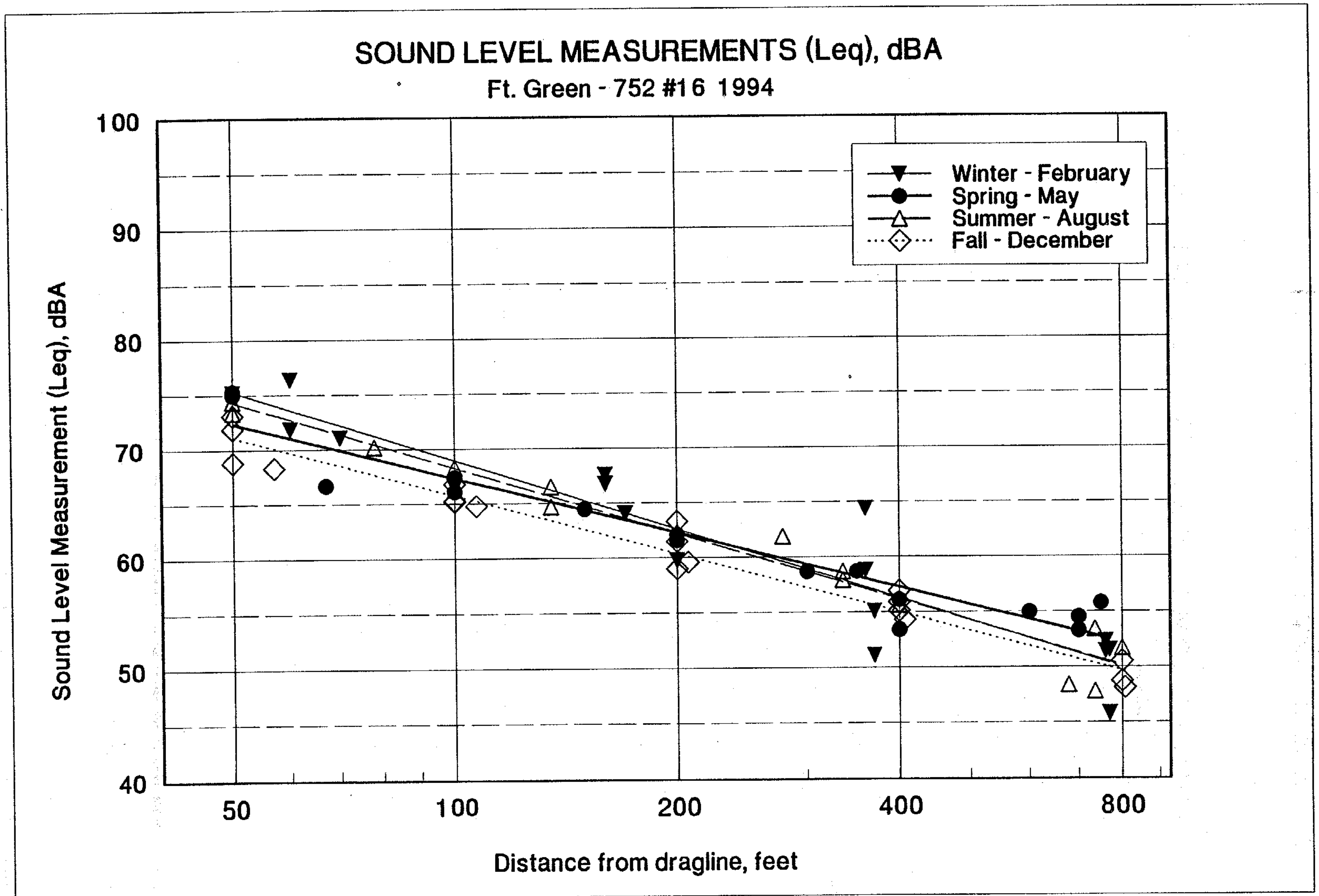


Figure 5.14 L_{eq} versus distance from dragline with respect to seasons for 752 #16 - Fort Green

morning measurement did seem slightly lower than the others. Moreover, machines used to clear and maintain the sites operated more frequently during daytime hours than during the night.

Again, since the dragline operations were not controlled during field monitoring, it is difficult to determine if the variability in the sound levels arose from seasonal shifts in weather conditions, different daytime and nighttime levels or, from other uncontrollable factors.

Assessment of Dragline Noise

What noise level is “acceptable” to the public? What is “unacceptable”? This question often arises when dealing with community noises. For the purpose of providing information, literature was searched to find noise limit criteria previously established by government agencies and community officials. A summary of the search is presented in Table 5.3. Noise limit criteria from the literature was then used to assess acceptability levels for this report, and they are as follows (see Table 5.3):

Acceptable (All times): Less than 55 dBA
Discretionary (May be acceptable daytime): 55-65 dBA
Unacceptable (All times): Greater than 65 dBA

Once the noise limit criteria were established, Figures 5.3 through 5.6 were redrawn with ninety percent confidence interval bounds. The equations of the regression line and the upper confidence interval line were then used with the noise limits to define a range of distances from each dragline where mining noise may be acceptable or unacceptable (see Figures 5.15 through 5.18).

Setting one range of acceptable distances for all four draglines would have been statistically invalid since the dragline at Clear Springs has noticeably higher noise levels than the other draglines. For this reason, a range of distances were determined for each dragline according to the noise levels measured during the field monitoring program. Table 5.4 displays these distances (in feet) for each dragline.

Table 5.3 Summary of literature on noise limits

dBA: 40, 45, 50, 55, 60, 65, 70, 75, 80, 85

Source				
HUD Guidelines[1]	Cleary Acceptable	Normally Acceptable	Normally Unacceptable	Cleary Unacceptable
HUD, New Residential[2]	Acceptable	Discretionary, Annoying	Unacceptable	
EPA[3]	Indoor Annoyance		Outdoor Annoyance	Hearing Loss
Peoria, IL[4]	Nighttime Limit		Daytime Limit	
Inglewood, CA Machine Noise Limits[4]	Nighttime Limit		Daytime Limit	
Warrick, RI[4]	Nighttime Limit		Daytime Limit	
Hillsborough County, FL[5] & Manatee County, FL[6]	Nighttime Limit		Daytime Limit	
Limits based on literature	Acceptable	Discretionary, Acceptable Daytime	Unacceptable	

[1]Source: Magan, 1979. HUD-Department of Housing and Urban Development.

[2]Source: United States Department of Transportation, 1977. Criteria for funding new residential construction.

[3]Source: United States Environmental Protection Agency, 1974. Noise levels identified as neccesary to protect public health and welfare with an adequate margin of safety.

[4]Source: Lipscomb, 1978. Daytime 7:00 a.m.-10:00 p.m. Nighttime 10:00 p.m.-7:00 a.m.

[5]Source: "Rules of the Environmental Protection Commission of Hillsborough County", 1991. Receiving land use--residential. Daytime & Nighttime as above.

[6]Source: Manatee County Code of Laws, Sec. 2-21-31. Receiving land use--residential. Daytime 7:00 a.m.-10:00 p.m. Nightime 10:00 p.m.-7:00 a.m.

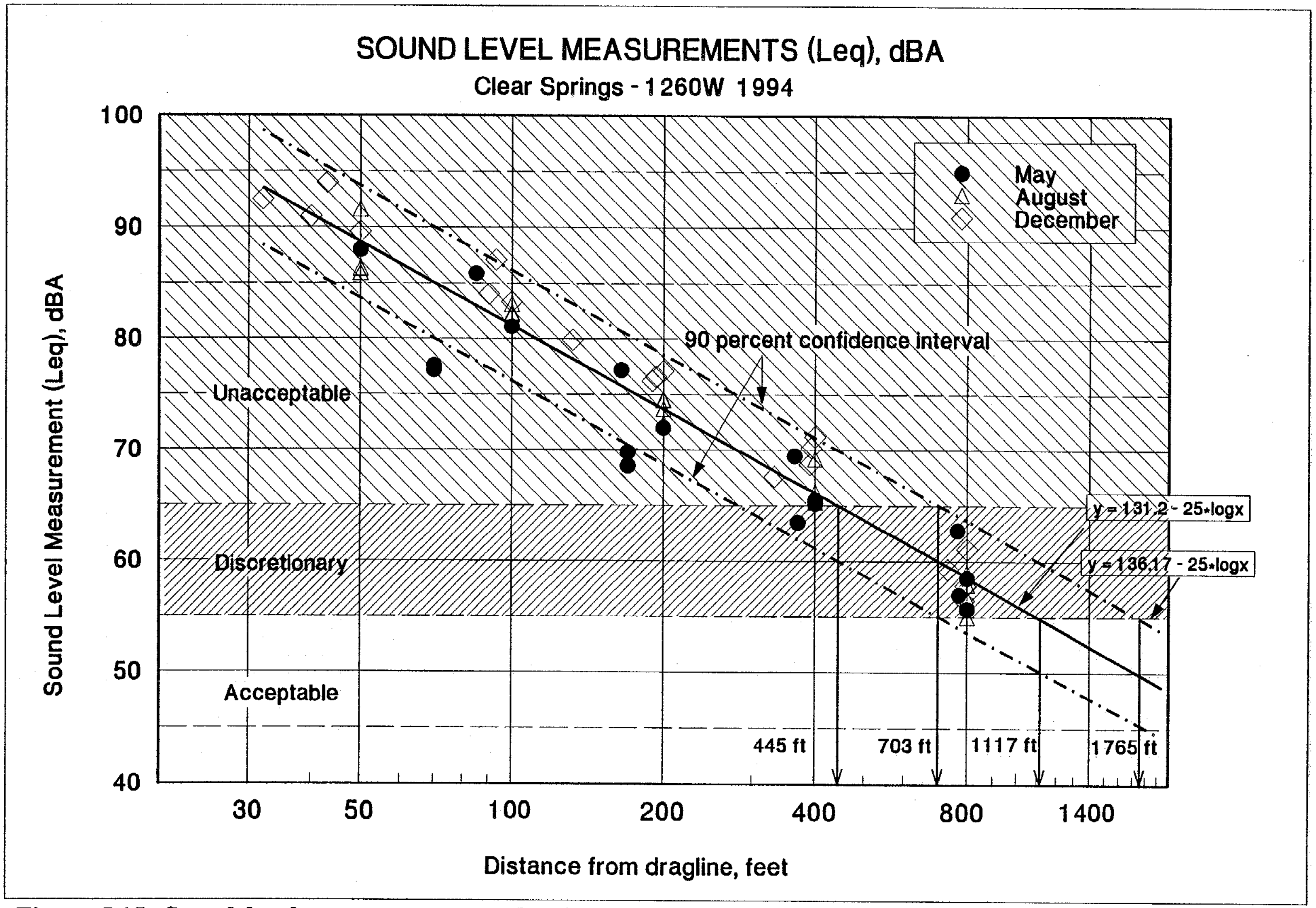


Figure 5.15 Sound level measurements and noise limit criteria for 1260W - Clear Springs

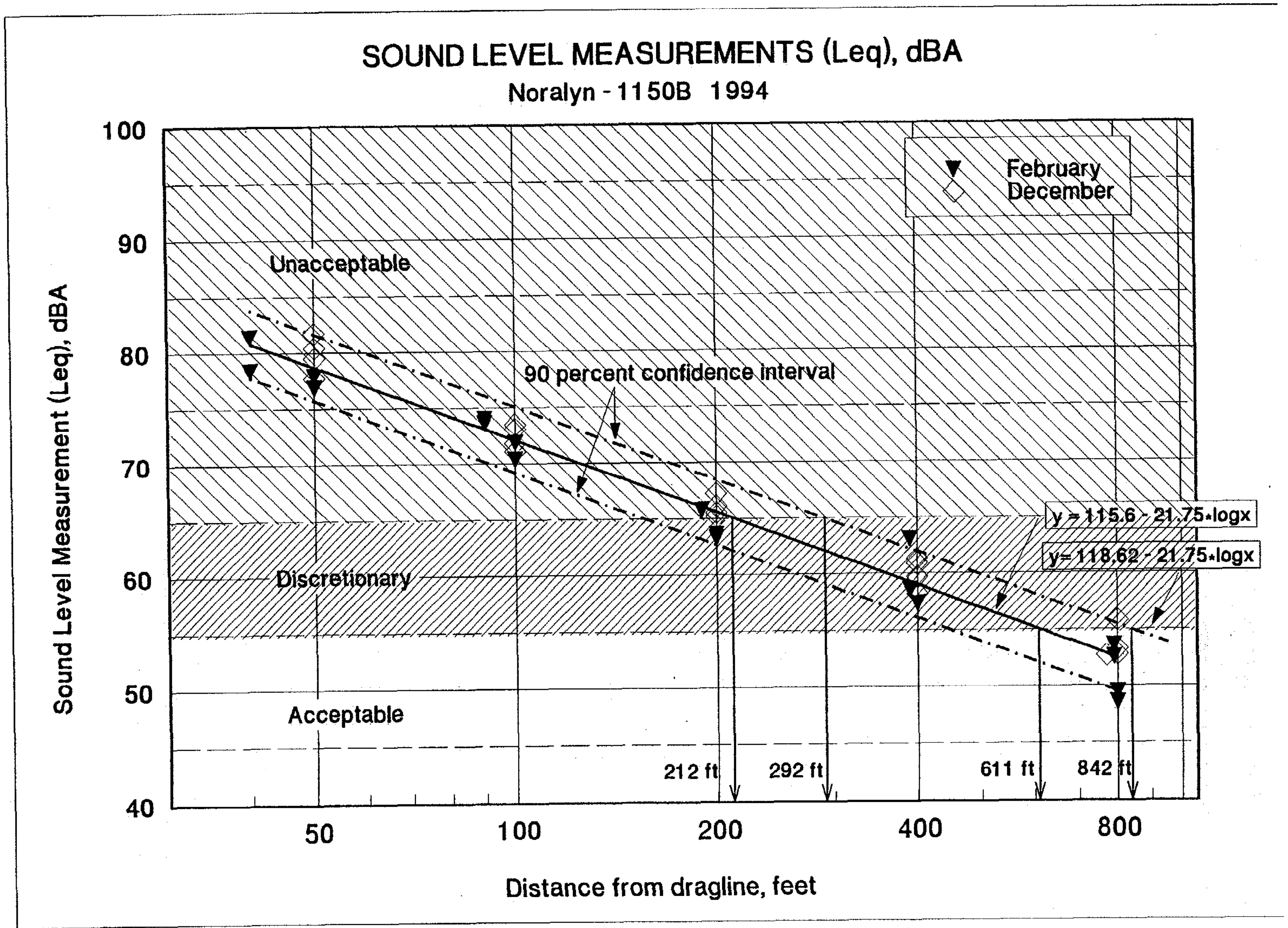


Figure 5.16 Sound level measurements and noise limit criteria for 1150B - Noralyn

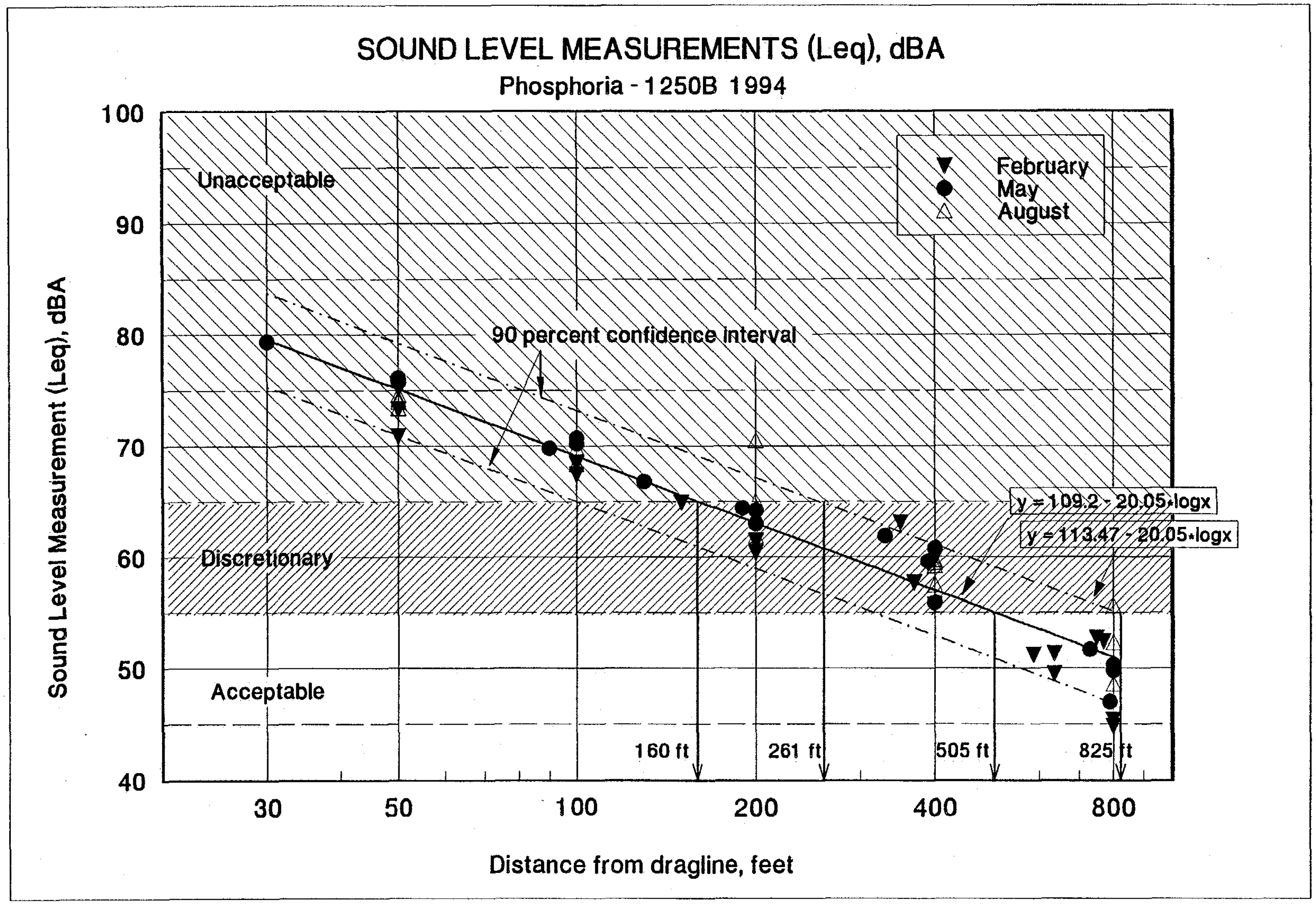


Figure 5.17 Sound level measurements and noise limit criteria for 1250B - Phosphoria

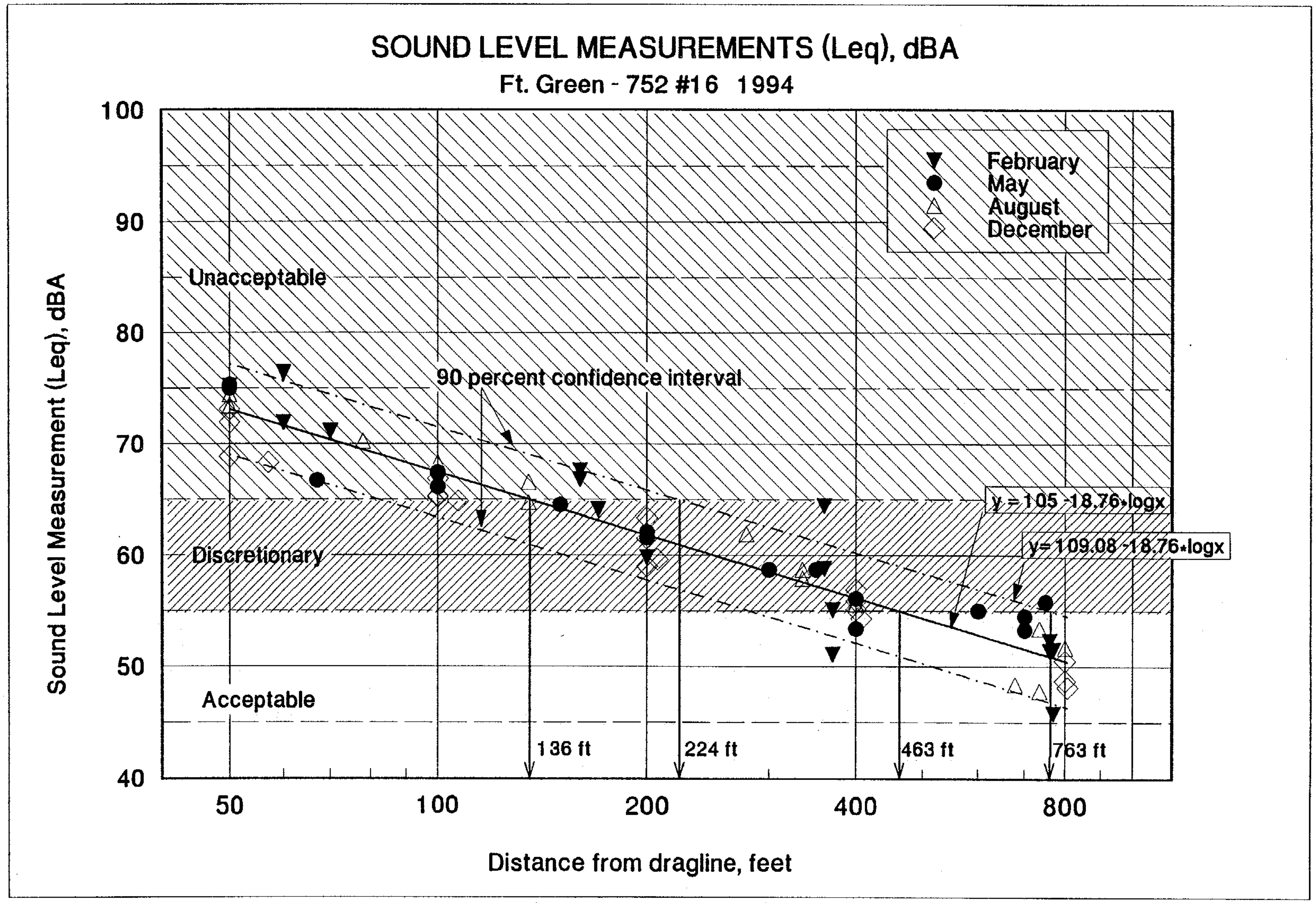


Figure 5.18 Sound level measurements and noise limit criteria for 752 #16 - Fort Green

Table 5.4 Acceptable and unacceptable distances according to noise limit criteria

FIPR Study	Acceptable Noise < 55 dBA		Unacceptable Noise > 65 dBA	
	Distance from Dragline (feet)		Distance from Dragline (feet)	
Site/Dragline	at 50 % C.I.*	at 90 % C.I.	at 50 % C.I.	at 90 % C.I.
Fort Green/752 Page #16	463	763	136	224
Phosphoria/1250B	505	825	160	261
Noralyn/1150B	611	842	212	292
Clear Springs/1260W	1117	1765	445	703

* C. I. - confidence interval

CHAPTER 6: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 SUMMARY

The primary objective of the project was to determine the levels of noise and ground vibration as a function of distance from working draglines. To accomplish this goal, a series of noise and vibration field measurements was conducted on four different walking draglines operating under various meteorological conditions in Polk and Hardee counties in central Florida. Noise and ground vibration levels arising from dragline operations were recorded continuously and simultaneously over a duration of approximately two minutes for each increment of distance from the dragline. The levels were monitored during each of the four seasons between February 15, 1994 and December 15, 1994.

Equivalent continuous sound levels were determined directly from the SLM 2236. Ground vibration signals were transferred from the DAT recorder to a computer whereby a FORTRAN program was utilized to calculate peak and rms particle velocities. The program was also employed to perform FFT frequency analysis on the recorded noise and ground vibration signals and to calculate the overall sound pressure levels.

The noise results were further analyzed in Chapter 5. The influence of various factors on the sound levels was determined. Regression analysis was applied to the L_{eq} readings of each of the four monitored draglines and then compared. The influence of time of day and seasons was also investigated. In addition, an assessment of the dragline noise was made, and acceptable noise levels were determined from the literature. Finally, a range of distances from each dragline where mining noise is considered as acceptable or unacceptable was established.

6.2 CONCLUSIONS

The noise and ground vibration levels recorded at each site were a composite of levels from many sources and directions, including noise and vibration levels associated with pit guns, bulldozers, irrigation pumps, distant traffic, and airplanes. Since these sounds are typical noises found in the phosphate mining environment, they were all included in the measurements. However, field notes were made when substantial increases in the measured noise levels were observed.

Since the operations of the draglines were not controlled in any manner, it is difficult to differentiate between different noise and vibration sources. In some instances, the noise resulting from the pit gun operation seemed to override the dragline noise. Furthermore, different dragline operators maneuvered the draglines at different speeds, sometimes swinging the bucket empty without mining or stripping overburden.

Noise

Type of Dragline. This study revealed a discernible gap between the noise levels of different draglines. Specifically, the sound levels resulting from the 1260W model at Clear Springs were noticeably higher than the sound levels resulting from the other monitored draglines. This may be due to the fact that the 1260W dragline is an older model dragline (refer to Table 2.2 for a list of the electrical equipment used by each dragline). The variability in the L_{eq} values for the 752 #16 dragline at Fort Green may be attributed, in part, to noticeably different operating speeds by different operators.

Effect of Season/Weather. For this report, no conclusion may be drawn as to the effect of the seasonal variations in the weather on the sound level readings. However, theoretically, the influence of temperature, relative humidity, and frequency on airborne sound may be determined from Table 5.1 in Chapter 5.

Effect of Time of Day. No conclusion may be drawn as to the effect of the time of day on the sound level readings. The different sound level readings obtained with respect to the time of day showed no noticeable difference between the daytime and nighttime readings. However, background noise levels during the early morning measurement did seem slightly lower than the other times of day.

Frequency Distribution. The frequency distribution of the prominent sound pressure levels occur within the 0 to 2000 Hertz range. The 1250B and the 1150B have consistent dominant frequencies of approximately 1617 and 1400 Hz respectively. In order to determine which mechanism of the dragline produced the sound levels at the dominant frequencies, the operation manuals for each dragline may be consulted.

Assessment of Dragline Noise. Noise limit criteria from the literature were used to assess acceptability levels for this report. From the noise acceptability levels, a range of distances were determined for each dragline according to the noise levels measured during the field monitoring program. Table 5.4 shows the minimum distances the draglines can be from a receiving property.

Vibration

All of the measured peak particle velocities were below 0.106 inch per second which is classified by NAVFAC DM 7.3 (1983) as “easily noticeable to persons”. In addition, most of the peak particle velocities measured beyond a distance of 200 feet from each dragline were below 0.037 inch per second which is classified as “barely noticeable to persons” by NAVFAC DM 7.3 (1983). However, the 1250B and 752 #16 draglines produced a few peak particle velocities greater than 0.037 inch per second beyond 200 feet. Comparison amongst the different draglines reveals that the 1250B dragline at Phosphoria produced the highest peak particle velocities.

FFT frequency analysis was also performed on eight selected ground vibration measurements to show how the particle velocity was distributed as a function of ground vibration frequency. The resulting vibration spectrograms show that the frequency ranges of the ground vibrations extend from 0 to just over 60 Hz. Most of the significant spectral energy, however, is contained between approximately 5 to 25 Hz.

6.3 RECOMMENDATIONS

Sound and vibration levels associated with the phosphate mining environment vary considerably from day to day. As such, the sound and ground vibration levels obtained from the 1260W, 1150B, 1250B, and 752 #16 draglines varied throughout the field monitoring program. Since the dragline operations during field study were not controlled, it was impossible to record background sound or vibration levels..

Based on the sound levels obtained from the four monitored draglines, it is recommended that the 1260W dragline be inspected to determine which mechanism (s) is contributing to the high sound levels. The contributions of different mechanisms of noise generation in the 1260W dragline may be readily isolated if each mechanism can be operated independently. Once the source (s) is determined, options for noise reduction should be considered and then the most feasible option should be selected.

It is also recommended that further research be undertaken to study sound levels related to dragline operations in phosphate mining. The study may be controlled in a manner such that certain dragline operations can be turned off or on at the request of the researcher. The scope of the work may be limited to a manageable level so that the cost of conducting such a controlled study can be contained. Another alternative would be to permanently monitor noise levels around mining sites and/or near property lines. With the technology available today, a permanent, weatherproof, noise monitoring station is definitely feasible.

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APPENDIX A

BASIC SOUND CHARACTERISTICS

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BASIC SOUND CHARACTERISTICS

The purpose of this appendix is to introduce some of the fundamental concepts of sound (noise) relevant to this research study. It is by no means an attempt to include every technical aspect of sound, for that goes beyond the scope of this project. An understanding of the wealth of information which follows is essential to interpret the noise results.

A.1 SOUND

Sound can be defined as *any pressure variation (in air, water or other medium) that the human ear can detect.* If variations in atmospheric pressure occur at least twenty times a second, they can be heard and thus are called sound (Bruel & Kjaer, 1984). Many sounds are unpleasant or unwanted -- these are called *noise.*

Properties of Sound Waves

Frequency. The number of pressure variations per second is called the frequency of the sound, and is expressed in Hertz (Hz). The frequency of a sound produces it's distinctive tone. For instance, the rumble of thunder has a low frequency, while a whistle has a high frequency. The normal frequency range of hearing for a healthy young adult is between 20 Hz and 20,000 Hz (Harris, 1991).

It must be noted that the ear is not equally sensitive at all frequencies. For this reason, even though the sound pressure level of two different noises may be the same, the first may be judged to be louder than the second if the sound power of the first is concentrated in a frequency region where the ear is more sensitive. Research has shown that sound with most of its energy concentrated in the middle frequencies (near 1000 Hz, for example) is perceived as louder than noise of equal energy but of low frequency (near 31.5 Hz) or of high frequency (near 20,000 Hz).

Speed of Sound. These pressure variations travel through any elastic medium, such as air, from the source of the sound to the listener's ear. The rate at which sound waves travel is known as the speed of sound. At a temperature of 20°C (68 °F) the speed of sound in air is approximately 344 m/s (1127 ft/s). The temperature of air has a significant effect on the speed of sound. The speed increases about 0.61 m/s for each increase in temperature of 1 °C.

Wavelength. If the speed and frequency of a sound are known, the wavelength can be calculated. The wavelength is the perpendicular distance between two wavefronts having the same phase, or more simply, the distance from one wave top or pressure peak to the next (see Figure A.1). Wavelength, denoted by the Greek letter lambda (λ), is related to the frequency (in Hertz) and the speed of sound by the following equation:

$$\textit{Wavelength}\ (\lambda) = \frac{\textit{speed of sound}}{\textit{frequency}}$$

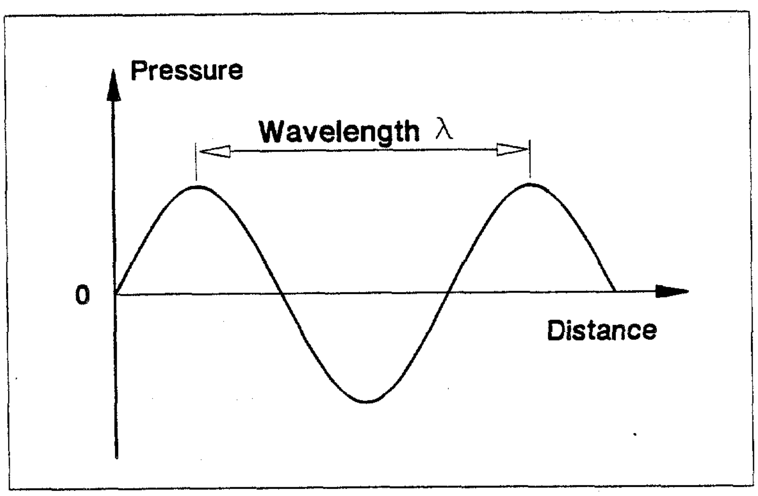

Figure A.1 Graphical representation of a sine wave

Simple Harmonic Motion: Pure Tones. A sound which has only one frequency is known as a *pure tone*. In practice pure tones are rarely encountered and most sounds are made of different frequencies. Most industrial noise consists of a wide mixture of frequencies known as *broad band noise* (Bruel & Kjaer, 1984).

A.2 SOUND LEVELS

The Decibel

The size or *amplitude* of pressure fluctuations is also used to describe a sound. The weakest sound a healthy human ear can detect has an amplitude of 20 millionths of a Pascal (20 µPa) which is five billion times less than normal atmospheric pressure. Amazingly, the ear can tolerate sound pressures higher than 200 Pa. Thus, if sound were measured in Pascal, large and unmanageable numbers would result. To avoid this, another scale is used -- the *decibel* or *dB* scale.

The decibel is not an absolute unit or measurement, it is a ratio between a measured quantity and an agreed reference level. The dB scale is logarithmic and uses the threshold of 20µPa as the reference level, which is defined as 0 dB. The decibel scale is very useful in that it compresses a range of a million into a range of only 120 dB. The sound pressure level in dB of sound waves having a sound pressure *p* is equal to:

$$\textit{Sound Pressure Level (dB)} = 20\log_{10}\left(\frac{p}{p_0}\right)$$

where: p = Sound pressure (rms), micropascals and,
p_0 = Reference pressure = 20 micropascals

Sound pressure levels (SPL) in dB and Pa of various familiar sounds are shown in Figure A-2.

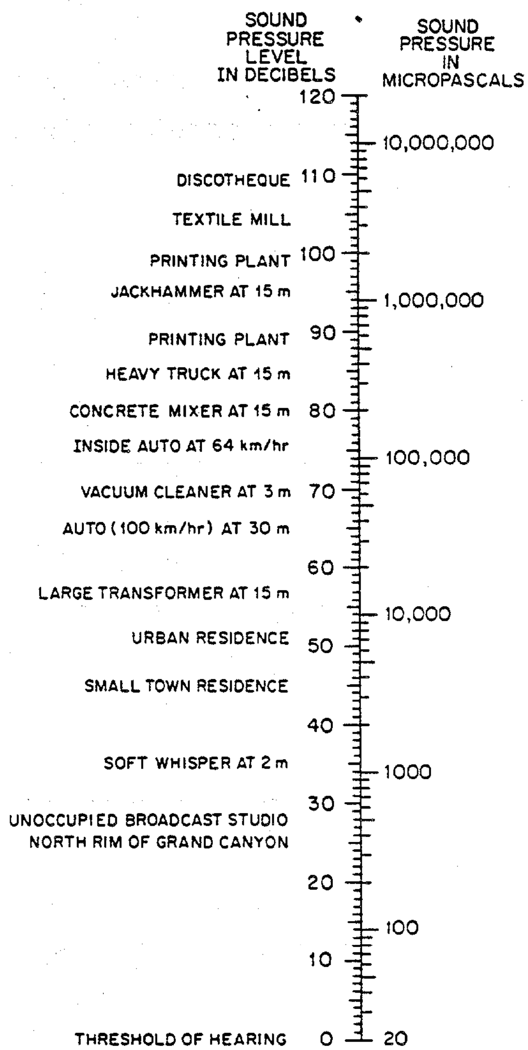

Figure A.2 Relation between sound pressure in micropascals and sound pressure level in decibels (*source: Harris, 1991*)

Weighted Sound Levels: Sound Level Meters

Weighted sound levels are levels obtained from readings of a sound level meter or they may be calculated from other measurements. The sound level meter is an instrument designed to respond to sound in approximately the same way as the human ear and to give objective, reproducible measurements of sound pressure level. Although different in detail, each system consists of a microphone, a processing section, and a read-out unit.

The microphone converts the sound signal to equivalent electrical signal. Since the electrical signal produced by the microphone is quite small, it is amplified by a preamplifier before being process. Several different types of processing may be performed on the signal; for example, the signal may pass through a *weighting network.*

In the meter, the electronic circuit simulates the sensitivity of the human ear (i.e., the sensitivity varies with frequency in the same way as the human ear). Consequently, this has resulted in three different internationally standardized characteristics termed the *"A", "B"*, and *"C" weightings* (see Figure A.3). The "A" weighting network weights a signal in a manner that approximates to an inverted equal loudness contour at low SPLs, the "B" network corresponds to a contour at medium SPLs, while the "C" network coincides to an equal loudness contour at high SPLs (Harris, 1991). In addition to these weighting networks, sound level meters usually have a linear network that enables the signal to pass through unadjusted.

Today, the "A" weighting network is the most widely used since the "B" and "C" weightings do not correlate well with subjective tests.

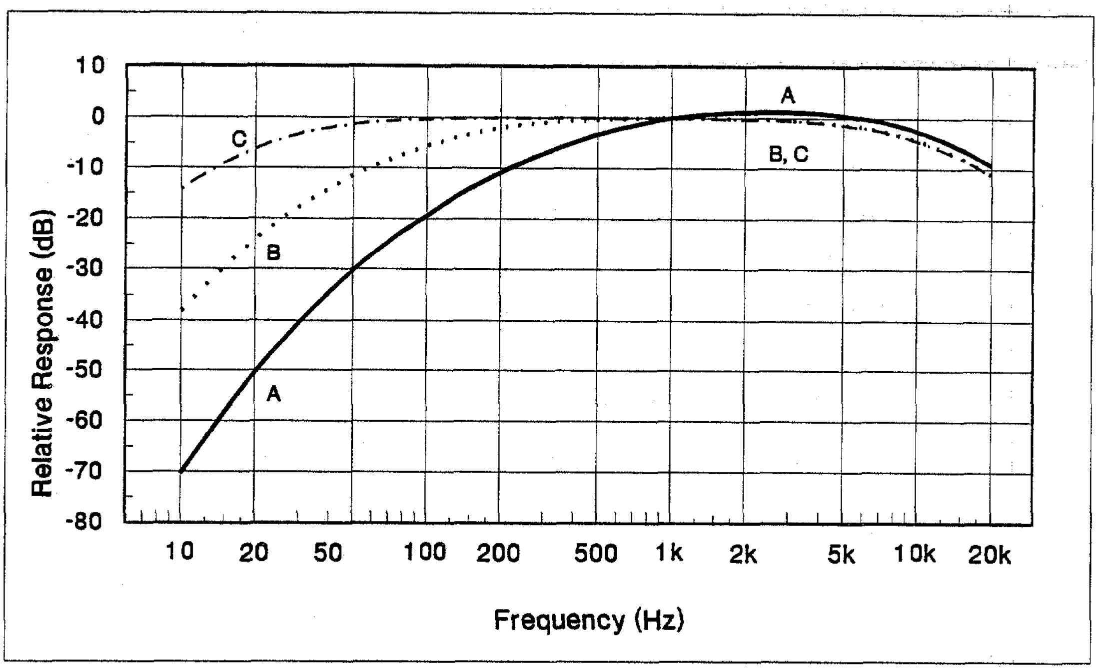

Figure A.3 Relative response curves for the "A", "B" and, "C" weightings (*redrawn from ANSI S1.4-1983*)

Equivalent Continuous Sound Level (L_{eq})

The equivalent continuous sound level or L_{eq} has the same energy content as the varying sound level. In addition to determining the hearing damage potential of a sound, L_{eq} measurements are commonly used for community noise-annoyance assessments (Bruel & Kjaer, 1984). The value of the L_{eq} is the most useful single number for describing the noise environment over a given short period of time.

A.3 SOUND LEVEL METER RESPONSE

Most sounds that need to be measured fluctuate in level. To measure the sound properly, these variations must be measured as accurately as possible. However, if the sound level fluctuates too rapidly, the meter indication will not follow these rapid fluctuations. For this reason, two types of exponential time-weighting were standardized. These are known as *"F"* (fast) and *"S"* (slow).

The “F” setting has a time constant of 1/8 second and provides a fast reacting display response enabling one to follow and measure not too rapidly fluctuating sound levels. The “S”, with a time constant of one second, gives a slower response which helps average-out the display fluctuations on an analogue meter, which would otherwise be impossible to read using the “F” time constant.

Today, many sound level meters have digital displays which largely overcome the problem of fluctuating displays, by indicating the maximum RMS value measured within the preceding second. Selection of the appropriate detector characteristic is then often dictated by the standard upon which the measurements are to be based.

APPENDIX B

DETAILED FIELD MONITORING SCHEDULES

APPENDIX B

NOISE AND VIBRATION FIELD MEASUREMENT #1

Summary of Field Activities

Date	Time	Activities
2-15-94	0800	Arriving at the FIPR office, Bartow, FL
	0800-0900	Having discussions with G. Nifong, J. Harris (FIPR), and D. Adams (IMC)
	0900-0930	Traveling to Noralyn site
	0930-1400	Field monitoring at Noralyn site (Dragline #1150B)
	1400-1500	Lunch break
	1500-1530	Traveling to Phosphoria site
	1530-1830	Field monitoring at Phosphoria site (Dragline #1250B)
	1830-1930	Dinner break
	1930-2000	Traveling to Phosphoria site
	2000-2150	Field monitoring at Phosphoria site (Dragline #1250B)
	2150-2210	Traveling to Noralyn site
	2210-2350	Field monitoring at Noralyn site (Dragline #1150B)
	2350-0020	Traveling to motel

2-16-94	0900	Meet J. Harris at FIPR
	0900-0920	Traveling to Phosphoria site
	0920-1100	Field monitoring at Phosphoria site (Dragline #1250B)
	1100-1140	Traveling to Fort Green site
	1140-1350	Field monitoring at Fort Green site (Dragline 752 #16)
	1350-1430	Traveling to Noralyn site
	1430-1630	Field monitoring at Noralyn site (Dragline # 1150B)
	1630-1640	Traveling back to FIPR
	1640-1730	Dinner break
	1730-1800	Traveling to Ft. Green site
	1800-1930	Field monitoring at Ft. Green site (Dragline 752 #16)
	1930-2010	Traveling to motel
2-17-94	0245	J. Harris picks us up at motel
	0245-0300	Traveling to Noralyn site
	0300-0425	Field monitoring at Noralyn site (Dragline #1150B)
	0425-0500	Traveling to Fort Green site
	0500-0600	Field monitoring at Fort Green site (Dragline 752 #16)
	0600-0715	Break
	0715-0830	Field monitoring at Fort Green site (Dragline 752 #16)

2-17-94	0830-0910	Traveling back to FIPR
2-18-94	0345	J. Harris picks us up at motel
	0345-0415	Traveling to Phosphoria site
	04 15-0600	Field monitoring at Phosphoria site (Dragline # 1250B)
	0600-0630	Traveling back to FIPR

Summary of First Field Measurement

Noralyn - #1150B			
Time of Day*	Date	Time Begin	Time End
EM	2-17	3:00 a.m.	4:25 a.m.
LM	2-15	9:30 a.m.	2:00 p.m.
A	2-16	2:30 p.m.	4:30 p.m.
N	2-15	10:10 p.m.	11:50 p.m.

Phosphoria - #1250B			
Time of Day*	Date	Time Begin	Time End
EM	2-18	4:15 a.m.	6:00 a.m.
LM	2-16	9:20 a.m.	11:00 a.m.
A	2-15	3:30 p.m.	6:30 p.m.
N	2-15	8:00 p.m.	9:50 p.m.

Ft. Green - 752 #16			
Time of Day*	Date	Time Begin	Time End
EM	2-17	5:00 a.m.	6:00 a.m.
LM	2-17	7:15 a.m.	8:30 a.m.
A	2-16	12:00 p.m.	1:50 p.m.
N	2-16	6:00 p.m.	7:30 p.m.

* EM - early morning
LM - late morning
A - afternoon
N - night

NOISE AND VIBRATION FIELD MEASUREMENT #2

Summary of Field Activities

Date	Time	Activities
5-11-94	0900	Arriving at the FIPR office, Bartow, FL
	0900-1000	Having discussions with G. Nifong, J. Harris (FIPR), and D. Adams (IMC)
	1000-1030	Traveling to Clear Springs site
	1030-1300	Field monitoring at Clear Springs site (Dragline # 1260W)
	1300-1400	Continuation of field monitoring at Clear Springs site (Dragline # 1260W)
	1400-1630	Traveling back to FIPR--the DAT recorder overheated
	1630-1700	Traveling back to Clear Springs site
	1700-1800	Continuation of field monitoring at Clear Springs site (Dragline #1260W)
	1800-1930	Continuation of field monitoring at Clear Springs site (Dragline #1260W)
	1930-2000	Traveling to motel
5-12-94	0430	Meet J. Harris
	0430-0450	Traveling to Clear Springs site

5-12-94	0450-0600	Field monitoring at Clear Springs site (Dragline #1260W)
	0600-0620	Traveling to Phosphoria site
	0620-0720	Break
	0720-0845	Field monitoring at Phosphoria site (Dragline #1250B)
	0845-0930	Traveling to Fort Green site
	0930-1340	Waiting at Fort Green site for Dragline to begin operating
	1340-1420	Traveling to Phosphoria site
	1420-1515	Field monitoring at Phosphoria site (Dragline #1250B)
	1515-1545	Traveling back to Fort Green site
	1545-1700	Field monitoring at Fort Green site (Dragline 752 #16)
	1700-1800	Dinner break
	1800-1840	Field monitoring at Fort Green site (Dragline 752 #16)
	1840-1910	Traveling to Phosphoria site
	1910-2010	Field monitoring at Phosphoria site (Dragline #1250B)
5-13-94	0300	Meet J. Harris at FIPR
	0300-0330	Traveling to Phosphoria site
	0330-0430	Field monitoring at Phosphoria site (Dragline #1250B)
	0430-0510	Traveling to Fort Green site

5-13-94	0510-0600	Field monitoring at Fort Green site (Dragline 752 #16)
	0600-0730	Field monitoring at Fort Green site (Dragline 752 #16)

Summary of Second Field Measurement

Clear Springs - #1260W			
Time of Day*	Date	Time Begin	Time End
EM	5-12	4:50 a.m.	6:00 a.m.
LM	5-11	10:30 a.m.	1:00 p.m.
A	5-11	1:00 p.m.	6:00 p.m.
N	5-11	6:00 p.m.	7:30 p.m.

Phosphoria - #1250B			
Time of Day*	Date	Time Begin	Time End
EM	5-13	3:30 a.m.	4:30 a.m.
LM	5-12	7:20 a.m.	8:45 p.m.
A	5-12	2:20 p.m.	3:15 p.m.
N	5-12	7:10 p.m.	8:10 p.m.

Ft. Green - 752 #16			
Time of Day*	Date	Time Begin	Time End
EM	5-13	5:10 a.m.	6:00 a.m.
LM	5-13	6:00 a.m.	7:30 p.m.
A	5-12	3:45 p.m.	5:00 p.m.
N	5-12	6:00 p.m.	6:40 p.m.

* EM - early morning
LM - late morning
A - afternoon
N - night

NOISE AND VIBRATION FIELD MEASUREMENT #3

Summary of Field Activities

Date	Time	Activities
8-23-94	0800	Arriving at the FIPR office, Bartow, FL
	0800-0930	Meet with G. Nifong and J. Harris
	0930-1000	Traveling to Clear Springs site
	1000-1130	Field monitoring at Clear Springs site (Dragline #1260W)
	1130-1200	Lunch break
	1200-1400	Continuation of field monitoring at Clear Springs site (Dragline #1260W)
	1400-1430	Traveling to Phosphoria site
	1430-1700	Field monitoring at Phosphoria site (Dragline #1250B)
	1700-1730	Traveling to Clear Springs site
	1730-1800	Dinner Break
	1800-1900	Field monitoring at Clear Springs site (Dragline #1260W)
	1900-1930	Traveling to motel
8-24-94	0300	Meet J. Harris at FIPR
	0300-0330	Traveling to Clear Springs site

8-24-94	0330-0450	Field monitoring at Clear Springs site (Dragline #1260W)
	0450-0520	Traveling to motel
	0520-0830	Break
	0830	Meet J. Harris at FIPR
	0830-0930	Traveling to Fort Green site
	0930-1100	Field monitoring at Fort Green site (Dragline 752 #16)
	1100-1200	Break
	1200-1330	Continuation of field monitoring at Fort Green site (Dragline 752 #16)
	1330-1400	Traveling to Clear Springs site
	1400-1440	Field monitoring at Clear Springs site (Dragline #1260W)-Property line
	1440-1510	Traveling to FIPR
	1510-1800	Dinner break
	1800	Meet J. Harris at FIPR
	1800-1900	Traveling to Ft. Green site
	1900-1930	Field monitoring at Ft. Green site (Dragline 752 #16)
	1930-2010	Traveling to Phosphoria site
	2010-2130	Field monitoring at Phosphoria site (Dragline #1250B)
	2130-2200	Traveling to motel
	2200-0300	Break

8-25-94	0300	Meet J. Harris at FIPR
	0300-0330	Traveling to Phosphoria site
	0330-0440	Field monitoring at Phosphoria site (Dragline #1250B)
	0440-0520	Traveling to Fort Green site
	0520-0600	Field monitoring at Fort Green site (Dragline 752 #16)
	0600-0630	Traveling to Phosphoria site
	0630-0800	Field monitoring at Phosphoria site (Dragline #1250B)
	0800-0820	Traveling to FIPR
	1000	Traveling back to Tallahassee

Summary of Third Field Measurement

Clear Springs - #1260W			
Time of Day*	Date	Time Begin	Time End
EM	8-24	3:30 a.m.	4:50 a.m.
LM	8-23	10:00 a.m.	11:30 a.m.
A	8-23	12:00 p.m.	2:00 p.m.
N	8-23	6:00 p.m.	7:00 p.m.

Phosphoria - #1250B			
Time of Day*	Date	Time Begin	Time End
EM	8-25	3:30 a.m.	4:40 a.m.
LM	8-25	6:30 a.m.	8:00 a.m.
A	8-23	2:30 p.m.	5:00 p.m.
N	8-24	8:00 p.m.	9:30 p.m.

Ft. Green - 752 #16			
Time of Day*	Date	Time Begin	Time End
EM	8-25	5:20 a.m.	6:00 a.m.
LM	8-24	9:30 a.m.	11:00 a.m.
A	8-24	12:00 p.m.	1:30 p.m.
N	8-24	7:00 p.m.	7:30 p.m.

* EM - early morning
LM - late morning
A - afternoon
N - night

NOISE AND VIBRATION FIELD MEASUREMENT #4

Summary of Field Activities

Date	Time	Activities
12-13-94	0800	Arriving at the FIPR office, Bartow, FL
	0800-0900	Meet with G. Nifong and J. Harris
	0900-0930	Traveling to Clear Springs site
	0930-1200	Field monitoring at Clear Springs site (Dragline #1260W)
	1200-1350	Continuation of field monitoring at Clear Springs site (Dragline #1260W)
	1350-1420	Traveling to Noralyn site
	1420-1620	Field monitoring at Noralyn site (Dragline #1150B)
	1620-1640	Traveling to Clear Springs site
	1640-1800	Dinner break
	1800-1900	Field monitoring at Clear Springs site (Dragline #1260W)
	1900-1930	Traveling to Noralyn site
	1930-2050	Field monitoring at Noralyn site (Dragline #1150B)
	2050-2110	Traveling to FIPR

12-14-94	2110-0230	Break
	0230	Meet J. Harris at FIPR
	0230-0300	Traveling to Clear Springs site
	0300-0400	Field monitoring at Clear Springs site (Dragline #1260W)
	0400-0430	Traveling to Noralyn site
	0430-0530	Field monitoring at Noralyn site (Dragline #1150B)
	0530-0600	Break
	0600-0700	Field monitoring at Noralyn site (Dragline #1150B)
	0700-0800	Traveling to Fort Green site
	0800-0950	Field monitoring at Fort Green site (Dragline 752 #16)
	0950-1040	Traveling to FIPR
	1040-1530	Lunch break
	1530	Meet J. Harris at FIPR
	1530-1630	Traveling to Fort Green site
	1630-1730	Field monitoring at Fort Green site (Dragline 752 #16)
	1730-1800	Break
	1800-1840	Continuation of field monitoring at Fort Green site (Dragline 752 #16)
	1840-1930	Traveling to FIPR
	1930-0400	Break

12-15-94	0400	Meet J. Harris at FIPR
	0400-0500	Traveling to Fort Green site
	0500-0540	Field monitoring at Fort Green site (Dragling 752 #16)
	0540-0640	Traveling to FIPR
	1100	Traveling back to Tallahassee

Summary of Fourth Field Measurement

Noralyn - #1150B			
Time of Day*	Date	Time Begin	Time End
EM	12-14	4:30 a.m.	5:30 a.m.
LM	12-14	6:00 a.m.	7:00 p.m.
A	12-13	2:20 p.m.	4:20 p.m.
N	12-13	7:30 p.m.	8:50 p.m.

Clear Springs - #1260W			
Time of Day*	Date	Time Begin	Time End
EM	12-14	3:00 a.m.	4:00 a.m.
LM	12-13	9:30 a.m.	12:00 p.m.
A	12-13	12:00 p.m.	1:50 p.m.
N	12-13	6:00 p.m.	7:00 p.m.

Ft. Green - 752 #16			
Time of Day*	Date	Time Begin	Time End
EM	12-15	5:00 a.m.	5:40 a.m.
LM	12-14	8:00 a.m.	9:50 a.m.
A	12-14	4:30 p.m.	5:30 p.m.
N	12-14	6:00 p.m.	6:40 p.m.

* EM - early morning
LM - late morning
A - afternoon
N - night

APPENDIX C

FORTRAN PROGRAM

APPENDIX C

FORTRAN PROGRAM

```
*************************************************************
*                          PART I                           *
*************************************************************
*************************************************************
*    THIS PROGRAM IS DESIGNED TO READ CHANNELS ONE AND TWO *
*    FROM A SONY DAT RECORDER. FOR CHANNEL ONE, SPECTRUM    *
*    ANALYSIS IS PERFORMED ON THE DATA. FOR CHANNEL TWO,    *
*    PEAK PARTICLE VELOCITY AND RMS VALUES ARE RETURNED.    *
*************************************************************

      PROGRAM FIPR
      CHARACTER*1 A(16384)
      CHARACTER*7 FILENM
      CHARACTER*11 BNAME,DNAME,LNAME,PNAME
      INTEGER II,JJ,P,K,L,M,N,E,RAN,IMO,SUM,RAN1,RAN2,NT
      INTEGER LEVEL,NUMCHS,IM2
      INTEGER*2 KK,KM,IM(16384)
      REAL AVG,RMS,PPV,SMO,R,R1,R2,SUMT

*************************************************************
*     OPENS A LOG FILE WITH THE NAMES OF THE BINARY FILES   *
*     TO BE PROCESSED. THE LOG FILE ALSO TELLS THE PROGRAM  *
*     WHETHER TO ANALYZE BOTH CHANNELS 1 AND 2, OR JUST     *
*     CHANNEL 2. THE LOG FILE ALSO GIVES THE SLM LEVEL.     *
*************************************************************

       OPEN(UNIT=5,FILE='FILEN.DAT',STATUS='OLD')
       DO 3000 L=1,1
      READ(5,10)FILENM,NUMCHS,LEVEL
10       FORMAT(A7,1X,I1,1X,I2)
      BNAME=FILENM//'.BIN'
      DNAME=FILENM//'.DAT'
      LNAME=FILENM//'.LOG'
      PNAME=FILENM//'.PPV'
      OPEN(UNIT=1,FILE=BNAME,ACCESS='SEQUENTIAL',FORM='BINARY',
     +     STATUS='OLD')
      OPEN(UNIT=2,FILE=DNAME,STATUS='UNKNOWN')
      OPEN(UNIT=3,FILE=LNAME,STATUS='OLD')
      OPEN(UNIT=6,FILE=PNAME,STATUS='UNKNOWN')

*************************************************************
*     THIS SECTION READS IN CHANNEL 2 HEX-DECS IN THE FORM  *
*     OF ASCII CHARACTERS THEN CONVERTS THEM TO DECIMAL     *
*     INTEGERS.  IT ALSO COUNTS THE NUMBER OF CHANNEL 2     *
*     VALUES AND FINDS THE END OF FILE (EOF).               *
*************************************************************
```

```
      SUMT=0
      NT=0
      SUM=0
      E = 0
        DO 500 P=1,69
      N=0
          DO 400 I=1,8
            J = 0
20          IF(.NOT. EOF(1)) THEN
              J = J + 1
               READ(1) A(J)
              IF(J.EQ.16384) THEN
                 GO TO 30
              ENDIF
              GO TO 20
            ELSE
              E = 1
            ENDIF
30              DO 300 II=4,J,8
                 JJ=II-1
                 N=N+1
                 KK=ICHAR(A(II))
                 KM=ICHAR(A(JJ))
                 IM(N)=(KK*256+KM)
                 WRITE(2,*)IM(N)
300             CONTINUE
         IF(E.EQ.1) THEN
           GO TO 405
         ENDIF
400       CONTINUE

************************************************************
*    THIS SECTION FINDS MAXIMUM VALUE OF ALL THE DECIMAL    *
*    VALUES (ABS(IM(N)) AND COMPUTES THE SUM AND THE        *
*    AVERAGE.                                               *
************************************************************

405       IF(P.EQ.1) THEN
          IMO=IM(1)
        ENDIF
         DO 450 K=1,N
             IF(ABS(IM(K)).GT.ABS(IMO)) THEN
            IMO=IM(K)
             ENDIF
             SUM=SUM+IM(K)
450      CONTINUE
        SUMT=0
        SUMT=SUMT + SUM
        NT = NT + N
        IF(E.EQ.1) THEN
          GO TO 505
```

```
       ENDIF
500    CONTINUE
505    AVG=SUMT/NT

************************************************************
*    THIS SECTION REWINDS THE DAT FILE IN ORDER TO FIND     *
*    SMO WHICH IS NEEDED IN THE RMS CALCULATION AND         *
*    REQUIRES THE AVERAGE OF THE ENTIRE FILE WHICH WAS      *
*    FOUND ABOVE (505).                                     *
************************************************************

     REWIND 2
     SMO = 0
     DO WHILE (.NOT. EOF(2))
       READ(2,*)IM2
       SMO=SMO+(IM2-AVG)**2
     END DO

************************************************************
*    THIS SECTION OPENS THE LOG FILE AND FINDS THE DAT      *
*    RECORDER RANGE SETTING FOR COMPUTATION OF ROOT-MEAN-   *
*    SQUARE (RMS) AND PEAK-PARTICLE-VELOCITY (PPV).         *
************************************************************

      READ(3,50)RAN1,RAN2
50    FORMAT(////////////////////,T1,2I1)
      DO 600 M=1,2
       IF (M.EQ.1) THEN
         RAN=RAN1
        ELSE
         RAN=RAN2
       ENDIF
       IF (RAN.EQ.0) THEN
            R=20.
          ELSE IF (RAN.EQ.1) THEN
             R=10.
          ELSE IF (RAN.EQ.2) THEN
             R=5.
          ELSE IF (RAN.EQ.3) THEN
             R=2.
          ELSE IF (RAN.EQ.4) THEN
             R=1.
          ELSE
            R=0.5
       ENDIF
       IF (M.EQ.1) THEN
          R1=R
        ELSE
          R2=R
       ENDIF
600    CONTINUE
```

```
************************************************************
*    THIS SECTION COMPUTES RMS AND PPV VALUES IN IN./SEC. *
************************************************************

     RMS=(SQRT((1./NT)*SMO)/24576.)*R2*100./2540.
     PPV=((IMO-AVG)/24576.)*R2*100./2540.
     WRITE(6,*)'PEAK PARTICLE VELOCITY (IN/S)=',PPV
     WRITE(6,*)'ROOT-MEAN-SQUARE (IN/S)=',RMS
     WRITE(6,*)'AVERAGE=',AVG
     IF (NUMCHS.EQ.1) THEN
         GO TO 1900
       ELSE
         REWIND 1
     ENDIF
      CALL NOISE(FILENM,R1,LEVEL)
1900  CLOSE(1)
      CLOSE(2, STATUS= 'DELETE')
      CLOSE(3)
      CLOSE(6)
3000  CONTINUE
      CLOSE(5)
      STOP
4000  END

************************************************************
*                         PART II                          *
************************************************************

     SUBROUTINE NOISE(FILENM,R1,LEVEL)
************************************************************
*    THIS SUBROUTINE READS IN CHANNEL 1 HEX-DECS IN THE    *
*    FORM OF ASCII CHARACTERS THEN CONVERTS THEM TO        *
*    DECIMAL INTEGERS. IT ALSO FINDS THE AVERAGE.          *
************************************************************
       CHARACTER*1 A(16384)
       CHARACTER*7 FILENM
       CHARACTER*11 SNAME
       DIMENSION PS(4096),W1(16384)
       INTEGER*2 KL,KM,TM(16384)
       INTEGER KK,LL,II,J,I,Y,LEVEL
       REAL AVG,SPLDB(2048),R1,SUM,SUMTM,TM3,TMNEW,LV,OVASPL
       REAL SUMPL
       SNAME=FILENM//'.SPE'
       OPEN(UNIT=9,FILE='TMWOAVG')
       OPEN(UNIT=4,FILE=SNAME,STATUS='UNKNOWN')
       OPEN(UNIT=10,FILE='SCRATCH')

       SUMTM=0
       NT=0
      DO 800 I=1,60
       N=0
```

```
        DO 400 Y=1,8
         READ(1)  (A(J),J=1,16384)
          DO 200 II=2,16384,8
           N=N+1
           LL=II-1
           KL=ICHAR(A(II))
           KM=ICHAR(A(LL))
           TM(N)=(KL*256+KM)
           SUMTM=SUMTM+TM(N)
           WRITE(9,*)TM(N)
200       CONTINUE
400     CONTINUE
      NT=NT+N
800   CONTINUE
      AVG=SUMTM/NT
      REWIND 9
      DO WHILE(.NOT. EOF(9))
        READ(9,*)TM3
        TMNEW=((TM3-AVG)/24576.)*R1
        WRITE(10,*)TMNEW
      END DO
      REWIND 10
      CLOSE(UNIT=1)
      CLOSE(UNIT=9,STATUS = 'DELETE')
      TR=1./24000.
      MM=2048
      KK=120
        CALL SPCTRM(PS,MM,KK,W1)
      SUM=0
      IF (LEVEL.EQ.20) THEN
        LV =.249
        ELSE
         LV =.0788
      ENDIF
      DF=1./TR/FLOAT(MM)/2.
      SUMPL=0.
      DO JK=1,MM
        FF=(JK-1)*DF
        SPLDB(JK)=94.1+20*(LOG10(SQRT(PS(JK))/LV))
        IF (SPLDB(JK).LE.0) THEN
          GO TO 16
        ENDIF
        SUMPL=SUMPL+10.**((SPLDB(JK)/10.))
16      WRITE(4,*)FF,SPLDB(JK)
      END DO
      OVASPL=10*LOG10(SUMPL)
      WRITE(4,*)'OVERALL SOUND PRESSURE LEVEL=',OVASPL
      CLOSE(10,STATUS = 'DELETE')
      CLOSE(4)
      RETURN
      END
```

```
      SUBROUTINE SPCTRM(P,M,K,W1)
************************************************************
*    THIS ROUTINE RETURNS THE NOISE DATA'S POWER AT A      *
*    FREQUENCY OF (J-1)/(2*M) CYCLES PER GRIDPOINT.        *
************************************************************
      DIMENSION P(M),W1(4*M)
      WINDOW(J)=(1.-ABS(((J-1)-FACM)*FACP))
      MM=M+M
      M4=MM+MM
      M44=M4+4
      M43=M4+3
      DEN=0.
      FACM=M-0.5
      FACP=1./(M+0.5)
      SUMW=0.
      DO 11 J=1,MM
        SUMW=SUMW+WINDOW(J)**2
11    CONTINUE
      DO 12 J=1,M
        P(J)=0.
12    CONTINUE
      DO 18 KK=1,K
        DO 15 JOFF=-1,0,1
          READ (10,*)  (W1(J),J=JOFF+2,M4,2)
15      CONTINUE
        DO 16 J=1,MM
         J2=J+J
         W=WINDOW(J)
         W1(J2)=W1(J2)*W
         W1(J2-1)=W1(J2-1)*W
16      CONTINUE
       CALL FOUR1(W1,MM,1)
         P(1)=P(1)+W1(1)**2+W1(2)**2
        DO 17 J=2,M
         J2=J+J
         P(J)=P(J)+W1(J2)**2+W1(J2-1)**2+W1(M44-J2)**2
            +   +W1(M43-J2)**217
17      CONTINUE
       DEN=DEN+SUMW
18    CONTINUE
      DEN=M4*DEN
       DO 19 J=1,M
         P(J)=P(J)/DEN
19     CONTINUE
      RETURN
      END

      SUBROUTINE FOUR1(DATA,NN,ISIGN)
************************************************************
*    THIS ROUTINE REPLACES 'DATA' BY ITS DISCRETE FFT      *
************************************************************
```

```
      REAL*8 WR,WI,WPR,WPI,WTEMP,THETA
       DIMENSION DATA(*)
       N=2*NN
       J=1
       DO 11 I=1,N,2
          IF(J.GT.I)THEN
           TEMPR=DATA(J)
           TEMPI=DATA(J+1)
           DATA(J)=DATA(I)
           DATA(J+1)=DATA(I+1)
           DATA(I)=TEMPR
           DATA(I+1)=TEMPI
          ENDIF
         M=N/2
1       IF ((M.GE.2).AND.(J.GT.M)) THEN
          J=J-M
          M=M/2
         GO TO 1
        ENDIF
        J=J+M
11     CONTINUE
      MMAX=2
2     IF (N.GT.MMAX) THEN
       ISTEP=2*MMAX
       THETA=6.28318530717959D0/(ISIGN*MMAX)
       WPR=-2.D0*DSIN(0.5D0*THETA)**2
       WPI=DSIN(THETA)
       WR=1.D0
       WI=0.D0
       DO 13 M=1,MMAX,2
         DO 12 I=M,N,ISTEP
          J=I+MMAX
          TEMPR=SNGL(WR)*DATA(J)-SNGL(WI)*DATA(J+1)
          TEMPI=SNGL(WR)*DATA(J+1)+SNGL(WI)*DATA(J)
          DATA(J)=DATA(I)-TEMPR
          DATA(J+1)=DATA(I+1)-TEMPI
          DATA(I)=DATA(I)+TEMPR
          DATA(I+1)=DATA(I+1)+TEMPI
12       CONTINUE
        WTEMP=WR
        WR=WR*WPR-WI*WPI+WR
        WI=WI*WPR+WTEMP*WPI+WI
13     CONTINUE
      MMAX=ISTEP
      GO TO 2
      ENDIF
      RETURN
      END
```

APPENDIX D

FREQUENCY ANALYSIS RESULTS

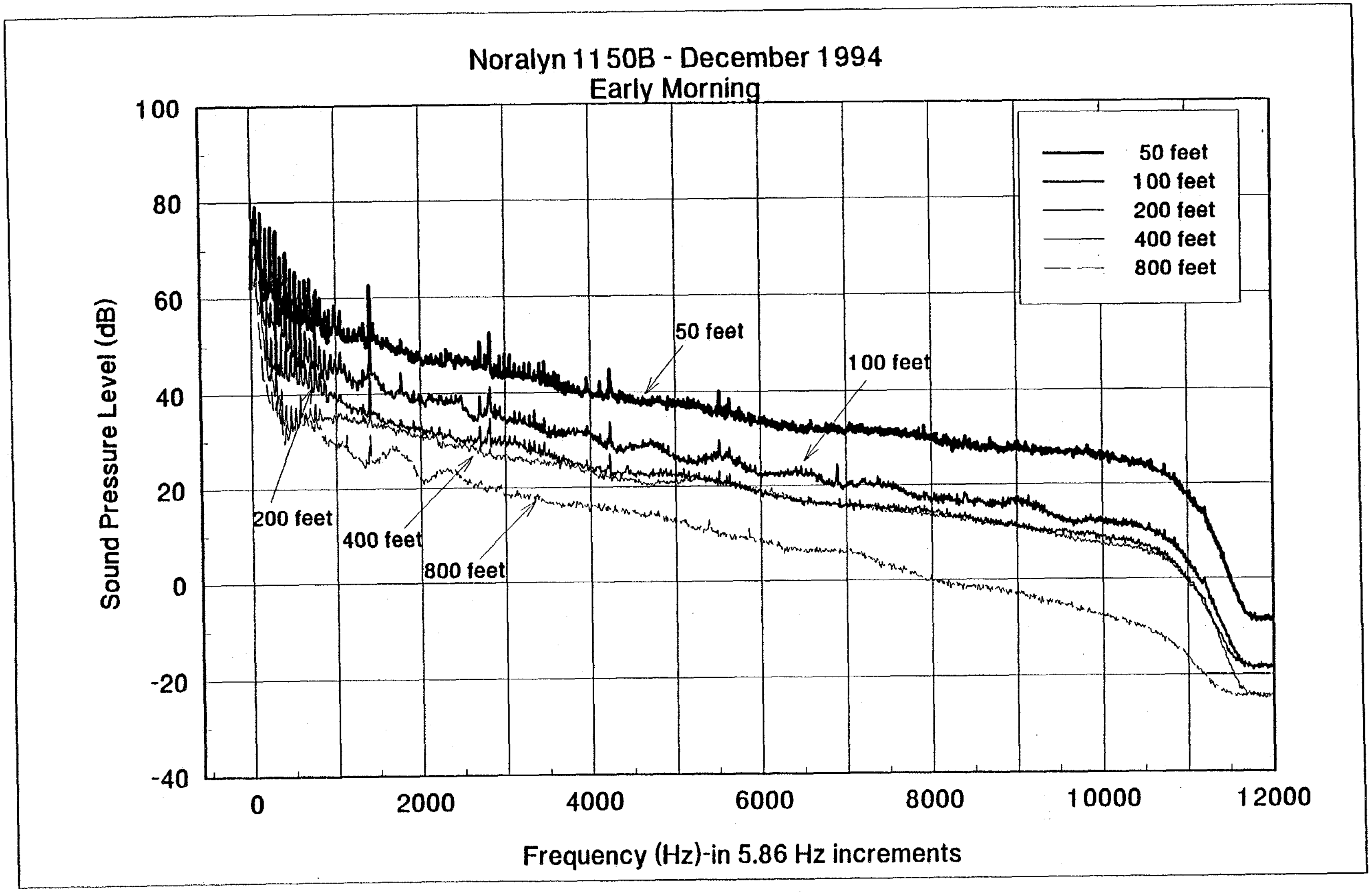

Figure D.1 Sound pressure spectrum for 1150B from 0 to 12000 Hz

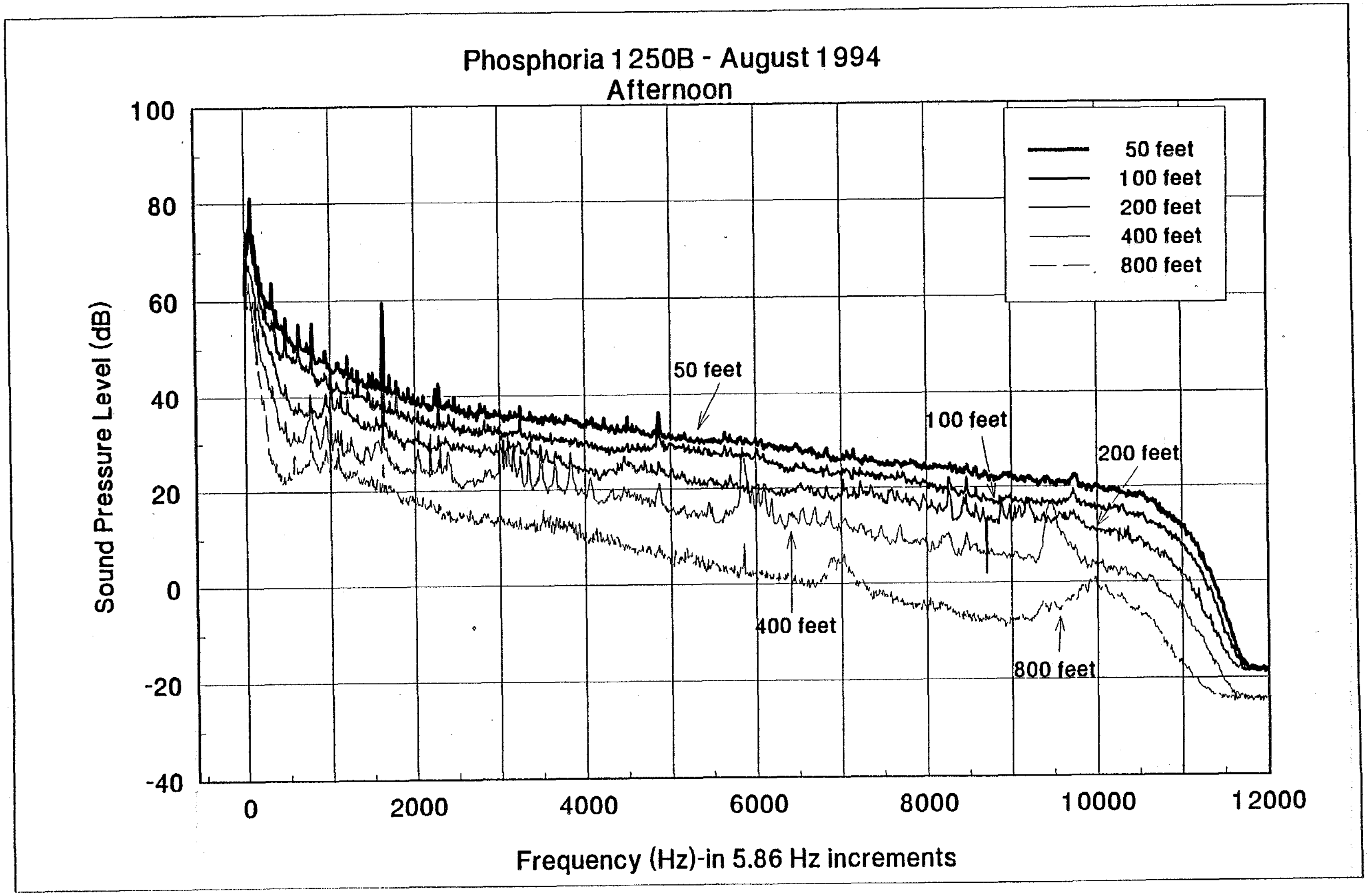

Figure D.2 Sound pressure spectrum for 1250B from 0 to 12000 Hz

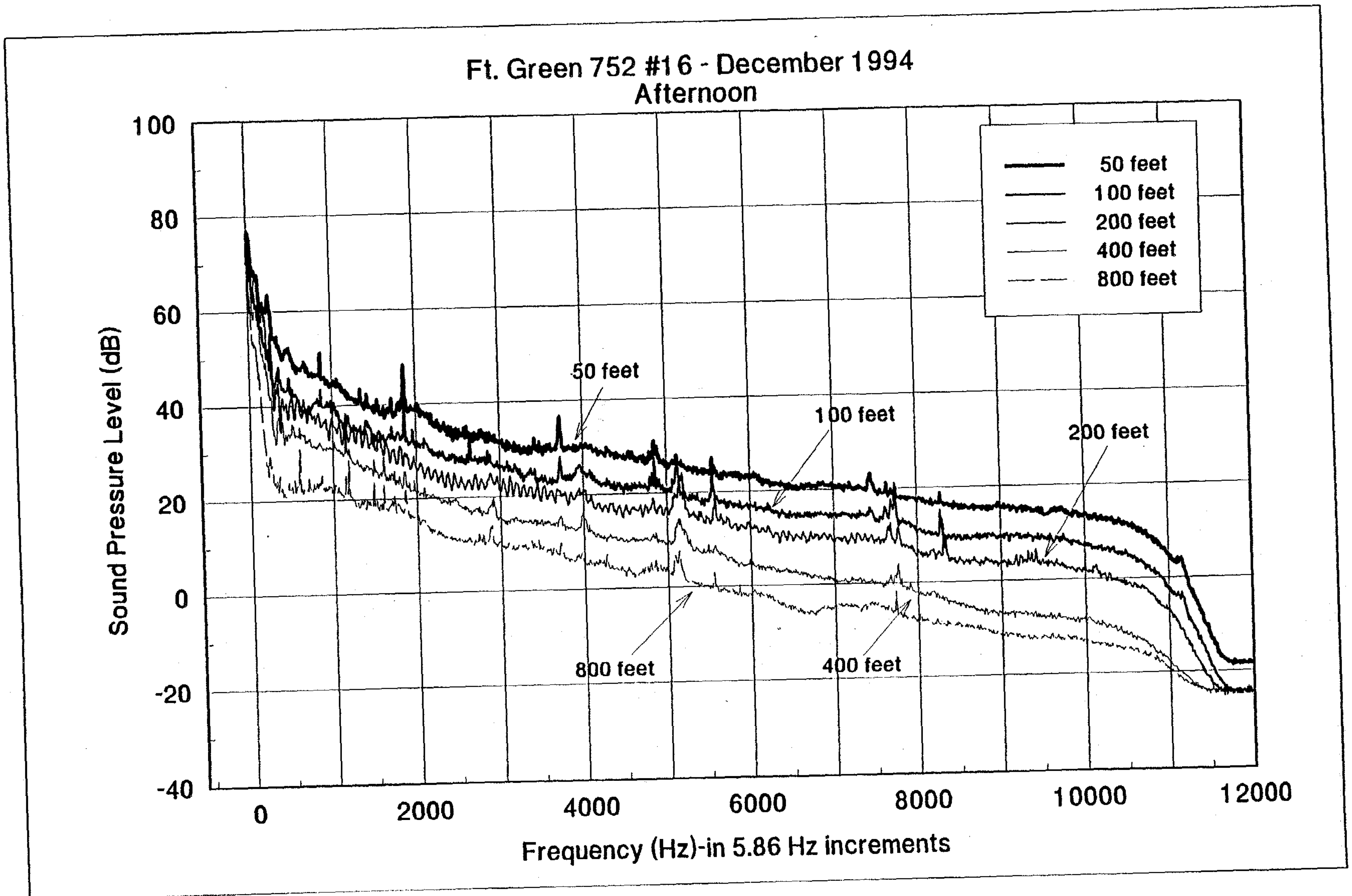

Figure D.3 Sound pressure spectrum for 752 #16 from 0 to 12000 Hz

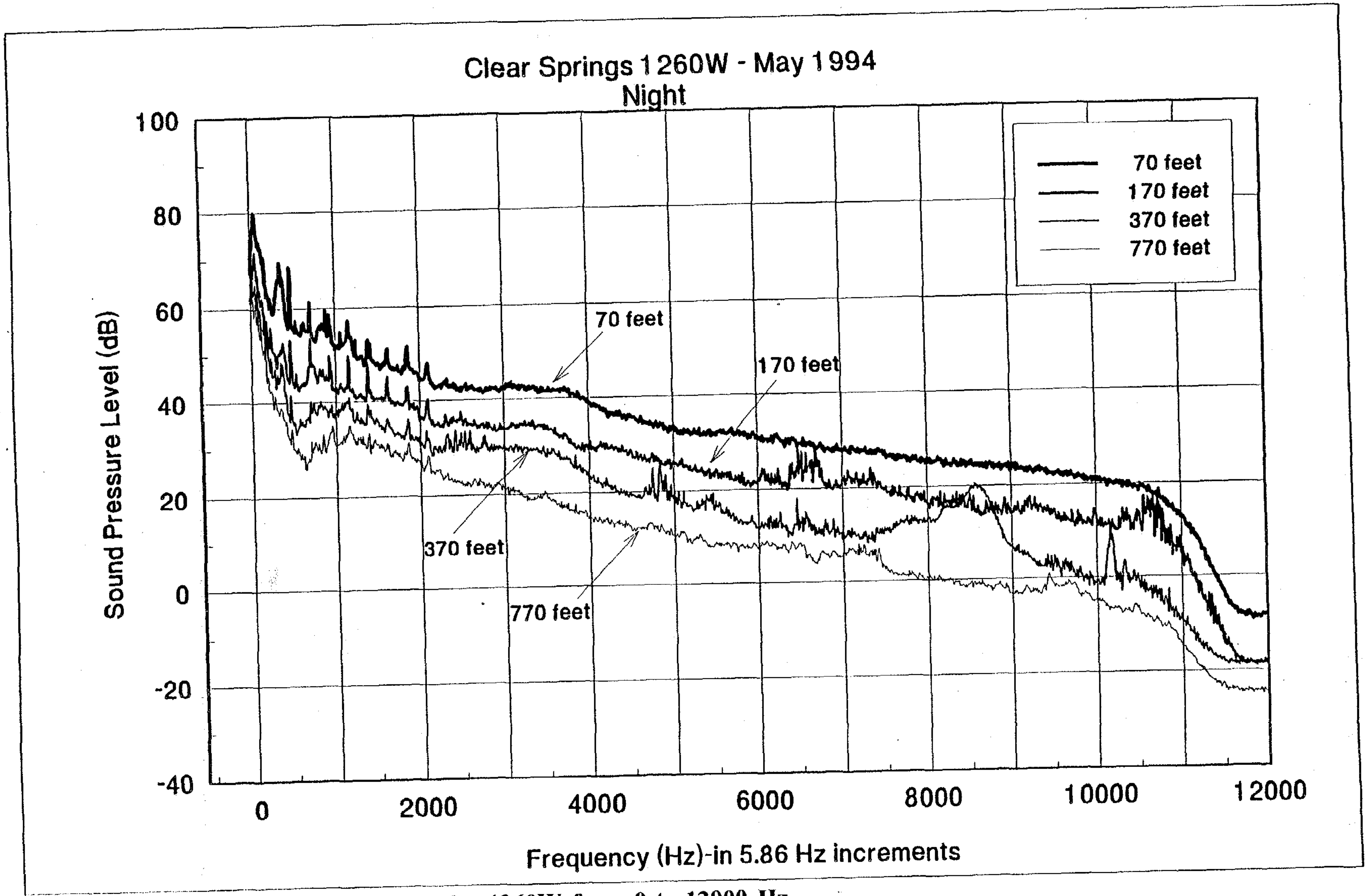

Figure D.4 Sound pressure spectrum for 1260W from 0 to 12000 Hz

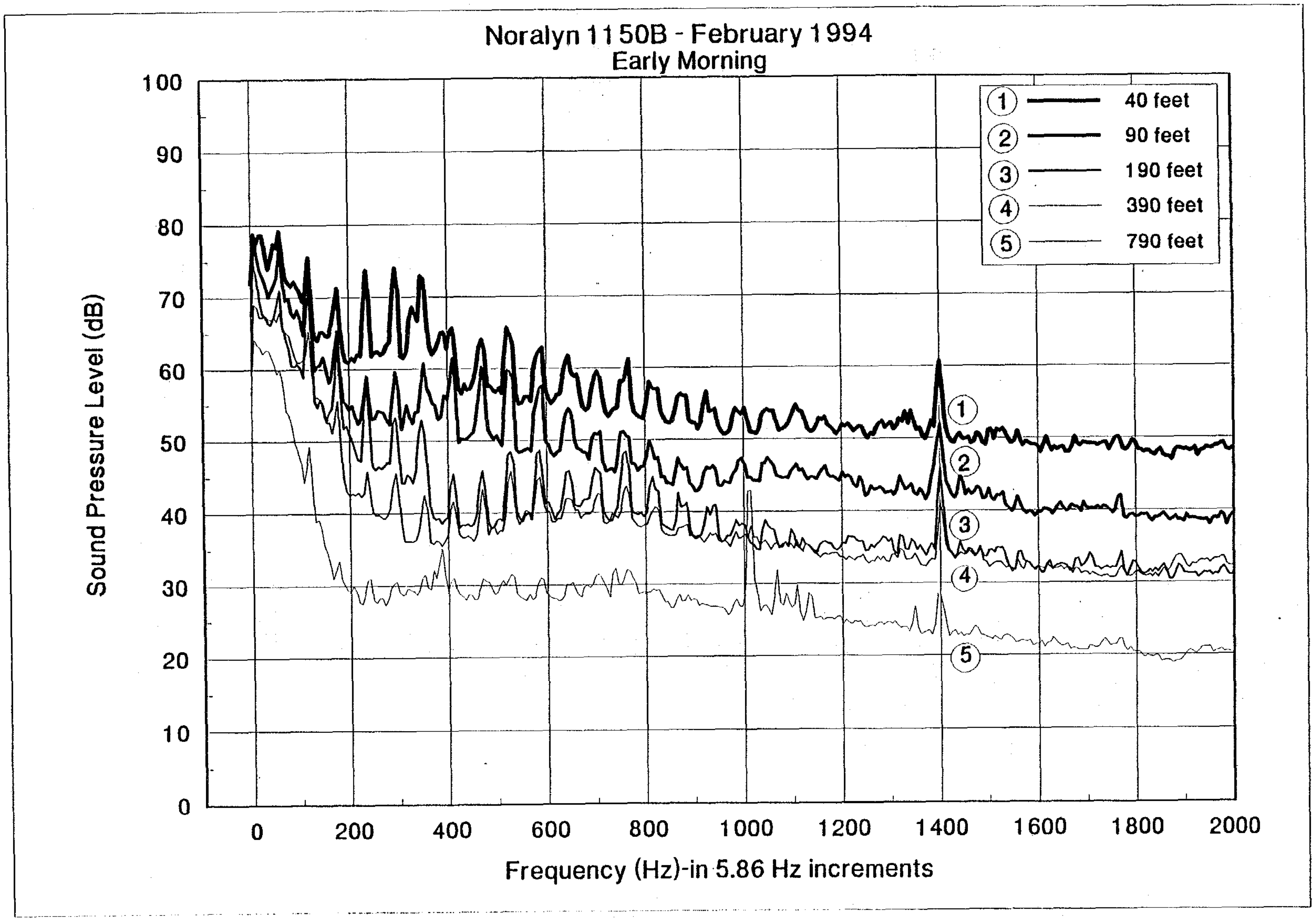

Figure D.5 Sound pressure spectrum for 1150B--Phase I (Early morning)

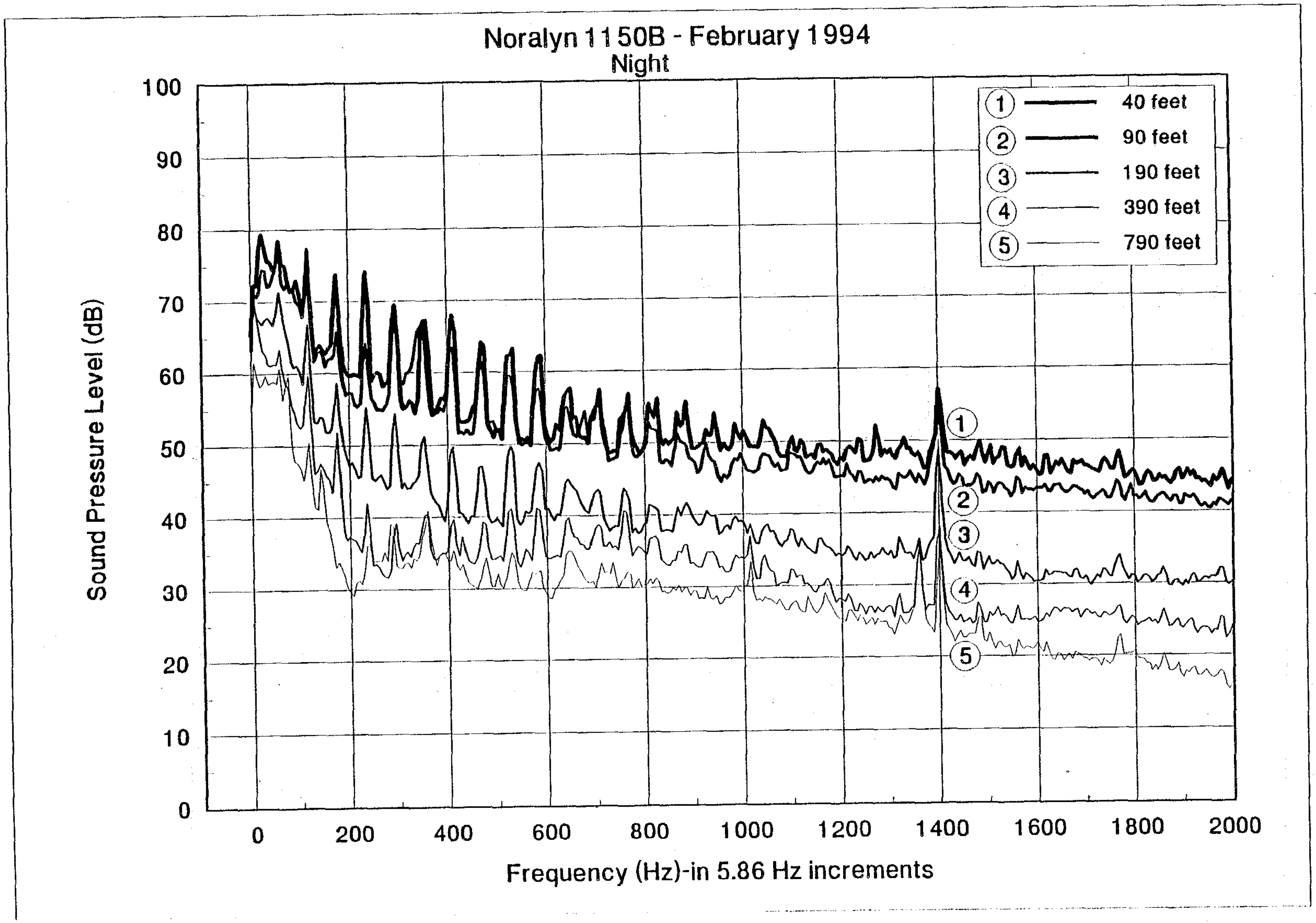

Figure D.6 Sound pressure spectrum for 1150B--Phase I (Night)

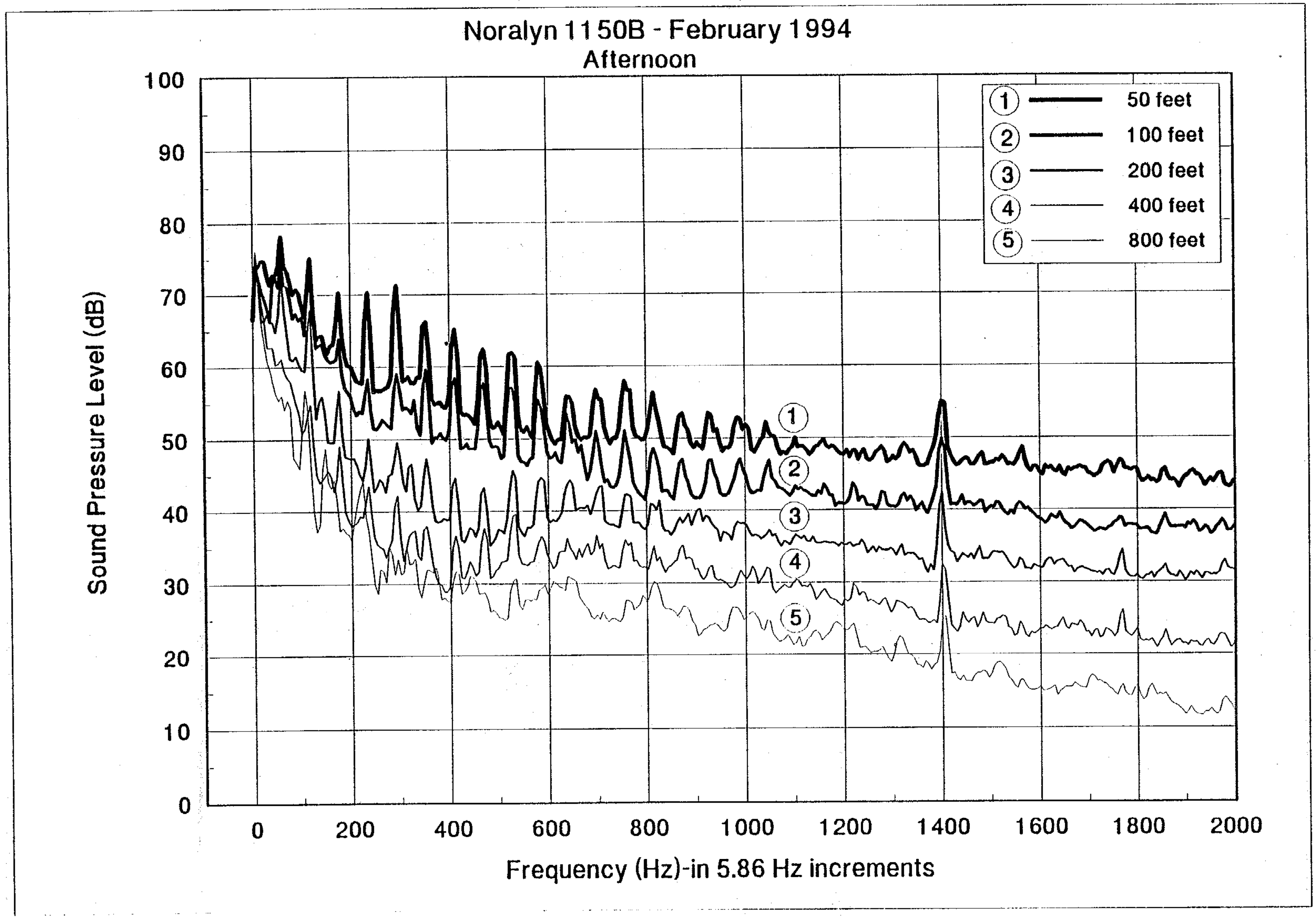

Figure D.7 Sound pressure spectrum for 1150B--Phase I (Afternoon)

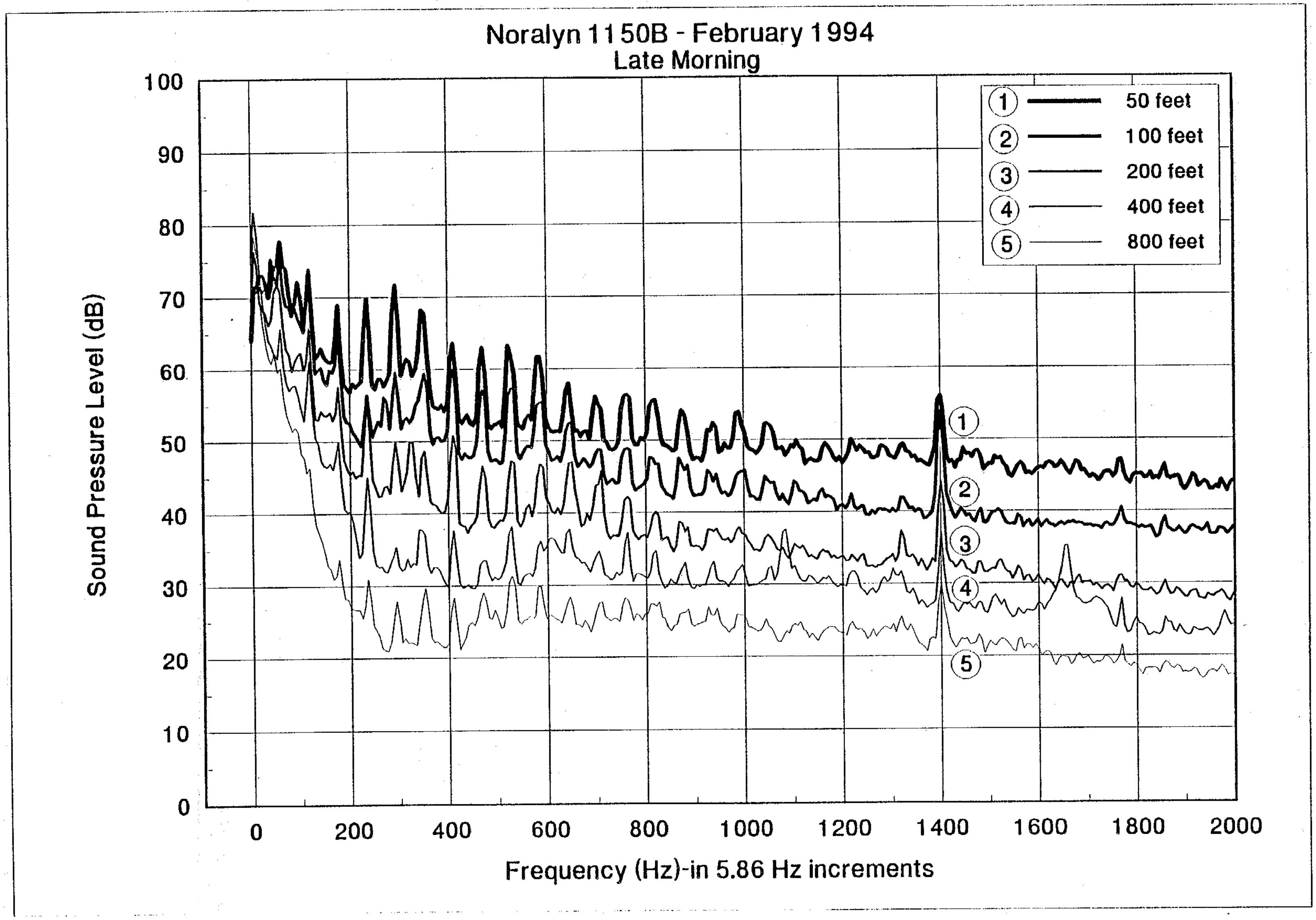

Figure D.8 Sound pressure spectrum for 1150B--Phase I (Late morning)

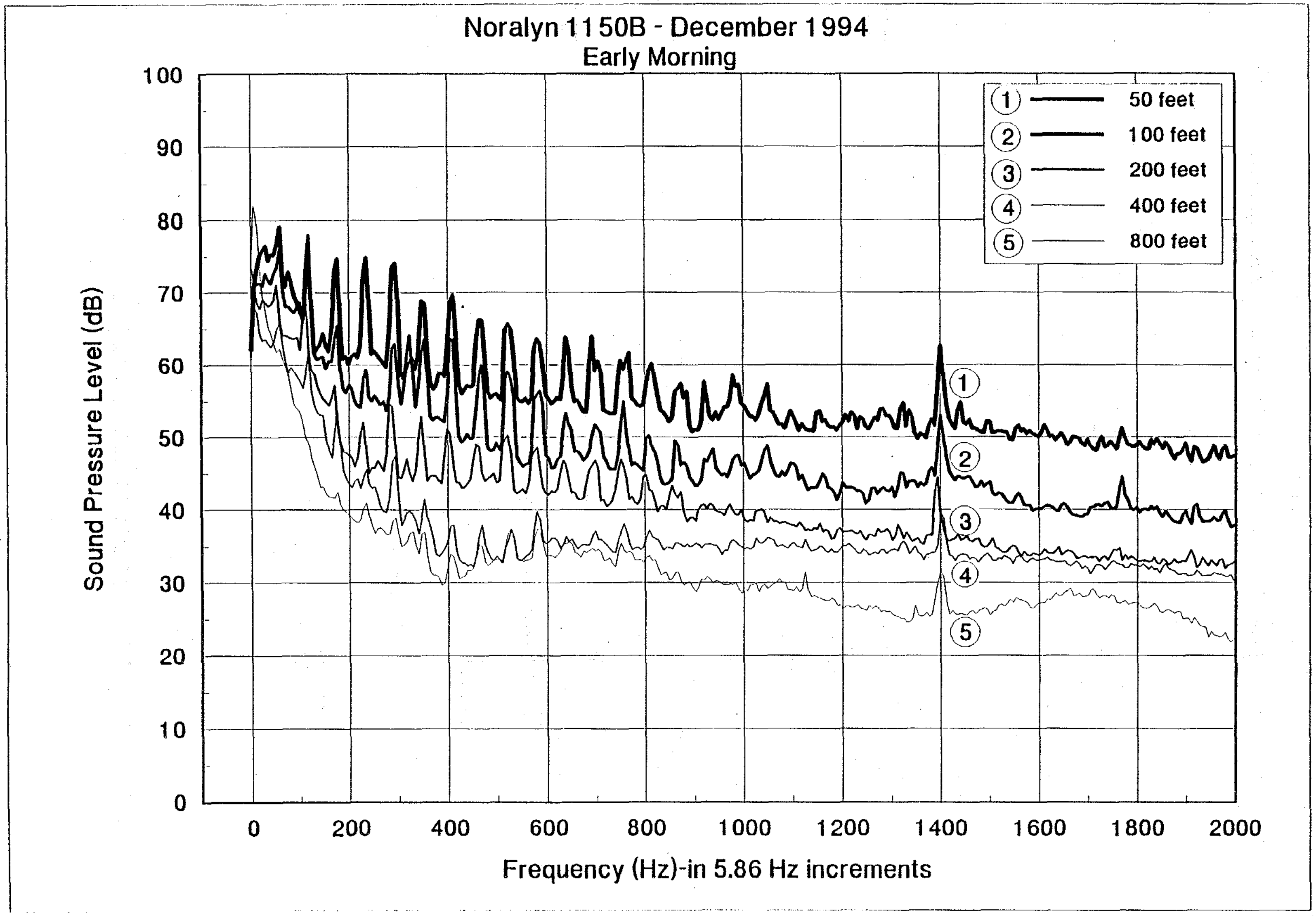

Figure D.9 Sound pressure spectrum for 1150B--Phase IV (Early morning)

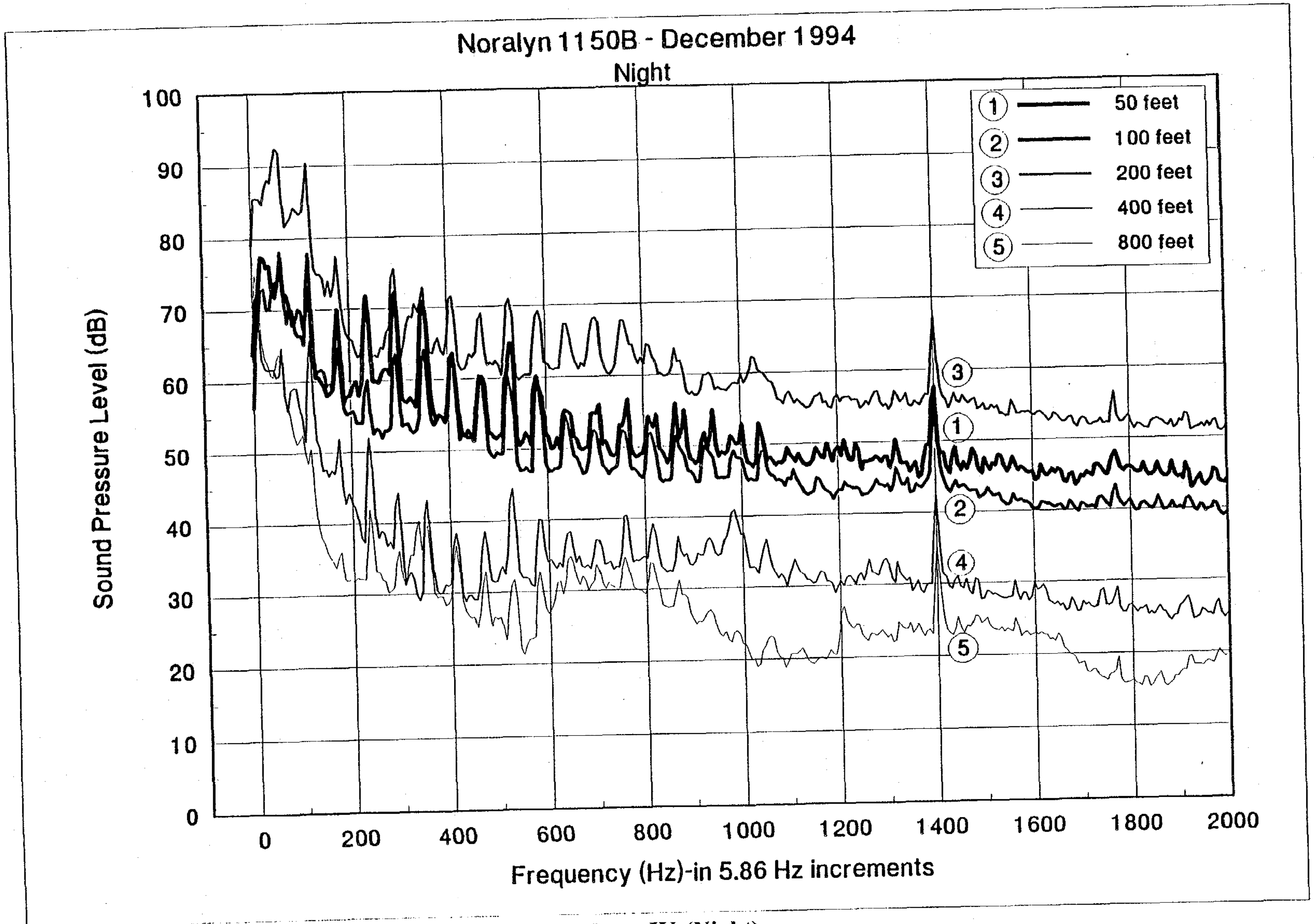

Figure D.10 Sound pressure spectrum for 1150B--Phase IV (Night)

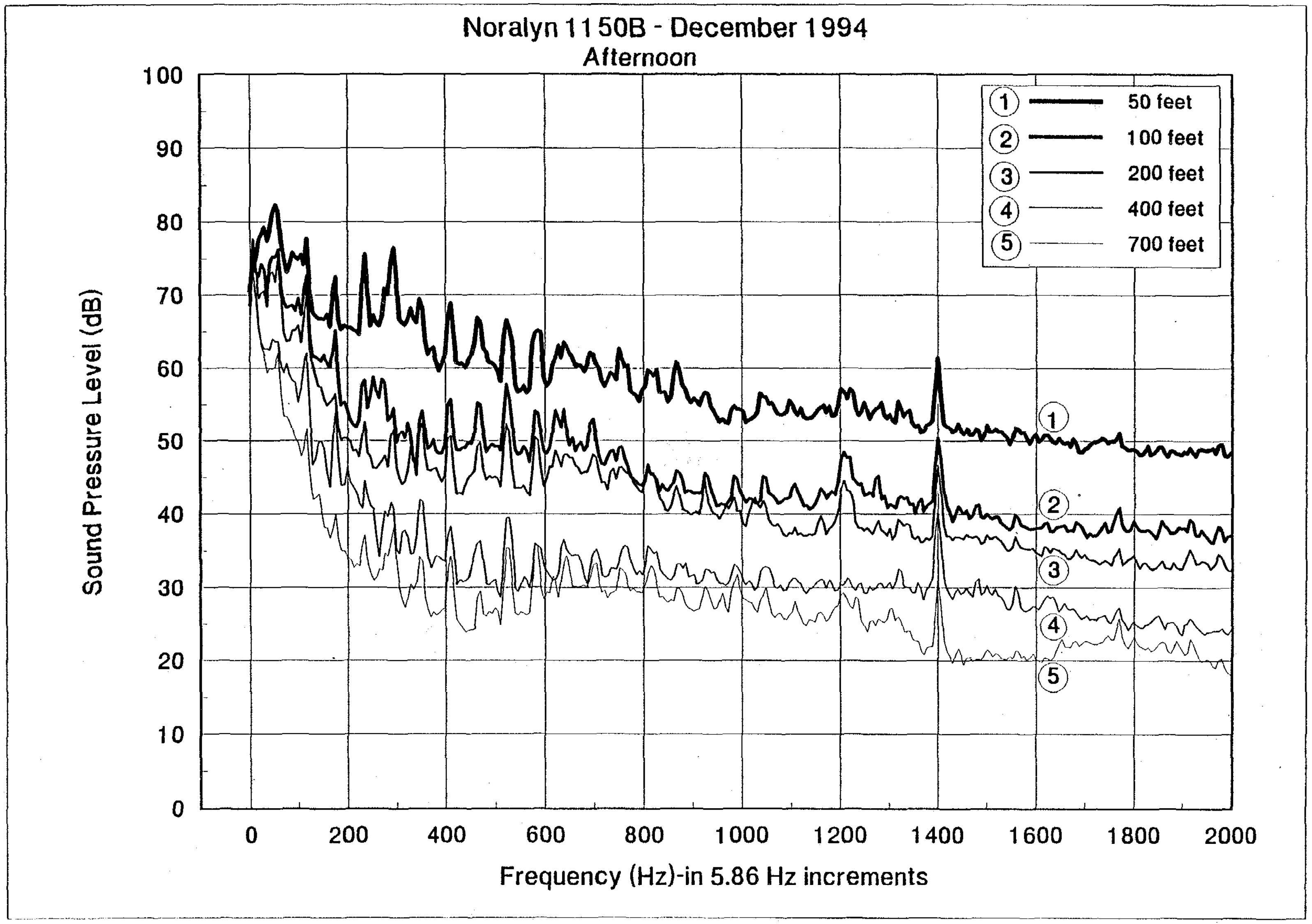

Figure D.11 Sound pressure spectrum for 1150B--Phase IV (Afternoon)

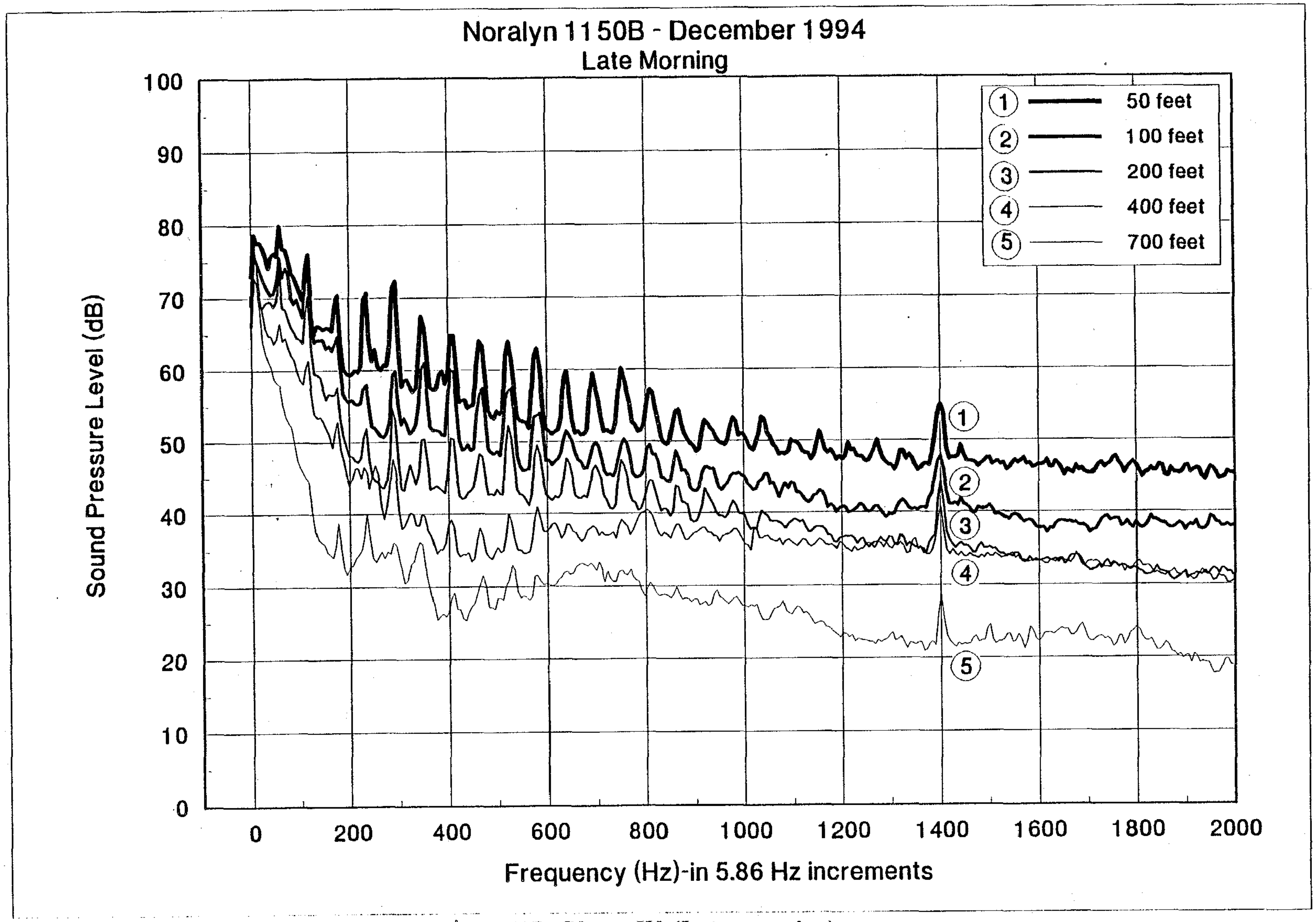

Figure D.12 Sound pressure spectrum for 1150B--Phase IV (Late morning)

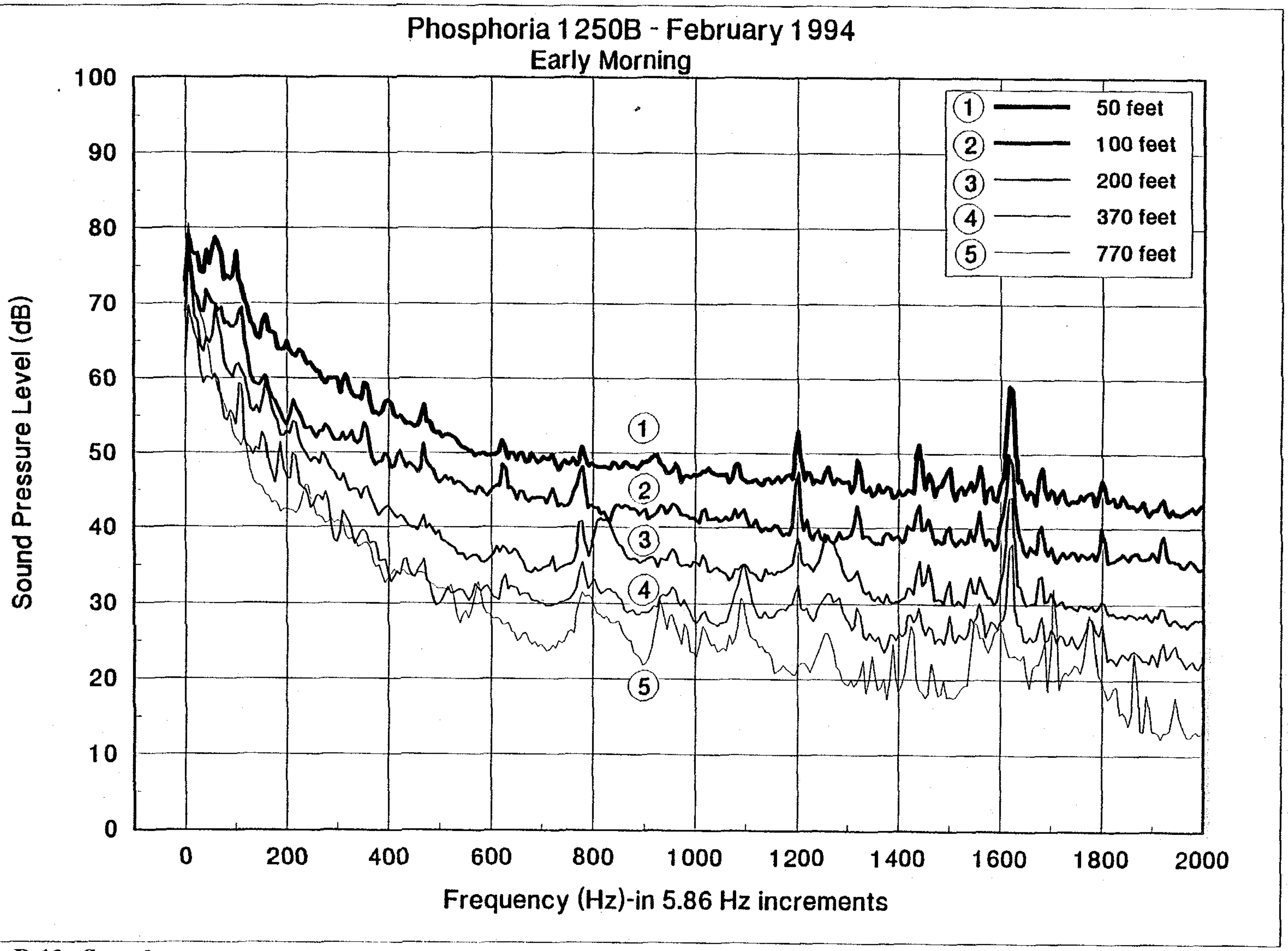

Figure D.13 Sound pressure spectrum for 1250B--Phase I (Early morning)

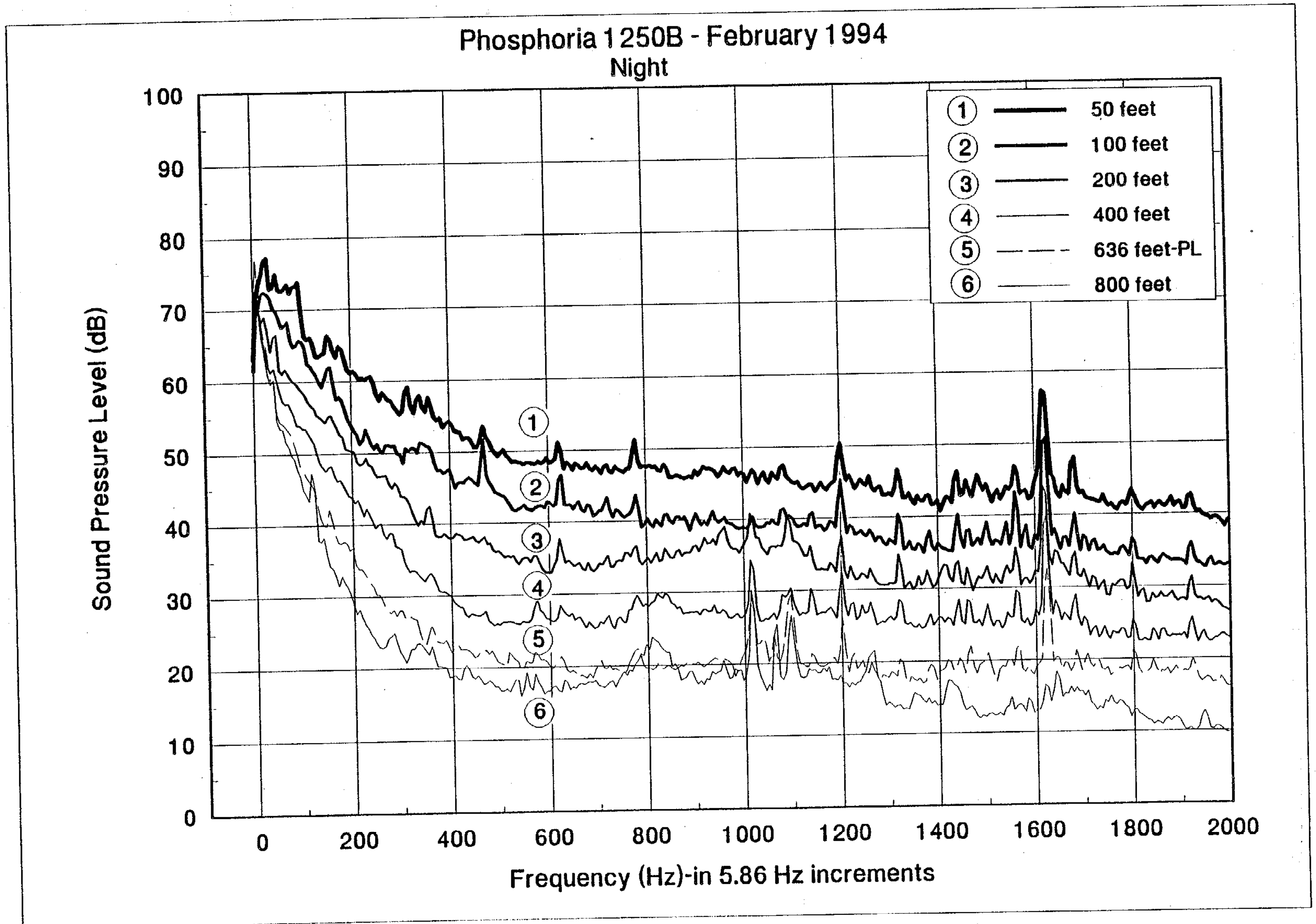

Figure D.14 Sound pressure spectrum for 1250B--Phase I (Night)

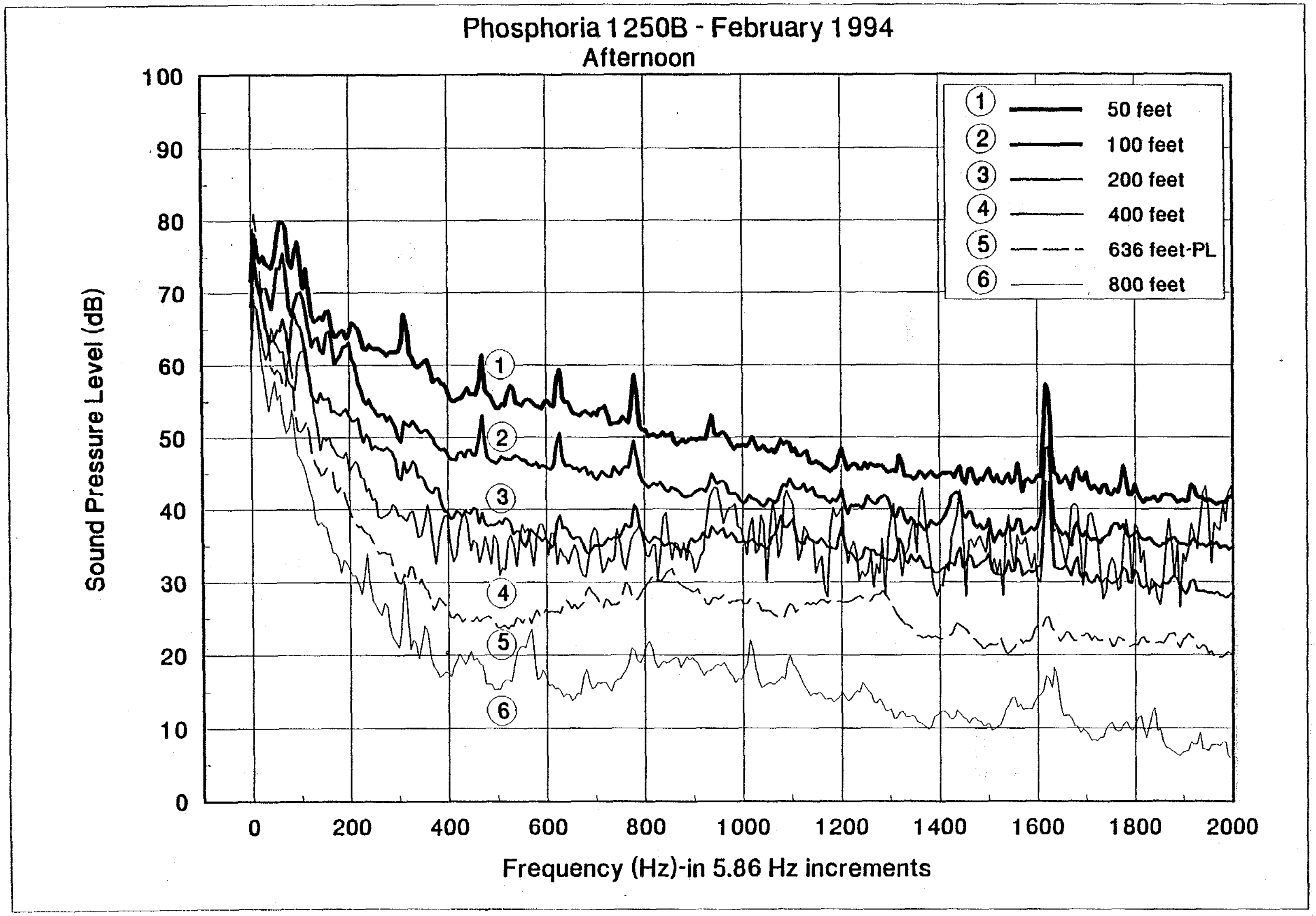

Figure D.15 Sound pressure spectrum for 1250B--Phase I (Afternoon)

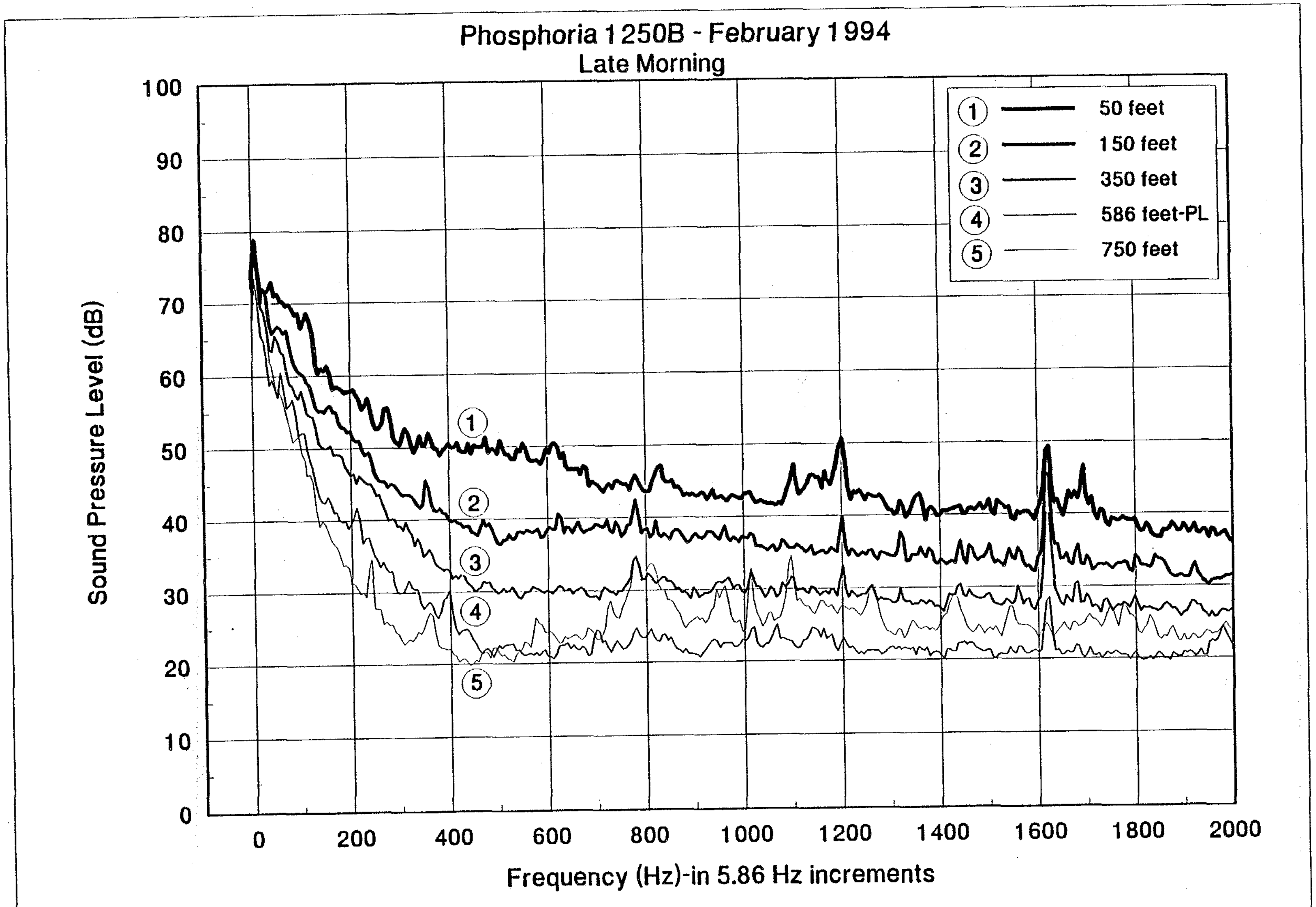

Figure D.16 Sound pressure spectrum for 1250B--Phase I (Late morning)

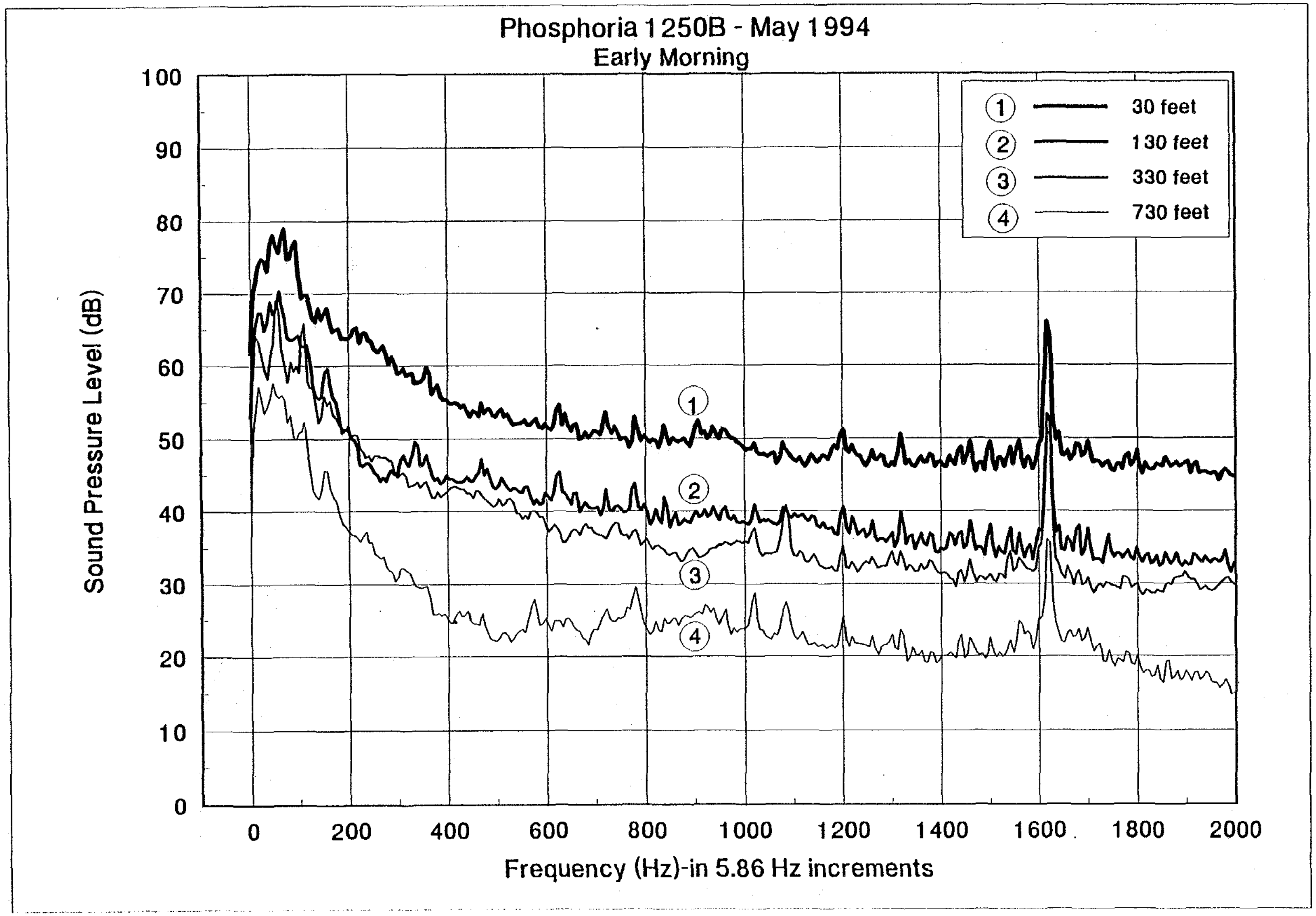

Figure D.17 Sound pressure spectrum for 1250B--Phase II (Early morning)

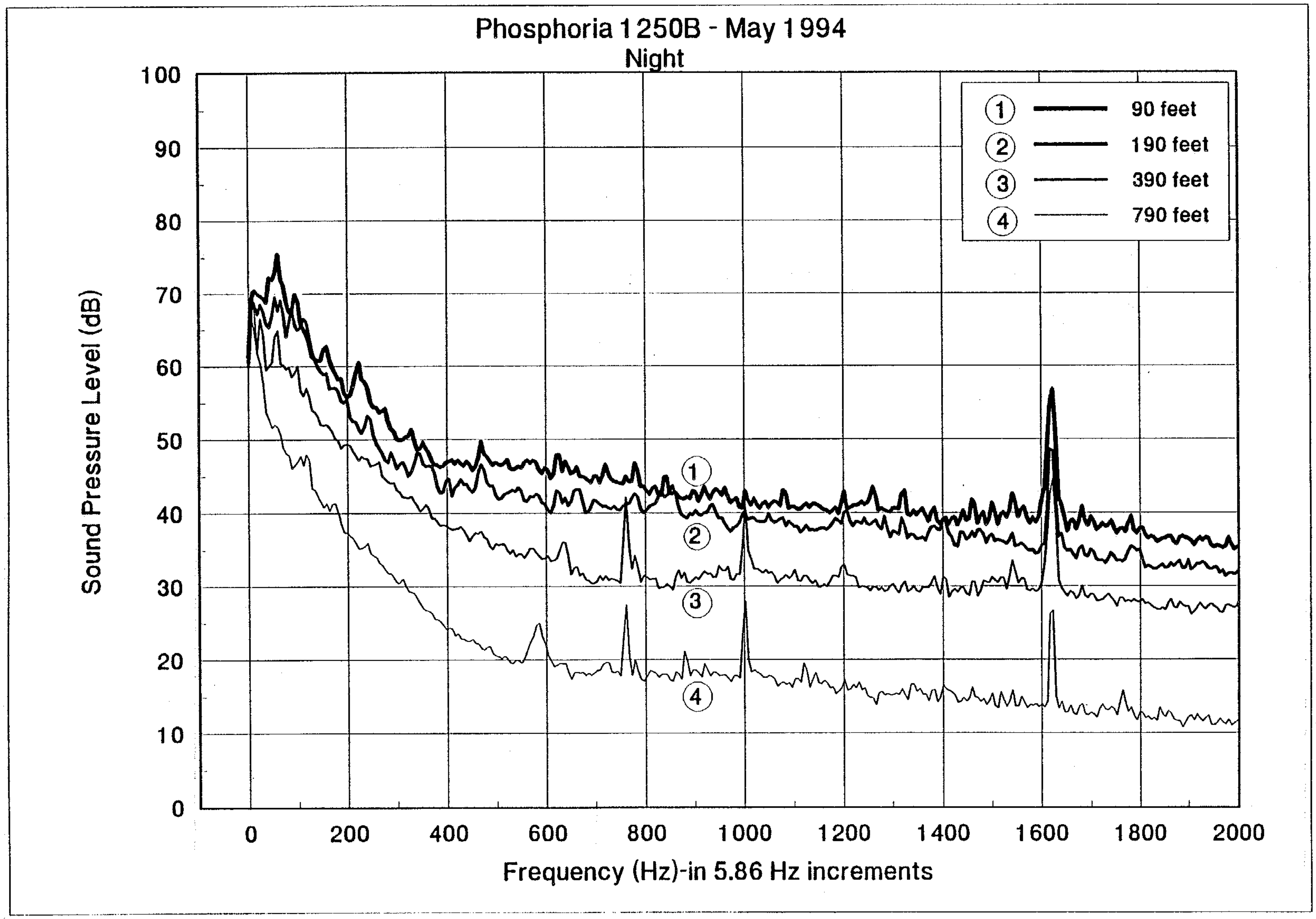

Figure D.18 Sound pressure spectrum for 1250B--Phase II (Night)

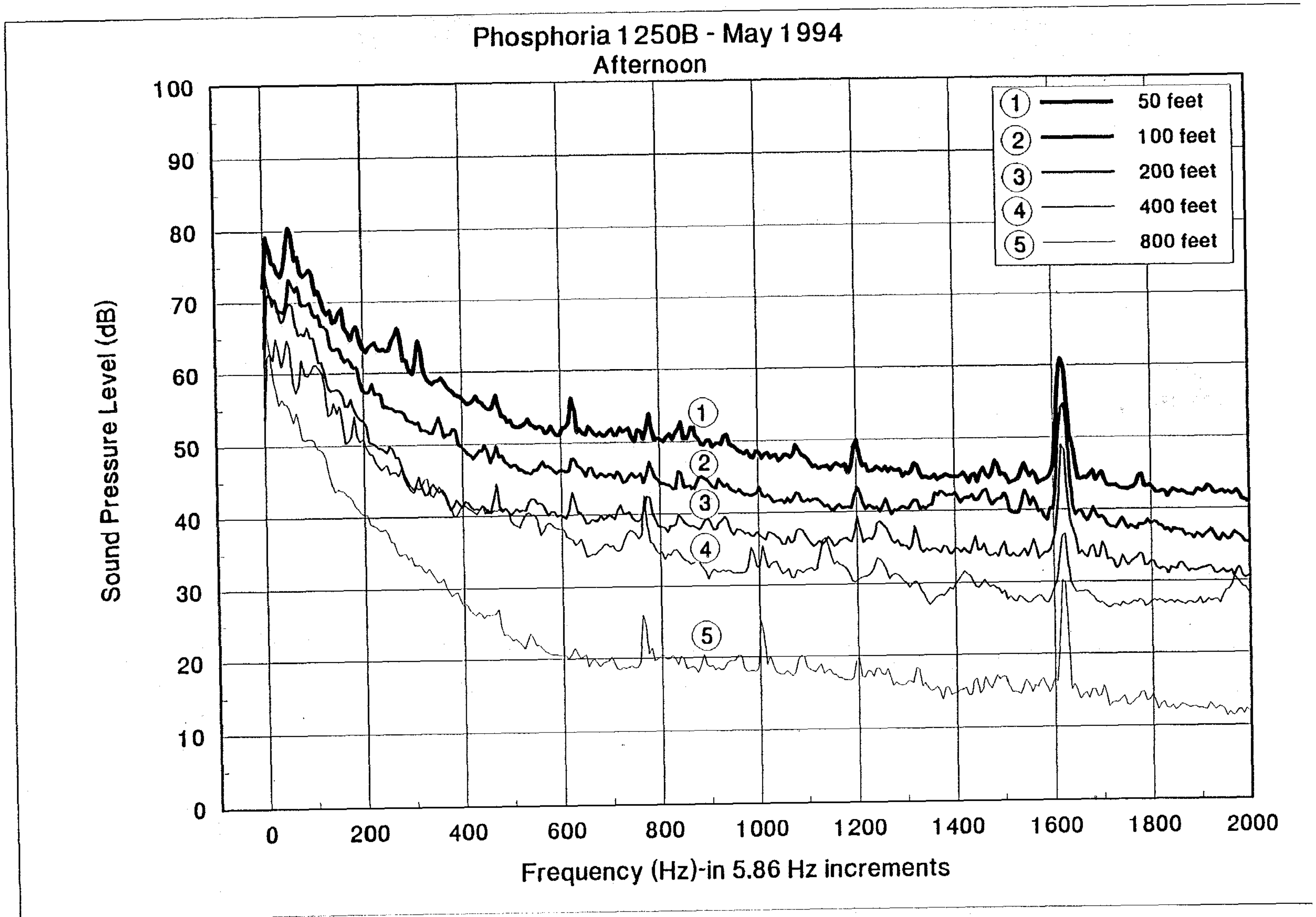

Figure D.19 Sound pressure spectrum for 1250B--Phase II (Afternoon)

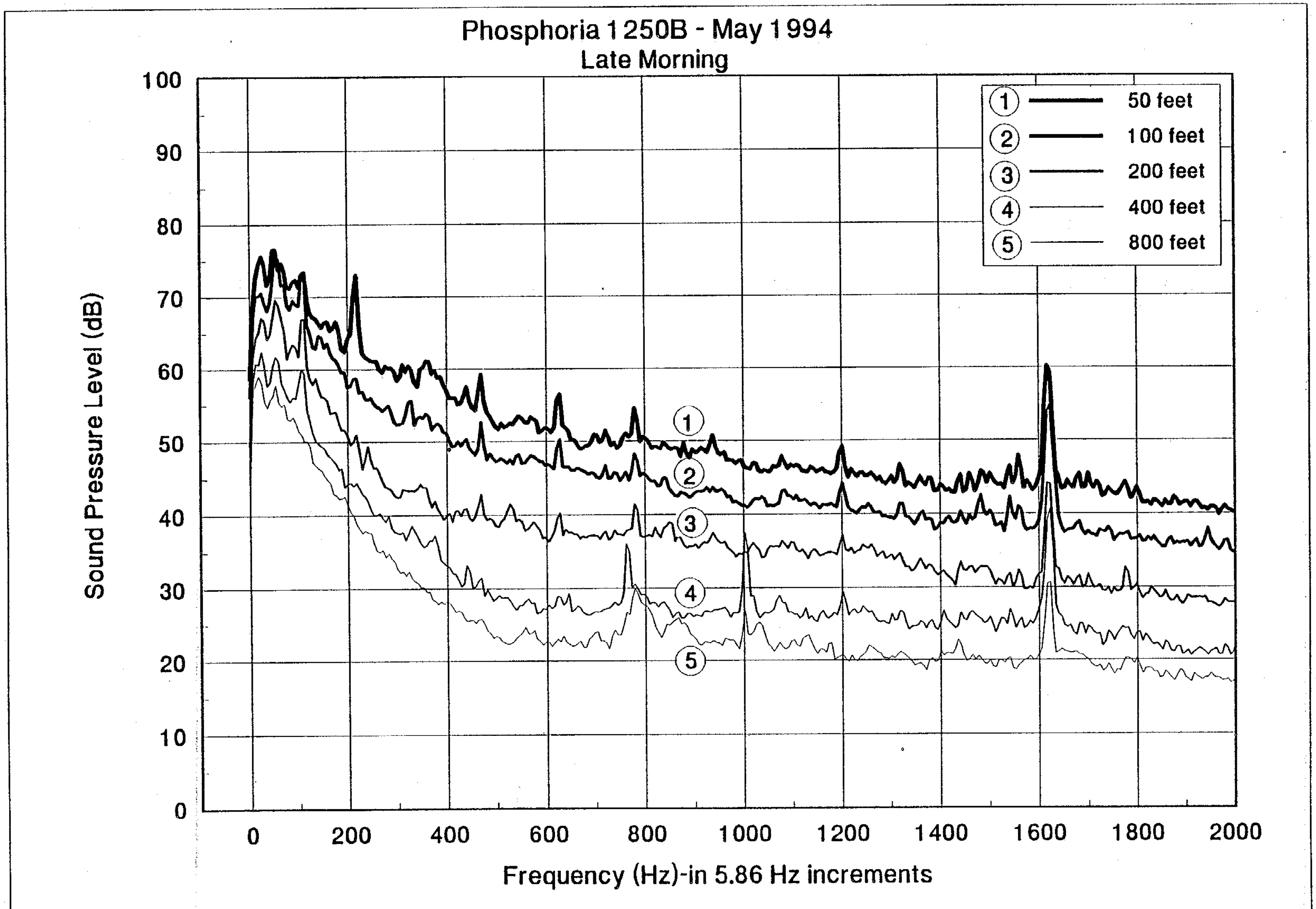

Figure D.20 Sound pressure spectrum for 1250B--Phase II (Late morning)

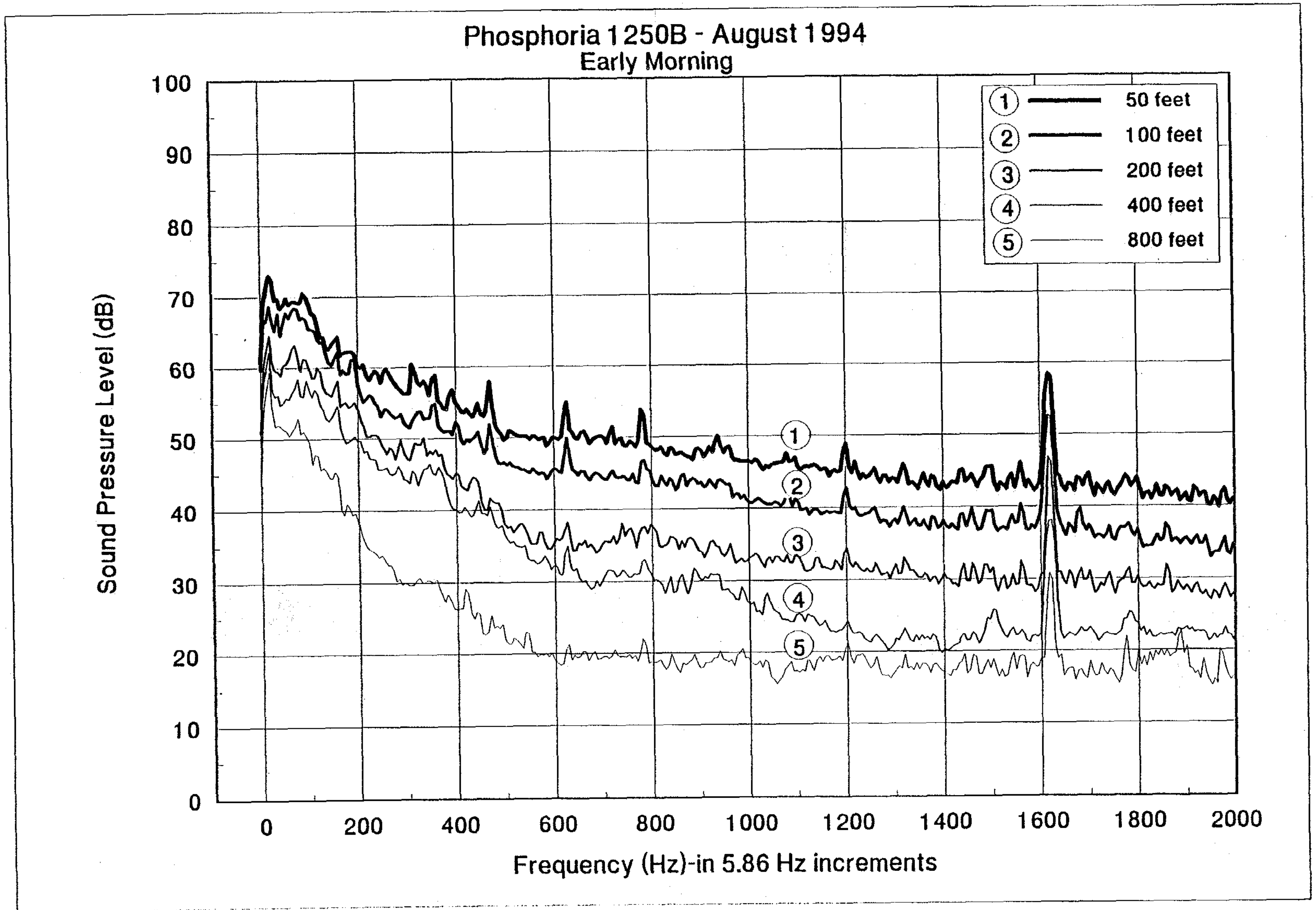

Figure D.21 Sound pressure spectrum for 1250B--Phase III (Early morning)

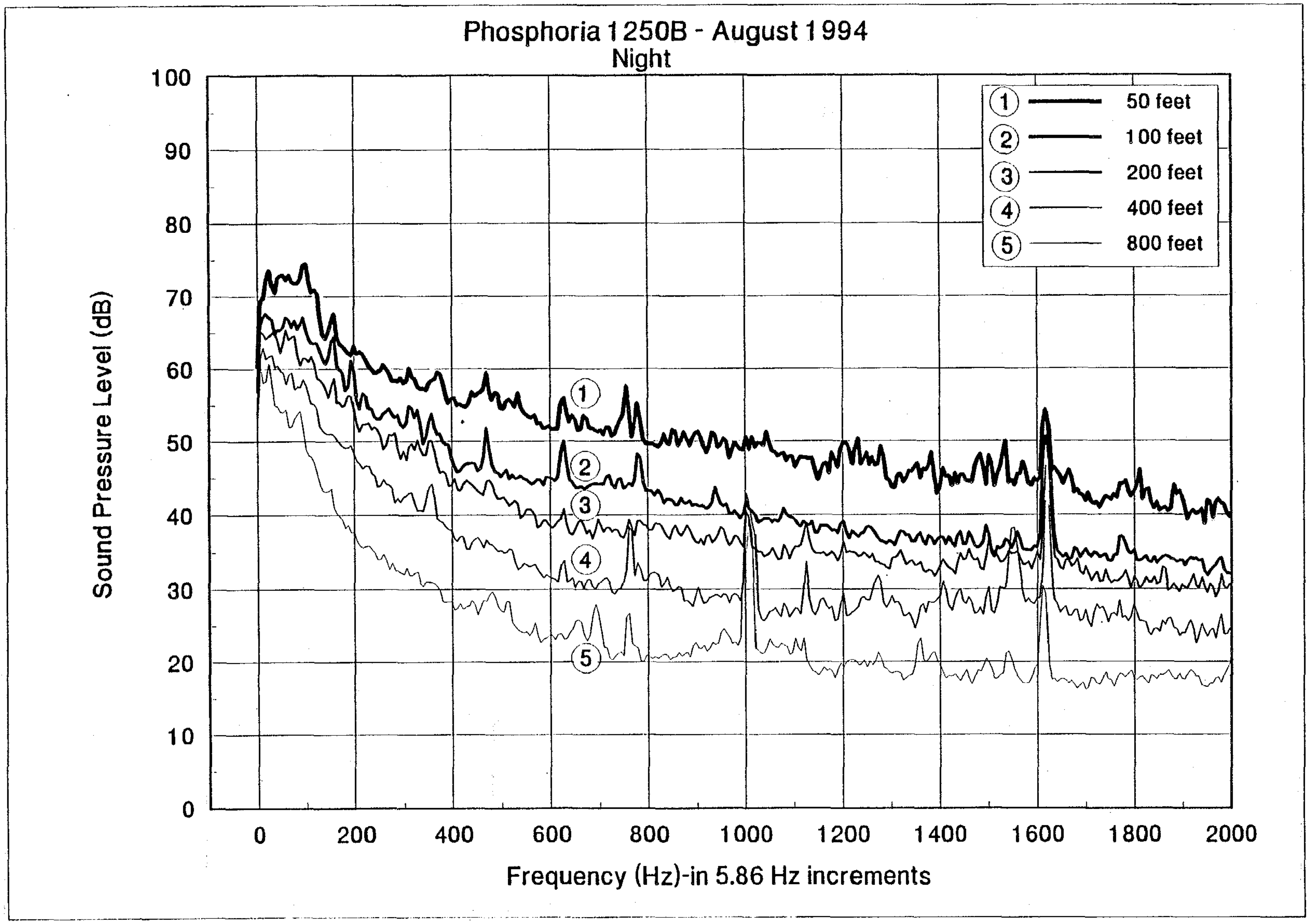

Figure D.22 Sound pressure spectrum for 1250B--Phase III (Night)

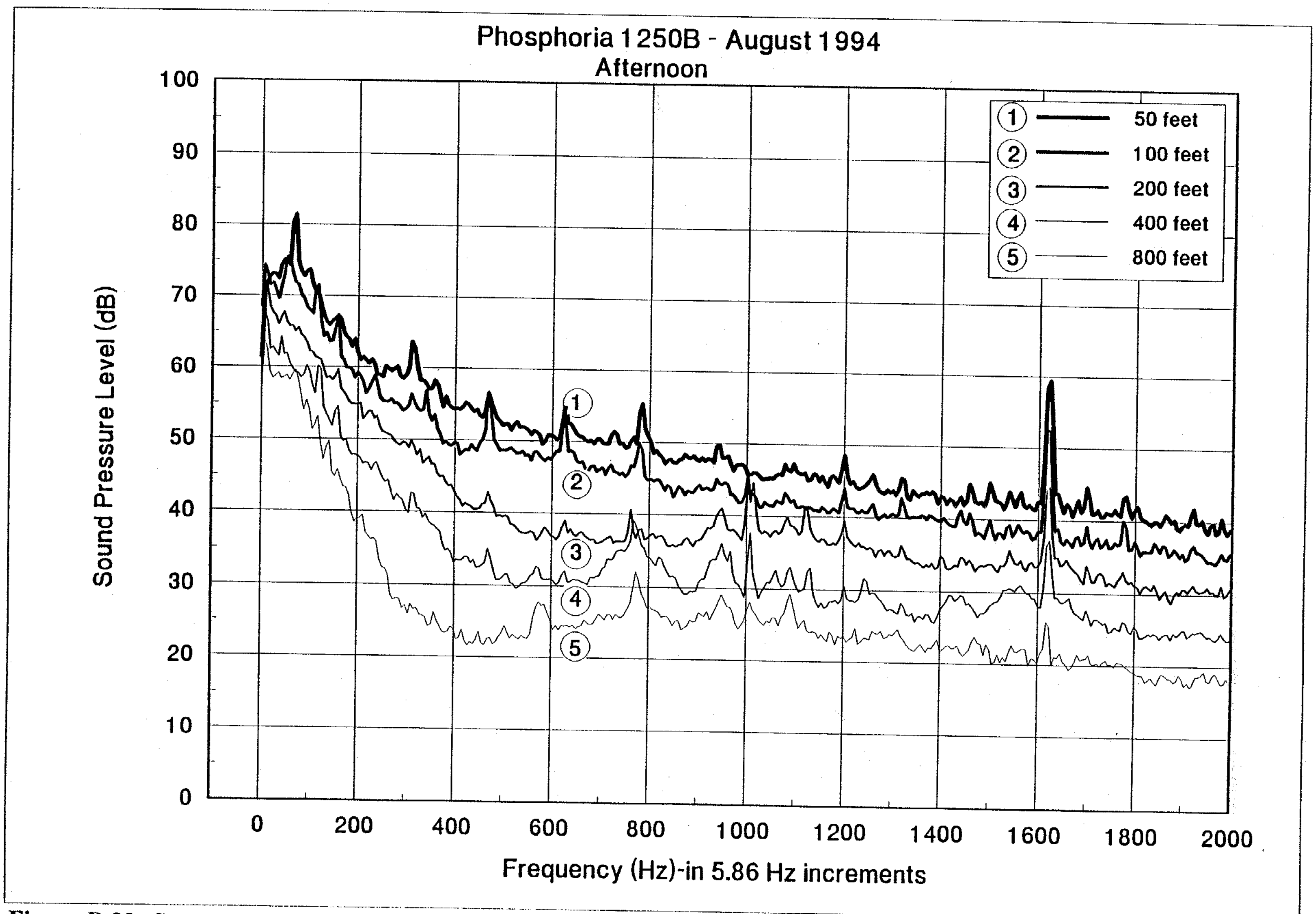

Figure D.23 Sound pressure spectrum for 1250B--Phase III (Afternoon)

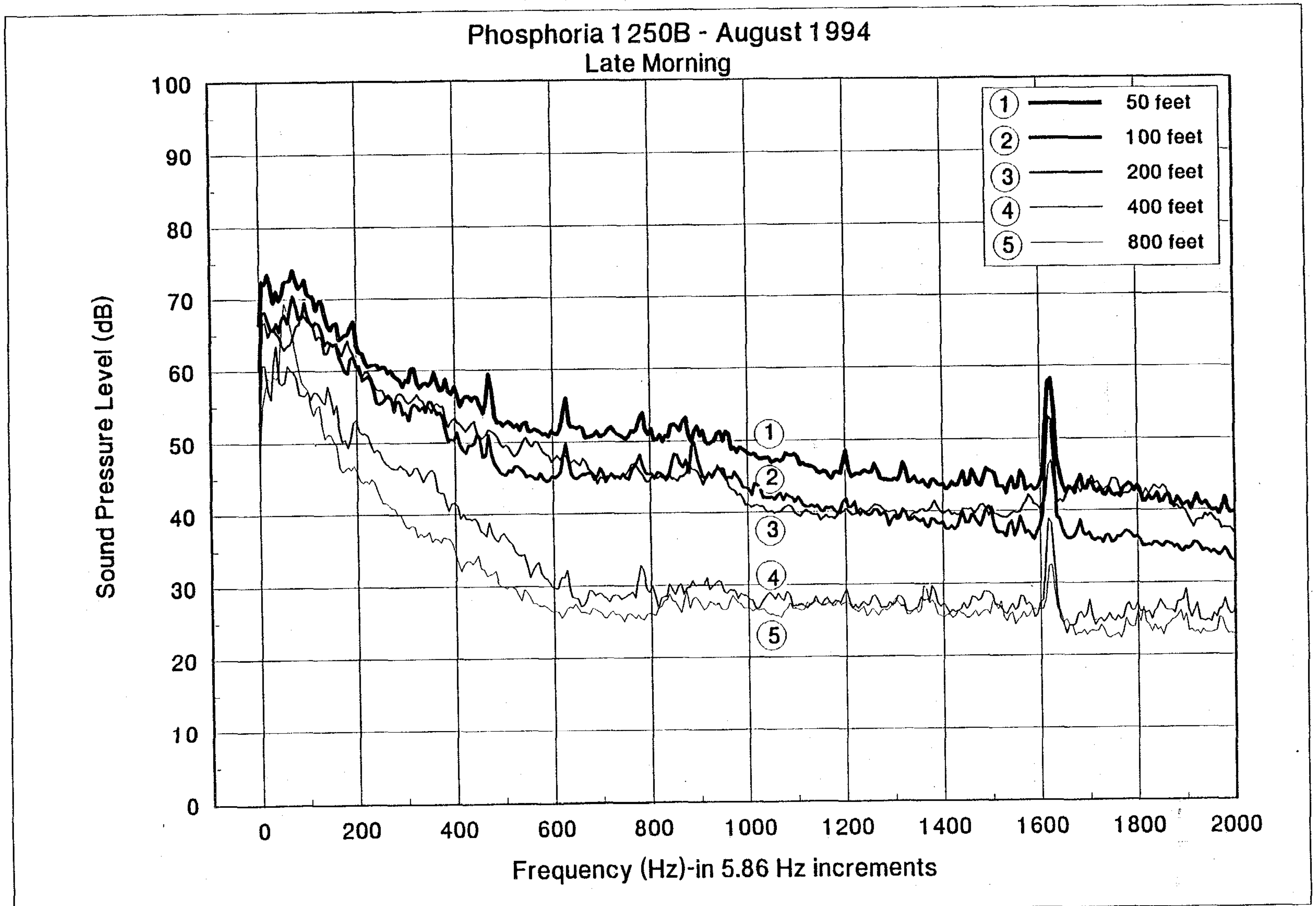

Figure D.24 Sound pressure spectrum for 1250B--Phase III (Late morning)

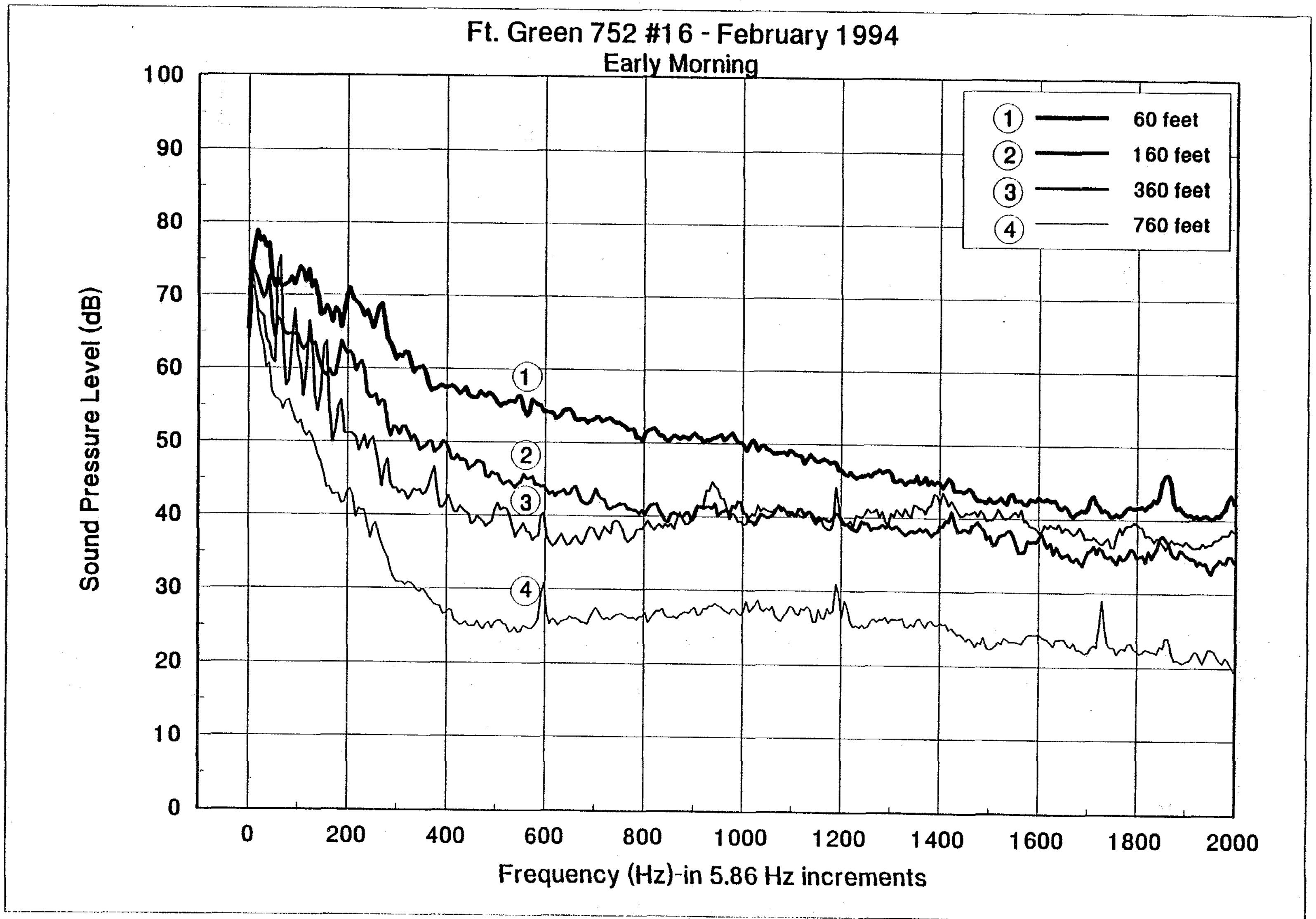

Figure D.25 Sound pressure spectrum for 752 #16--Phase I (Early morning)

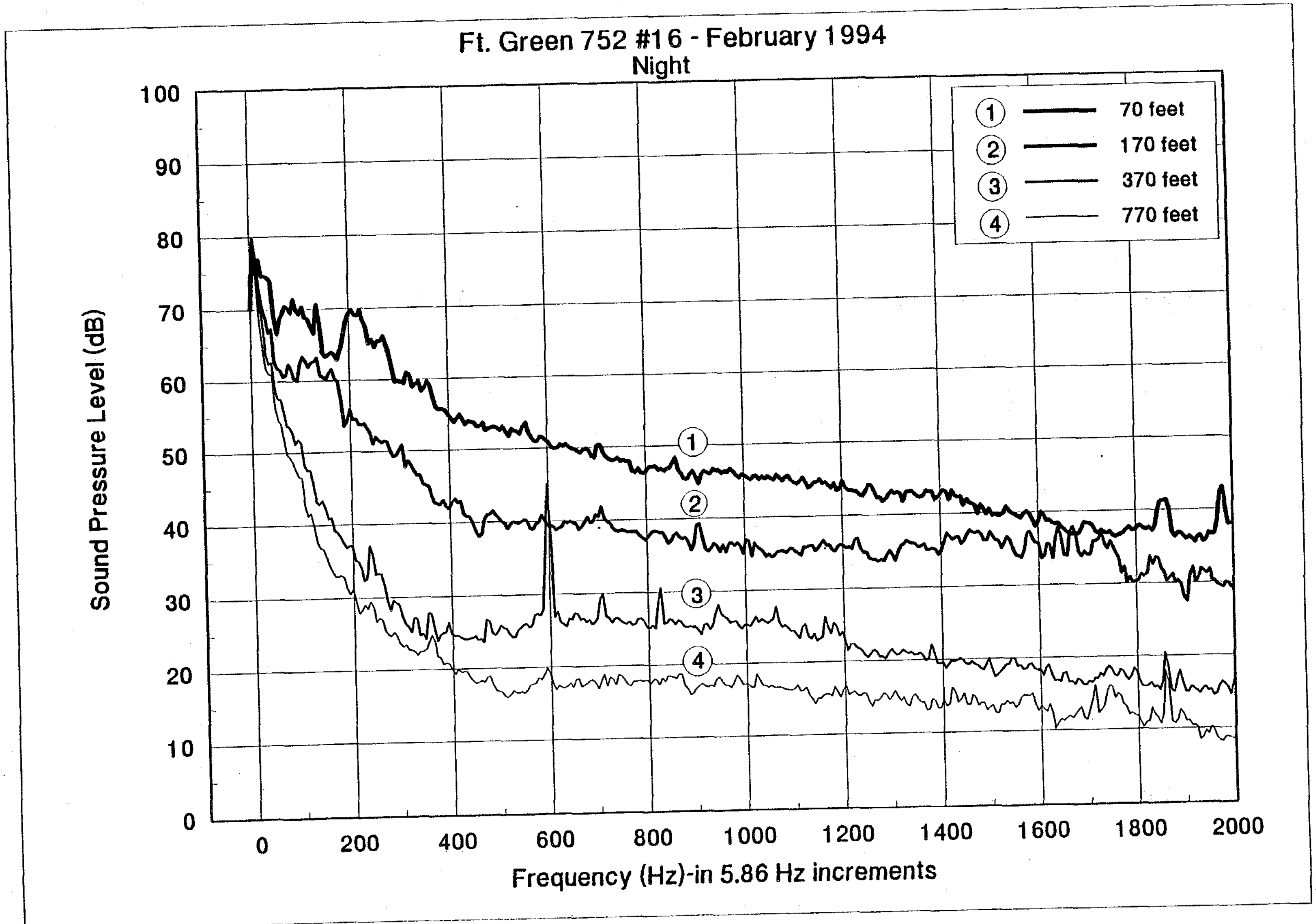

Figure D.26 Sound pressure spectrum for 752 #16--Phase I (Night)

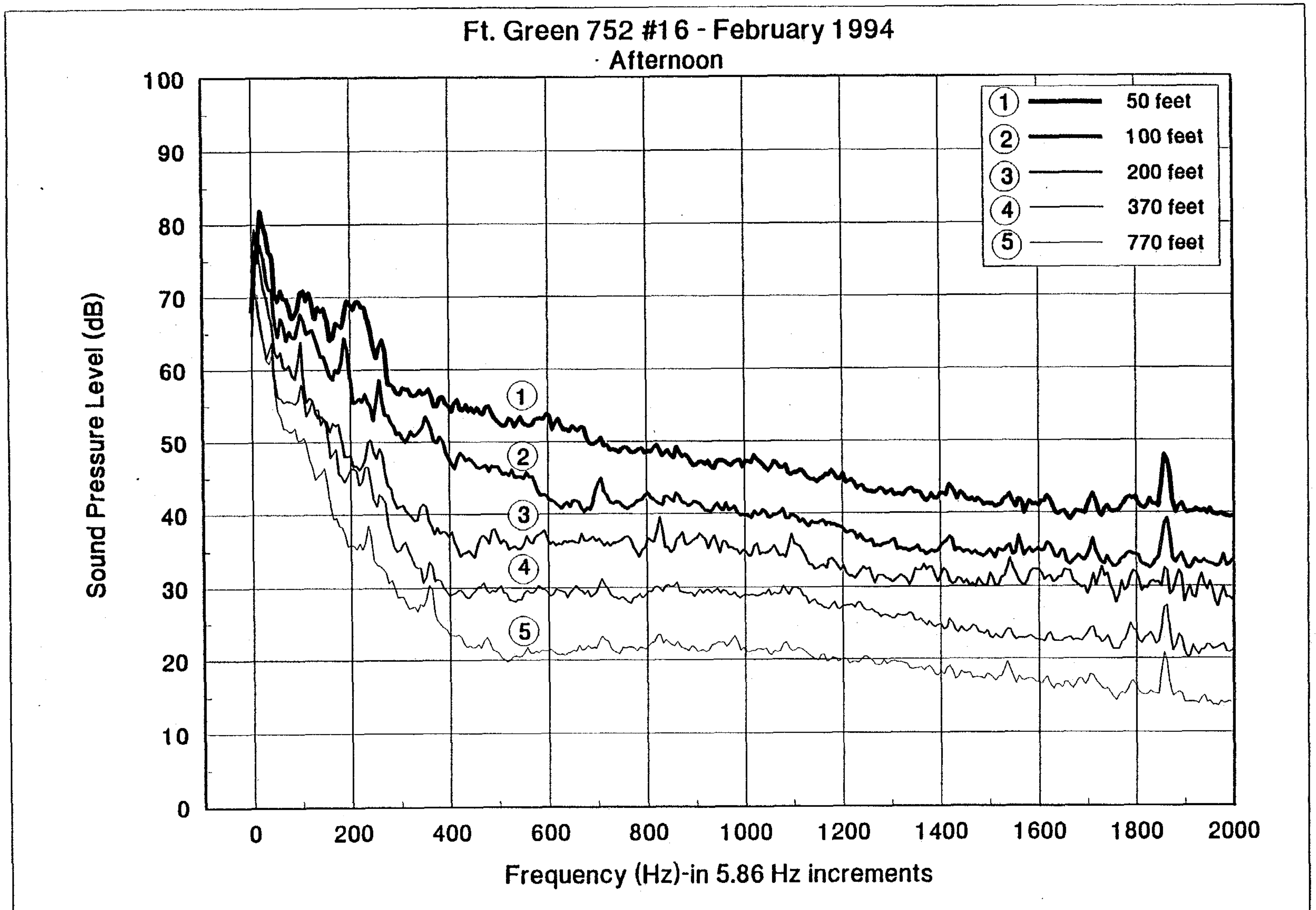

Figure D.27 Sound pressure spectrum for 752 #16--Phase I (Afternoon)

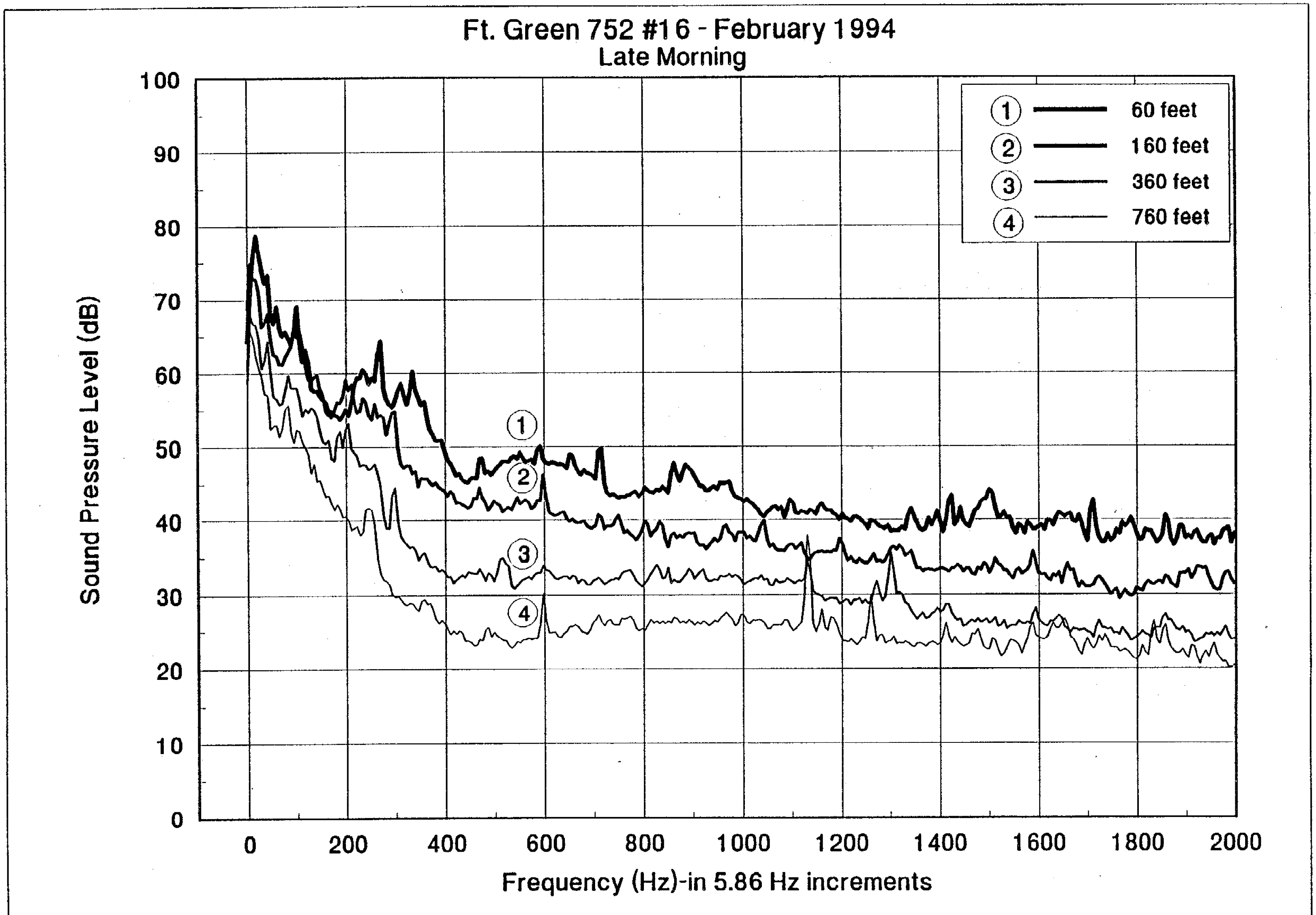

Figure D.28 Sound pressure spectrum for 752 #16--Phase I (Late morning)

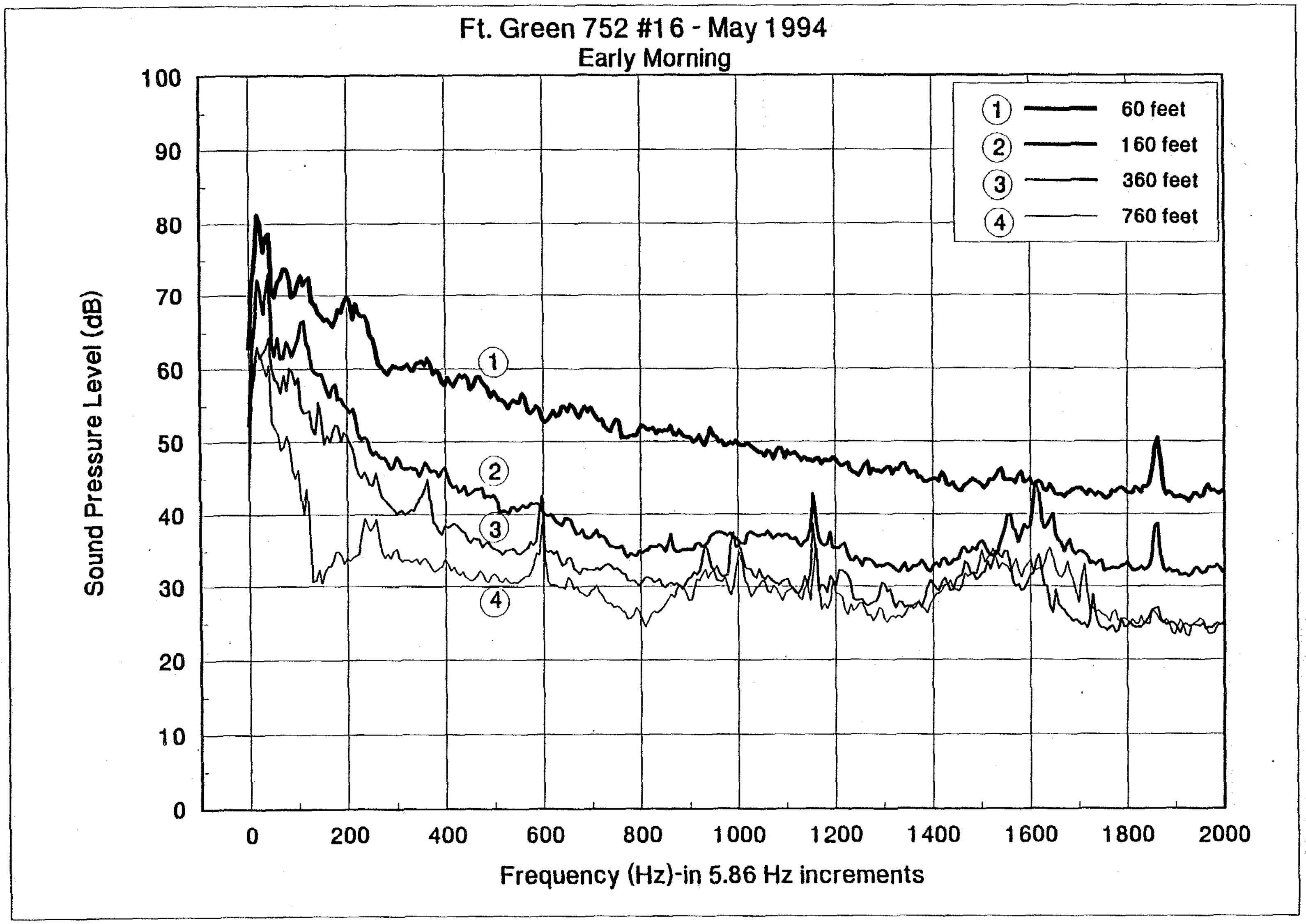

Figure D.29 Sound pressure spectrum for 752 #16--Phase II (Early morning)

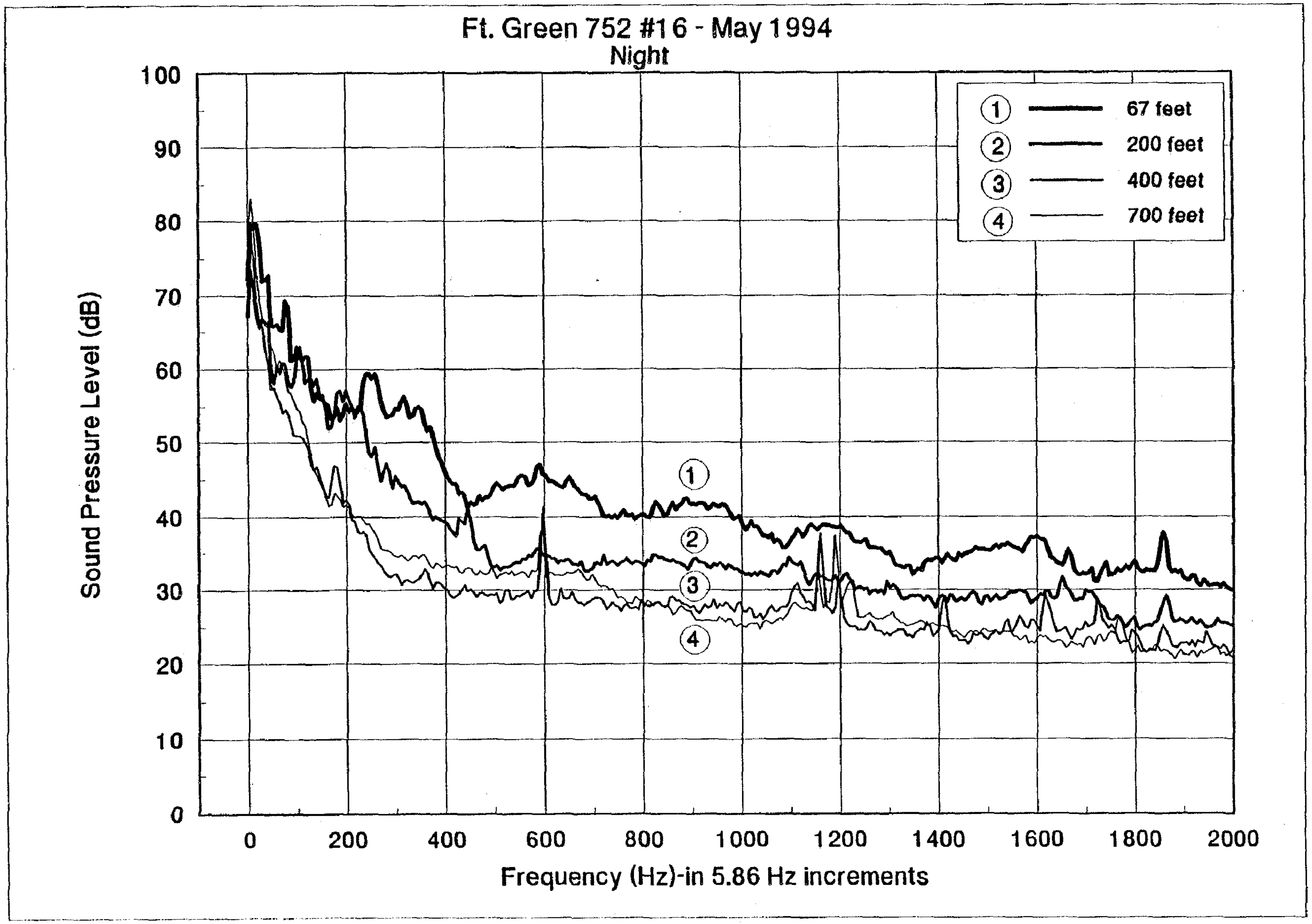

Figure D.30 Sound pressure spectrum for 752 #16--Phase II (Night)

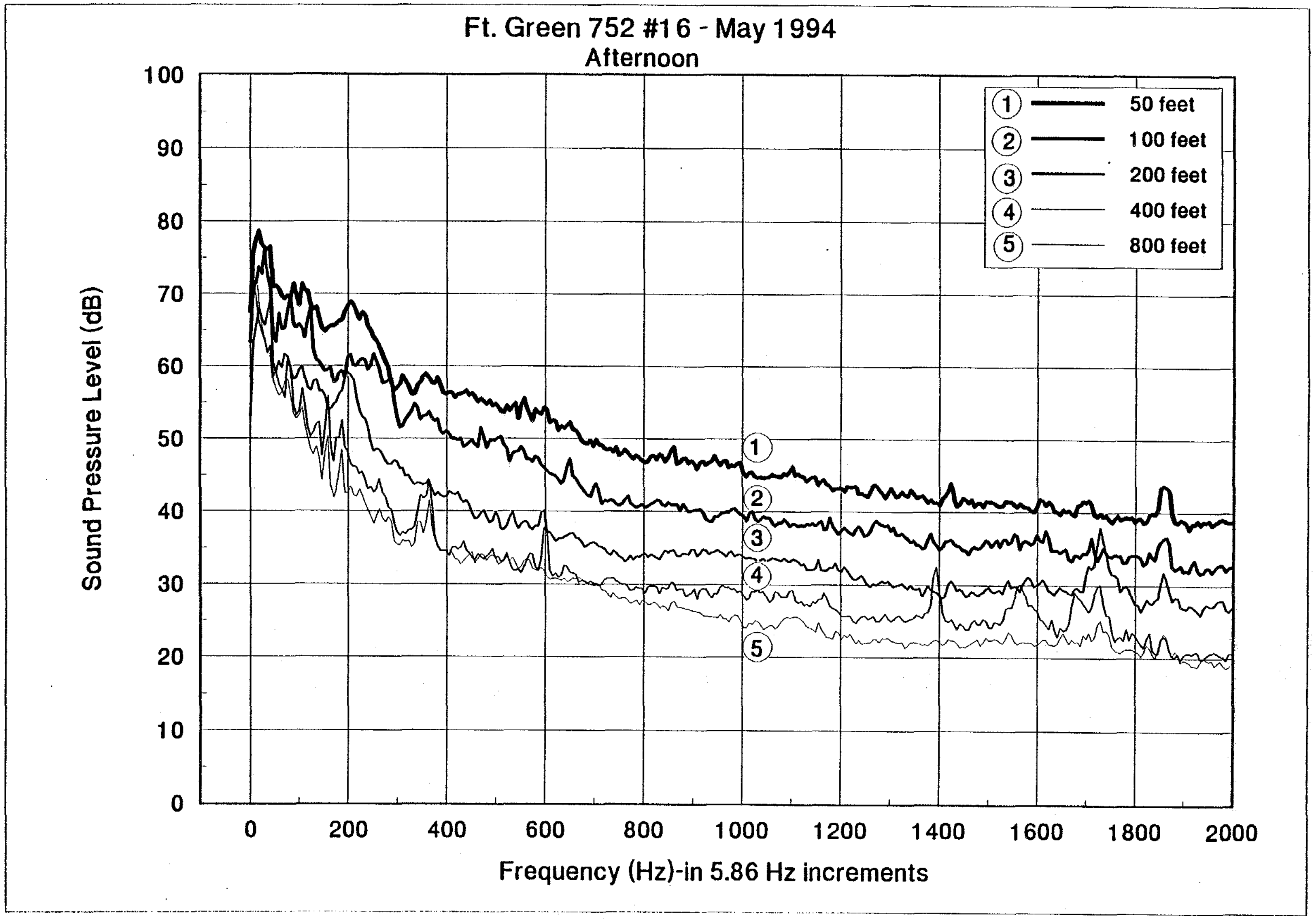

Figure D.31 Sound pressure spectrum for 752 #16--Phase II (Afternoon)

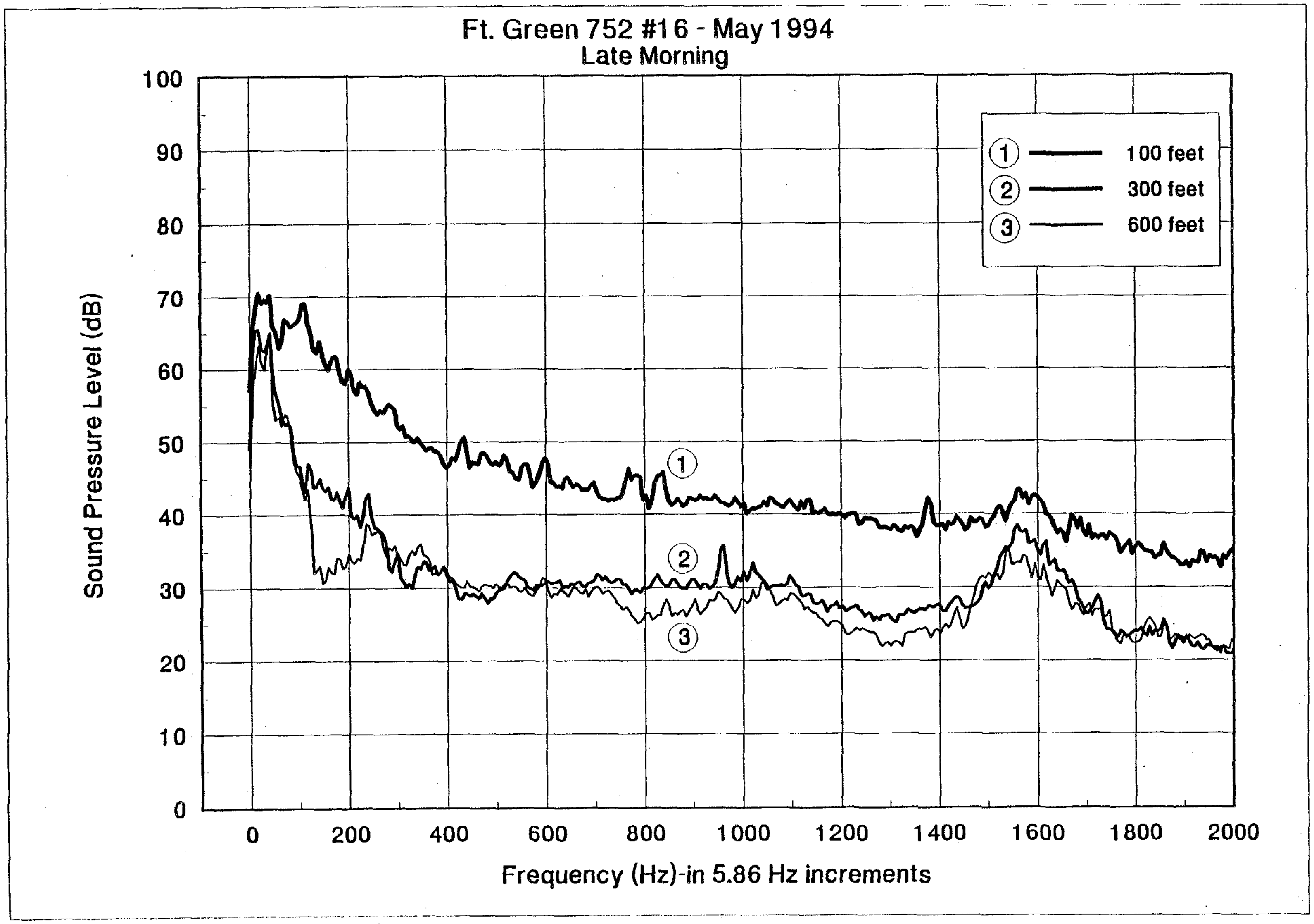

Figure D.32 Sound pressure spectrum for 752 #16--Phase II (Late morning)

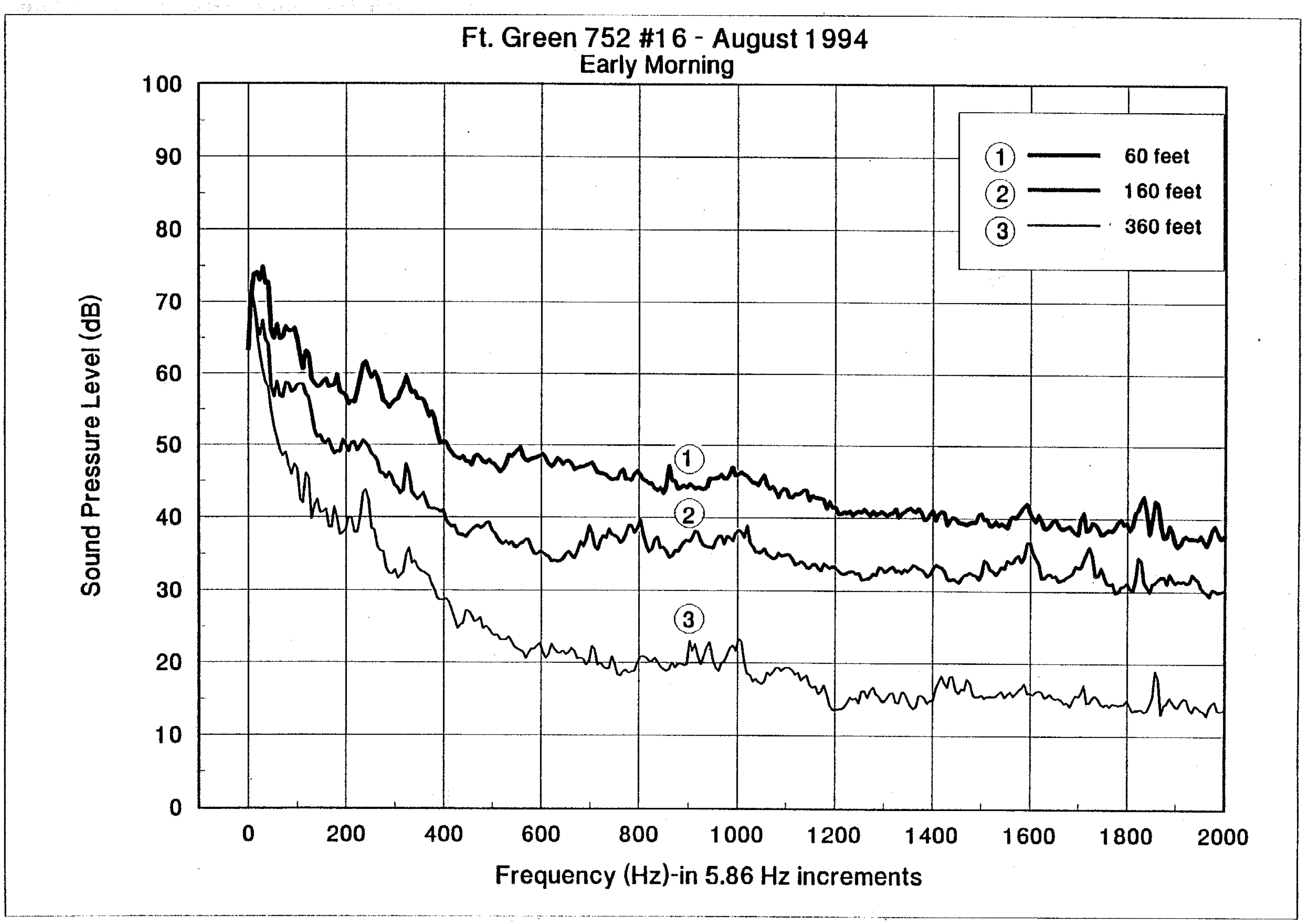

Figure D.33 Sound pressure spectrum for 752 #16--Phase III (Early morning)

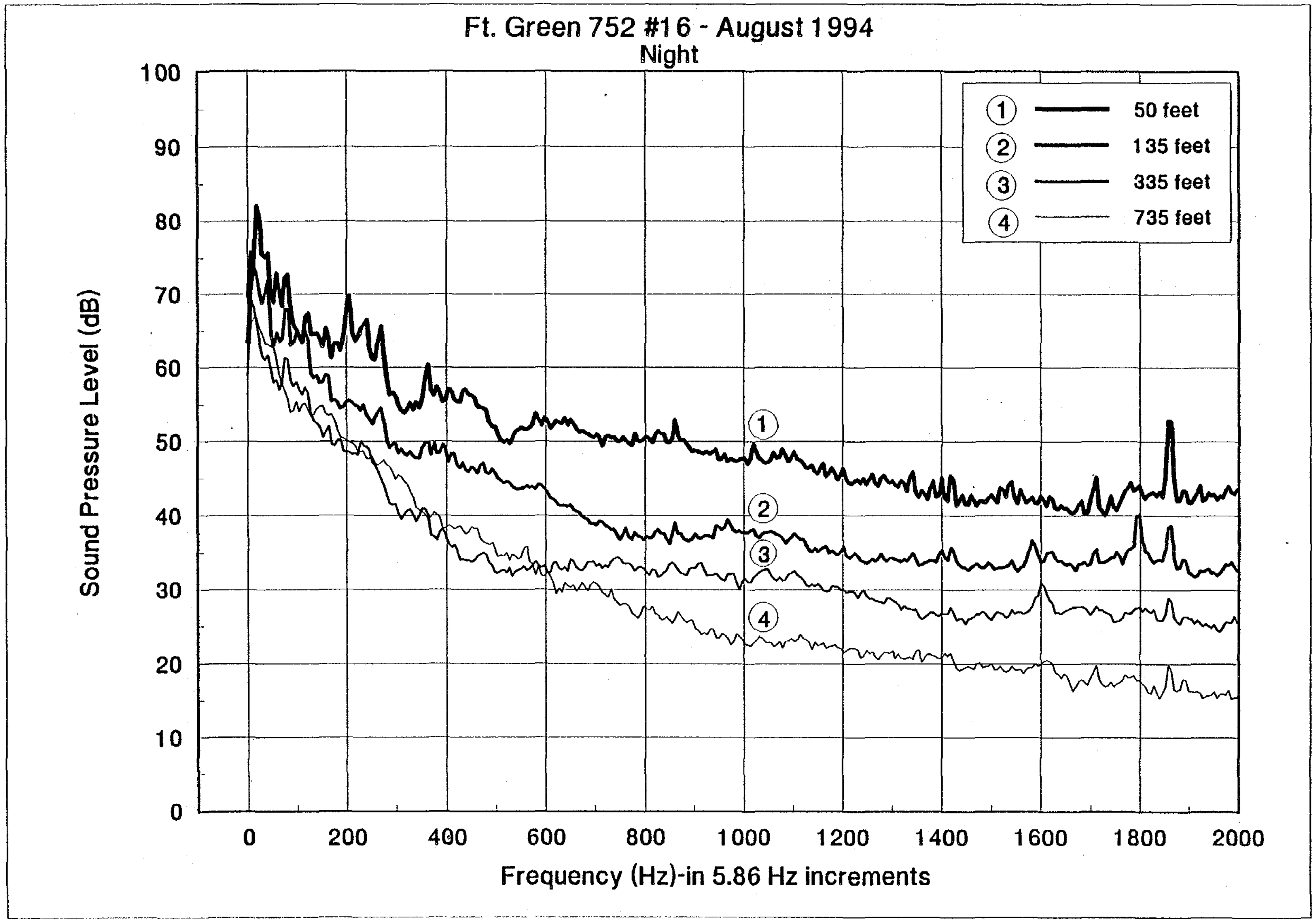

Figure D.34 Sound pressure spectrum for 752 #16--Phase III (Night)

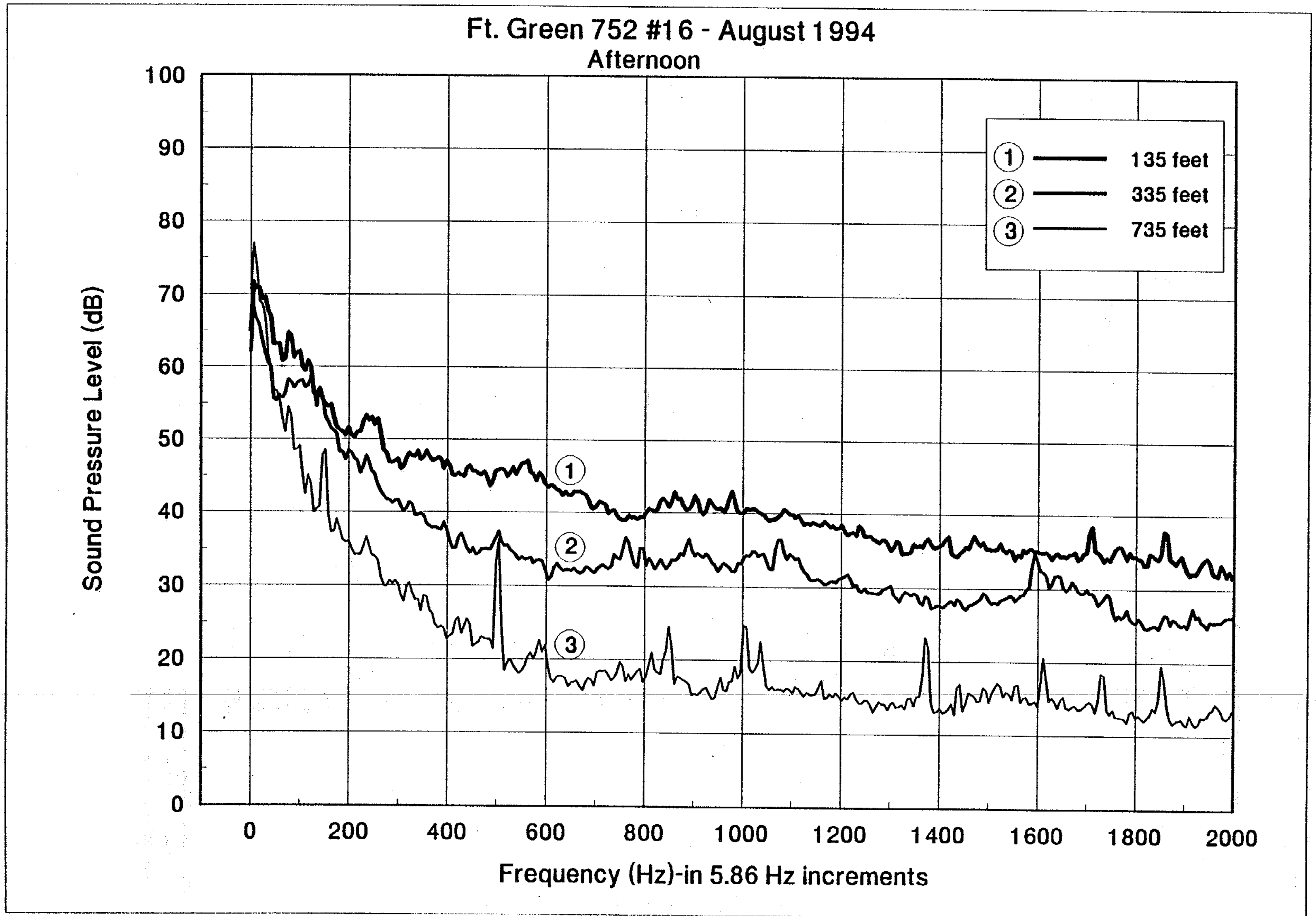

Figure D.35 Sound pressure spectrum for 752 #16--Phase III (Afternoon)

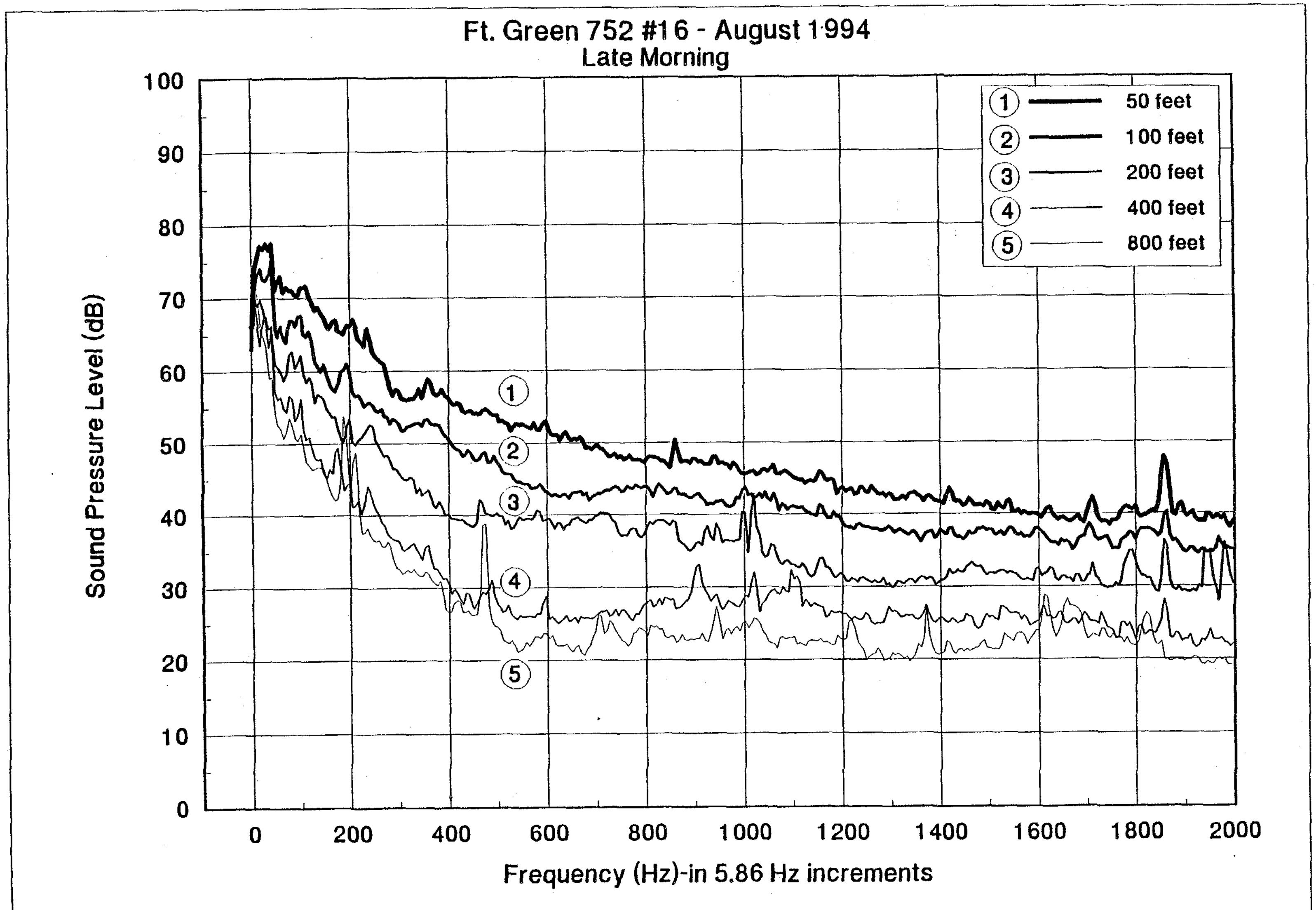

Figure D.36 Sound pressure spectrum for 752 #16--Phase III (Late morning)

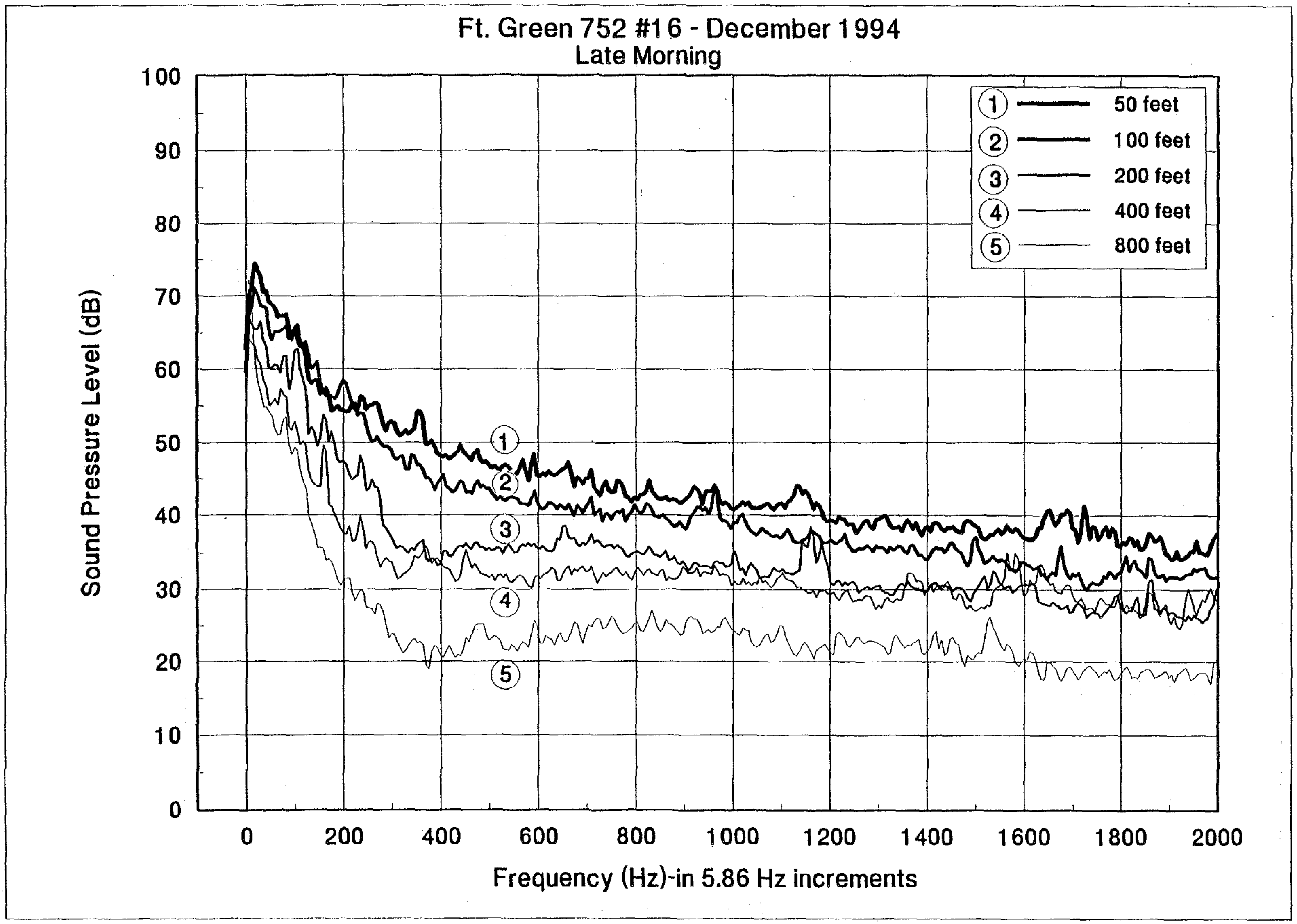

Figure D.40 Sound pressure spectrum for 752 #16--Phase IV (Late morning)

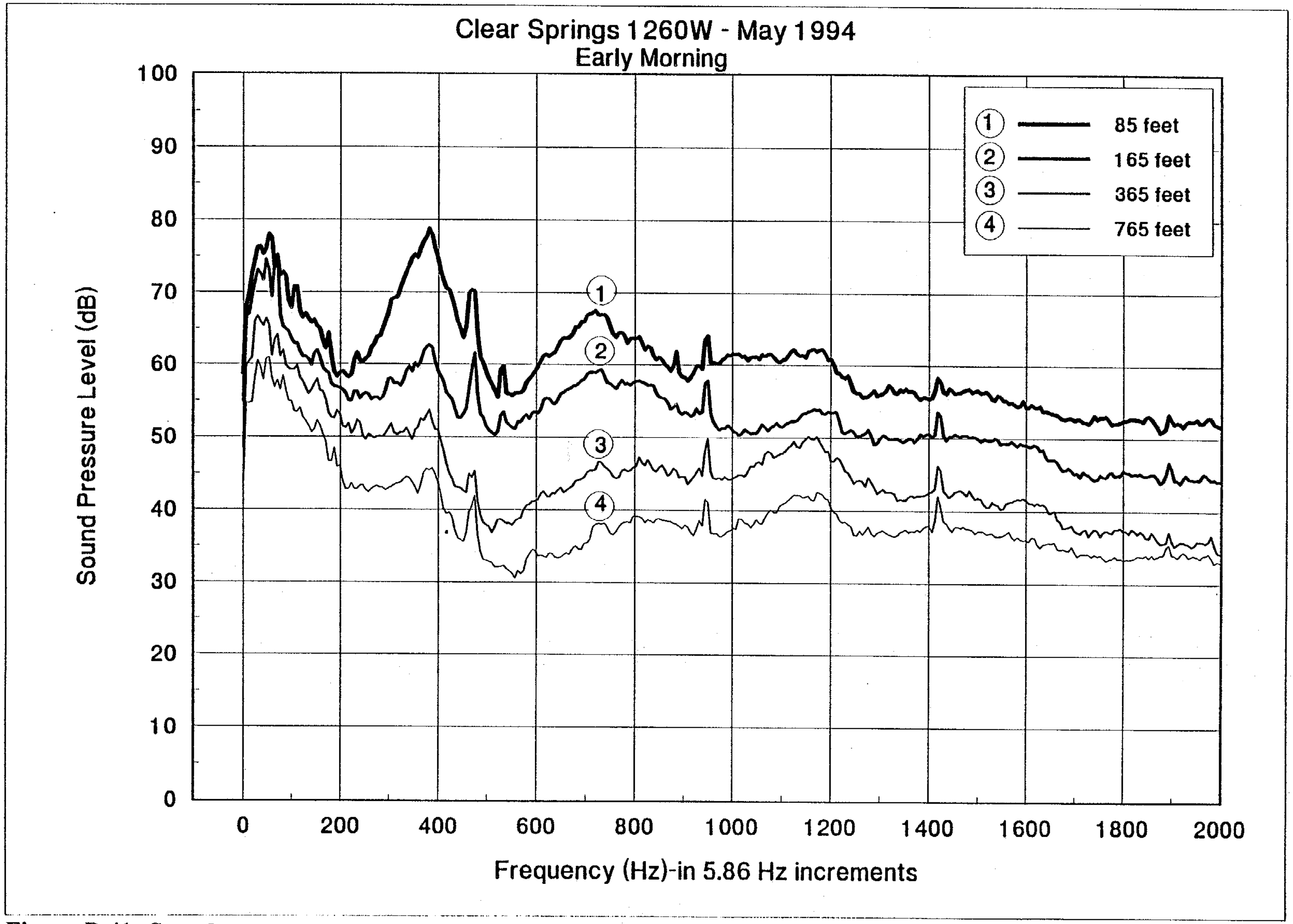

Figure D.41 Sound pressure spectrum for 1260W--Phase II (Early morning)

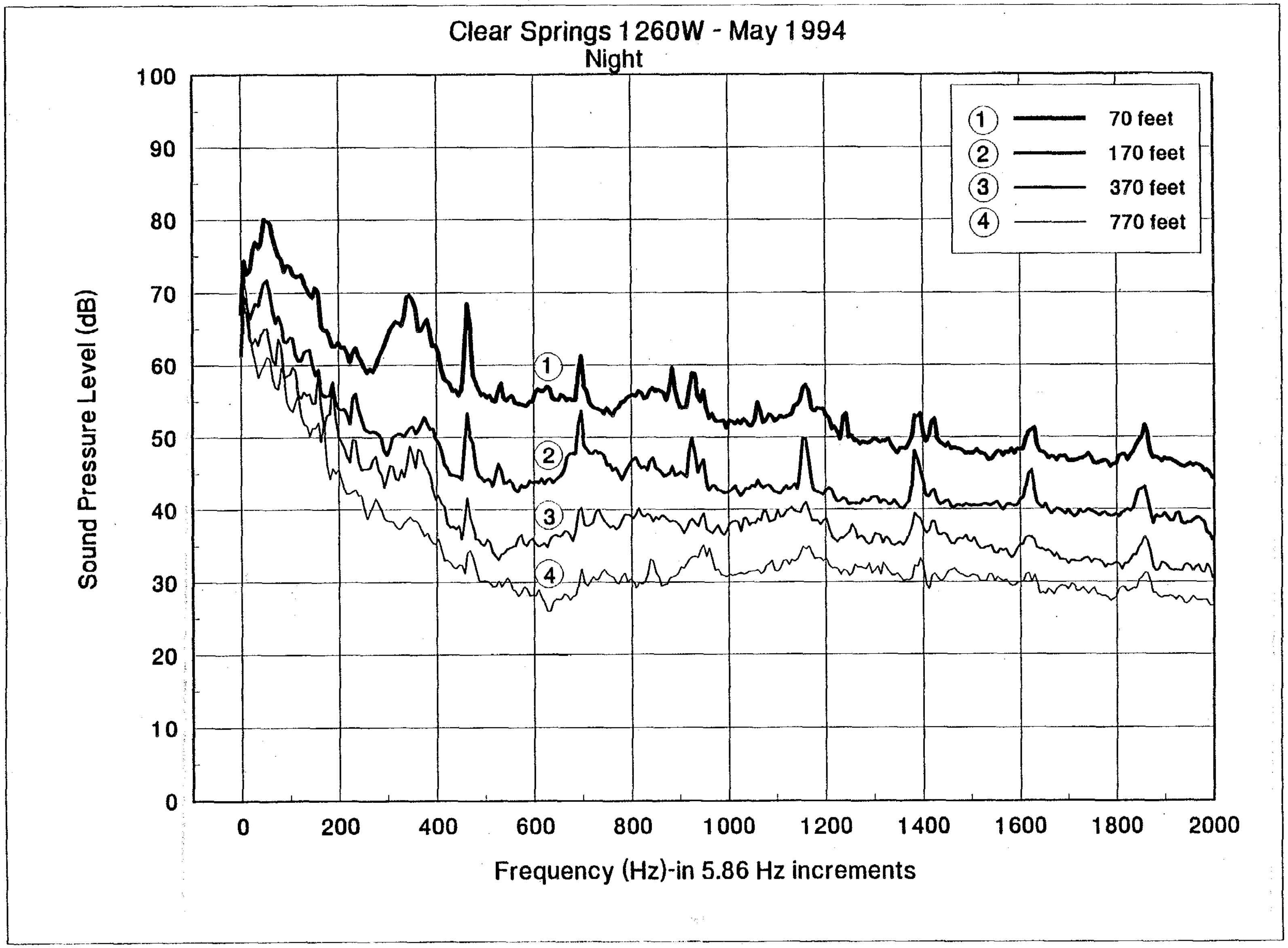

Figure D.42 Sound pressure spectrum for 1260W--Phase II (Night)

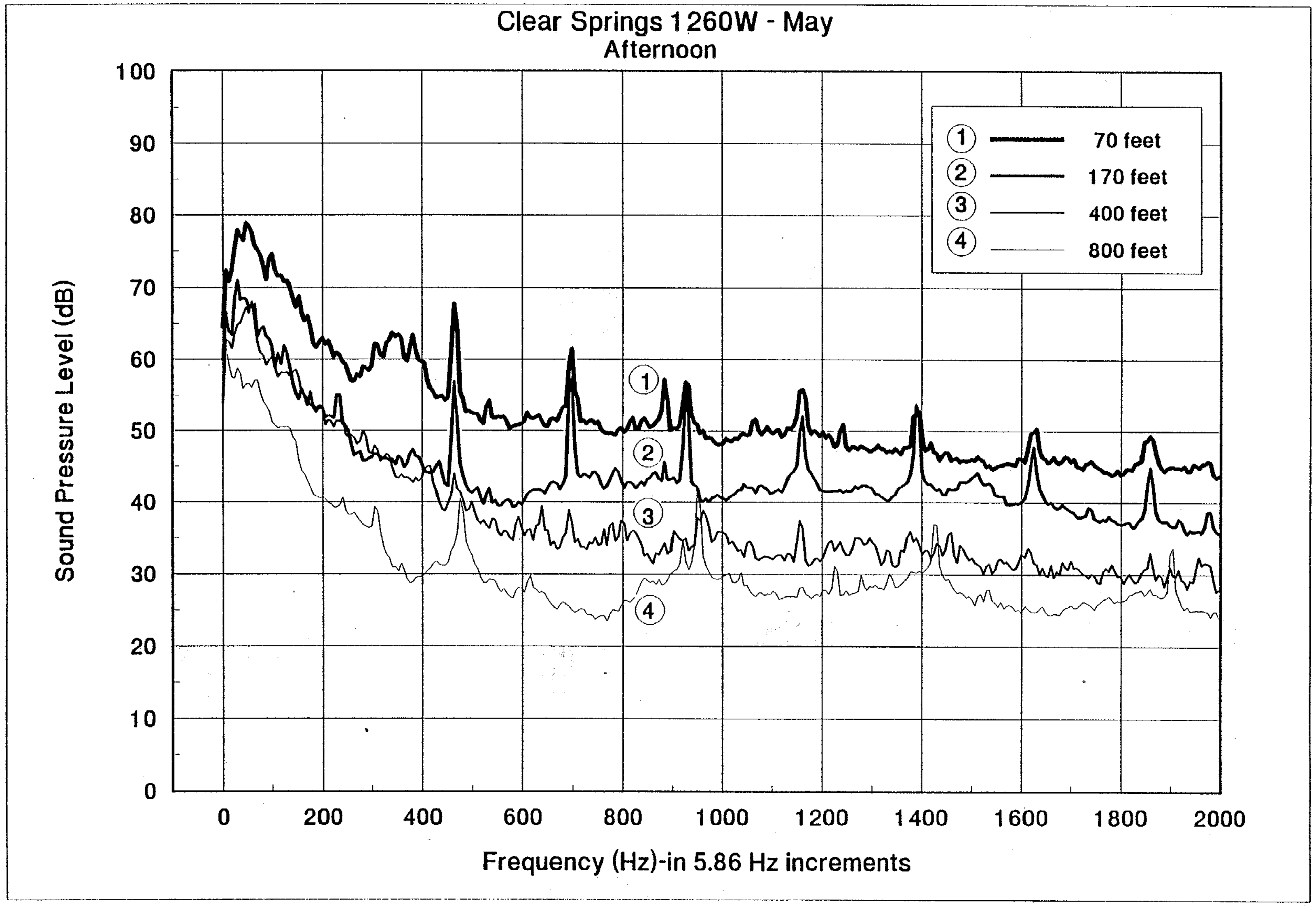

Figure D.43 Sound pressure spectrum for 1260W--Phase II (Afternoon)

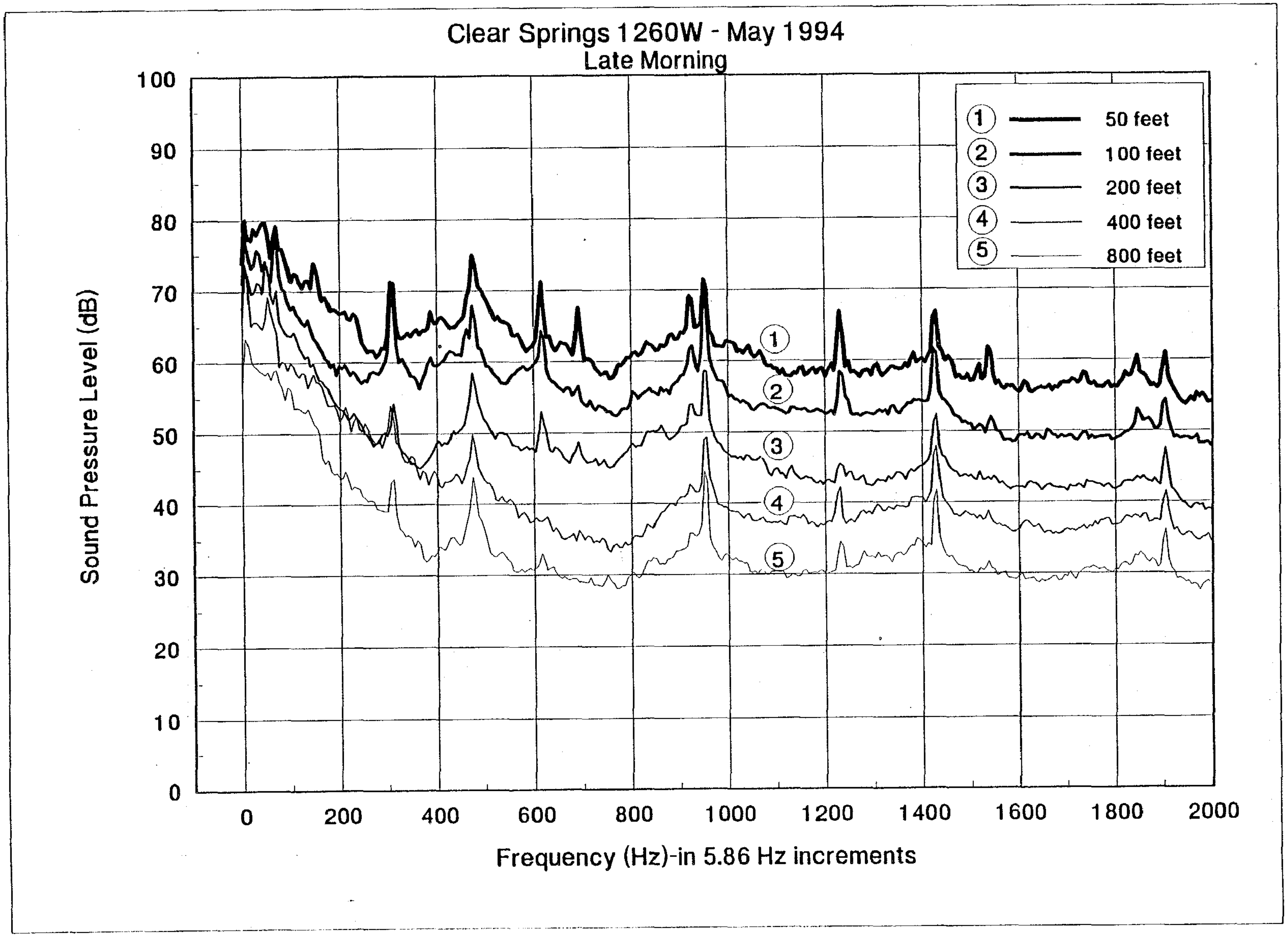

Figure D.44 Sound pressure spectrum for 1260W--Phase II (Late morning)

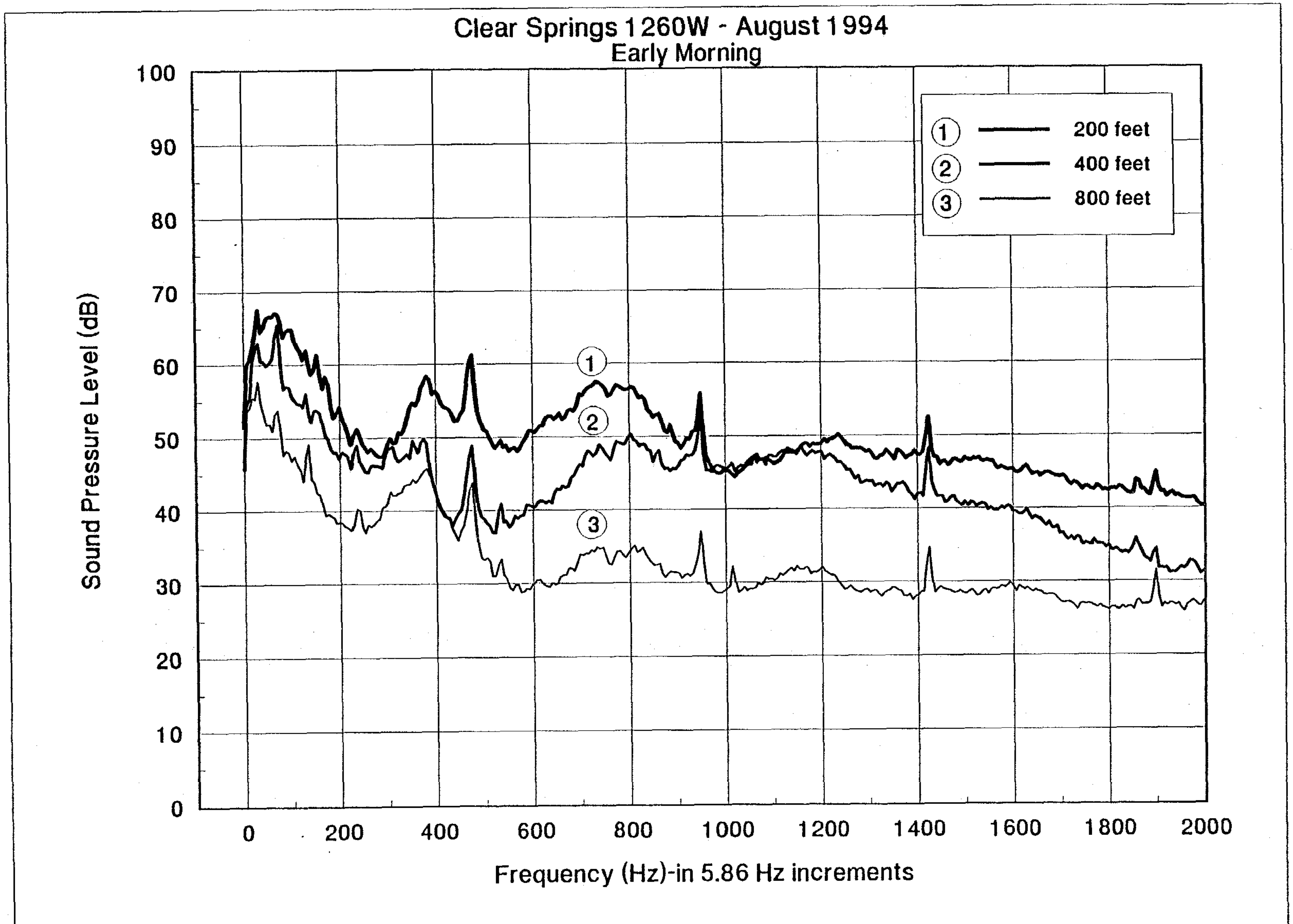

Figure D.45 Sound pressure spectrum for 1260W--Phase III (Early morning)

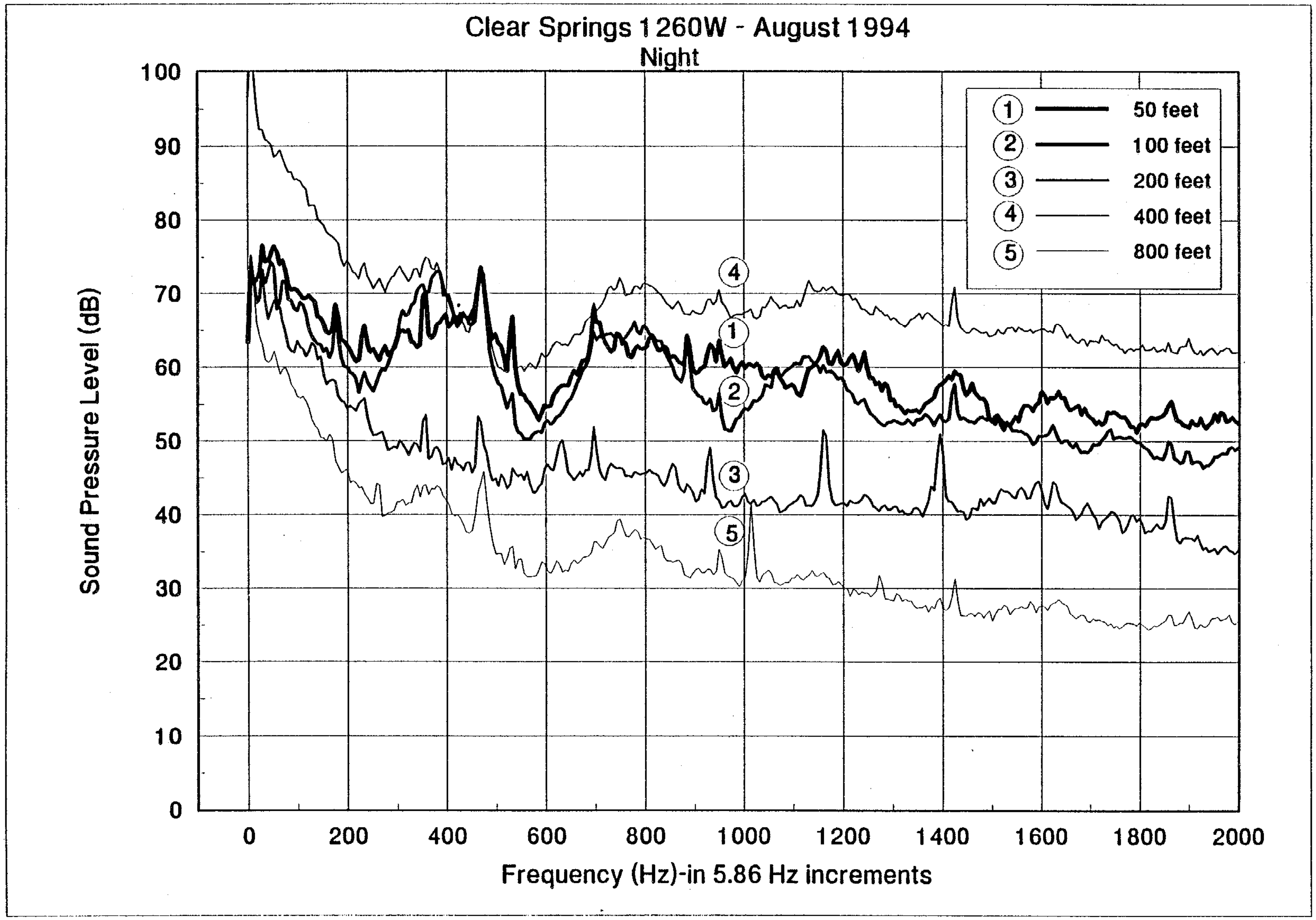

Figure D.46 Sound pressure spectrum for 1260W--Phase III (Night)

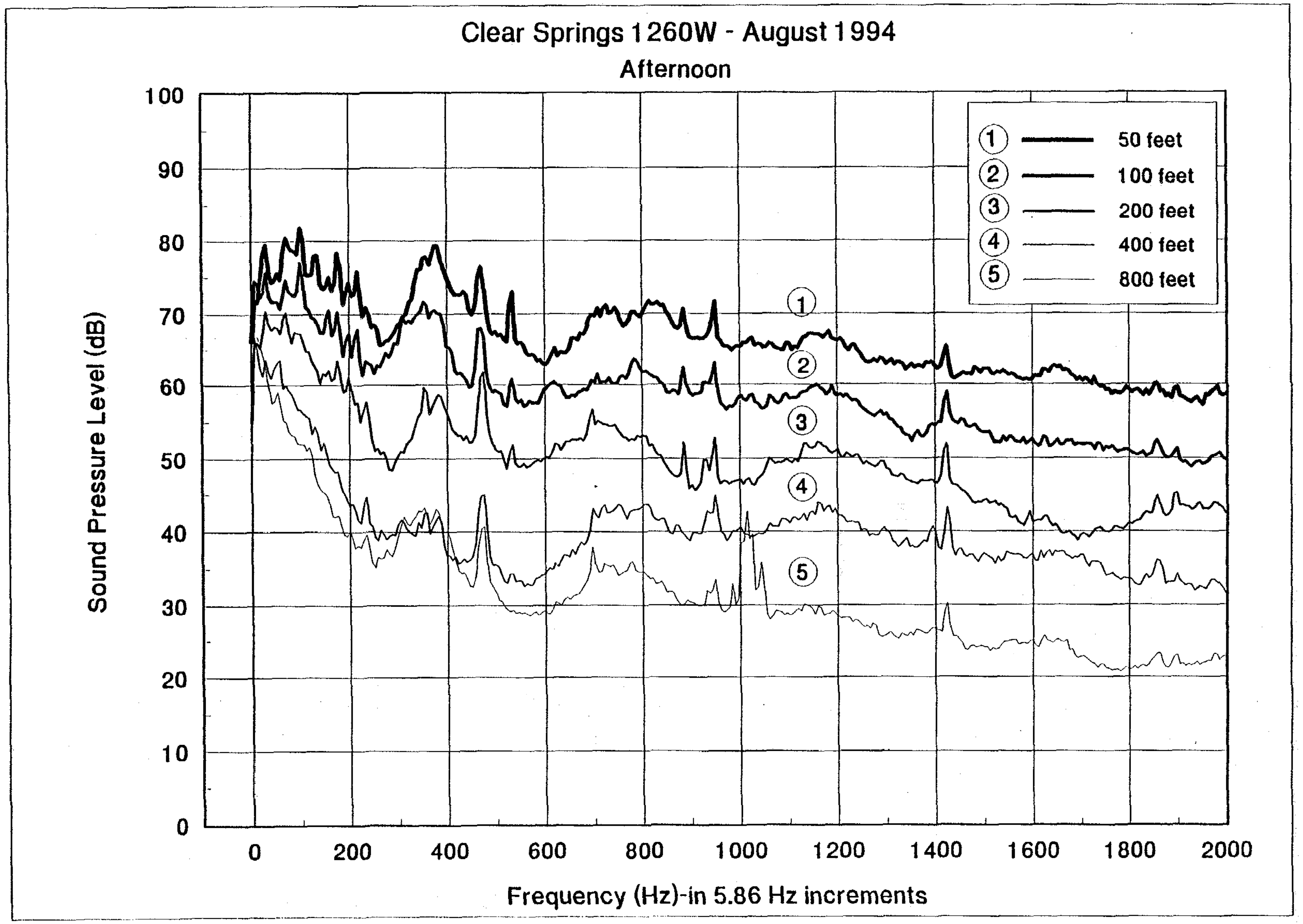

Figure D.47 Sound pressure spectrum for 1260W--Phase III (Afternoon)

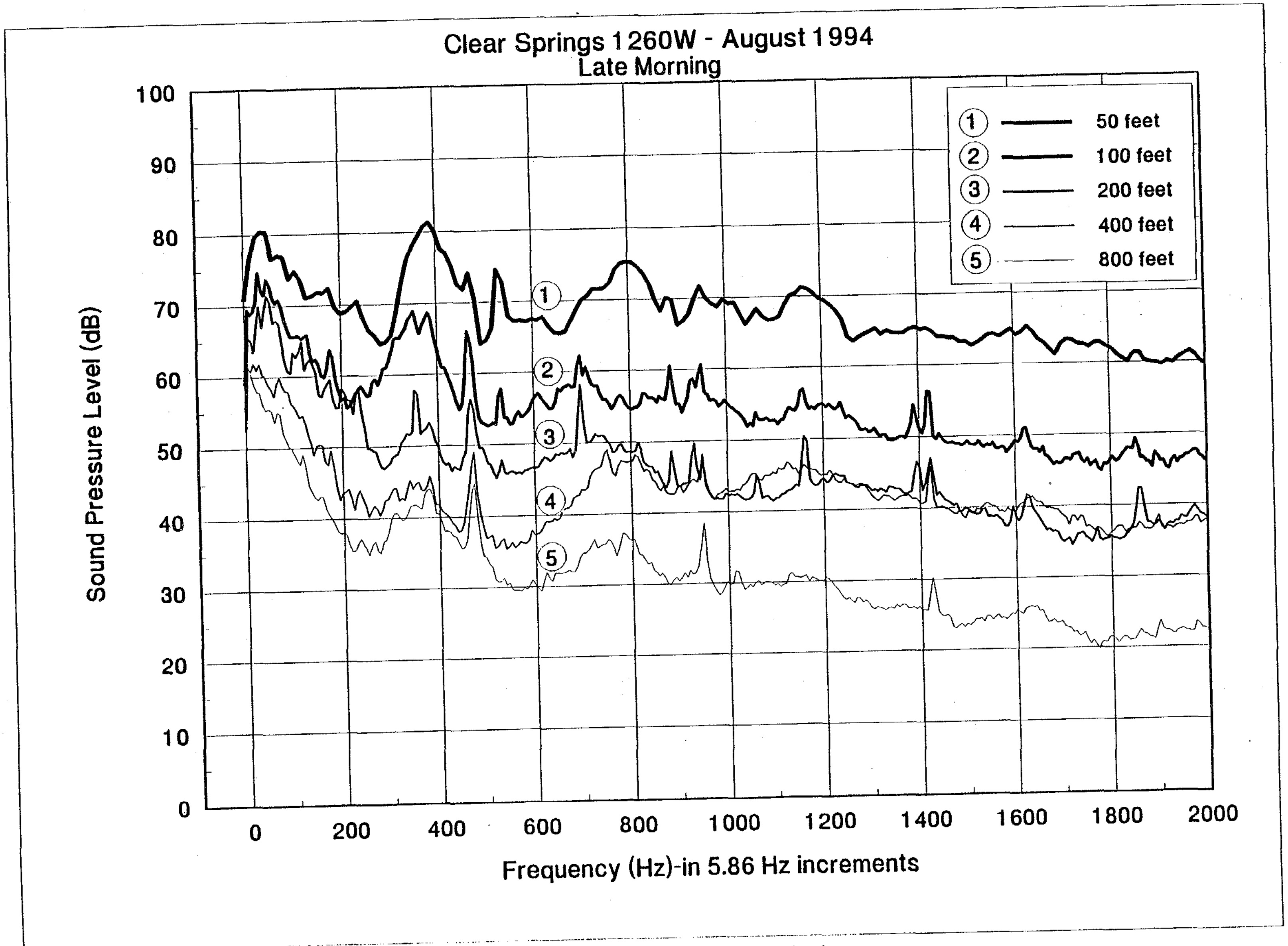

Figure D.48 Sound pressure spectrum for 1260W--Phase III (Late morning)

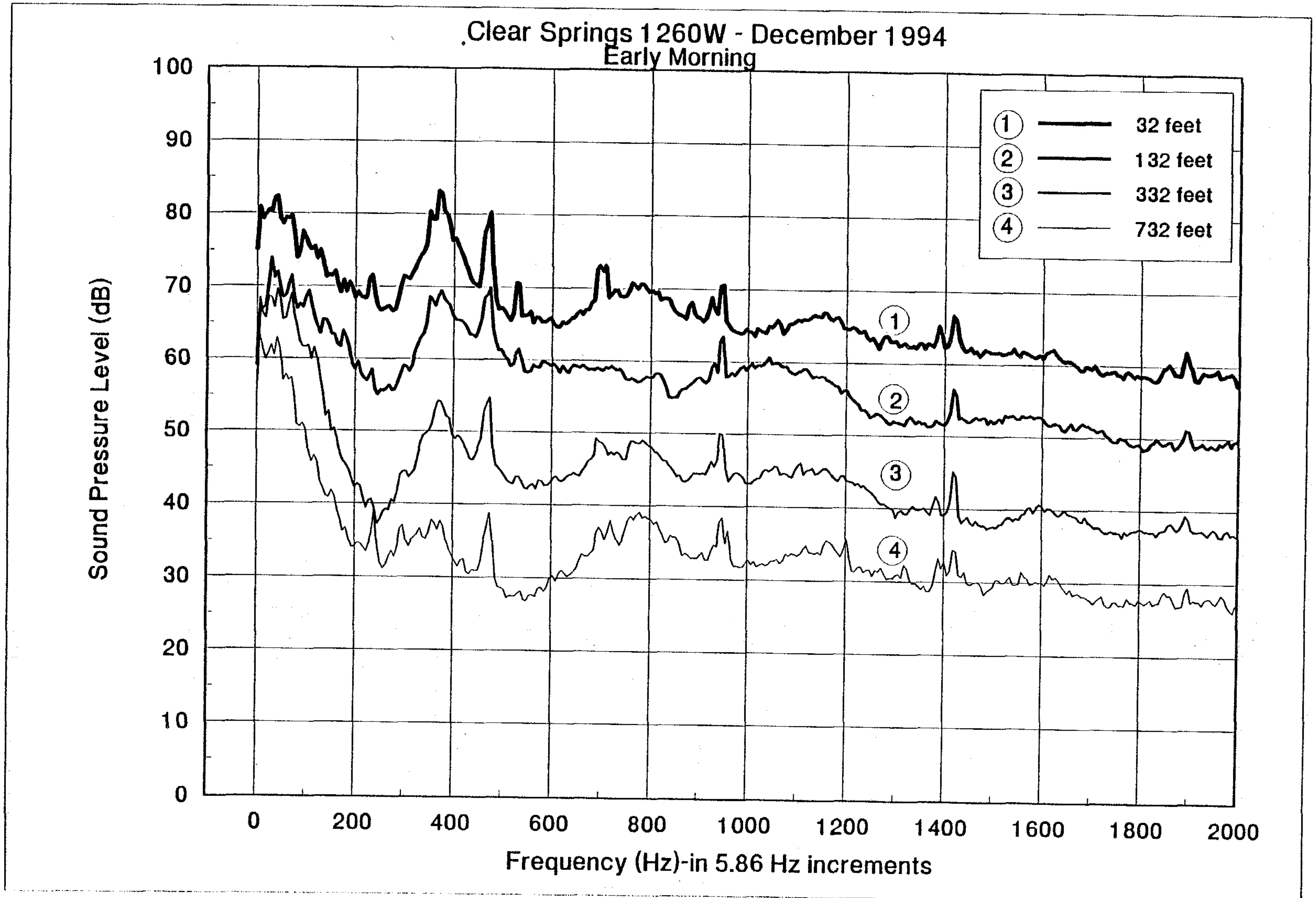

Figure D.49 Sound pressure spectrum for 1260W--Phase IV (Early morning)

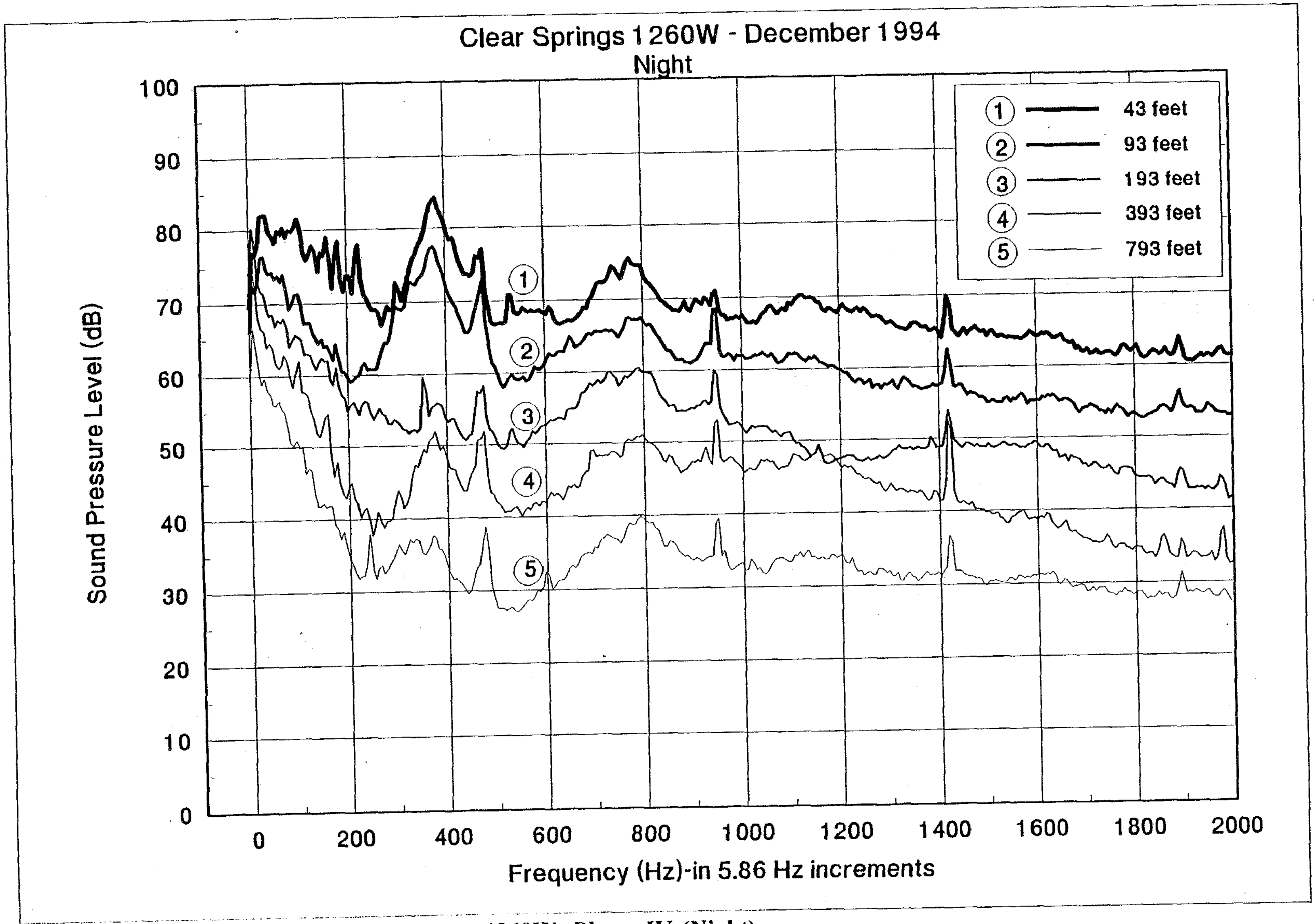

Figure D.50 Sound pressure spectrum for 1260W--Phase IV (Night)

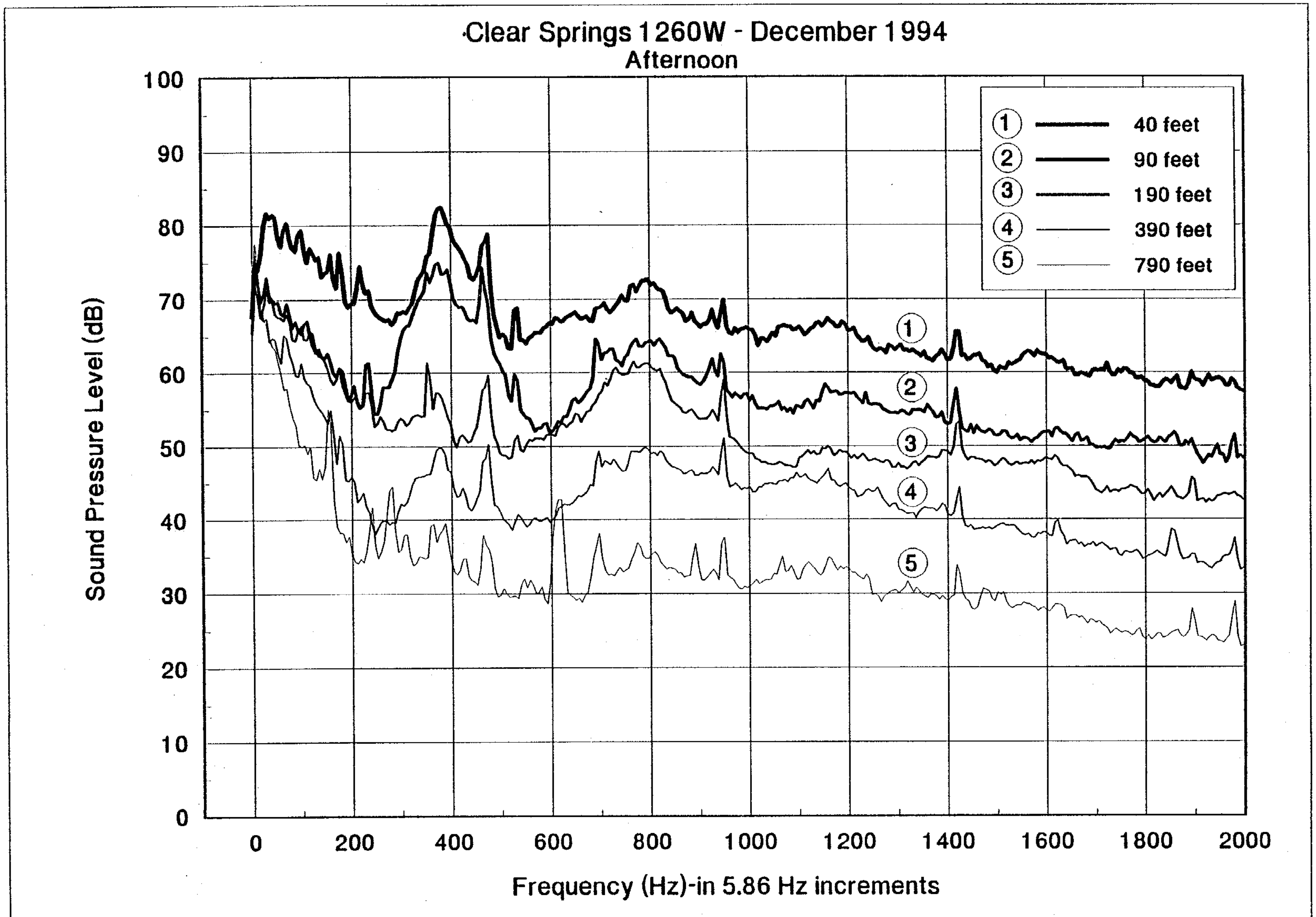

Figure D.51 Sound pressure spectrum for 1260W--Phase IV (Afternoon)

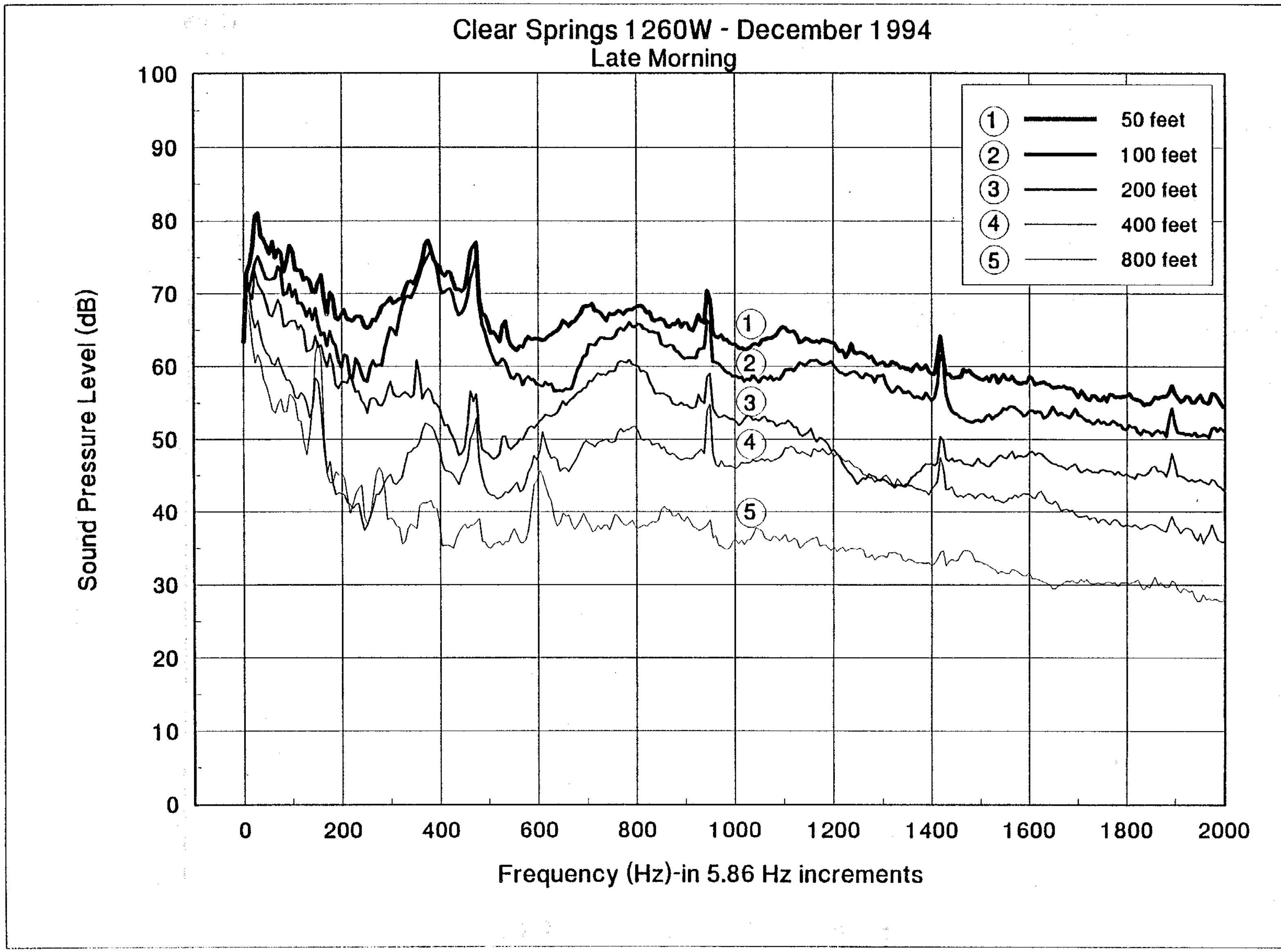

Figure D.52 Sound pressure spectrum for 1260W--Phase IV (Late morning)

Table D.1 Overall Sound Pressure Levels (dB)--Phase I, February 1994

NORALYN 1150B							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	87.15	50	87.68	40	89.23	40	90.52
100	84.89	100	84.60	90	87.23	90	86.66
200	82.36	200	81.20	190	80.22	190	81.85
400	84.95	400	79.60	390	76.23	390	79.46
800	81.78	800	79.05	790	70.83	790	72.88

FT. GREEN 752 #16							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
60	85.12	50	88.90	70	87.34	60	89.29
160	81.80	100	84.51	170	84.07	160	82.99
360	75.56	200	83.60	370	82.36	360	81.61
760	71.88	370	76.37	770	80.03	760	77.84
		770	77.19				

PHOSPHORIA 1250B							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	85.57	50	89.82	50	87.01	50	89.65
150	82.81	100	84.78	100	82.50	100	84.30
350	82.46	200	81.20	200	78.67	200	81.05
586-PL	77.38	400	76.61	400	66.33	370	75.77
750	81.66	636-PL	84.26	636-PL	79.73	770	83.99
		800	73.30	800	79.14		

Table D.2 Overall Sound Pressure Levels (dB)--Phase II, May 1994

CLEAR SPRINGS 1260W							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	92.81	70	89.28	70	90.44	85	91.75
100	88.21	170	79.98	170	81.63	165	85.06
200	83.48	400	77.46	370	77.07	365	77.65
400	79.81	800	70.22	770	76.82	765	71.84
800	72.46						

FT. GREEN 752 #16							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
100	81.85	50	88.03	67	86.54	50	89.42
300	73.28	100	83.75	200	79.32	150	80.66
600	70.96	200	77.58	400	81.12	350	73.72
		400	76.86	700	86.09	750	69.72
		800	79.97				

PHOSPHORIA 1250B							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	87.75	50	89.88	90	83.98	30	89.15
100	84.89	100	84.12	190	80.93	130	79.71
200	79.12	200	81.73	390	75.78	330	76.68
400	72.63	400	75.51	790	73.93	730	67.57
800	68.82	800	70.82				

Table D.3 Overall Sound Pressure Levels (dB)--Phase III, August 1994

CLEAR SPRINGS 1260W							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	93.84	50	95.87	50	89.76	200	80.55
100	86.25	100	89.68	100	88.82	400	75.14
200	81.13	200	82.49	200	82.43	800	67.04
400	73.79	400	75.23	400	107.22		
800	69.33	800	74.01	800	77.56		

FT. GREEN 752 #16							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	88.04	135	80.13	50	88.04	78	83.70
100	83.66	335	75.27	135	82.85	278	77.56
200	78.59	735	80.44	335	76.22	678	76.29
400	76.21			735	75.79		
800	77.54						

PHOSPHORIA 1250B							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	86.32	50	88.60	50	86.50	50	84.13
100	82.19	100	85.73	100	80.47	100	81.09
200	81.13	200	80.32	200	77.63	200	75.43
400	73.48	400	75.73	400	73.27	400	71.74
800	75.82	800	71.95	800	70.32	800	66.24

Table D.4 Overall Sound Pressure Levels (dB)--Phase IV, December 1994

NORALYN 1150B							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	90.10	50	92.38	50	87.94	50	89.42
100	86.43	100	86.08	100	86.13	100	85.89
200	82.67	200	84.54	200	100.88	200	81.82
400	81.96	400	78.22	400	76.47	400	76.60
800	79.28	770	78.33	800	78.60	800	85.28

FT. GREEN 752 #16							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	83.01	50	86.07	50	86.86	57	83.81
100	80.75	100	80.13	100	82.30	107	82.75
200	76.54	200	81.66	200	80.02	207	109.93
400	72.06	400	75.83	400	74.31	407	74.66
800	75.31	800	71.23	800	77.44	807	68.45

CLEAR SPRINGS 1260W							
Late Morning		Afternoon		Night		Early Morning	
Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB	Distance from dragline, feet	Overall sound pressure level, dB
50	93.81	40	96.74	43	98.38	32	96.64
100	90.35	90	88.87	93	91.41	132	86.69
200	84.02	190	83.34	193	85.93	332	79.96
400	78.91	390	80.96	393	80.37	732	72.01
800	75.44	790	81.24	793	71.98		

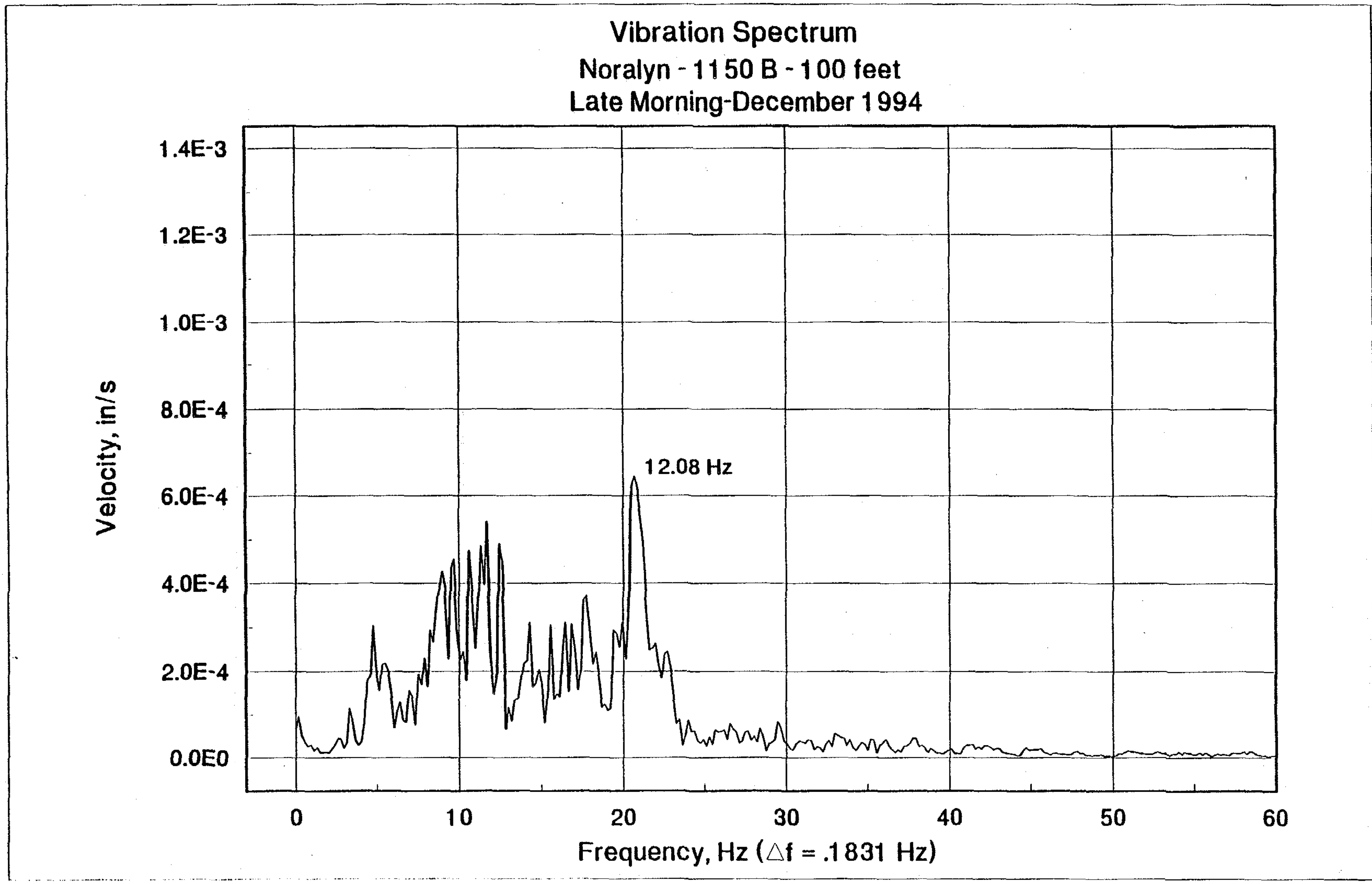

Figure D.53 Particle velocity spectrum for 1150B

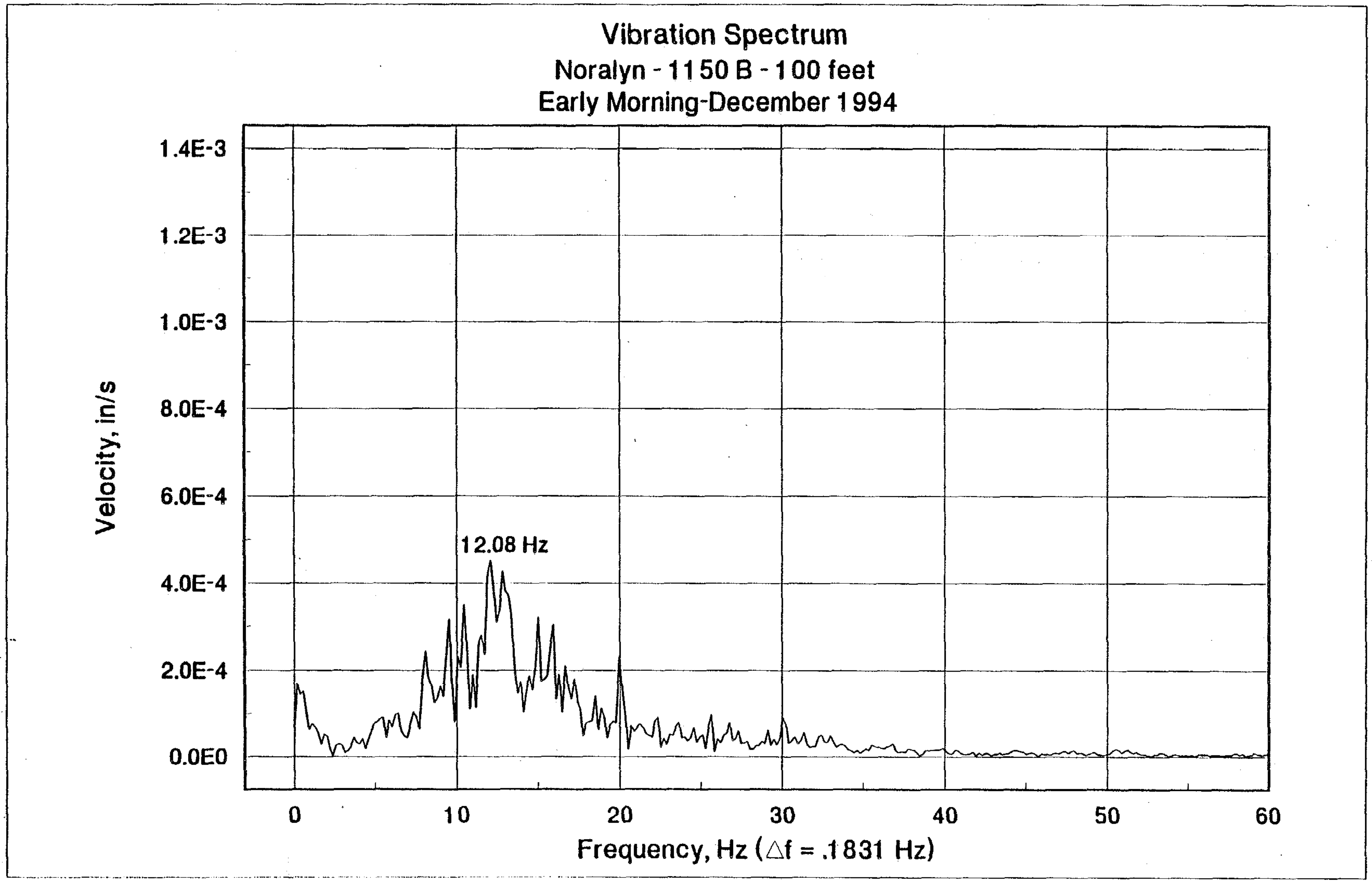

Figure D.54 Particle velocity spectrum for 1150B

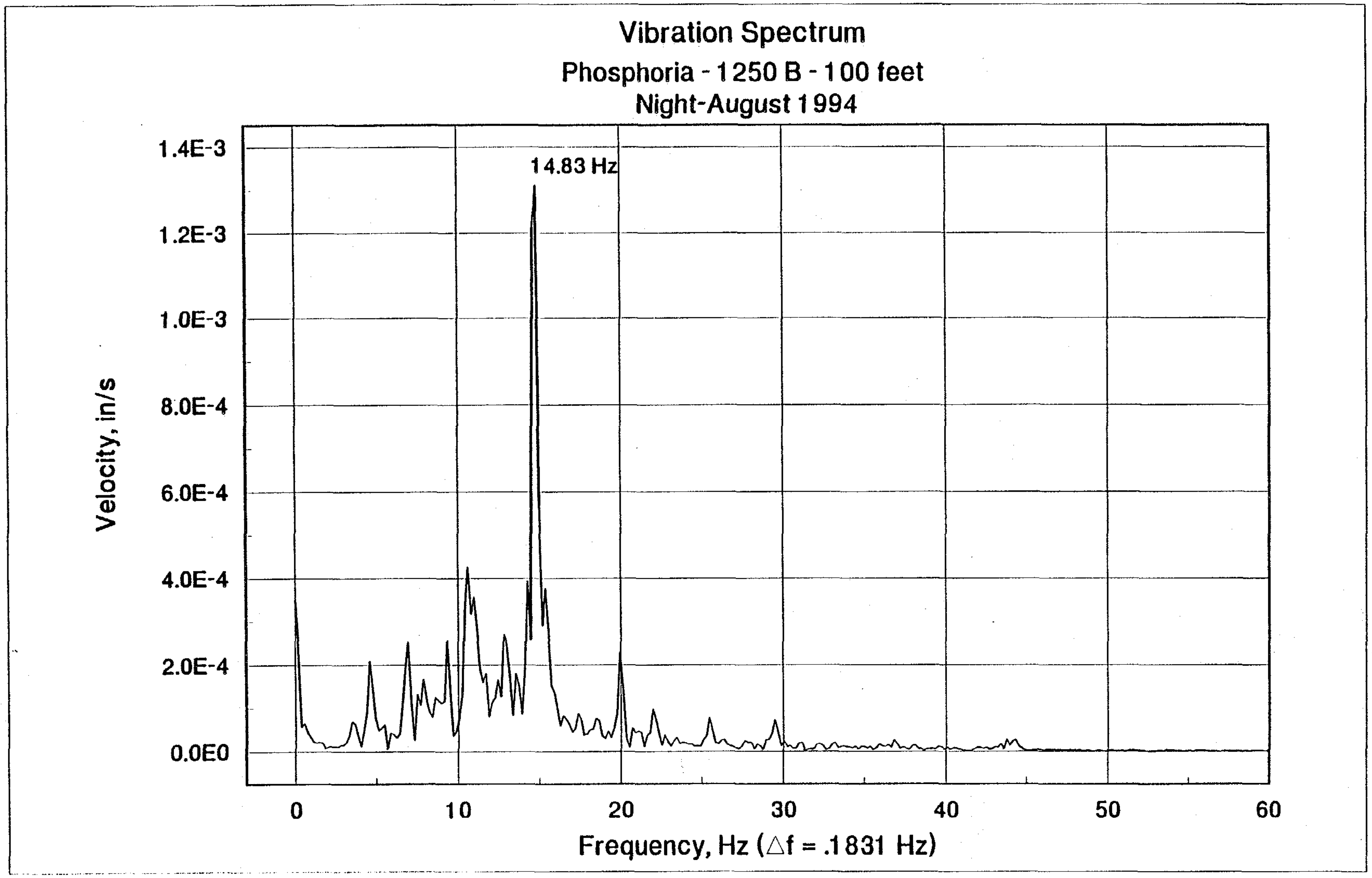

Figure D.55 Particle velocity spectrum for 1250B

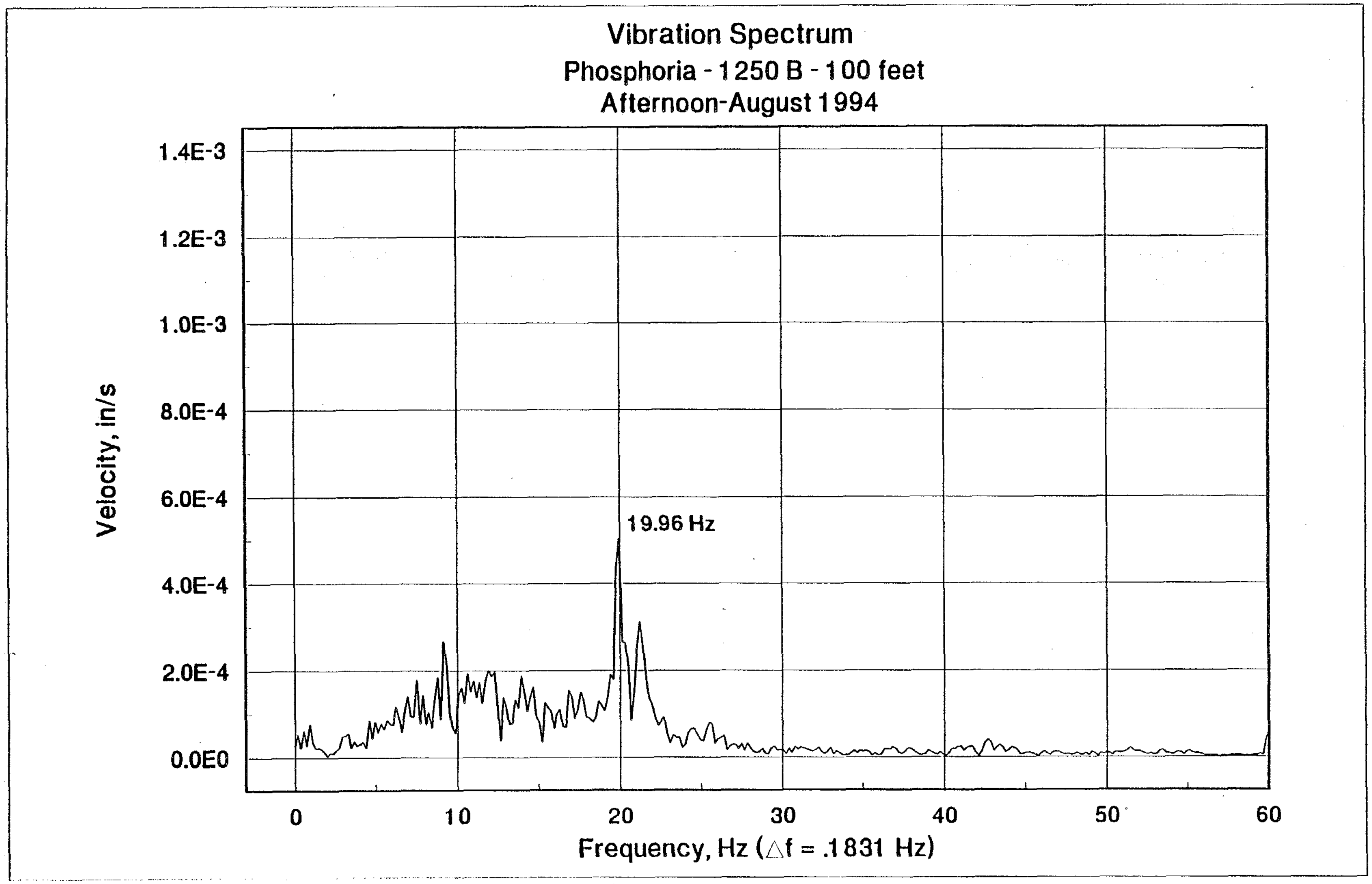

Figure D.56 Particle velocity spectrum for 1250B

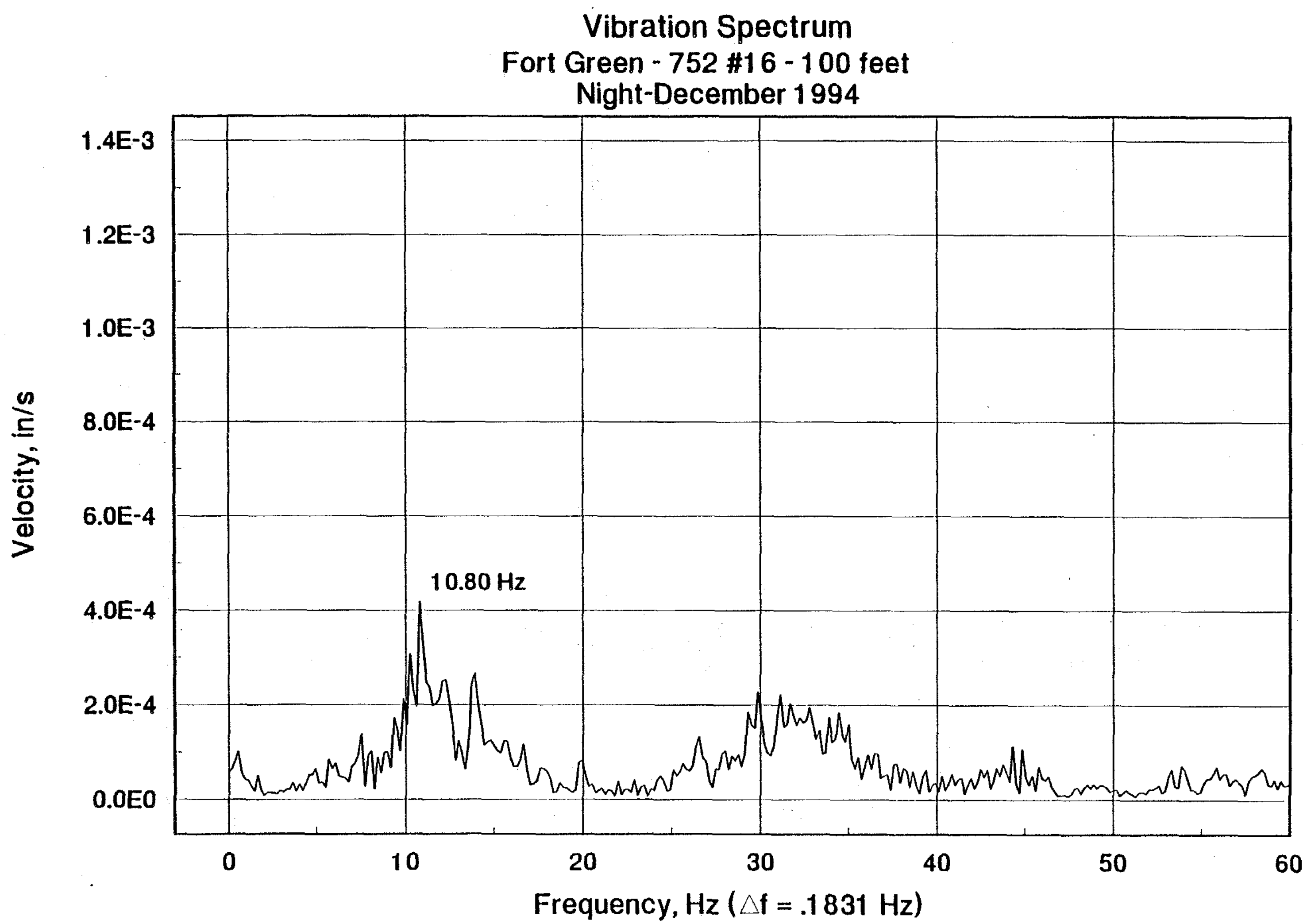

Figure D.57 Particle velocity spectrum for 752 #16

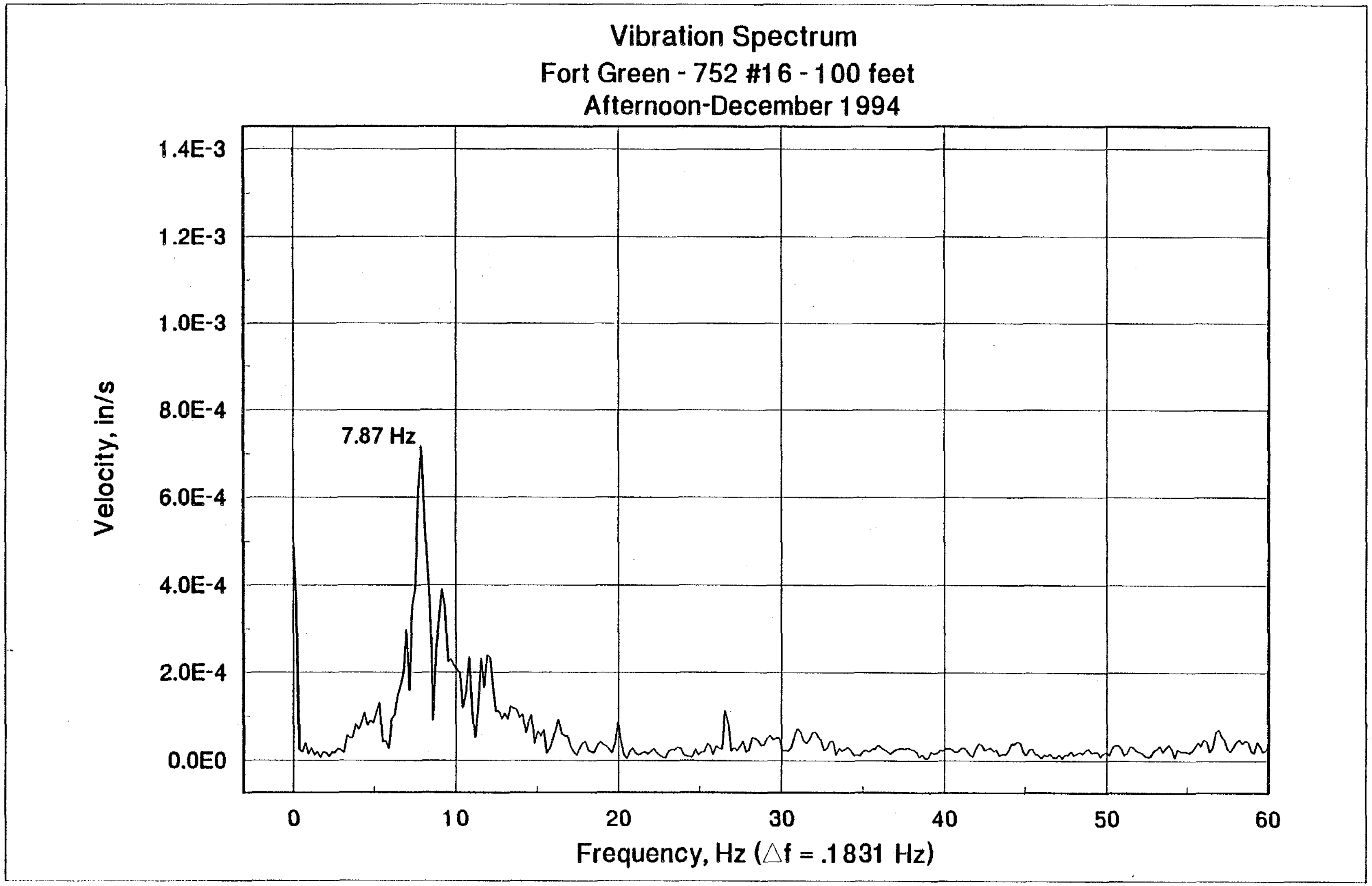

Figure D.58 Particle velocity spectrum for 752 #16

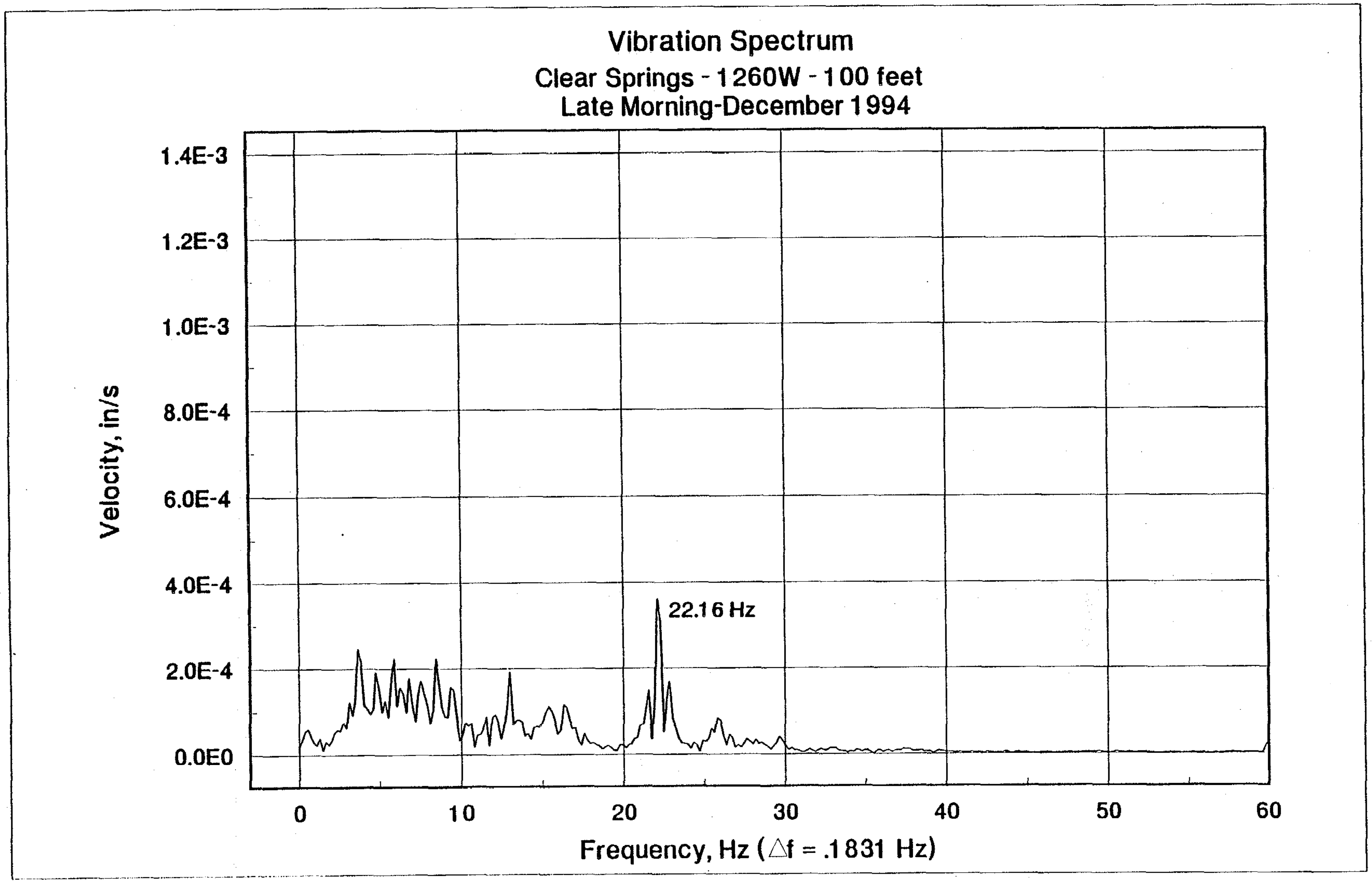

Figure D.59 Particle velocity spectrum for 1260W

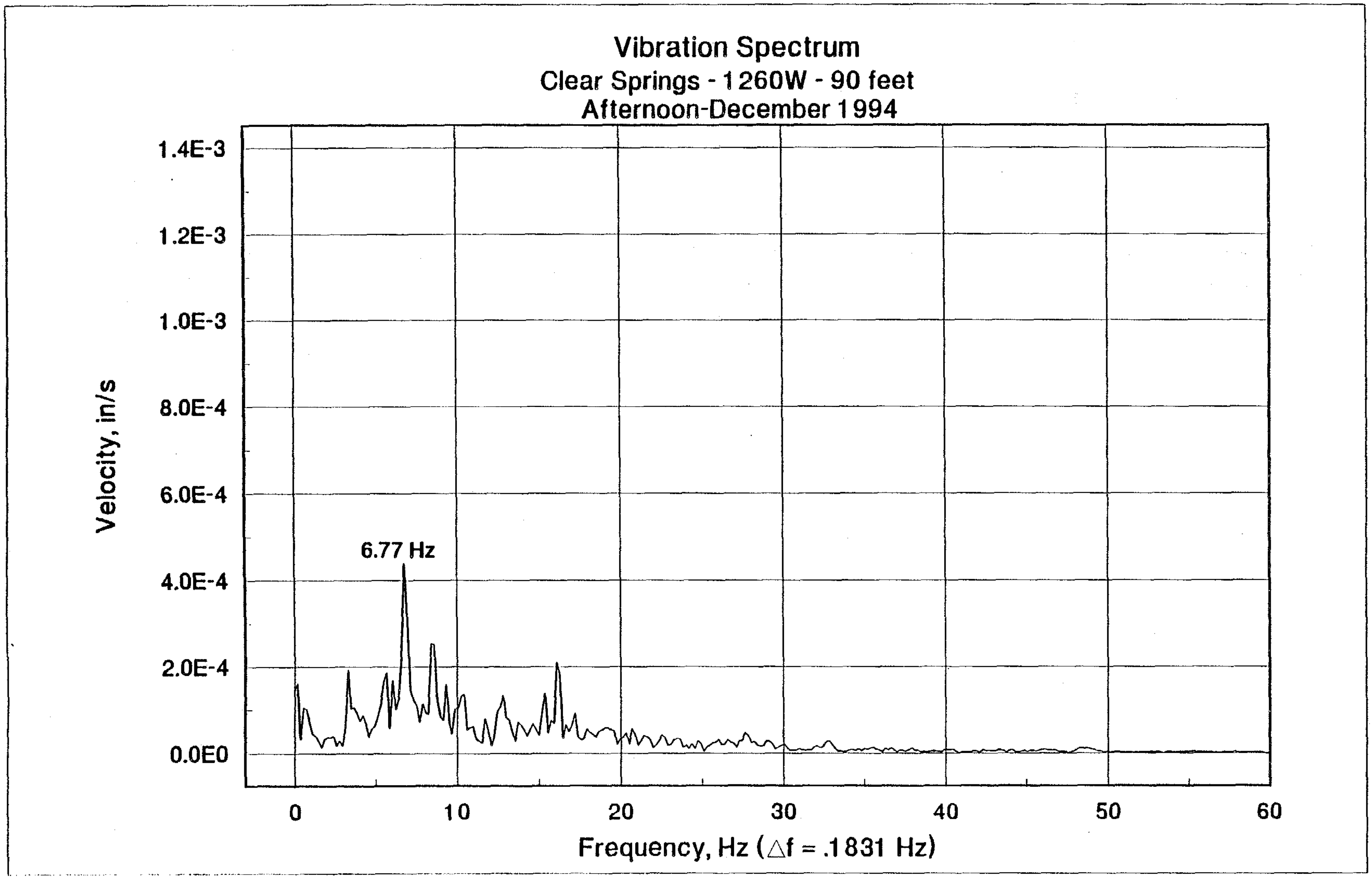

Figure D.60 Particle velocity spectrum for 1260W

APPENDIX E

INSTRUMENTATION SPECIFICATIONS

Table E.1 Sound Level Meter Specifications (*source: Brüel & Kjaer, 1993*)

Standards:
Conforms with ANSI S1.4-1983 and Draft S1.43, 6th September, 1992 Type 1, and IEC 651 1979) and 804 (1985) Type 11

Measuring Ranges:

Range (dB)	Max. Peak Level	Upper limit (RMS) for signals with crest factor =10 (20dB)
10 - 90	93	73
20 - 100	103	83
30 - 110	113	93
40 - 120	123	103
50 - 130	133	113
60 - 140	143	123

Frequency Weighting: Selected independently for RMS and Peak
RMS: A, C according to IEC651 Type 1
Peak:
C according to IEC651 Type 1
L: As shown in Fig. 6.1 with Type 1 tolerances

Detectors: Simultaneous RMS and Peak with independent frequency weightings
Linearity Range: 80dB
Pulse Range: 83 dB
Peak Detector Rise Time: < 50μs

Time Weighting: S, F, I according to IEC651 Type I

Parameters: MaxL, MinL, MaxP, Peak, SPL, L_{eq}, $L_{AV,4}$, $L_{AV,5}$, L_{1m}, SEL, IEL, L_{EPd}, L_N (3 values with L_{90}, L_{50} and, L_{10} as default)
Resolution:
L_N Values: 0.5 dB
Other Parameter: 0.1 dB

Exchange Rate: 3, 4 or 5 dB

Result Logging: Leq, L10 and L90
Logged Every: 0.1, 1, 10s, 1, 10, 30min. and 1 hour
Memory Capacity: 128KBytes (Type 2236 A-007).

Microphone: Type 4188 prepolarized free-field 1/2" condenser microphone
Sensitivity: -30dB re 1 V/Pa ±2dB
Frequency Range: 8Hz to 12.5kHz ±2dB
Capacitance: 12pF

Calibration Conditions:
Reference Frequency: 1000Hz
Reference SPL: 94dB (pressure field)

Environmental Effects:
Operating Temperature: -10 to +50°C (14 to 122°F)
Effect of Temperature: < 0.5dB (-10 to +50°C)
Effect of Humidity: < 0.5dB for 30%<RH<90% (at 40°C, 1kHz)

Table E.2 Accelerometer Specifications

Reference Sensitivity at 50 Hz, 100 ms^{-2} and 24°C

Charge Sensitivity* 31.6 pC/ms^{-2} or 310 pC/g

Voltage Sensitivity* (incl. AO 0038) 24.5 mV/ms^{-2} or 240 mV/g

Capacitance (incl. cable) 1291 pF

Maximum Transverse Sensitivity (at 30 Hz, 100 ms^{-2}) 1.8%

Typical Undamped Natural Frequency 13 kHz

Typical Transverse Resonance Frequency, using Exciter Table 4809 with accelerometer mounted on a steel cube 3.8 kHz

Polarity is positive on the center of the connector for an acceleration directed from the mounting surface into the body of the accelerometer

Resistance minimum 20,000 MΩ at room temperature

<u>Environmental</u>:

Humidity: Welded, Sealed
Temperature Range: -50 to +250°C (-58 to +482°F)
Max. Shock Acceleration: 20 kms^{-2} peak
Typical Acoustic Sensitivity: 0.001 ms^{-2} at 154 dB SPL (2-100 Hz)
Typical Temperature Transient Sensitivity (3 Hz LLF): 0,001 ms^{-2}/°C
Specifications obtained in accordance with ANSI S2.11-1969

Electrical Connector: Coaxial 10-32 UNF-2A
Material: Stainless Steel AISI 316
Sensing Element: Piezoelectric Material PZ 23
Weight: 175 grams
Construction: Delta Shear

*This calibration is traceable to the National Bureau of Standards Washington D.C.